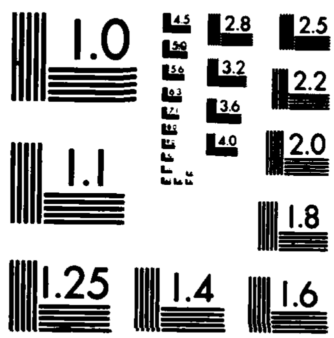
AD-A174 091 AVGAS/AUTOGAS (AVIATION GASOLINE/AUTOMOBILE GASOLINE) 1/1
COMPARISON WINTER GRADE FUELS(U) FEDERAL AVIATION
ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT
UNCLASSIFIED A M FERRARA JUL 86 DOT/FAA/CT-86/21 F/G 21/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(2)

DOT/FAA/CT-86/21

FAA TECHNICAL CENTER
Atlantic City Airport
N.J. 08405

AVGAS/AUTOGAS COMPARISON: WINTER FUELS

GRADE

Augusto M. Ferrara

July 1986

Interim Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

US Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-86/21	AD-A174 091	

4. Title and Subtitle

AVGAS/AUTOGAS COMPARISON: WINTER GRADE FUELS

5. Report Date

July 1986

6. Performing Organization Code

ACT-320

7. Author(s)

Augusto M. Ferrara

8. Performing Organization Report No.

DOT/FAA/CT-86/21

9. Performing Organization Name and Address

Federal Aviation Administration
Technical Center
Atlantic City Airport, New Jersey 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, New Jersey 08405

13. Type of Report and Period Covered

Interim

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report describes dynamometer tests which simulated conditions found in a general aviation aircraft. In these tests, automobile gasoline was tested and compared with aviation gasoline. The tendency for vapor lock and detonation was measured as a function of gasoline grade, Reid Vapor Pressure, and the age of the fuel.

17. Key Words

Aviation Gasoline (Avgas)
Automobile Gasoline (Autogas)
Reid Vapor Pressure
Octane Number
Detonation
Vapor Lock
Weathered Fuel
Soured Fuel
Dynamometer Tests

18. Distribution Statement

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)

A

ACKNOWLEDGEMENT

The author would like to extend his thanks to the Cessna Aircraft Company for supplying the FAA Technical Center with the C-172 fuel system used in this study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

ADR	Air density ratio
ASTM	American Society of Testing and Materials
avgas	Aviation gasoline
autogas	Automobile gasoline
BMEP	Brake mean effective pressure - psi
BSFC	Brake specific fuel consumption - lbm/hp-hr
BTDC	Before top dead center
CHT	Cylinder head temperature - degC or degF
deg	Degrees of rotation
degC	Degrees Celsius
degF	Degrees Fahrenheit
EAA	Experimental Aircraft Association
EGT	Exhaust gas temperature - degC or degF
FAA	Federal Aviation Administration
FT	Full throttle
ft-lbs	Foot pounds (typically torque)
gph	Gallons per hour
hp	Horsepower
hr	Hour
IBP	Initial boiling point - degC
inHg	Inches of mercury (typically manifold pressure)
inH_2O	Inches of water (typically fuel or cowling pressure)
lbm	Pound mass
MAP	Manifold pressure - inHg
MON	Motor Octane Number
NIPER	National Institute of Petroleum and Energy Resources
P_{amb}	Ambient pressure - inHg absolute
psi	Pound per square inch
psig	Gauge pressure in pounds per square inch
RON	Research Octane Number
RPM	Revolutions per minute
RVP	Reid vapor pressure - psig
sl	Sea level (used as a subscript)
STC	Supplemental Type Certificate
T_{amb}	Ambient temperature - degC or degF
T_{dew}	Dew point - degC or degF
VAC	Volts alternating current
VDC	Volts direct current
W_f	Fuel flow - gph
100LL	100 octane avgas with a low lead content

EXECUTIVE SUMMARY

This report describes dynamometer tests which simulated conditions found in a general aviation aircraft's fuel system. In these tests, automobile gasoline was tested and compared with aviation gasoline. The tendency for vapor lock and detonation was measured as a function of gasoline grade, Reid Vapor Pressure, and the age of the fuel. The most significant observations from these tests are as follows:

1. The fuel temperature at which vapor lock testing is conducted is critical. The most severe case of vapor lock with autogas occurs when the tank temperature lies between 100 and 110 degrees Fahrenheit (38 to 43° C). It is interesting to note that this temperature range is above the initial boiling point of the fuels tested.

