U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: TYPE CERTIFICATION OF OXYGENATES AND OXYGENATED GASOLINE FUELS IN PART 23 AIRPLANES WITH RECIPROCATING ENGINES

Date: 4/24/96
Initiated By: ACE-100

AC No: 23.1521-2
Change: 1

1. PURPOSE. This change transmits revised pages for the subject advisory circular (AC).

2. EXPLANATION OF CHANGE. This change has been initiated to clarify the Scope and to make the Scope and Purpose of this AC consistent with AC 23.1521-1B, Type Certification of Automobile Gasoline in Part 23 Airplanes with Reciprocating Engines. The asterisks (*) in the right and left margins indicate the beginning and end of the change.

3. DISPOSITION OF TRANSMITTAL. After filing the revised page, this change transmittal should be retained.

PAGE CONTROL CHART

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1. PURPOSE. This advisory circular (AC) provides information and guidance concerning an acceptable means, but not the only means, of compliance with part 23 of the Federal Aviation Regulations (FAR), applicable to approval procedures for certification of alternate fuels. These procedures also apply to those airplanes approved/certificated under previous regulations superseded by part 23. This material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. RELATED FAR SECTIONS. Sections 21.93(b), 23.23, 23.901(e), 23.903(a)(1), 23.903(f), 23.909, 23.951, 23.954, 23.955, 23.959, 23.961, 23.1041, 23.1093, 23.1521(d), 23.1541, and 23.1581.

3. RELATED READING MATERIAL. Related advisory circulars and other reading material are listed in appendixes 1 and 2, respectively.

4. SCOPE.

a. Fuels covered by this AC include oxygenates and oxygenated gasolines. This includes methyl-tertiary-butyl ether (MTBE), methanol, ethanol, other oxygenates, and gasolines containing these or other oxygenates, except for automobile gasoline including those containing 11 percent or less alcohol by volume. Currently, gasolines are manufactured to at least three different specifications available from the American Society for Testing and Materials (ASTM). These specifications are ASTM D 910 for aviation gasoline and D 439 and D 4814 for automobile gasoline. D 4814 supersedes D 439. ASTM D 4814 is intended to describe both straight gasoline and gasoline-oxygenate blends. Guidance for certification of automobile gasoline including those containing 11 percent or less alcohol by volume is contained in AC 23.1521-1B Type Certification of Automobile Gaoline in Part 23 Airplanes with Reciprocating Engines or later revision.

b. Section 23.1521(d) requires the minimum fuel grade be established so that it is not less than that required for the operation of the engine. The Type Certificate Data Sheet (TCDS) for the engine specifies fuel(s) that has (have) been substantiated during type certification of the engine. The fuel must have a documented specification to define the fuel properties.

c. The product produced by mixing of alternate fuels is considered a new alternate fuel and requires a separate approval for use. Therefore, mixing of alternate fuels is prohibited unless the mixture is separately certified and the mixture documented by approved fuel specification. The alternate fuel specification should include the fuel properties (including visibility of flame), composition specification, and composition limits. An alternate fuel should be compatible with 100LL aviation gasoline and/or other fuels approved for use in the airplane.

5. BACKGROUND.

a. It is necessary to evaluate each engine and airplane model for compliance with the applicable FAR and determine that it is safe for operation. Therefore, a Supplemental Type Certificate (STC) or Type Certification (TC) is required for each different series or sub-series of engine and airplane models, for which approval is requested. An STC or TC is issued to an applicant who demonstrates to the FAA that the airplane meets the applicable regulations. The STC does not automatically apply to other airplanes. The STC or TC data developed by the applicant including drawings, reports, etc., are proprietary. A person wanting to operate an airplane on alternate fuel may either obtain an STC, if one is available, from the STC owner and comply with the STC requirements or the person may request certification from the appropriate FAA certification office and develop the data required for certification.

b. Applicants have applied for STC's to allow for the use of fuels other than aviation gasoline in part 23 reciprocating engine airplanes. The FAA Technical Center conducted a study to determine the conditions that are most likely to result in operational problems, should fuels other than aviation gasoline be used in general aviation reciprocating engine airplanes. The fuels studied range from automotive gasolines to automotive and aviation gasolines containing alcohol to straight alcohol fuels. The reports are included in the related reading material.

