

## FUEL SYSTEMS TECHNOLOGY OVERVIEW

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Fuel system research and technology studies are being conducted to investigate the correlations and interactions of aircraft fuel system design and environment with applicable characteristics of the fuel.

### Fuel Properties and the Fuel System

Voluntary industry standards for aviation turbine fuel (ASTM D 1655, ref. 1) include over 25 items of specification, but only a few of these are of concern to the fuel system design and operation. The proceedings of a 1977 NASA-sponsored workshop on fuels (ref. 2) identified several fuel properties worthy of further research with respect to their influence on the performance of present and future aircraft fuel systems. These properties include water solubility, viscosity, flashpoint, aromatics content, and freezing point. Water solubility is a minor characteristic, but it is a property sensitive to fuel composition; and changes in the fuel chemical constituents may increase the solubility and cause cleanliness problems. Viscosity is of concern with respect to low-temperature pumpability, but proposed research on viscosity can be included with the freezing-point studies discussed later. Flashpoint was not included among the cited properties in the reference 2 workshop proceedings. The workshop participants discussed flashpoint but concluded that safety and altitude boiloff limits made any changes or research on flashpoint unlikely. Subsequent to this workshop, an ASTM symposium reviewed the question of jet fuel flashpoint, its measurement, and the advantages and disadvantages of changes in the flashpoint specification. A compilation of the flashpoint symposium papers has been recently published (ref. 3).

The significance of increased content of aromatic compounds in jet fuels has already been discussed in this symposium, with respect to combustion and emission effects. Aromatic compounds can also degrade the performance of polymeric materials used as seals in the fuel system. Limited laboratory tests of material compatibility have been conducted by the Jet Propulsion Laboratory (ref. 4) and other organizations. In some of the JPL tests a test specimen was supported in a bath of fuel within a constant-temperature oven. The tension required to maintain a fixed gage length was measured by a load cell. Test results on one elastomer are shown in figure 1 as a plot of stress relaxation over a period of time. Tests were conducted in air and with the elastomer exposed to Jet A (20 percent aromatics) and Jet A blended with tetralin (40 and 60 percent aromatics). The rapid degradation of elastic qualities with increased aromatics content is obvious in the results of these accelerated tests. Figure 2 shows test results with

the 60-percent aromatics fuel at three temperatures. Comparison of figures 1 and 2 shows that an increase from 20 to 60 percent aromatics is analogous to a decrease of 30° C in operating temperature.

### Freezing Point

The jet fuel property which is of greatest concern to the fuel system performance is, of course, the freezing point (refs. 5 and 6). The 1977 NASA fuels workshop (ref. 2) made five recommendations for continuing and future research on freezing point and its relation to fuel system performance. These are

- (1) Analyses of in-flight temperatures
- (2) Design of aircraft fuel systems for use with high-freezing-point fuels
- (3) Experimental study of low-temperature pumpability
- (4) Full-scale fuel tank simulator studies
- (5) Development of a rapid freezing-point measurement technique

Analysis of in-flight fuel temperatures. - In the past two decades, some flight fuel temperature data have been collected by airlines and airframe companies. Recently, the Boeing Company made a comprehensive analysis of 8000 fuel and ambient minimum temperature measurements furnished by flight crews of cooperating International Air Transport Association airlines (ref. 7). Figure 3 is one example from this survey, a distribution plot of percent of flights for stated minimum fuel temperatures over a given route. The data are separated according to airplane type, but the different curves reflect the variations in flight speed and fuel management rather than inherent differences in fuel system design. Despite the large number of data points, this study still covers a small statistical range of limited seasonal and geographic variations. The principal purpose of the compilation was the corroboration of a Boeing in-flight fuel temperature computing routine (refs. 8 and 9). The fuel temperature calculations were shown to be accurate by comparison with the data. The fuel temperature computer program permits the prediction of fuel temperatures for a large range of ambient conditions, flight times, fuel management, and tank configurations, including military and general-aviation airplanes as well as commercial models. The calculations and the measurement data are single-point, bulk fuel temperatures. A refinement of the computing program is being devised to include realistic temperature gradients within the fuel tank. The paper by Frederick Tolle of Boeing describes the computing program modification. A NASA program is now under way to obtain selected in-flight measurements of these temperature gradients.

