CAN GENERAL AVIATION SURVIVE WITH A LOWER OCTANE UNLEADED AVGAS?

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AVGAS GRADE DESIGNATIONS INDICATE THEIR MINIMUM MOTOR OCTANE AND SUPERCHARGE PERFORMANCE LABORATORY RATINGS.

- HIGHER AVGAS GRADES PROVIDE HIGHER COMBUSTION DETONATION PROTECTION CHARACTERISTICS.

- GRADE 100/130 AVGAS (GREEN) DENOTES:
  MOTOR OCTANE/SUPERCHARGE PERFOMANCE RATINGS

- AVGAS MOTOR AND SUPERCHARGE OCTANE RATINGS ARE ESTABLISHED ON LABORATORY CFR TEST ENGINES.

- AS THE TEL (LEAD) CONTENT OF AVGAS IS REDUCED, ITS DETONATION INHIBITION OR SUPPRESSION CHARACTERISTICS ARE ALSO REDUCED.

- IN OTHER WORDS, AS THE TEL (LEAD) CONTENT IS REDUCED, THE MOTOR (MON) OCTANE RATINGS OF THE AVGAS MUST BE INCREASED TO MAINTAIN A CONSTANT LEVEL OF DETONATION PROTECTION IN THE FULL SIZE ENGINES.

- TO MATCH THE DETONATION PERFORMANCE OF 100LL AVGAS, A 3 MOTOR OCTANE RATING INCREASE IS REQUIRED WITH UNLEADED HYDROCARBON AVGAS.

- THEREFORE, TO MATCH THE DETONATION PERFORMANCE OF 100LL AVGAS ON FUEL INJECTED FULL SIZE ENGINES, A MINIMUM UNLEADED HYDROCARBON 103UL AVGAS IS REQUIRED.

- WITH THE TOTAL REMOVAL OF TEL (LEAD) FROM A TYPICAL 100LL AVGAS, THE OCTANE RATING OF THE FUEL IS REDUCED TO APPROXIMATELY A 91 UL (UNLEADED) GRADE.

THE HIGH OCTANE AVIATION FUELS OUTLOOK.

- AFTER SOME 25 YEARS OF INDUSTRY- WIDE EFFORTS, NOT A SINGLE TRANSPARENT, PRACTICAL AND AFFORDABLE UNLEADED ALTERNATIVE TO 100LL AVGAS HAS BEEN DEVELOPED OR IDENTIFIED.

- THE MAXIMUM MON OCTANE RATING ATTAINABLE WITH AN UNLEADED HYDROCARBON FUEL CONTINUES TO BE A HOTLY DEBATED ISSUE.

  - WE KNOW THAT A 91UL (UNLEADED) AVGAS IS ATTAINABLE BY REMOVING TEL (LEAD) FROM CURRENT 100LL AVGAS.

  - WE ALSO KNOW THAT A 103UL (UNLEADED) HYDROCARBON AVGAS IS REQUIRED, TO MATCH THE DETONATION PERFORMANCE OF 100LL (LEADED) AVGAS.

- TO ADDRESS THIS 12 MON OCTANE DEFICIT OR GAP, WE MAY CONSIDER TWO OPTIONS AS FOLLOWS:

  - DEVELOPMENT OF NEW TRANSPARENT FUELS WITH A SIGNIFICANT REDUCTION OF TEL (LEAD) CONTENT.

  - ENGINE MODIFICATIONS AND/OR OPERATIONAL CHANGES CAPABLE OF PARTIALLY OR TOTALLY COMPENSATING THE UNLEADED FUELS OCTANE DEFICITS.

NEW AVIATION PISTON ENGINE FUELS WITH SIGNIFICANT REDUCTIONS OF TEL (LEAD) CONTENT.

- THE PETITION REQUESTING EPA RULEMAKING TO LIMIT LEAD EMISSIONS FROM GENERAL AVIATION, DOES NOT EXPLICITLY SUGGEST A COMPLETE REMOVAL OF TEL (LEAD) FROM FUELS.

- WITH THE INTRODUCTION OF BIO-FUEL COMPONENTS SUCH AS ETBE, IT IS POSSIBLE TO SIGNIFICANTLY REDUCE TEL (LEAD) CONTENT REQUIREMENTS, WHILE MAINTAINING THE DETONATION, VOLUMETRIC FUEL CONSUMPTION, STABILITY AND OTHER 100LL AVGAS REQUIRED CHARACTERISTICS.

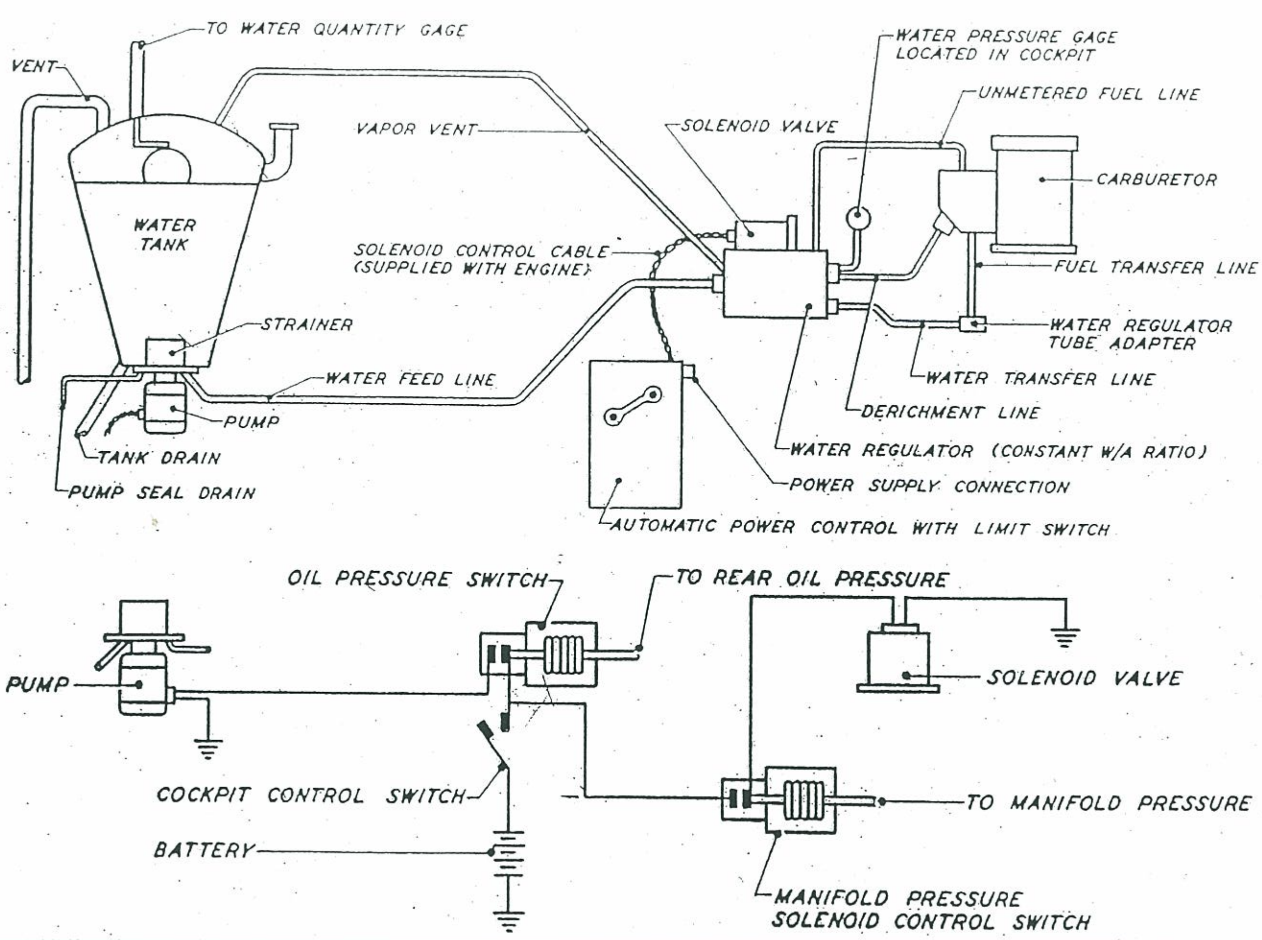
- THESE ULTRA LOW LEAD FUELS WOULD NOT REQUIRE AIRCRAFT/ENGINE MODIFICATIONS.