6. CERTIFICATION PROCEDURES.

a. It is mandatory that the engine (including turbocharger/intercoolers) and engine/propeller combination be approved for operation on the alternate fuel before it is eligible for approval in the airplane. Operation of the engine with any alternate fuel should be shown to meet the minimum design requirements for the engine and be approved. Advisory Circular 20-24B, "Qualification of Fuel, Lubricants, and Additives for Aircraft Engines, dated December 20, 1985, describes an acceptable method of obtaining approval for the engine to operate on alternate fuel. It may be possible for testing of the engine and airplane to be conducted concurrently.

b. The fuel for which approval is requested must be documented by a specification that is written in sufficient detail to provide at least the composition, physical properties, and limits by which uniform quality and composition can be maintained. The applicant is responsible for providing to the FAA certification office the fuel specification and test methods and procedures to determine compliance with the specification.

c. Prior to FAA authorization for test, the applicant should submit a report to substantiate that the fuel has undergone sufficient test and development to show that, under the conditions in which it will be used in the airplane, it is compatible with the applicable engine and airplane materials. The data should include compatibility with materials, lubricants, and additives that are approved for the engine, propellers (where applicable), and the airplane. The data submitted to document the fuel used should include the fuel composition and test methods used as well as identify the test laboratory or organization performing the test.

d. A material compatibility and fuel aging deterioration tests should be performed. This test should be for 180 days. A fuel tank representing a typical airplane fuel tank should be filled to three-fourths full with the appropriate fuel. The tank should be placed outdoors and exposed to sunlight for the 180 days. Samples of material and components used in the airplane fuel system should be placed partially in the fuel and partially out of the fuel. The fuel and material and component samples should be evaluated after 90 and 180 days to determine deterioration. Standard tests conducted in accordance with the procedures published by ASTM, Society of Automotive Engineers (SAE), and other organizations may be used instead of the 180-day test. Particular attention should be directed to oxygenated fuel effects on bladder fuel cells and non-metallic composite material fuel tanks.

e. A description of the test program and equipment that the applicant proposes to use in demonstrating the airworthiness of the fuel to be approved should be submitted for approval. The engine(s) and airplane fuel system(s), exhaust systems, and oil system(s) components should be subjected to a pretest and post-test inspection to verify their conformity and condition prior to and after testing. The test procedures should provide all the specific information required to perform the test (i.e., test fuel specification, test location, engine model to be tested, specific test hardware and instrumentation to be used, engine minimum and maximum operating parameters, engine lubricant to be used, lubricant change interval, list of all information to be recorded during the test including changes to oil properties, intervals at which this data is to be recorded, etc.).

f. Five hundred hours of airplane flight test should be performed with the objective of showing that the subject fuel will provide satisfactory performance and operation, will not cause an unsafe condition, and will not cause deterioration or any other unsatisfactory condition on or in any of the airplane fuel or oil-wetted parts. The flight test performed under paragraph 8 of this AC may be included in the 500 hours of flight test. It should be possible to conduct these 500 hours of test concurrently with the controlled flight test referenced in AC 20-24B, "Qualification of Fuel, Lubricants, and Additives for Aircraft," dated December 20, 1985, paragraph 5b.

g. If the 150 hour engine endurance test (Section 33.49) is conducted in lieu of the 500 hour controlled flight test referenced in AC 20-24B, paragraph 5b and the other requirements of AC 20-24B are satisfactorily accomplished for engine certification with the alternate fuel, then 150 hours of airplane flight test may be performed in lieu of the 500 hour airplane flight test in paragraph 6f of this AC. The flight test performed under paragraph 8 of this AC may be included in the 150 hour airplane flight test.

h. At the completion of the airplane test, a report(s) should be submitted which includes at least the following:

(1) A description of the airplane and engine(s) in which the fuel was tested.