2. For this fuel system, the onset of vapor lock depended on the fuel flow rate. The occurrence of percolation in the system implies that the fuel system design can also have an effect. This needs to be investigated further.

3. The engine cooling air temperature did not have a significant effect on the tendency to vapor lock, but flight tests for certification should be conducted on as hot a day as possible to minimize cooling the fuel in the tanks.

4. Whenever the fuel temperature in the system exceeds the initial boiling point of the fuel, there is vapor in the system. This vapor affects both the fuel flow meter and the fuel pressure. For a gravity feed fuel system such as is found on the C172, either fuel flow or fuel pressure would be a useful indicator of the onset of vapor lock.

5. The engine used during these tests was a Lycoming O-320, designed to operate on 91/96 octane avgas. All the autogas samples tested with this engine detonated to some extent. The Motor Octane Number for a particular sample is more useful in predicting detonation than the Research Octane Number.

6. Carburetor foaming occurs when operating at low power settings with relatively cool autogas. For this engine, it did not cause an operational problem, but it deserves further investigation.

7. For this fuel system, there was a slight material compatibility problem with autogas. The o-rings in the fuel selector valve would swell when the engine was shut down on autogas.

8. The horsepower does not vary significantly between avgas and autogas unless detonation is occurring.

9. Detonation could not be induced in this engine when operating with 100LL avgas. Likewise, vapor lock could not be induced when testing with 100LL avgas in this fuel system.

INTRODUCTION

The Experimental Aircraft Association (EAA) and other organizations have actively pursued obtaining Supplemental Type Certificates (STC's) which allow the use of automobile gasoline (autogas) in low compression aircraft engines. Typically, the aircraft which qualify for these STC's are older aircraft whose engines were originally certified for 80 octane aviation gasoline. The driving force behind these STC's is the reduced availability of 80 octane aviation gasoline and the large price difference between aviation gasoline (avgas) and autogas.

As the price differential between avgas and autogas grows, there is increasing pressure to substitute autogas for other grades of avgas. This raises a number of questions which need to be answered. The broader distribution of constituents in autogas, when compared with avgas, tends to increase the Reid Vapor Pressure (RVP) of the fuel which in turn adversely affects the amount of vapor formed in the aircraft fuel system. The lower initial boiling point associated with autogas means that vapor will be formed at lower temperatures than with avgas and the use of 110 degrees Fahrenheit (°F) during certification of aircraft may not apply when certifying an aircraft to Federal Aviation Regulation 23.961 with autogas. The octane rating techniques differ between avgas and autogas and the ratings typically associated with autogas may not apply to aircraft engines. As the fuel ages (sours), autogas will lose a greater percentage of its constituents than avgas and there is the possibility that this loss will adversely affect the octane rating.

The Central and New England Regions of the Federal Aviation Administration (FAA), who are responsible for the certification of general aviation aircraft and their engines, requested a program be initiated at the FAA Technical Center which would address these concerns. This report discusses the program and its results.

BACKGROUND.

The typical performance profile for an aircraft engine is substantially different than the typical performance profile of an automobile engine. At cruise speeds an automobile engine will operate between 10 and 30 percent of its rated horsepower. An aircraft engine will operate between 50 and 75 percent of its rated power during normal cruise conditions. During takeoff and climb an aircraft engine will be operating at its maximum rated power (less the performance loss due to the prevailing pressure altitude) for extended periods of time. Even during acceleration, it is unusual for an automobile engine to operate at its rated horsepower. Tne operating temperatures of an aircraft engine are higher than those of an automobile engine and the higher the operating temperature the greater the tendency for detonation to occur. Also, the greater the power, the greater the tendency for detonation to occur. This explains in part why there are different procedures for determining the octane rating of autogas when compared to avgas.