- IF UNDER THE TERMS OF PROPOSED EMISSIONS REGULATIONS, THIS APPROACH CAN ONLY BE CONSIDERED TRANSITIONAL IN NATURE, THE NEW ULTRA LOW LEAD FUELS COULD PROVIDE AN EXPANDED TIME WINDOW FOR THE CONTINUED EXPLORATION FOR OTHER UNLEADED FUEL SOLUTIONS.

ENGINE/AIRCRAFT MODIFICATIONS AND OPERATIONAL CHANGES THAT COULD PROVIDE PARTIAL OR COMPLETE OCTANE DEFICIT COMPENSATIONS.

- WATER-METHANOL INJECTION SYSTEMS SHOWN IN FIGURE 1, REPRESENT THE ONLY PROVEN DETONATION SUPPRESSION ACCESSORIES CAPABLE OF COMPENSATING OVER 15 OCTANE NUMBER DEFICITS, WITHOUT ENGINE PERFORMANCE PENALTIES.
  - WHILE WIDELY USED BY THE MILITARY IN WW II, THE SYSTEMS WERE LARGELY PHASED OUT IN COMMERCIAL OPERATIONS THAT FOLLOWED.
  - A REFINED AND MORE PRACTICAL VERSION OF THESE SYSTEMS WAS DEVELOPED SPECIFICALLY FOR GENERAL AVIATION APPLICATIONS BY PETERSEN AVIATION OF MINDEN, NEBRASKA.

FIGURE 1 PRATT & WHITNEY ENGINE WATER INJECTION SYSTEM



UPDATING OF ENGINE ACCESSORY SYSTEMS TO REDUCE ENGINE OCTANE REQUIREMENTS.

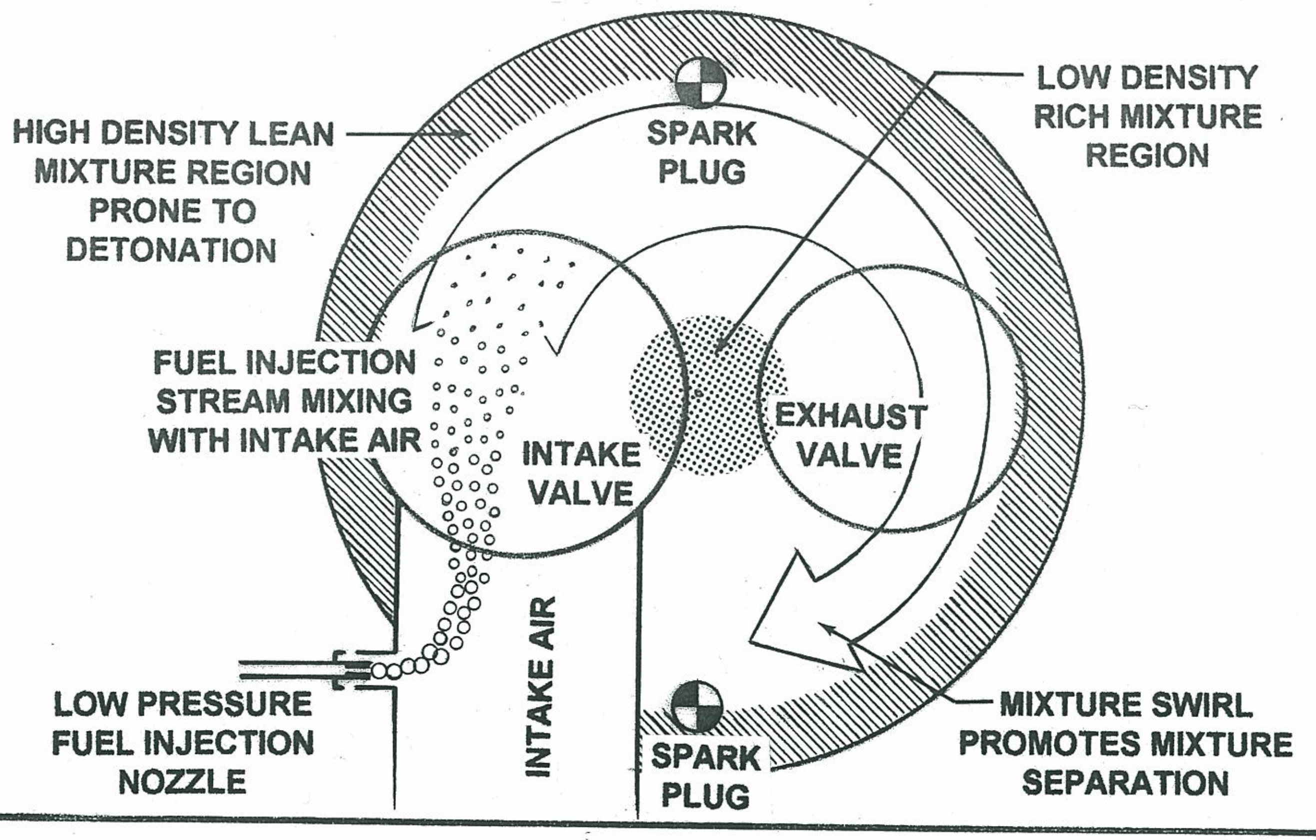
- ENGINE FUEL METERING AND SPARK IGNITION SYSTEMS PLAY AN IMPORTANT ROLE IN THE MINIMUM OCTANE REQUIREMENTS OF PISTON ENGINES.
- CARBURETORS, FUEL INJECTION SYSTEMS AND MAGNETO IGNITION SYSTEMS HAVE REMAINED BASICALLY UNCHANGED FOR SOME 65 YEARS.
- UPDATED FUEL METERING AND SPARK IGNITION SYSTEMS CAN REDUCE THE MINIMUM OCTANE REQUIREMENTS, ALLOWING THE ENGINES TO SAFELY OPERATE WITH LOWER GRADE FUELS AT NO DETRIMENT TO PERFORMANCE.
- IT IS CONSIDERED ESSENTIAL TO UPGRADE THE FUEL METERING AND IGNITION SYSTEMS, AS A FIRST STEP TOWARDS REDUCING THE MINIMUM OCTANE REQUIREMENTS OF THE ENGINES.
  - SUCH UPGRADES WOULD ALSO REDUCE FUEL CONSUMPTIONS AND EMISSIONS, WITH IMPROVED OPERATION SMOOTHNESS AND STARTING CHARACTERISTICS.
  - WHILE THE REDUCED MINIMUM ENGINE OCTANE REQUIREMENT MAY PROVE INSUFFICIENT TO OPERATE SOME POWERPLANTS WITH THE AVAILABLE REDUCED OCTANE UNLEADED FUELS, THE UPGRADES COULD NARROW THE OCTANE DEFICIT GAP BY 4-5 MON OCTANE NUMBERS.
  - ADDITIONAL MODIFICATIONS AND/OR OPERATION PROCEDURES CHANGES COULD THEN BE APPLIED, IF REQUIRED BY REMAINING OCTANE DEFICITS.

THE INFLUENCE OF FUEL INJECTION SYSTEMS ON DETONATION.

- REPLACEMENT OF CARBURETORS WITH TYPICAL LOW PRESSURE FUEL INJECTION SYSTEMS, IMPROVED THE MIXTURE DISTRIBUTIONS AMONG CYLINDERS, BUT DEGRADED THE HOMOGENITY OF THE FUEL/AIR MIXTURES.