(2) A chronological history of test conditions and engine performance, including r.p.m., power or thrust levels achieved during the test, fuel and oil consumption, oil changes, parts replacement, and other pertinent test results.

(3) An analysis of lubricating oil samples taken before and after the test, and before each oil change.

(4) An analysis of material collected in the fuel and oil filters after the test and when filters are changed.

(5) An analysis of the fuel used during the test. For substantiation testing, these analyses should demonstrate minimum or "worst case" properties.

(6) A description of abnormal wear, deposits, metal attack, or other harmful effects that occurred as a result of the test.

(7) A description of any deterioration, excessive seal swelling shrinkage, hardness, or unsatisfactory condition on or in any of the airplane (including turbocharger/intercooler) fuel, exhaust, or oil-wetted parts that occurred as a result of the test.

7. CERTIFICATION CONSIDERATIONS. The FAR require that the critical operating conditions for both the engine and airframe be considered during airplane certification. Tests are required to demonstrate the ability of the airplane fuel system to function under all critical operating conditions. The following are some areas which require special consideration as a consequence of using alternate fuels in general aviation reciprocating engine airplanes.

a. The energy per unit volume of the fuel affects the amount of fuel which is metered to the engine in order for it to operate satisfactorily. The lower the energy, the greater the amount of fuel required to complete the same flight profile. In general, the gasolines containing alcohols have less energy than aviation gasoline, and the straight alcohols have less energy than the gasolines which contain alcohols. The energy of MTBE lies between gasoline and the alcohols.

b. The fuel consumption varies with the energy density of the fuel. Typically, the lower the energy density, the greater the fuel consumption. Many of the alternate fuels have lower energy densities than aviation gasoline. A means to set the fuel flow rate for the specific fuel in use should be provided if the airplane is intended to be operated on more than one type of fuel. Additional fuel pumps (main and emergency) may be required to satisfy fuel flow requirements due to changes in fuel density/heating value. Fuel consumption effects, if any, on airplane range should be addressed.

c. The octane rating of the fuel affects the tendency of the fuel to detonate in the airplane engine. The higher the rating, the lower the probability of encountering detonation. This in turn means higher compression ratios may be used which increase the power and efficiency of the engine. There are a number of octane ratings established by the ASTM and the ratings of interest to the aviation community are the Aviation Lean Octane rating and the Aviation Rich Octane rating. The Motor Octane Number (MON) associated with automobile gasolines is similar to the Aviation Lean Octane Number.

d. The antiknock index is the average of the MON and the Research Octane Number (RON) (an octane rating, which currently applies to automobile gasoline only). This is the number associated with regular or premium autogas (i.e., R+M/2 as displayed on the fuel pump). Regular unleaded automotive gasoline typically has an antiknock index of 87 (minimum MON of 82) and premium unleaded automotive gasoline has an antiknock index of 91.0 or higher.

e. Engine operations in high ambient temperatures and at low pressure altitudes increase engine operating temperatures. Likewise, power setting and the air-to-fuel ratio affects the operating temperature of the engine. The higher the operating temperature, the greater the probability of detonation or preignition occurring.

f. Abnormal combustion (detonation, preignition, knock, etc.) characteristics of a fuel in an engine are affected by many variables. These many variables include combustion temperature, combustion pressure, and air-to-fuel ratio. High combustion temperature and pressure are conducive to abnormal combustion such as detonation or preignition. Engines operated at or near stoichiometric air-to-fuel ratios are most likely to result in detonation or preignition. Alternate fuels have different combustion characteristics from gasoline, partly due to the oxygen in the fuel, and the following should be considered in evaluating these fuels. (See references 5 through 8 in appendix 2 for discussion of abnormal combustion phenomena.)