Fuel systems for high-freezing-point fuels. - Heat transfer from the fuel during flight can be reduced by insulation or the fuel temperature can be increased by heating in order to increase the minimum fuel temperature and remove some restrictions on the freezing-point specification. Boeing design analyses (refs. 8 to 10) have concluded that, at present, fuel heating, using engine heat rejection or conversion of a small fraction of engine

power, is most feasible. Suggested techniques are discussed in the paper by Tolle.

Experimental study of low-temperature pumpability. - The relationship of fuel flow or pumpability at low temperature to the freezing point has been investigated in several programs. A NASA-supported study by the Lockheed-California Company (refs. 11 and 12) used a scale-model apparatus that represented a segment of an airplane fuel tank. The upper and lower surfaces of the tank were chilled to duplicate the in-flight fuel tank environment. The paper by Francis Stockemer discusses these tests and their results in terms of the unpumpable "holdup" of frozen fuel. Other results from laboratory and scale-model tests conducted by the Boeing Company are included in Tolle's paper. Continuing studies by Lockheed use an apparatus which adds a heated fuel recirculating system to the chilled tank model (fig. 4). These tests can thus simulate the behavior of fuel in an advanced fuel system with in-flight fuel heating.

Full-scale fuel tank simulation. -The 1977 fuels workshop recommended that studies be conducted in a full-scale fuel tank demonstrator to relate the fuel pumpability findings to behavior at realistic conditions and configurations. No program of this scope has been initiated, however.

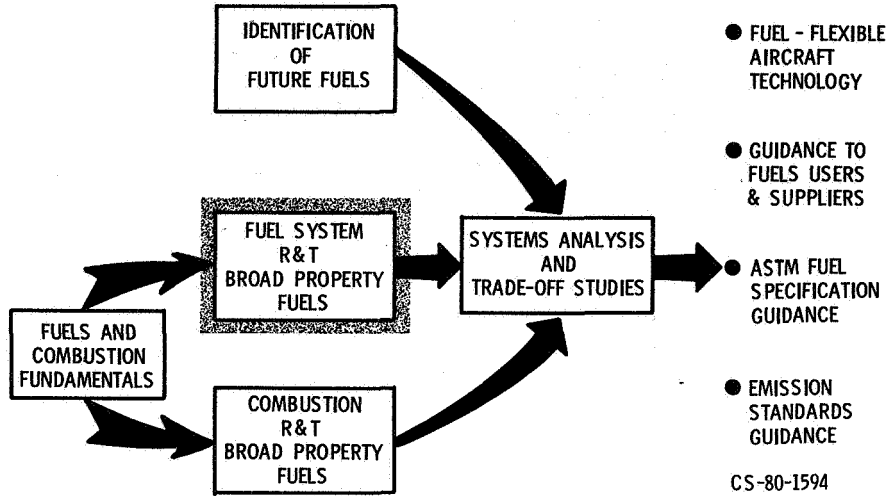
Rapid freezing-point measurement. - If the freezing point of a jet fuel were determined at the time of delivery to the airplane, minimum in-flight temperature limits could be permitted near the actual rather than the conservative specification freezing point. The present means of measurement, while accurate and precise, is cumbersome and unsuited for field measurements. A NASA program, to start in 1980, will investigate techniques suitable for rapid freezing-point measurements.

#### REFERENCES

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12. Friedman, R.; and Stockemer, F. J.: Temperature and Flow Measurements on Near-Freezing Aviation Fuels in a Wing-Tank Model. ASME Paper 80-GT-63, March 1980.