- REDUCED HOMOGENITY OF FUEL/AIR MIXTURES INCREASED IGNITION DELAYS, REDUCED COMBUSTION RATES AND INCREASED COMBUSTION VARIABILITIES WITH AN ADVERSE IMPACT ON DETONATION (FIGURE 2).

FIGURE 2 TYPICAL TCM OR LYCOMING FUEL INJECTED ENGINE COMBUSTION CHAMBER



- INJECTED LIQUID FUEL THAT BREAKS DOWN IN DROPLETS, IS THEN LARGELY ATOMIZED AND EVAPORATED AS IT IS EXPOSED TO SPARK IGNITION AND INITIAL COMBUSTION EVENTS, WITHIN A TOTAL TIME PERIOD OF LESS THAN 7 MILLISECONDS @2500 RPM.

EVALUATION OF DETONATION CHARACTERISTICS WITH MISCELLANEOUS FUEL INJECTION SYSTEMS.

- DETONATION CHARACTERISTICS OF A LYCOMING 360 SERIES ENGINE WITH A MARVEL SCHEBLER MA-4 SPA CARBURETOR, WERE COMPARED WITH THOSE OF A BENDIX RSA-5AD1 FUEL INJECTION SYSTEM (FIGURE 3).

- DETONATION CHARACTERISTICS OF AN AVIATION CONVERTED GENERAL MOTORS HT V-6 ENGINE WITH A STANDARD MULTI - PORT ELECTRONIC FUEL INJECTION SYSTEM, WERE COMPARED WITH THOSE OF A BENDIX RSA-5AD1 FUEL INJECTION SYSTEM (FIGURE 4).

  - WHILE THE MULTI-PORT ELECTRONIC SYSTEM ALLOWED THE USE OF 91 AKI MOTORGASOLINE, THE BENDIX FUEL INJECTION INSTALLATION REQUIRED 100LL AVGAS TO PREVENT DETONATION.

- DETONATION CHARACTERISTICS OF AN AIRCRAFT CONVERTED AUDI 5000 I-5 ENGINE WITH A STANDARD MECHANICAL BOSCH K JETRONIC FUEL INJECTION SYSTEM, WERE COMPARED WITH THOSE OF A BENDIX RSA-5 AD1 FUEL INJECTION SYSTEM (FIGURE 5).

- DETONATION CHARACTERISTICS OF A TCM TSIO 520 SERIES ENGINE WITH A STANDARD TCM FUEL INJECTION SYSTEM, WERE COMPARED WITH THOSE EXPERIENCED WITH PRESSURIZED NOZZLES AIR EMULSION, PROVIDED BY A REGULATED ENGINE DRIVEN AIR PUMP.

- IN ALL INSTANCES, INCREASED NOZZLE FUEL DISCHARGE PRESSURES, TIMED OR INTERMITTENT INJECTION FLOWS AND PRESSURIZED NOZZLE AIR EMULSION FUNCTIONS, IMPROVED THE DETONATION CHARACTERISTICS OF THE ENGINES (REDUCED OCTANE REQUIREMENTS).

- NO ATTEMPTS WERE MADE TO IMPROVE THE COMPARABLY GOOD DETONATION SUPPRESSION CHARACTERISTICS OF CARBURETORS.

COMPARISON OF CYLINDER HEAD TEMPERATURES OF A LYCOMING 360 SERIES ENGINE WITH A CARBURETOR AND WITH A BENDIX LOW PRESSURE FUEL INJECTION SYSTEM (FIGURE 3).

FIGURE 3 Cylinder Head Temperatures at Comparable Power Settings

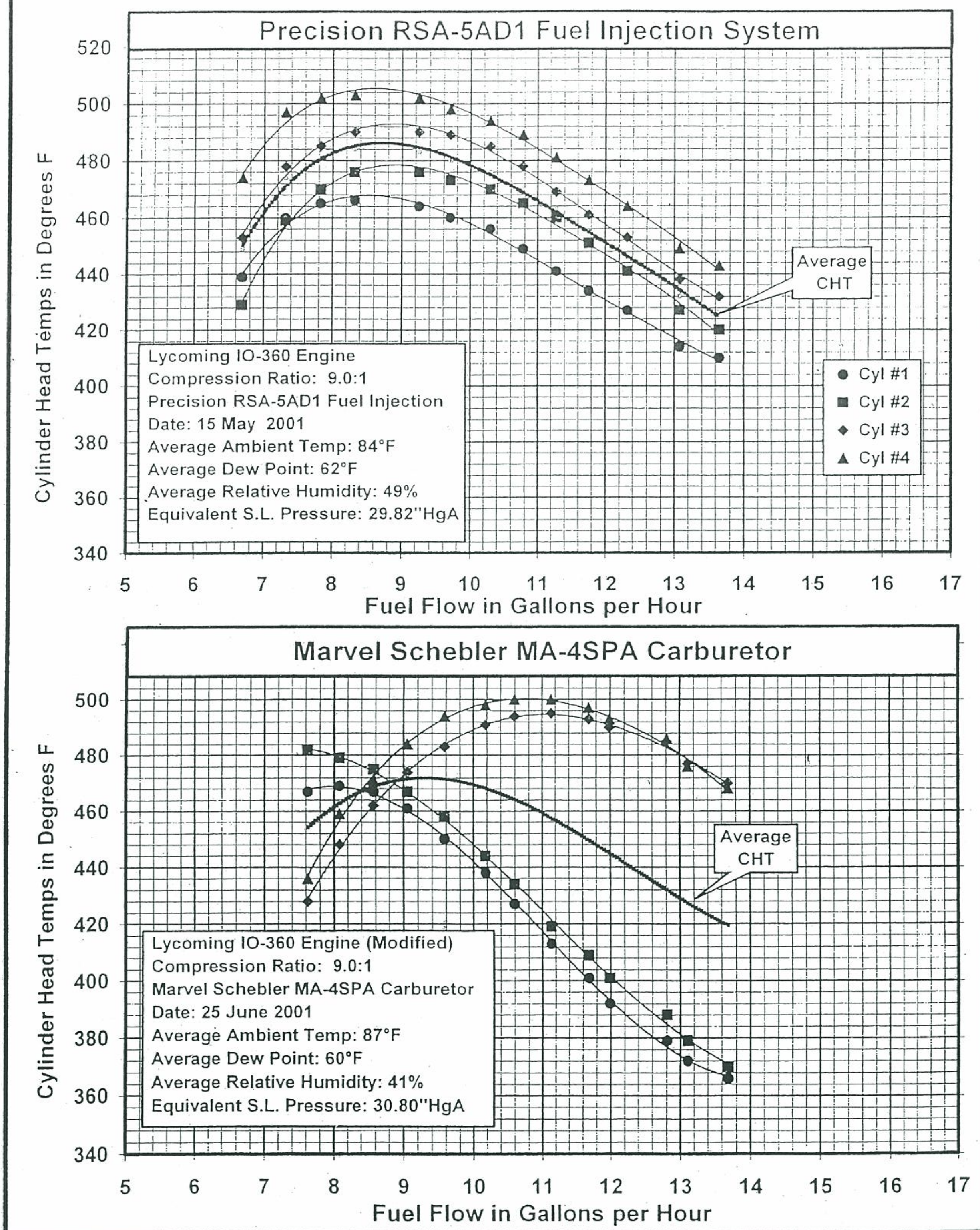
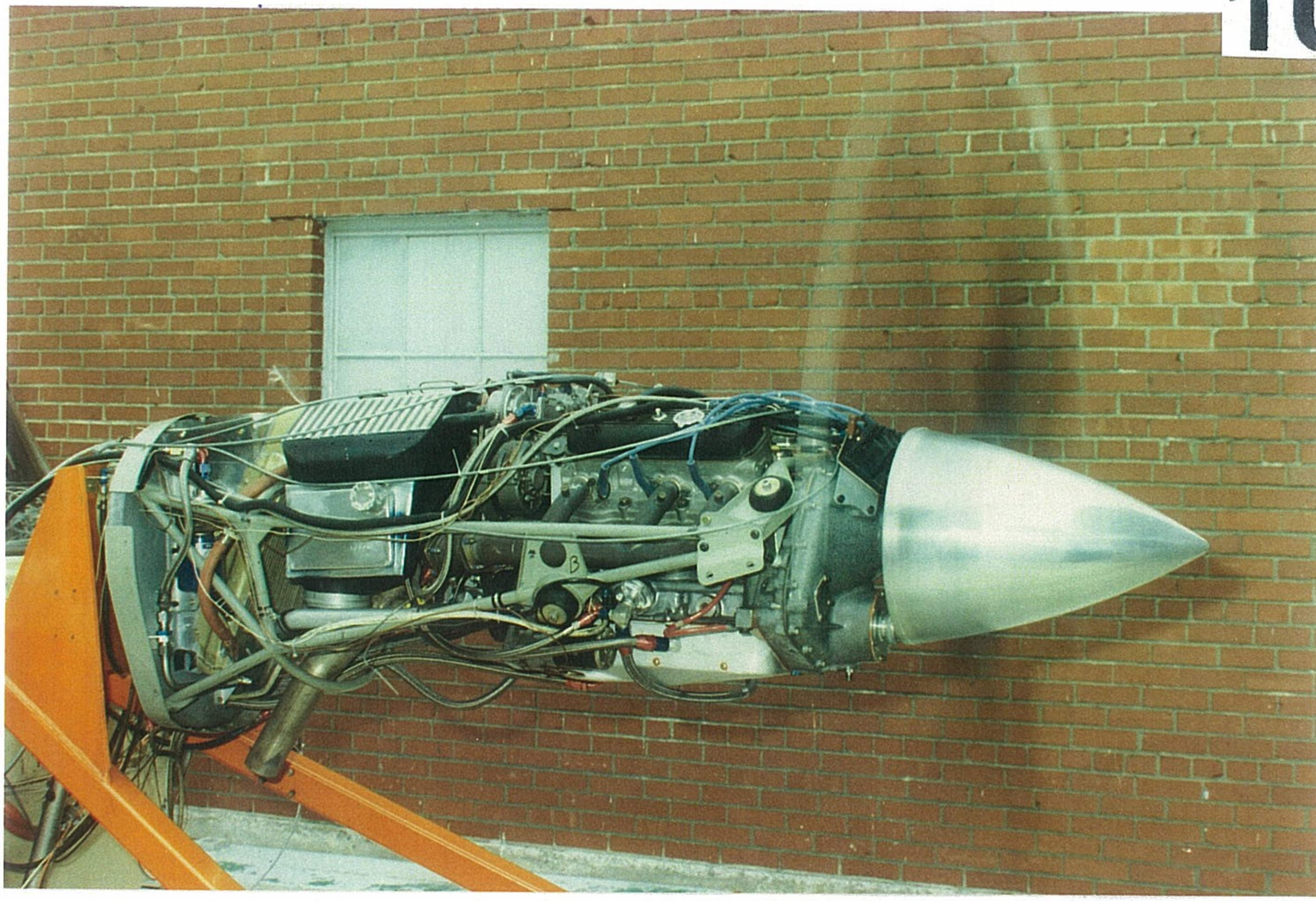