There are three different octane rating techniques of interest to this program: the Research Method, American Society of Testing and Materials (ASTM) standard D-2699; the Motor Method, ASTM standard D-2700, and the Aviation Supercharge method, ASTM D-909. The principle difference between the methods involves changes in the operating speed and temperature to reflect the operating environment to which the fuel will be exposed. The Research Octane Number (RON) is generally applicable to engines which are subject to relatively light duty cycles, where as the Motor Octane Number (MON) (which is related to Aviation Lean Octane Number) is applicable to engines which are subject to heavy or severe duty cycles. The Aviation Supercharge Octane Number is meant for heavy duty applications where the fuel-to-air ratio is kept rich to help suppress detonation. Table 1 outlines some of the key differences between the techniques. For more detail refer to the appropriate ASTM standards.

TABLE 1. SOME DIFFERENCES BETWEEN THE VARIOUS ASTM OCTANE RATING STANDARDS

Test Variable	Aviation Supercharge Method	Research Method	Motor Method
Engine speed (RPM)	1800	600	900
Timing (deg BTDC)	45	13	variable
Oil Temperature (degF)	165	135	135
Coolant Temperature (degF)	375	212	212
Air Temperature (degF)	125	83 (initial)	100
Manifold or Mixture Temperature (degF)	225	N/A	300
Fuel System	Injected	-- Carburetor --	
Key Variable	Manifold Pressure	-- Compression Ratio --	

Gasolines are intended to be volatile and the Reid Vapor Pressure (RVP) is a general measure of the volatility of a fuel. Essentially, the RVP is the vapor pressure of the fuel at 100° F and it can be interpreted as an indicator of the amount of vapor a fuel will generate when it is heated in the fuel system. An aircraft not only has higher operating temperatures, it also operates at reduced atmospheric pressures when at altitude. Both of these factors aggravate the formation of vapor. This explains why the maximum RVP allowed for aviation fuels is lower than for autogas. The maximum RVP for avgas is 7.0 psi. The maximum RVP for autogas varies with the season. Class E fuels (winter grades) are allowed to reach 15 psi, whereas class A fuels, which are sold in the Southwest during the summer, may have a maximum RVP of 9.0 psi. Summer fuels in New Jersey are class C fuels (11.5 psi maximum).

The longer the fuel remains in vented tanks, the more likely the fuel will lose the more volatile components. The loss of the more volatile components may alter the octane rating of the fuel. In addition, the more heavy ends (higher molecular weight and, conversely, higher boiling point) the greater the tendency to form gum deposits as the fuel sits in the tank. A typical aircraft will be operated about once a week, whereas a typical car is operated at least once a day. As a consequence, fuel tends to sit in general aviation aircraft for longer periods of time than in an automobile. The distillation procedure described in ASTM D-86 is a rough measure of the distribution of components found in the fuel. During a distillation, the operator measures the temperature reached as a given percentage of the fuel is collected from the condenser. (Typical distillation curves for avgas and autogas are found in figure 1.) For this reason, avgas has a narrower distribution of constituents than autogas and this is reflected in the distillation curve.

With the drive towards using automobile gasoline in general aviation aircraft, certification procedures need to be evaluated to insure the necessary margin of safety. This program studied the effect of changes in RVP and octane rating on the tendency to vapor lock and detonate in a Lycoming 0-320 engine mounted on the Technical Center's dynamometer.