## AIRCRAFT RESEARCH AND TECHNOLOGY FOR FUTURE FUELS

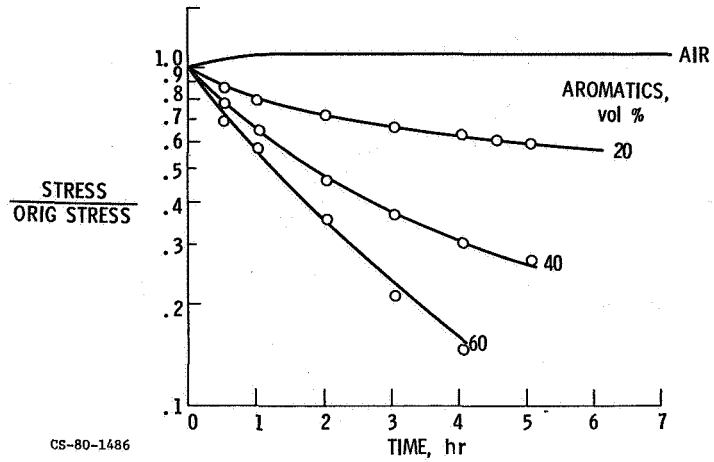


### RECOMMENDED RESEARCH FOR FUEL SYSTEMS-1977 NASA WORKSHOP

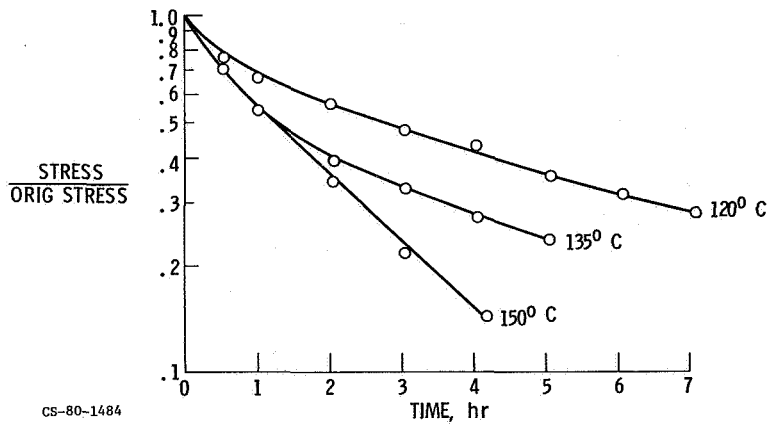
JET FUEL PROPERTY	RESEARCH AND TECHNOL NEEDS
WATER SOL AND CLEANLINESS FLASH POINT VISCOSITY AROMATIC CONTENT FREEZING POINT ↓	TRENDS WITH FUEL COMPOSITION NO RECOMMENDATION LOW TEMPERATURE BEHAVIOR MATERIAL COMPATIBILITY ANALYSIS OF IN-FLIGHT TEMPERATURES DESIGN OF SYSTEM MOD. FOR HIGH F. P. EXPERIMENTAL STUDY OF LOW TEMP PUMPABILITY FULL-SCALE WING TANK SIMULATOR RAPID FREEZING PT MEASUREMENT METHOD