(1) Many alternate fuels burn with very lean air-to-fuel ratios. If certification testing is conducted at only lean air-to-fuel ratios, then substantiation should be provided to ensure that stoichiometric air-to-fuel ratios are not attainable in that installation. (Stoichiometric air-to-fuel ratios for some fuels are: gasoline - 14.7 to 1; MTBE - 11.7 to 1; ethanol - 9.0 to 1; and methanol - 6.45 to 1, from reference 5 in appendix 2.)

(2) An additional condition that may result in detonation or preignition is operation on a fuel with a lower energy density immediately following operations on fuel with a higher energy density. Detonation or preignition characteristics of an alternate fuel should be evaluated by operating the engine on a lower energy density fuel immediately following operation on a higher density fuel. Detonation is possible even though the air-to-fuel ratio is lean of stoichiometric.

g. The Reid Vapor Pressure is a rough measure of the volatility of the fuel. Higher values of Reid Vapor Pressure are more conducive to vapor formation in fuel systems. Other indicators are the initial boiling point of the fuel and the latent heat of vaporization. A fuel with high volatility starts easier and provides a more uniform fuel distribution in the engine. The alcohols have low Reid Vapor Pressures, high initial boiling points, and high latent heats of vaporization. All of these affect the volatility of the fuel. The volatility of MTBE is close to that of gasoline. Gasolines containing alcohols may have higher vapor formation, and low Reid vapor pressure readings may not be representative of vapor formation characteristics particularly when water is dissolved in the fuel. The vapor liquid ratio may be a good indicator of volatility.

h. The Flash Point of a fuel is the temperature where sufficient vapors are released to result in a fire if an ignition source is present. The flash point of the alcohols is such that a combustible mixture may be present in the fuel tanks at ambient temperatures. Gasolines have flash points that are well below common ambient temperatures; and typically, the fuel/air mixture in the fuel tanks is too rich in fuel to support combustion. MTBE has a flash point between aviation gasoline and the alcohol fuels.

i. Since flammable fuel/air mixtures may be present in the airplane tanks with some alternate fuels, particular attention should be directed toward minimizing potential ignition sources. Small amounts of gasoline (or other volatile substance) may prevent the existence of these explosive fuel/air mixtures.

j. Methanol is a strong solvent and is corrosive to aluminum, copper, zinc, lead, and magnesium. Methanol is also poisonous and toxic and regulated by the Federal Hazardous Substance Act. Procedures of the American Industrial Hygiene Association should be followed when handling methanol and other alcohol fuels.

k. Material compatibility presents an area of concern. Many of the materials currently found in general aviation airplanes are susceptible to attack by alternate fuels. Examples include:

(1) Corrosion of components in fuel systems may be a problem.

(2) The metals in the combustion chamber and exhaust system may be attacked by some high acidic content by-products of combustion that are associated with some of the alternate fuels.

(3) Swelling, cracking, and failure of the synthetic and natural rubbers, which are contained in the airplane fuel system, may occur. This may be a problem when using alternate fuels containing alcohol or other oxygenates. Oxygenated fuel may also swell or soften plastics used in fuel systems.

(4) Decomposition of fuel tank and access cover sealants may occur over an extended period of time.

l. Some alternate fuels dissolve the gums and residues that build up over time and these gums may be deposited in filters and metering orifices. This may present a problem for airplanes that operate alternately on aviation gasoline then on an alternate fuel. Fuels which contain oxygenates may exhibit this behavior.

m. Existing engine oils may not be compatible with some alternate fuels. Possible problems include large quantities of unburned fuel in the oil, unusually acidic by-products of combustion, and excessive water contamination. These problems may be more severe if the engine is operated infrequently. Alternate fuels may scavenge lead deposits which accumulate during operation on aviation gasoline. These deposits may accumulate in the engine oil. Fuel in the oil system may affect oil system components and materials.