FIGURE 4 GENERAL MOTORS AIRCRAFT CONVERTED HT V-6 ENGINE



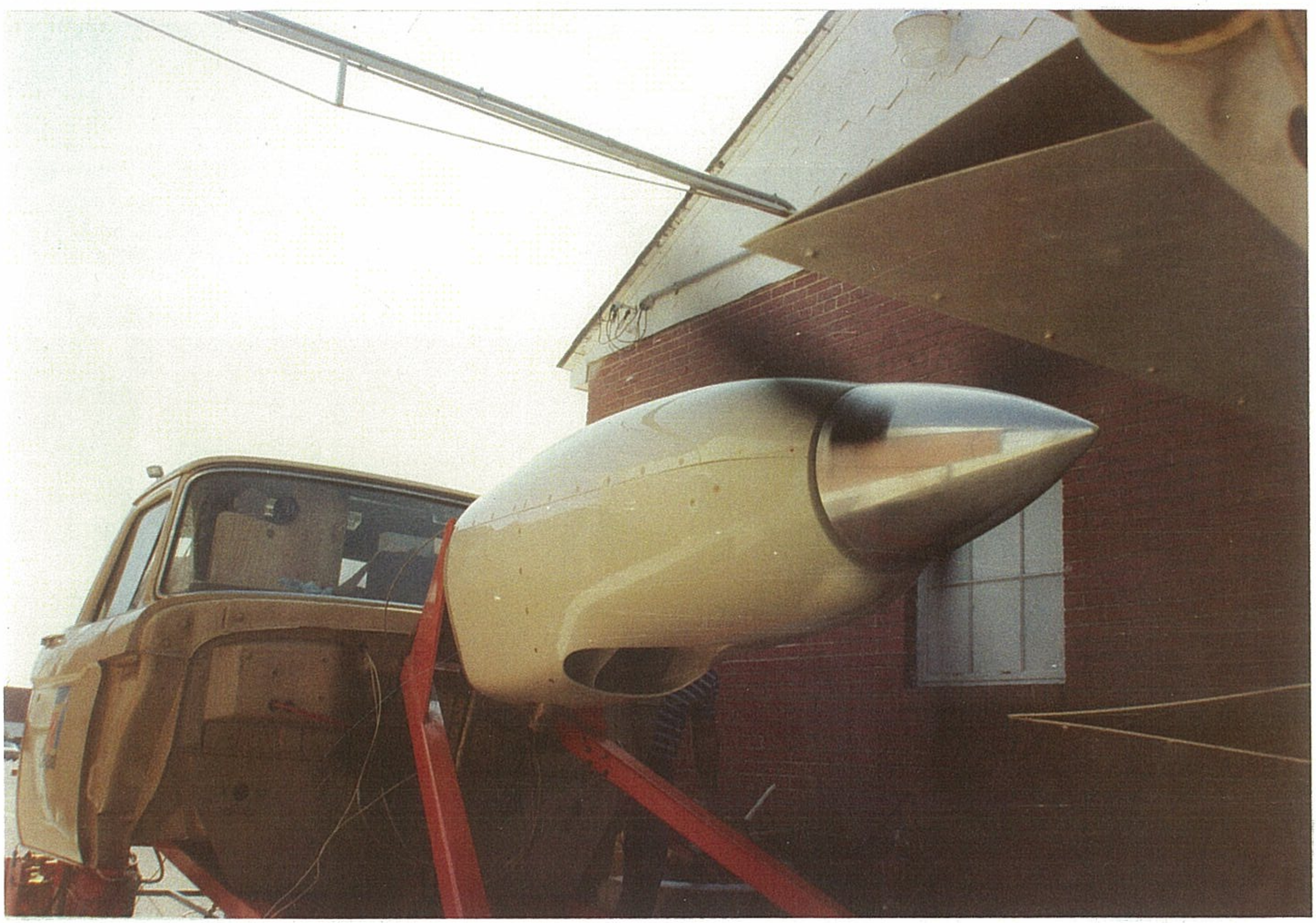
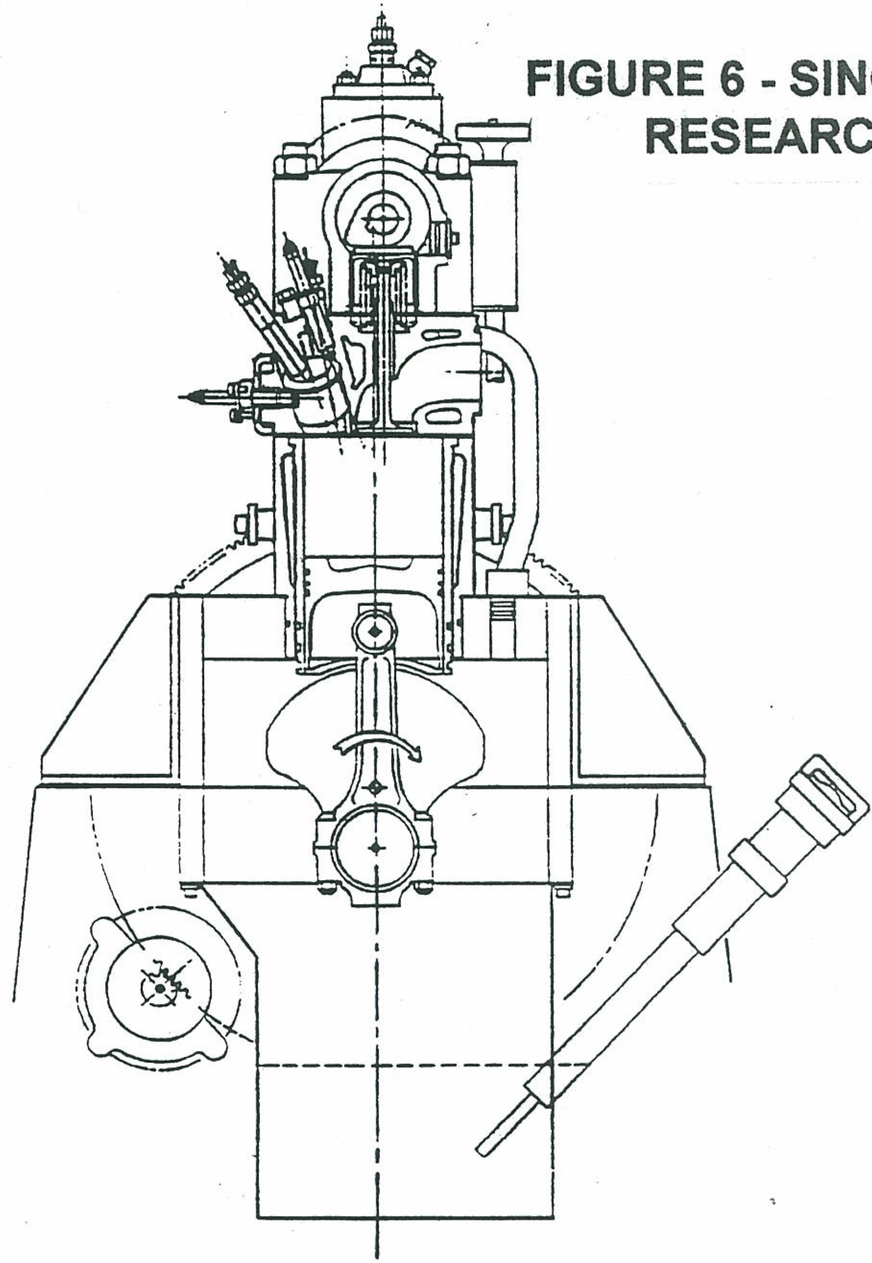