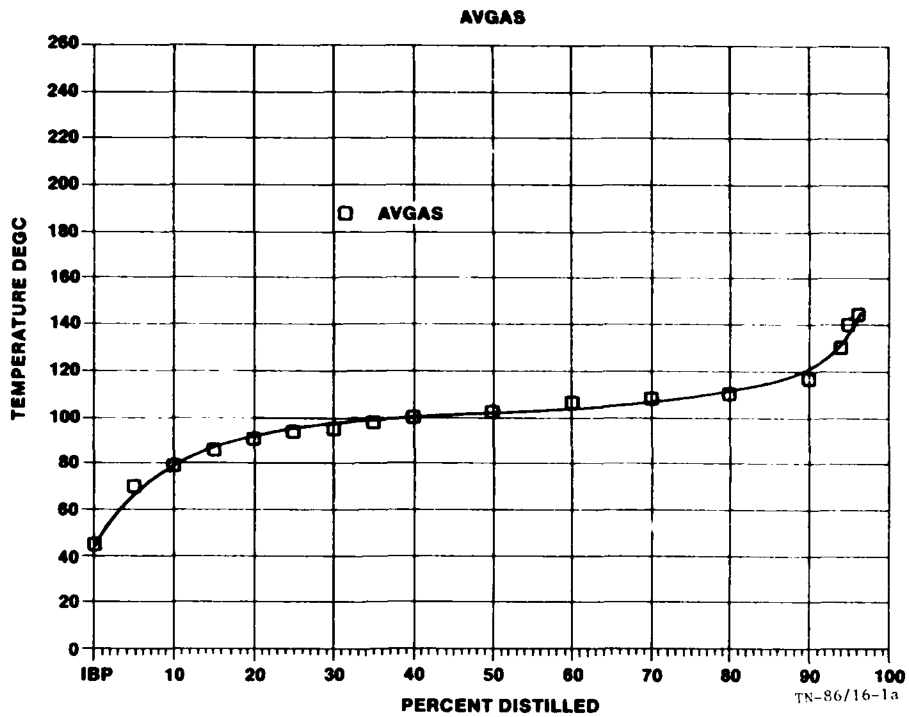
TEST APPARATUS

The vapor lock and detonation tests were conducted using the Technical Center's dynamometer. A Lycoming 0-320 is mounted on the dynamometer and fuel is supplied to the 0-320 through a Cessna 172 fuel system. Figure 2 shows the general location of the principle components.

The Cessna fuel system is mounted in the same location relative to the engine as is found on the C-172 installation. The tanks were modified to incorporate heat exchangers for regulating the temperature of the test fuel. The heat exchangers consist of approximately 20 feet of 3/8-inch copper tubing laid out in a regular pattern across the bottom and inside of each tank. Separate controllers regulate the supply of water to each heat exchanger in order to either heat or cool the fuel as is required for the particular run. The fuel lines to the engine are wrapped with electrical heating tape and the temperature of individual segments are regulated with automatic controllers. With this system, vapor lock studies were conducted with hot fuel in one tank while cool fuel is available in the other tank, so that a recovery can be made without restarting the engine should vapor lock occur.

The Lycoming engine is similar to the 0-320 found in a Cessna 172 but it is not an airworthy engine and it does not match an existing model designation. The engine has an 8.5:1 compression ratio; it is carbureted and it was designed to operate on 91/96 avgas (which is no longer available). The engine cooling air is regulated to provide the desired temperature and pressure and it is supplied through a test cell cooling hood. The oil temperature is automatically maintained at the desired temperature and the temperature and humidity of the carburetor inlet air is regulated using two window air-conditioners and a heat exchanger which is mounted on the exhaust stack. The engine speed and the torque developed are measured and recorded automatically. The fuel consumption of the engine is measured using a Fuelgard™ system similar to those used in airworthy aircraft.

The engine is equipped with a Lycoming Detonation Analyzer which consists of vibration pickups mounted on each cylinder and electronics, which allows one to look at the compression stroke for the cylinder selected. As the operating conditions approach those conducive to detonation, the amplitude of the signal increases. When detonation occurs, the region of high amplitude vibration is fairly wide and the oscilloscope screen appears to "flash." The number of flashes coincides with the number of times that cylinder detonates. Typically, detonation is reported as the number of flashes per minute.