n. Water contamination of an alternate fuel may affect the characteristics of the fuel. Some examples are listed below:

(1) Gasolines containing alcohols are subject to phase separation. This may occur when liquid water is accidentally added to the fuel during handling, when water is absorbed from the air, or when the fuel is subject to temperature changes. Typically, the precipitate (water, alcohol, and high octane components of the gasoline) will not burn in the airplane engine. If the precipitate contains a significant amount of the high octane components,

detonation may result. The usable fuel remaining should have an octane rating higher than required by the airplane engine. Some means for handling the precipitate or preventing the phase separation should be provided.

(2) An emulsion may be formed when liquid water is added to an alternate fuel which consists primarily of one component (for example, fuel grade methanol which contains small amounts of gasoline to denature the fuel). Typically, these emulsions will not burn in an airplane engine.

(3) Fuels which are mutually miscible with water may contain more water than an engine/fuel system can handle. If so, some method of identifying the water content of the fuel should be available to the pilot. Fuel tank and/or fuel system modifications may be required.

o. Switching from a tank containing one fuel to a tank containing another may result in an engine stoppage. There are two possible causes for this.

(1) The resulting air-to-fuel ratio may be beyond either the lean or rich combustion limit for the second fuel. Provisions may be required to provide for the proper air-to-fuel ratio as the fuel in use is changed.

(2) Straight gasoline and fuels containing oxygenates may not readily mix. As a consequence, the fuel flow may be interrupted between the selector valve and the engine due to the formation of fuel vapors at the interface of the fuels. Provisions to ensure the flow of fuel may be required.

p. Operation at the lean combustion limit may result in engine stoppage when switching tanks if the fuel in the second tank does not have at least the same energy density as the fuel in the first tank.

q. Fuel evaporating from the airplane tanks may entrain liquid fuel. The airplane tank vents should be designed to separate the liquid and return it to the tank, or the airplane range should be adjusted to reflect the possible loss of up to 25% of the fuel onboard. Fuel evaporating from the tanks may alter the octane characteristics of the remaining fuel. The long-term effects of aging should be evaluated.

r. Adding fuel to a tank containing a different fuel, which is not soluble in the first fuel, will probably result in an engine stoppage or other operating problems. Provisions to prevent this from occurring, or a means to drain the tank prior to refueling should be provided.

s. Airplane exposure to high ambient temperatures and direct sunlight may result in fuel temperatures of 125°F (52°C), or higher. These high temperatures increase the amount of vapor formed in the fuel system which could then result in fuel interruption. The exact effect depends on the type of fuel and the fuel system design.

t. The hot weather (fuel) certification procedures (vapor tolerance tests) are intended to establish margins for fuel supply partial or total liquid flow discontinuities and depend upon the fuel being evaluated (reference AC 23.961-1, "Procedures for Conducting Fuel System Hot Weather Operation Tests," dated January 14, 1987). In general, the certification test for any fuel should be conducted on days when the ambient temperature exceeds 30°C (85°F), and when the engine is up to normal operating temperatures. Normally, the critical fuel level is the minimum amount of fuel required to complete the certification tests. To ensure the most severe conditions are evaluated, the fuel being tested should be handled and stored in sealed containers at or below 10°C (50°F), and the fuel should not be heated until it is in the airplane tanks. Several methods of heating the fuel are available including: heat exchangers placed in the airplane tank, exposure to direct sunlight or heat lamps, and forcing hot air over the airplane tanks. The fuel should not be agitated or handled during the heating process. Below are some considerations for alternate fuels:

(1) Gasolines containing alcohol may be more likely to form vapor under the following conditions:

(i) a fuel temperature in the tank of from 35° to 38°C (95° to 100°F);

(ii) an alcohol concentration of 15% on a weight/weight basis;

(iii) a Reid Vapor Pressure at the maximum for which approval is requested (or the maximum allowed for that class of fuel); and,

(iv) takeoff fuel flow.