FIGURE 5 AUDI 5000 AIRCRAFT CONVERTED AUTOMOTIVE ENGINE



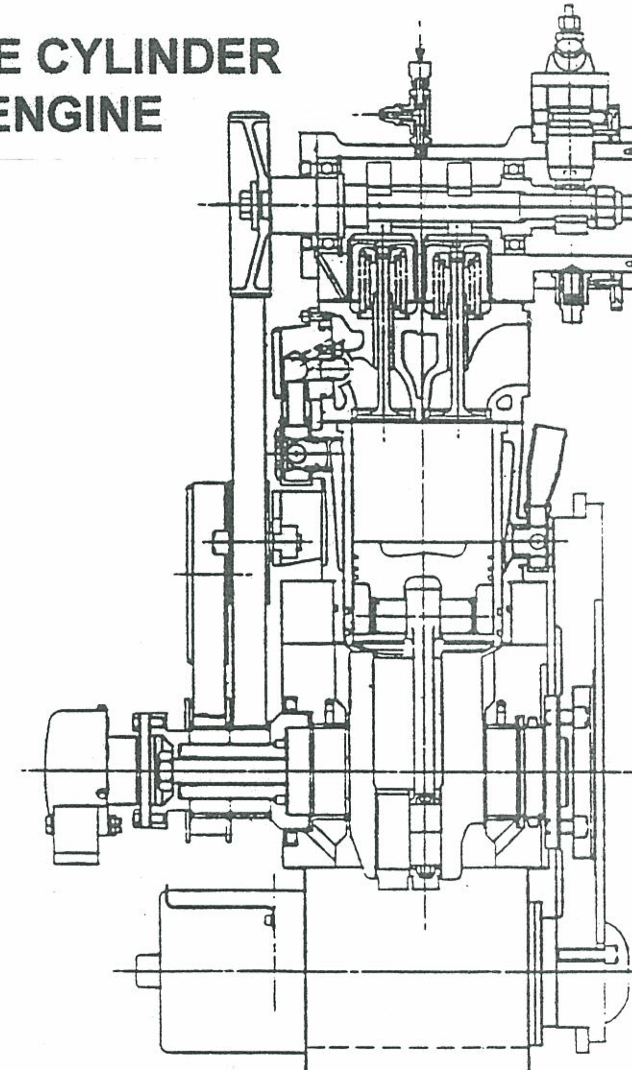
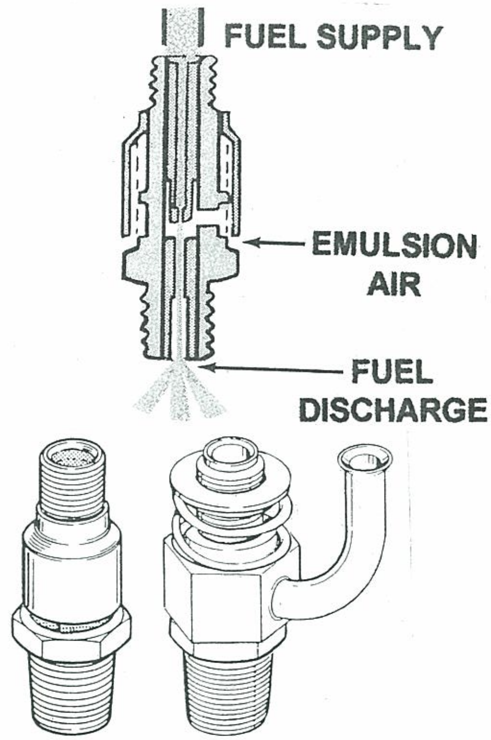


FIGURE 6 - SINGLE CYLINDER
RESEARCH ENGINE

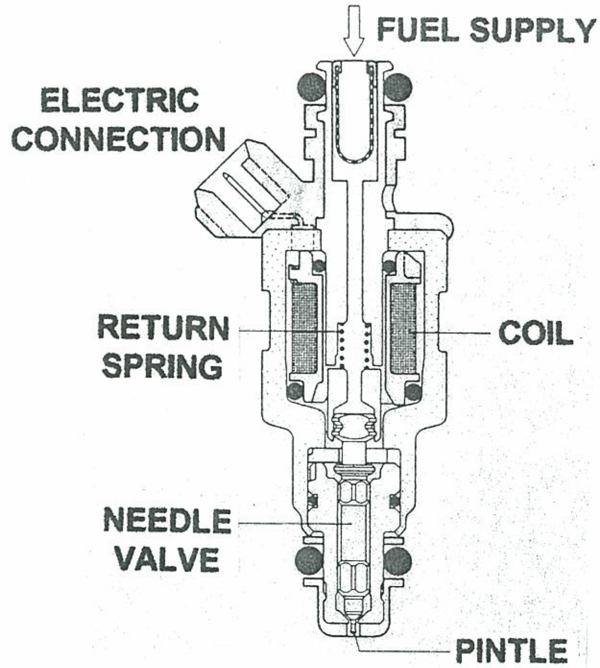
FUEL INJECTION NOZZLES INVOLVED IN THE EVALUATION OF DETONATION CHARACTERISTICS OF MISCELLANEOUS FUEL INJECTION SYSTEMS.