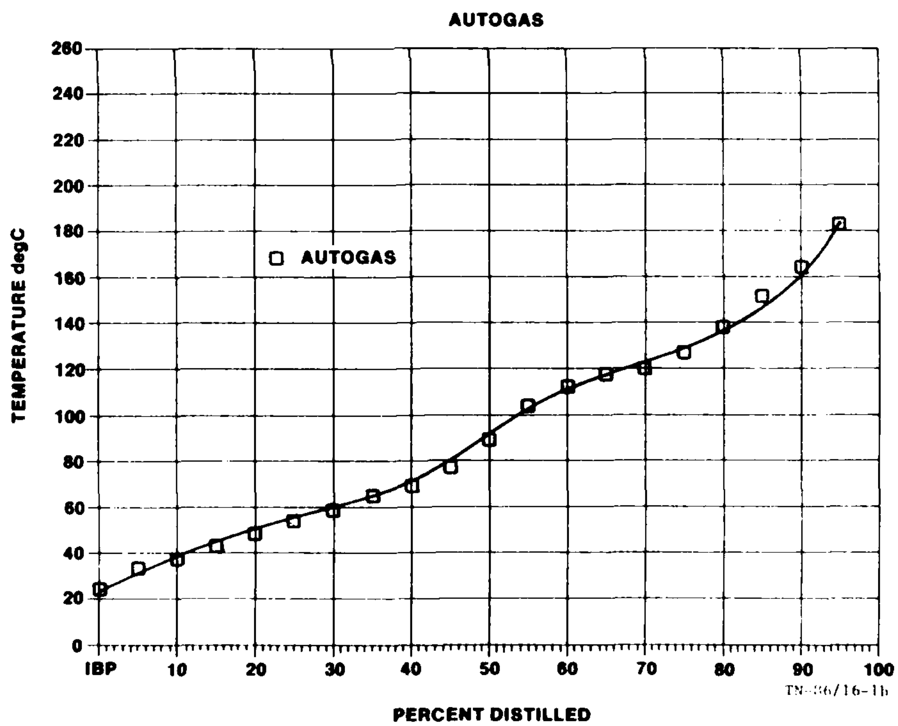


FIGURE 1. TYPICAL DISTILLATION CURVES FOR AVGAS AND AUTOGAS

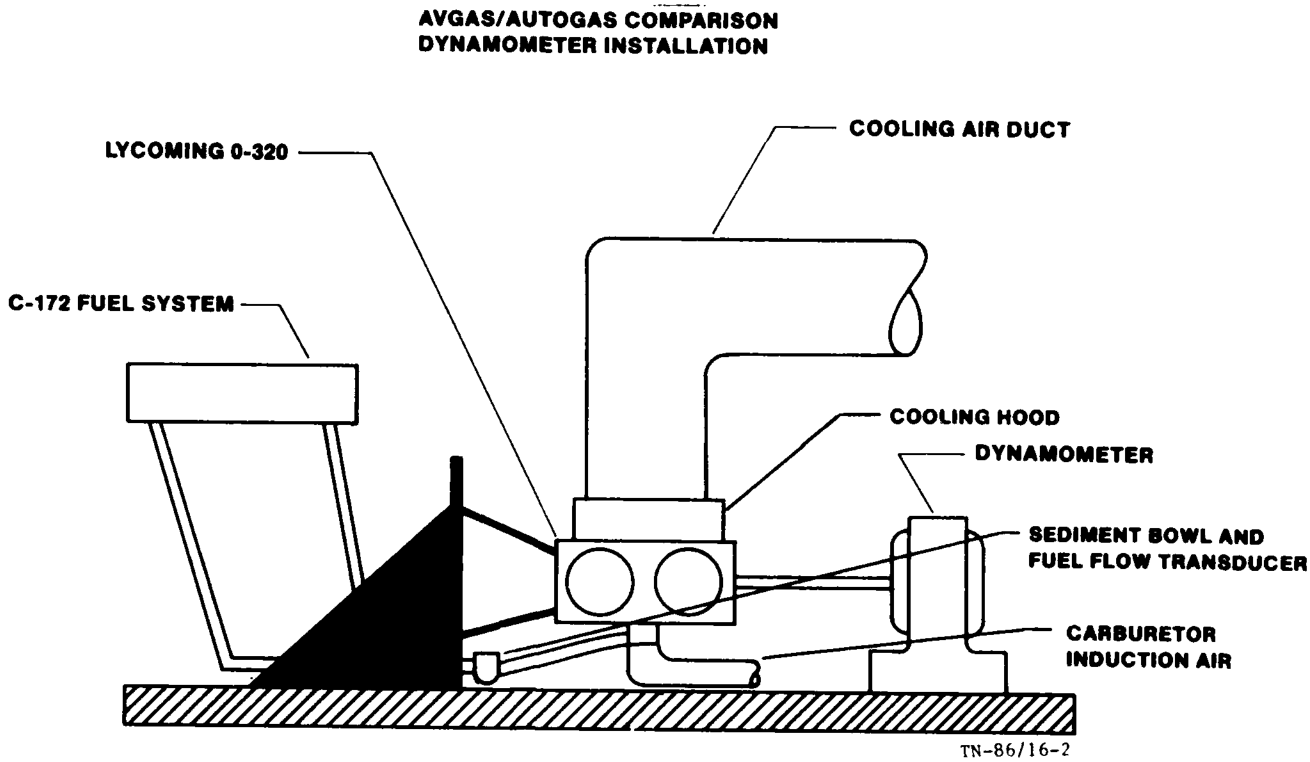


FIGURE 2. GENERAL LOCATION OF THE PRINCIPAL DYNAMOMETER COMPONENTS

The dynamometer allows regulation of either the engine speed or the load on the engine. The specific load or speed conditions can be manually entered or varied using a computer and the appropriate interface cards. The dynamometer can handle engine speeds up to 5000 RPM and engines of up to 500 horsepower. The throttle position and the mixture position are integrated into the dynamometer controls and are recorded automatically.

Table 2 lists the data which is recorded on an automatic data acquisition system. During a typical run the data are recorded every fifteen seconds, though the data acquisition system can handle a scan rate of less than a second to several hours. The operator has the ability to trigger an event marker which is recorded along with the other parameters. The detonation data is recorded separately, since it requires some judgement on the part of the operator.

The RVP and distillation tests are conducted at the Technical Center using the procedures and equipment specified in the appropriate ASTM specifications. The octane measurements and selected RVP tests were conducted at Sun Refining and Marketing, Marcus Hook, Pennsylvania, under contract to the Technical Center.