If more than one alcohol is used in a gasoline alcohol blend, then a total alcohol concentration of 15% on a weight/weight basis may be the most likely to result in vapor formation. The gasoline blends made with methanol are more prone to vapor formation than gasoline blends made with ethanol.

(2) Fuels which consist primarily of one constituent (e.g., MTBE or methanol), present a special condition. For this class of fuels, the worst case for vapor formation may be takeoff fuel flow and a fuel temperature near the boiling point of the principal constituent. The results of a temperature survey conducted by the FAA Technical Center indicate that the maximum fuel temperature one could expect to experience is 52°C (125°F). Since

the boiling point of this class of fuel is typically higher than 52°C, a fuel temperature between 52° to 55°C (125° to 131°F) may be the most critical and may provide realistic certification criteria.

(3) Service experience with automotive gasoline has indicated that a critical condition for high vapor pressure fuels with a hydrocarbon base may be fuel at 85°F.

(4) Some other conditions may be the most critical for vapor formation dependent upon the fuel composition. The applicant should investigate and propose the most critical conditions for the hot fuel testing.

u. During the flight test for hot weather (fuel) certification, the following criteria should be considered:

(1) The takeoff and climb should be made as soon as possible after the fuel in the tank reaches the desired temperatures determined in paragraph 7t. The airspeed should be the same as that used to meet the requirements of § 23.65 with the exception the airplane weight should be the weight with the critical fuel level, minimum crew, and ballast as necessary to maintain center of gravity limits.

(2) Power settings should be maintained at the maximum approved levels for takeoff and climb to provide for the maximum fuel flow.

(3) The climb should be continued to the maximum operating altitude desired or previously approved for the airplane. Appropriate limitations should be noted in the Airplane Flight Manual (AFM) Supplement or Supplemental Airplane Flight Manual.

(4) Tests should be conducted with the fuel system operating in accordance with the normal procedures outlined in the AFM.

(5) The following data should be recorded for the flight test:

(i) Fuel temperature in the tank.

(ii) Fuel pressure at the start of the test and continuously (recording device or manually) during climb noting any pressure failure, fluctuation, or variations.

(iii) Main and emergency fuel pump operation, as applicable.

(iv) Pressure altitude.

(v) Ambient air temperature.

(vi) Airspeed.

(vii) Engine power, cylinder head temperature, turbocharger temperature, torque, r.p.m., exhaust gas temperature, manifold pressure, and fuel flow, as appropriate.

(viii) Comments on engine operations.

(ix) Fuel quantities in the fuel tank(s) during takeoff.

(x) Fuel vapor pressure of the fuel to be used during the test.

(xi) Fuel grade or designation, determined prior to test.

(6) A fuel pressure failure is considered to occur when the fuel pressure decreases below the minimum prescribed by the engine manufacturer or the engine does not operate satisfactorily.

(7) The emergency fuel pumps should be inoperative if they are being considered for use as backup pumps. This test may be used to establish the maximum pressure altitude for operation with the pumps off.

(8) It should not be necessary to provide additional heat for the fuel system after the original fuel sample is heated to temperature during the hot weather tests.

(9) If significant fuel pressure fluctuations occur during testing of the critical flight condition but pressure failure does not occur, additional testing should be considered to determine that pressure failure does not occur during any expected operating mode. Also, the fuel system should be evaluated for vapor formation during cruise flight at maximum approved altitude in smooth air at low to moderate power setting and low fuel flow and during idling approach to landing. It is possible for vapor lock or fuel boost pump cavitation to be critical at a reduced power and fuel flow rate.

(10) Appropriate AFM instructions may be necessary concerning proper use of fuel pumps during hot weather operations. Also, any limitation on the outside air temperature as a result of hot weather tests should be included in the AFM.