- FUEL INJECTION NOZZLES ARE A DETERMINANT FACTOR ON THE HOMOGENITY OF THE FUEL/AIR MIXTURES, COMBUSTION VARIABILITIES AND DETONATION CHARACTERISTICS (FIGURE 7)

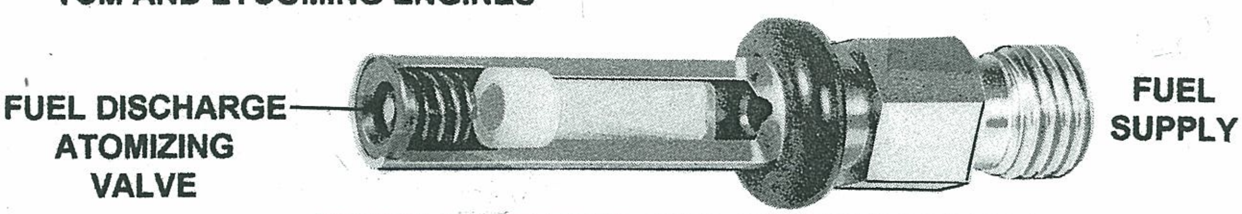
FIGURE 7 FUEL INJECTION NOZZLES INVOLVED ON TESTS



TYPICAL TCM OR BENDIX/ PRECISION LOW PRESSURE CONTINUOUS FLOW FUEL NOZZLE TCM AND LYCOMING ENGINES



MODERN SOLENOID NOZZLE FOR TIMED FUEL INJECTION AT 30 - 40 PSI GENERAL MOTORS HT V-6 ENGINE



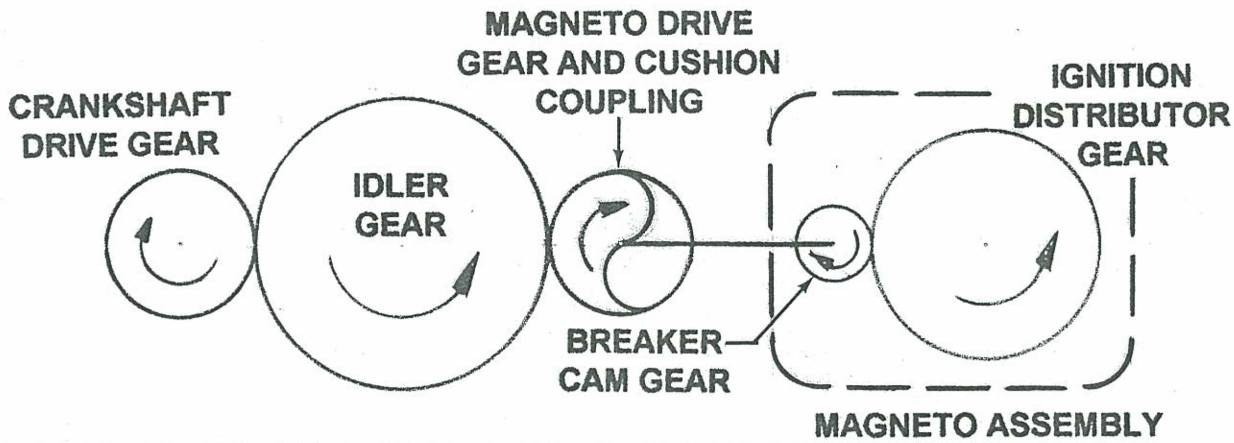
BOSCH K JETRONIC FUEL INJECTION NOZZLE CONTINUOUS FLOW AT 50 PSI PRESSURE AUDI 5000 AVIATION CONVERTED ENGINE

- THE LIMITED INVESTIGATIONS OF ALTERNATIVE FUEL INJECTION SYSTEMS, YIELDED AN ESTIMATED 2-3 MON OCTANE REQUIREMENT REDUCTION WITH INCREASED INJECTION PRESSURES, INTERMITTENT OR TIMED INJECTION, OR PRESSURIZED NOZZLES AIR EMULSION PROVISIONS.

THE INFLUENCE OF IGNITION SYSTEMS ON DETONATION.

- TRADITIONAL IGNITION MAGNETOS ARE DRIVEN BY MULTIPLE GEARS AND CUSHIONED COUPLINGS IN SERIES, THAT INTRODUCE SIGNIFICANT BACKLASH AND ELASTIC SPARK TIMING VARIATIONS (FIGURE 8).

FIGURE 8 - SCHEMATIC OF ENGINE IGNITION MAGNETO DRIVE



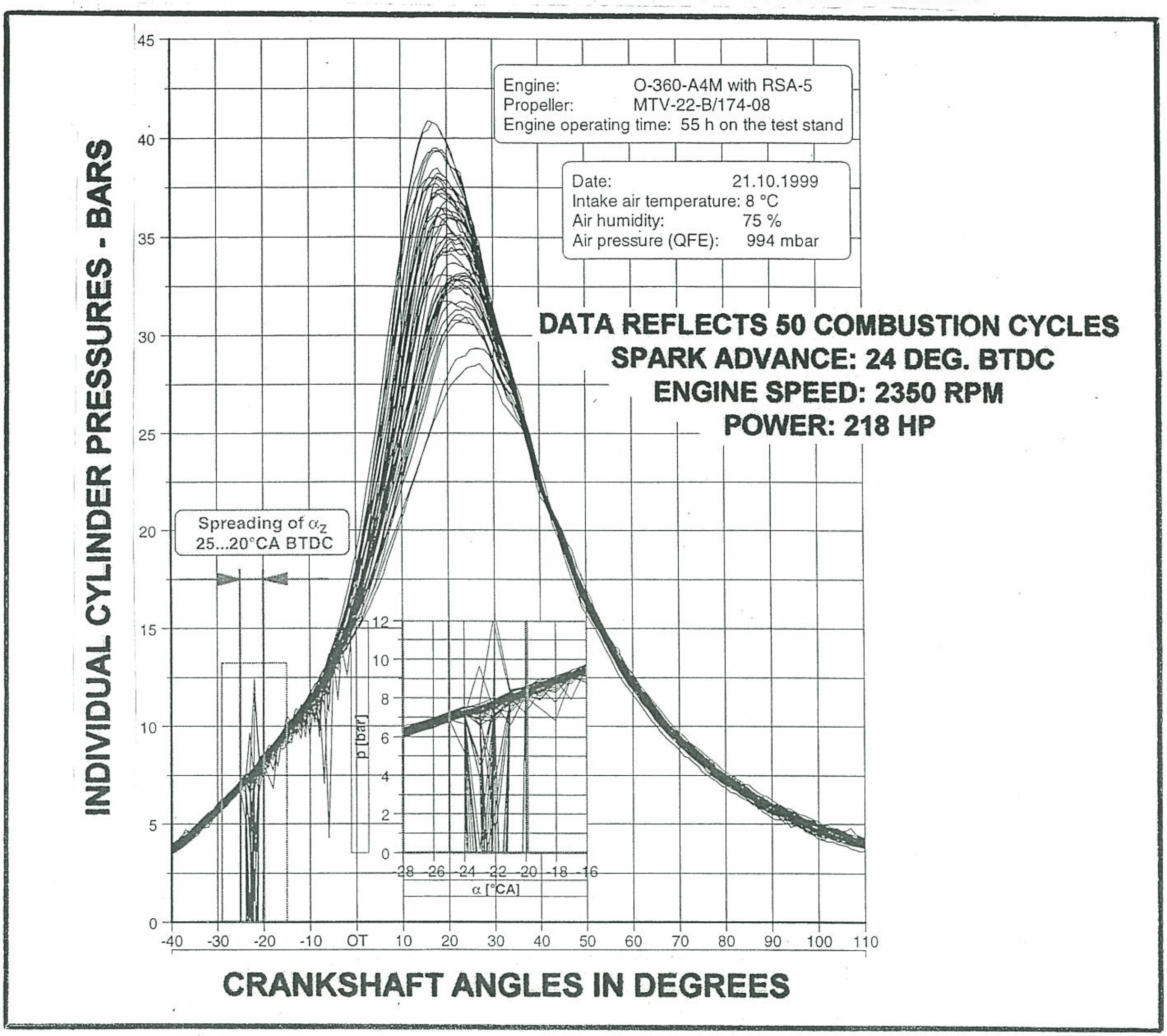
- MECHANICAL MAGNETO BREAKER POINTS AND CONDENSER PROVISIONS CONTRIBUTE TO ADDITIONAL SPARK TIMING VARIATIONS OF UP TO 5 CRANK ANGLE DEGREES, AS SHOWN ON FIGURE 9 FOR A FOUR CYLINDER ENGINE.