TABLE 2. DATA WHICH ARE RECORDED ON THE AUTOMATIC DATA ACQUISITION SYSTEM

Description	Units
Engine torque	ft-lbs
Engine speed	RPM
Manifold pressure	inHg (absolute)
Engine cooling air	inH_2O
Fuel pressure	inH_2O
Oil pressure	psig
Event marker, operator triggered	VDC
Fuel flow	gph
Throttle position	percent
Mixture position	percent
Tank in use indicator	VDC
Carburetor supply air dew point	deg C
#1 cylinder head temperature	deg C
#2 cylinder head temperature	deg C
#3 cylinder head temperature	deg C
#4 cylinder head temperature	deg C
Fuel temperature, top of avgas tank	deg C
Fuel temperature, bottom of avgas tank	deg C
Fuel temperature, top of autogas tank	deg C
Fuel temperature, bottom of autogas tank	deg C
Fuel temperature, avgas line	deg C
Fuel temperature, autogas line	deg C
Fuel temperature, sediment bowl	deg C
Fuel temperature, carburetor bowl	deg C
Oil temperature	deg C
Air temperature, carburetor inlet	deg C
Air temperature, upstream of carburetor	deg C
Cooling air temperature	deg C
Air temperature in carburetor area	deg C
Carburetor supply air temperature	deg C
#1 exhaust gas temperature	deg C
#2 exhaust gas temperature	deg C
#3 exhaust gas temperature	deg C
#4 exhaust gas temperature	deg C
Ambient air temperature	deg C

TEST PROCEDURES

The test procedures for the various types of test are listed below. Appendices A, B, and C contain the checklists used prior to each run.