(11) The hot weather tests may have to be repeated if the critical fuel tank for the particular installation cannot be positively identified.

v. Engine starting characteristics may be affected by the use of alternate fuels. Tests should be conducted to verify the airplane engine restart capability at altitude. Also, engine starting capability at cold and hot ambient temperatures should be verified.

w. An alternate fuel that requires aviation gasoline for starting or other conditions thereby necessitating two fuel types should be evaluated for safe changeover operation. Altitude restart with the fuel should be addressed (see paragraph 8(11)).

x. If the fuel flame of the alternate fuel is not visible when the fuel is burning, then some means of making the flame visible should be provided. The flame should be as visible as that produced by ethanol burning in bright sunlight.

8. AIRPLANE CERTIFICATION EVALUATION.

a. Evaluation of an application for certification of an alternate fuel should include those items in paragraph 7 of this AC and the following items:

(1) The fuel must be approved by STC or TC for use in the engine (including turbocharger/intercooler).

(2) An analysis of the fuel used for each test should be accomplished. For certification testing, the analysis should demonstrate minimum or critical properties.

(3) A hot weather operation test (§ 23.961) should be conducted. The airplane should be tested with the fuel to the maximum altitude for which approval is requested (see paragraph 7t and u).

(4) Engine cooling (§ 23.1041) should be evaluated for compliance with the regulations.

(5) Evaluate for normal engine operation (§ 23.951) during all approved airplane maneuvers; e.g., takeoff and landing, balked landing, stall, spins, etc. Also, evaluate engine operation (§ 23.955(e)) when changing from one tank to another.

(6) Carburetor heat rise (§ 23.1093) should be evaluated for compliance with regulations. Keep in mind that some of the alternate fuels result in an unusually large temperature drop in carbureted fuel systems.

(7) Suction lift fuel systems are more critical than gravity (low pressure) feed systems with respect to vapor formation. Both types of systems should be evaluated by analysis and/or flight test for operational problems.

(8) Evaluate the engine for proper operation and ensure that engine rated horsepower is within the limitations specified on the applicable Airplane Type Certificate Data Sheet. Airplanes with fixed pitch propellers may be evaluated by determining the static r.p.m. and manifold pressure are within TCDS limits. If engine power is changed with use of the fuel, evaluation of these effects on airplane performance is necessary. Detonation testing with critical specification fuel should be accomplished (reference AC 33.47-1).

(9) Establish compatibility of airplane fuel wetted and oil wetted materials (elastomers, sealants, seals, liners, hoses, etc.) and components (including propeller system components and materials if engine oil is used for propeller operation) with the fuel. Industry standards such as Society of Automotive Engineers (SAE) procedures and ASTM specifications may be used to establish compatibility.

(10) Establish compatibility of the fuel quantity gauging system with the fuel and evaluate the unusable fuel quantity (§ 23.959).

(11) Establish the inflight restart envelope (§ 23.903(f)) with the fuel.

(12) Evaluate the compatibility of carburetor deicing fluid and the fuel and any effects on airplane operation.

(13) Evaluate the fuel flow (§ 23.955).

(14) Evaluate the effects of the alternate fuel weight per volume difference on load distribution limits (§ 23.23).

(15) If the alternate fuel will result in an increase in aircraft noise (due to changed performance or changed engine operating parameters), then an acoustical change in accordance with § 21.93(b) should be addressed.

b. Preparation of a Supplemental AFM or AFM Supplement (§ 23.1581), as applicable, is necessary to specify the airplane's proper operating procedures and limitations. A Supplemental AFM is used with airplanes that were originally certificated without an AFM, whereas an AFM Supplement is used with airplane models having an AFM. Procedures for determining that fuel is free of contamination (not dissolved water), does not contain unapproved materials, and meets the minimum specification for which approval was obtained, should be provided by the applicant and should be included in the AFM. It is the operator's responsibility to determine that the fuel used satisfies the approved fuel requirements. Advisory Circular 20-43C, "Aircraft Fuel Control," dated October 26, 1976, contains advisory material concerning fuel handling procedures and methods to prevent contamination.