- DETONATION SUPPRESSION GAINS ARE ATTAINABLE WITH IGNITION SYSTEMS TRIGGERED BY PROXIMITY OR OPTICAL SENSORS, THAT ACCURATELY SENSE CRANKSHAFT POSITIONS, AND WITH THE CORRESPONDING DELETION OF BREAKER POINTS AND CONDENSERS.

- SPARK TIMING VARIATIONS CONTRIBUTE TO COMBUSTION VARIABILITIES THAT PROMOTE DETONATION.

- FIGURE 9 EXHIBITS SPARK TIMING VARIATIONS OF UP TO 5 CRANK ANGLE DEGREES AND CORRESPONDING COMBUSTION CYCLE VARIATIONS, AS RECORDED BY THE DRESDEN UNIVERSITY OF TECHNOLOGY IN GERMANY, ON A LYCOMING 360 SERIES ENGINE FITTED WITH A BENDIX RSA-5 FUEL INJECTION SYSTEM.

FIGURE 9 COMBUSTION PRESSURE AND IGNITION TIMING VARIATIONS ON A LYCOMING 360 SERIES ENGINE



- INVESTIGATION OF EXTENDED SPARK DURATIONS WITH AN A/C EPIC IGNITION SYSTEM ON A SINGLE CYLINDER ENGINE, REDUCED IGNITION DELAYS AND ENGINE OCTANE REQUIREMENTS.

- EXTENDED SPARK DURATIONS REDUCED COMBUSTION VARIABILITIES, BY TRANSITIONING FROM A CHEMICALLY DOMINATED IGNITION PROCESS, TO A MIXING DOMINATED PROCESS.

- EXTENDED SPARK DURATIONS OF ONLY 4 CRANK ANGLE DEGREES REDUCED COMBUSTION VARIATIONS AND DETONATION TENDENCIES, WHILE SPARK DURATIONS OF 15 CRANK ANGLE DEGREES IMPROVED ENGINE COLD STARTING.

ENGINE MANAGEMENT PROCEDURES TO AVOID DETONATION

- EXTENDED GROUND AND FLIGHT OPERATIONS WITH ENGINE COOLING COWL FLAPS OPEN TO REDUCE CYLINDER HEAD, OIL AND INSTALLATION TEMPERATURES.

- REDUCED POWER AND HIGHER CLIMB AIRSPEEDS WHEN ALLOWED BY SAFETY CONSIDERATIONS.

- ON AIRPLANES FEATURING CONSTANT SPEED PROPELLERS, OPERATION OF THE ENGINE AT HIGHER RPM'S AND REDUCED MANIFOLD PRESSURES PROVIDES MODEST REDUCTIONS OF OCTANE REQUIREMENTS.

    - THIS OPERATION MAINTAINS CONSTANT HORSEPOWER LEVELS AT REDUCED BMEP'S.

- AVOID EXTENDED MEDIUM OR HIGH POWER GROUND OPERATIONS, AND REDUCE ELECTRICAL AND AIR CONDITIONING LOADS.

- AVOID RAPID THROTTLE MOVEMENTS.

- WHEN DETONATION IS SUSPECTED, CLOSELY MONITOR MOMENTARY OR SUSTAINED EXHAUST GAS TEMPERATURE DROPS.

- INSURE THAT ALTERNATE HOT AIR PROVISIONS ARE DEACTIVATED ON CARBURETED ENGINES BEFORE ADVANCING THE THROTTLE.

- ON TURBOCHARGED ENGINES, SIGNIFICANT DETONATION AVOIDANCE GAINS ARE ATTAINABLE BY SIMPLY REDUCING MAXIMUM POWER FULL RICH CRITICAL ALTITUDES, AND ALSO BY REDUCING MAXIMUM CRUISE LEAN CRITICAL ALTITUDES.

IMPACT OF ENGINE PARAMETERS ON OCTANE REQUIREMENTS

THE FOLLOWING LITERATURE INFORMATION APPLIES TO NATURALLY ASPIRATED ENGINES, AND HAS BEEN PARTIALLY VERIFIED DURING ENGINE RESEARCH ACTIVITIES.

- AN AVERAGE DETONATION LIMITED SPARK ADVANCE OF 1 DEG. CRANK ANGLE, CORRESPONDS TO A 1 OCTANE NUMBER REQUIREMENT INCREASE.
- AN AVERAGE INTAKE MANIFOLD AIR TEMPERATURE RISE OF 13 DEG. F, CORRESPONDS TO A 1 OCTANE NUMBER REQUIREMENT INCREASE.
- OCTANE REQUIREMENTS PEAK AT AIR/FUEL RATIOS 5% RICH OF STOICHIOMETRIC MIXTURES (0.071F/A).
- OCTANE REQUIREMENTS THEN DECREASE AT A RATE OF APPROXIMATELY 2 OCTANE NUMBERS FOR EACH AIR/FUEL RATIO TOWARDS RICHER OR LEANER MIXTURES (0.069 F/A TO 0.081 F/A).
- AN INTAKE MANIFOLD AIR PRESSURE INCREASE OF 1 TO 1.3 "HG., CORRESPONDS TO A 1 OCTANE NUMBER INCREASE.
- A UNIT COMPRESSION RATIO INCREASE CORRESPONDS TO A 5-6 OCTANE NUMBER REQUIREMENT INCREASE ON LIQUID COOLED ENGINES, AND TO A 8-9 OCTANE NUMBER INCREASE ON AIR COOLED ENGINES.
- AN EXHAUST BACK PRESSURE INCREASE OF 9 "HG., CORRESPONDS TO A 1 OCTANE NUMBER REQUIREMENT INCREASE.
- A LIQUID COOLANT TEMPERATURE INCREASE OF 18 DEG. F, CORRESPONDS TO A 1 OCTANE NUMBER REQUIREMENT INCREASE.
- A LYCOMING IO-360 AIR COOLED ENGINE CYLINDER HEAD TEMP. RISE OF 10 DEG. F, CORRESPONDS TO A 1 OCTANE NUMBER REQUIREMENT INCREASE.

MISCELLANEOUS ENGINE MODIFICATIONS CAPABLE OF REDUCING OCTANE REQUIREMENTS.

THE FOLLOWING ENGINE MODIFICATIONS PROVIDE ADDITIONAL INCREMENTAL REDUCTIONS OF ENGINE OCTANE REQUIREMENTS.