BASELINE TESTS: The baseline performance tests were conducted as follows.

a. Fuel the tanks with avgas, draw a sample and measure the RVP and distillation curve.

b. Start the engine and allow the oil to rise to operating temperature. Conduct a magneto check, then set the engine cooling air temperature and pressure so that the cylinder head temperatures are in the normal operating range (175° to 200° C or 350° to 400° F).

c. Set the dynamometer to the speed control mode and select an engine speed of 2000 RPM and a manifold pressure of 20 inHg. If necessary, set the mixture to full rich.

d. Allow conditions to stabilize, then take a reading manually.

e. Increase (or decrease as appropriate) the manifold pressure in steps of 2 inHg to cover the full range of manifold pressures. Repeat step d for each manifold pressure selected.

f. Increase the engine speed in steps of 100 RPM to cover the range of engine speeds through 2700 RPM. Repeat steps d and e for each engine speed.

g. Gradually reduce the power and allow the engine to cool. Perform a magneto check and shut the engine down using the mixture control.

VAPOR LOCK TESTS: The vapor lock tests were conducted in the following manner.

1. Fuel the tanks with the proper test fuel; draw a sample and test the RVP and distillation. Select the desired initial tank temperature and turn the tank heaters on. Allow the fuel in the tank to rise to operating temperature. Draw a sample and measure the RVP.

2. Start the engine and allow the oil to rise to operating temperature. Perform a magneto check. Make sure the engine cooling air temperature and pressure are set to the desired point.

3. Set the engine speed and manifold pressure to obtain a fuel flow rate of 2.5 gph. Allow conditions to stabilize; observe for signs of vapor lock.

4. If vapor lock does not occur, turn the appropriate line heaters on to a setting of 150° F (the line heaters are proportional relative to the temperature of the outside wall of the fuel lines; the inside wall never reaches this temperature). Observe for signs of vapor lock.

5. When or if vapor lock does occur, switch to the other tank; trigger the event marker and note the temperature in the fuel lines, the sediment bowl, and the carburetor bowl. As conditions stabilize, turn the line heaters off and return to the original tank in use.

6. Change the manifold pressure and engine speed to increase the fuel flow in increments of 2.5 gallons per hour (gph) until maximum power (usually 13.5 gph). Allow conditions to stabilize; observe for signs of vapor lock and repeat steps 4 and 5 as necessary.

7. Once again set the fuel flow to 2.5 gph. Repeat steps 3 through 5. Make note of any significant changes that occurred between the initial data point and this final data point.

8. Reduce the power and allow the engine to cool. Perform a magneto check then shut the engine down by setting the mixture control to full lean.

9. Draw a sample of gasoline from the tank in use and measure the RVP and the distillation curve if a drop of more than 3 psi is measured between the initial RVP and the posttest RVP.

10. Prepare a time history plot of the various fuel system temperatures and look for the point where the individual temperature begins to rise abruptly. This coincides with the onset of vapor lock. Compare this temperature with the onset of vapor lock for fuels with different Reid Vapor Pressures and initial tank temperatures.

DETONATION SURVEYS: The onset of detonation was measured as follows:

i. Fuel the tank with the test fuel. Draw a sample and measure the RVP, the distillation curve, and, as appropriate, the octane rating using the research and motor methods.

ii. Start the engine and allow the oil to reach normal operating temperature. Perform a magneto check and set the cowling air temperature and pressure to obtain cylinder head temperatures at or above the maximum limit (525° F).

iii. Set the mixture to full rich if necessary; increase the engine speed to 2300 RPM and set the manifold pressure to 20 inHg. Allow conditions to stabilize. Observe for signs of detonation.

NOTE: Whenever detonation occurs, trigger the event marker and make a note of the number of flashes per minute detected on the Lycoming detonation analyzer. DO NOT OPERATE AT SETTINGS WHICH RESULT IN DETONATION FOR EXTENDED PERIODS OF TIME.

iv. If no detonation occurs, reduce the fuel fuel flow in steps of 5 percent; allowing conditions to stabilize between reductions in fuel flow. Repeat until detonation or lean misfire occurs.

v. Reset the mixture to full rich and increase manifold pressure in increments of 2 inHg until full throttle. Repeat steps iii and iv for each setting selected.