CS-80-1485

STRESS RELAXATION OF ELASTOMER AT 150° C  
BUTADIENE-ACRYLONITRILE RUBBER



STRESS RELAXATION OF ELASTOMER IN 60% AROMATICS FUEL  
BUTADIENE-ACRYLONITRILE RUBBER

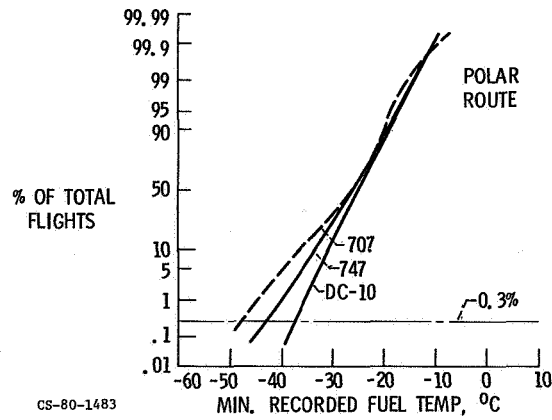


STATUS OF RECOMMENDATIONS ON FREEZING POINT RESEARCH

RECOMMENDATION	RESEARCH PROGRESS
ANALYSIS OF IN-FLIGHT FUEL TEMPERATURES	COMPLETED BOEING SURVEY; COMPLETED BUSINESS JET CALCULATIONS NASA IN-FLIGHT TEMP PROFILE SURVEY IN PROGRESS
DESIGN OF AIRCRAFT SYSTEMS FOR USE WITH HIGH F. P. FUELS	COMPLETED BOEING STUDIES
EXPERIMENTAL STUDY OF LOW TEMPERATURE PUMPABILITY	COMPLETED LOCKHEED STUDY; COMPLETED BOEING-A.F. STUDY; LOCKHEED HEATED FUEL STUDY IN PROGRESS
FULL-SCALE FUEL TANK SIMULATOR STUDIES	FUTURE
RAPID FREEZING POINT MEASUREMENT	PROJECT TO START IN 1980

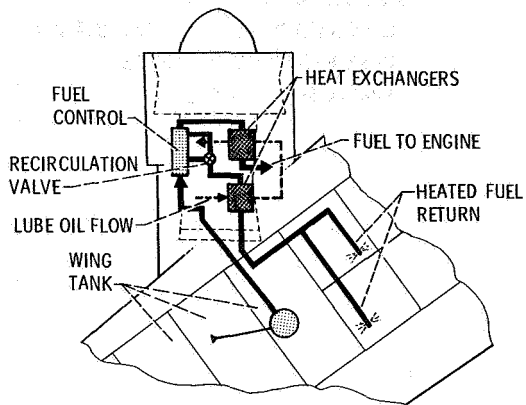
CS-80-1487

STATISTICAL SUMMARY OF FLIGHT DATA



CS-80-1483

FUEL HEATING SYSTEM STUDY-BOEING  
 FUEL/OIL HEAT EXCHANGER SYSTEM



ADVANTAGES

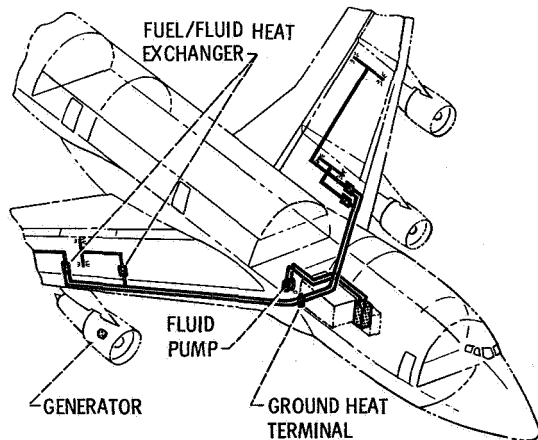
- USES EXISTING HEAT REJECTION HARDWARE
- LOW COST - LOW PENALTY
- SIMPLE SYSTEM, RELATIVELY MINOR MODIFICATION

DISADVANTAGES

- LIMITATION TO QUANTITY OF HEAT AVAILABLE (-34° C FREEZE PT MAX.)
- VARIABLE HEAT AVAILABLE, DEPENDENT ON ENGINE OPERATING POINT

CD-12314-07  
 CS-78-2880

FUEL HEATING SYSTEM STUDY-BOEING  
 ELECTRICAL HEATING SYSTEM



ADVANTAGES

- UNLIMITED HEAT AVAILABLE (UP TO -18° C FREEZE PT)
- INDEPENDENT CONTROL
- ADAPTABLE TO GROUND HEATING FOR LAYOVER

DISADVANTAGES

- MAJOR MODIFICATION-ADDITIONAL SYSTEM
- WEIGHT PENALTY
- CYCLE PENALTY WHEN USED

CD-12315-07  
 CS-78-2881



### FUEL PUMPABILITY APPARATUS WITH ADDED HEATING LOOP