c. Specify appropriate markings placards (§ 23.1541) to define the approved fuels and any operating limitations. The appropriate fuel specification should be included. Specify a placard to alert the pilot of a Supplemental AFM or AFM Supplement for proper operation.

d. The Flight Manual Supplement or Supplementary Flight Manual should contain a caution stating the following: "All airport, local, state, and federal regulations pertaining to airplane fueling operation must be complied with."

e. The applicant should provide for continued airworthiness (§ 23.1529). This should include all changed or added components of the engine, turbocharger/intercoolers, fuel system, oil system, and parts list.

MICHAEL GALLAGHER
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APPENDIX 1. ADVISORY CIRCULARS

The publications listed below may be obtained from the U.S. Department of Transportation, Utilization and Storage Section, M-443.2, Washington, D.C. 20590. Advisory Circular (AC) 23-8A can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, or from any of the Government Printing Office bookstores located in major cities throughout the United States.

1. Qualification of Fuel, Lubricants, and Additives for Aircraft Engines, AC 20-24B, Federal Aviation Administration, December 20, 1985.

2. Aircraft Fuel Control, AC 20-43C, Federal Aviation Administration, October 26, 1976.

3. Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning, AC 20-53A, Federal Aviation Administration, April 12, 1985.

4. Water in Aviation Fuels, AC 20-125, Federal Aviation Administration, December 10, 1985.

5. Flight Test Guide for Certification of Part 23 Airplanes, AC 23-8A, Federal Aviation Administration, February 9, 1989.

6. Substantiating Flow Rates and Pressures in Fuel Systems of Small Airplanes, AC 23.955-1, Federal Aviation Administration, June 10, 1985.

7. Unusable Fuel Test Procedures for Small Airplanes, AC 23.959-1, Federal Aviation Administration, January 14, 1985.

8. Procedures for Conducting Fuel System Hot Weather Operation Tests, AC 23.961-1, Federal Aviation Administration, January 14, 1987.

9. Certification of Non-Oxygenated Automobile Gasoline (Autogas) instead of Aviation Gasoline (Avgas) in Part 23 Airplanes with Reciprocating Engines, AC 23.1521-1A, Federal Aviation Administration, January 2, 1991.

10. Detonation Testing in Reciprocating Aircraft Engines, AC 33.47-1, Federal Aviation Administration, June 27, 1988.

11. Use of Alternate Grades of Aviation Gasoline for Grade 80/87, and Use of Automotive Gasoline, AC 91-33A, Federal Aviation Administration, July 18, 1984.

APPENDIX 2. RELATED READING MATERIAL

1. Automotive Fuels Handbook, Society of Automotive Engineers, (SAE), 1990.

2. Alternate Fuels for General Aviation Aircraft with Spark Ignition Engines, DOT/FAA/CT-88/05, Federal Aviation Administration, March 1988.

3. The Performance of Alternate Fuels in General Aviation, DOT/FAA/OT-88/13, Federal Aviation Administration, July 1988.

4. Straight Alcohol Fuels for General Aviation Aircraft, SAE Paper 891038, General Aviation Aircraft Meeting and Exposition, April 11-13, 1989.

5. Alcohols and Ethers, A Technical Assessment of Their Application as Fuels and Fuel Components, API Publication 4261, Second Edition, July 1988.

6. Aviation Fuels, Maxwell Smith, G. T. Fouks & Co. Ltd., 1970.

7. Powerplants for Aircraft, Joseph Liston, McGraw-Hill Book Company, Inc., 1953.

8. Internal Combustion Engines and Air Pollution, Edward Obert, Intext Educational Publishers, 1973.