- RESETTING IGNITION MAGNETOS TO UNIFORM IGNITION ADVANCE TIMINGS, ON ENGINES FEATURING DIFFERENT TIMINGS TO ASSIST STARTING.
  - THIS EXPEDIENT MAY REQUIRE THE ADAPTATION OF A SHOWER OF SPARKS SYSTEM FOR STARTING ASSISTANCE.
- INSTALLATION OF FREE- FLOW EXHAUST MUFFLERS TO REDUCE BACK PRESSURES AND RESIDUAL GASES THAT PROMOTE DETONATION.
- REPLACEMENT OF FLUSH AIR INLETS OR RELOCATION OF INDUCTION AIR INLETS TO REDUCE ENGINE INLET AIR TEMPS.
- TURBOCHARGED ENGINE INSTALLATIONS OFFER A LARGE NUMBER OF TURBO CONTROL SYSTEM MODIFICATIONS THAT COULD SIGNIFICANTLY REDUCE PART-THROTTLE LEAN MIXTURE OPERATION ENGINE OCTANE REQUIREMENTS.
  - REPLACEMENT OF FIXED POINT AND DENSITY CONTROLLERS, WITH SLOPED OR VARIABLE POINT CONTROLLERS.
  - ANY OTHER MODIFICATION THAT COULD REDUCE INTAKE AIR PRESSURES AND TEMPERATURES, AND EXHAUST BACK PRESSURES.
- FIGURE 10 DEPICTS AVIATION ENGINE TYPES AND INSTALLATION VARIATIONS, THAT COULD SUGGEST ADDITIONAL MEANS TO REDUCE ENGINE OCTANE REQUIREMENTS.

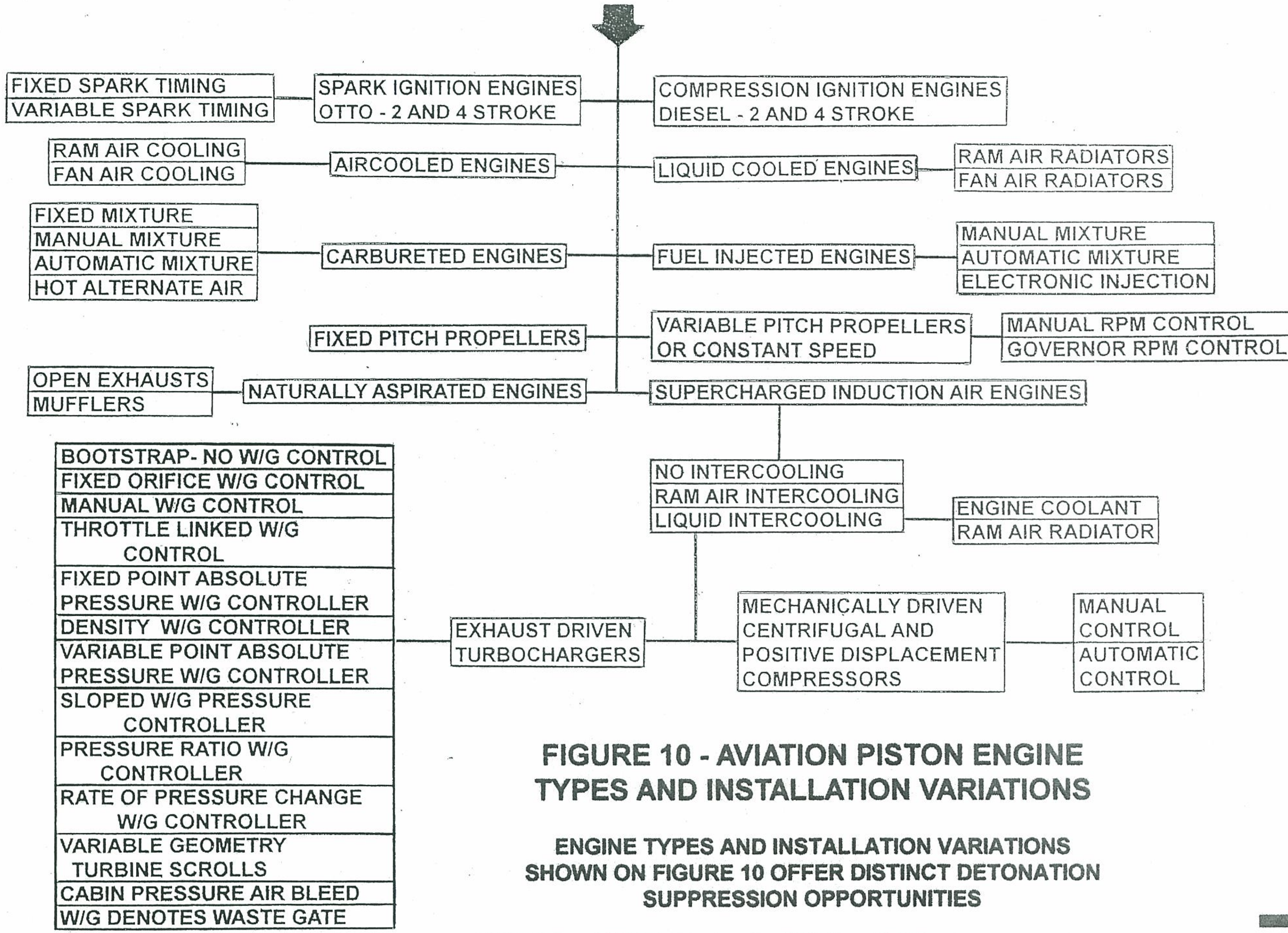


FIGURE 10 - AVIATION PISTON ENGINE TYPES AND INSTALLATION VARIATIONS

ENGINE TYPES AND INSTALLATION VARIATIONS SHOWN ON FIGURE 10 OFFER DISTINCT DETONATION SUPPRESSION OPPORTUNITIES

CONCLUSIONS

- THIS PRESENTATION ADVANCES THE FOLLOWING QUESTION:
  CAN GENERAL AVIATION SURVIVE WITH A LOWER OCTANE UNLEADED AVGAS?

- AT THIS POINT IN TIME THE ANSWER IS:
  IT ALL DEPENDS . . .

- WITH THE INTRODUCTION OF BIO-FUEL COMPONENTS SUCH AS ETBE TO AVGAS, IT IS POSSIBLE TO SIGNIFICANTLY REDUCE TEL (LEAD) CONCENTRATIONS AND EMISSIONS, WITHOUT ENGINE MODIFICATIONS OR OPERATIONAL CHANGES.

- ONLY WATER-METHANOL INJECTION DETONATION SUPPRESSION SYSTEMS HAVE PROVEN CAPABLE OF COMPENSATING FOR THE OCTANE DEFICIT CREATED BY THE TOTAL REMOVAL OF TEL (LEAD) FROM CURRENT 100LL AVGAS.

- WATER- METHANOL DETONATION SUPPRESSION MAY BE JUSTIFIABLE ON SOME TOP OF THE LINE PISTON PRODUCTS, BUT THEIR DEVELOPMENT AND CERTIFICATION FOR A MULTITUDE OF GENERAL AVIATION INSTALLATION VARIATIONS REPRESENTS A DAUNTING AND EXPENSIVE UNDERTAKING.

- CONSIDERATION SHOULD BE GIVEN TO THE DEVELOPMENT OF MODERN REPLACEMENTS, FOR THE VENERABLE BUT OUTDATED PISTON ENGINE FUEL METERING AND IGNITION SYSTEMS.

- SUCH NEW ACCESSORIES BASED ON GUIDELINES OFFERED BY THIS PRESENTATION, COULD REDUCE ENGINE OCTANE REQUIREMENTS, REDUCE FUEL CONSUMPTIONS AND EMISSIONS AND IMPROVE THE SERVICE AND OPERATION OF THE GENERAL AVIATION FLEET.

- THESE MODERN ACCESSORY SYSTEMS COULD ELIMINATE OR SIGNIFICANTLY NARROW THE OCTANE DEFICIT GAP THAT MAY DEVELOP WITH FUTURE UNLEADED FUELS, TO A DEGREE MANAGEABLE BY OTHER MEANS.

- TO FURTHER INCREASE THE DETONATION SUPPRESSION DIVIDENDS, THE NEW FUEL METERING AND IGNITION SYSTEMS SHOULD GO WELL BEYOND THE CAPABILITIES OF SYSTEMS INVOLVED ON INVESTIGATIONS CITED BY THIS PRESENTATION.