6. Increase the engine speed in steps of 100 RPM up to 2700 RPM. Repeat steps iii, iv and v for each setting selected.

7. Reduce the power setting and allow the engine to cool. Perform a magneto check and shut the engine down using the mixture control.

HORSEPOWER CORRECTION COMPUTATIONS: The horsepower measured will vary from day to day depending on the atmospheric pressure and the temperature of the air reaching the carburetor inlet. To make valid comparisons, the horsepower is corrected to what would be expected at standard atmospheric temperature and pressure. The computations were performed using equations found in the July 1979 edition of the Pratt and Whitney Aeronautical Vest Pocket Handbook.

The calculated horsepower is determined from the torque and engine speed using the following relationship:

$$hp = \frac{\text{RPM x Torque}}{5252}$$

where the torque is in ft-lbs.

The expected horsepower for standard sea level conditions is approximated by the following relationship:

$$hp_{sL} = \frac{hp \times 0.9}{ADR - 0.1}$$

where the air density ratio (ADR) is determined from the ambient atmospheric conditions using:

$$ADR = 17.336\ P_{amb}/T_{amb}$$

where P_{amb} is in inHg absolute and T_{amb} is in degrees Rankine.

SUMMARY OF RESULTS

BASELINE TESTS - AVGAS.

A series of tests were conducted to establish operating proficiency and familiarity with the engine's behavior. These tests were conducted with 100LL avgas, which had a Reid vapor pressure (RVP) of 5.3 psi and an initial boiling point (IBP) of 42° C.

The first test determined which cylinders had the leanest fuel-to-air ratio. This information is useful in predicting which cylinder would detonate first and it provided a feel for the fuel consumption at a given power setting. Since the individual exhaust gas temperature (EGT) probes had a different response in the same exhaust stack, i.e., for the same power setting one probe would consistently yield higher EGT readings, the leanest cylinder was determined by looking at EGT crossover instead of peak EGT. As the mixture is leaned, the EGT will rise until the cylinder is operating with a stoichiometric fuel-to-air ratio. As the mixture is leaned further, the EGT drops until lean misfire occurs.

Figure 3A shows the individual EGT traces as the mixture was leaned from full rich to six gph. The power setting was 25 inHg manifold pressure at 2,500 RPM for this part of the test. The fuel flow is shown in figure 3B. Figure 3C shows the calculated horsepower that was developed during this sequence. As can be seen, both the number one and number two cylinders experienced lean crossover as the flow was reduced to 8 gph and the number two cylinder suffered from lean misfire when an attempt was made to reduce the fuel flow from 7 to 6 gph. This sequence was repeated for several different combinations of engine speed and manifold pressure and the number two cylinder consistently behaved as though it had the leanest mixture with the number one cylinder having the second leanest fuel-to-air ratio.

An attempt was made to induce vapor lock with the same sample of avgas as was used above. The fuel in the tank was heated to 43° C (110° F) and the engine was allowed to stabilize in this configuration. The line heaters were then turned on and the system temperatures were monitored. This sequence of events was terminated when the sediment bowl temperature reached 75° C (167° F), not because the engine vapor locked. See figure 4 for a time history of the fuel system temperatures, the fuel pressure, and the fuel flow readings.

During this sequence, the fuel flow became erratic as the sediment bowl temperature exceeded the initial boiling point of the fuel and it remained erratic as the run continued. This is significant since the sediment bowl is just upstream of the fuel flow transducer and the temperature of the fuel in the sediment bowl is the same as the temperature of the fuel in the transducer. At the conclusion of this test, cool fuel was introduced by switching the tank in use and the fuel flow returned to normal. The vapor that was formed not only disturbed the fuel flow transducer but it started a percolation sequence which raised the temperature in the tank an additional 5° C. The percolation in the fuel lines dramatically affected the fuel pressure with readings anywhere from zero to 35 inH_2O observed. The normal reading was about 24 inH_2O. This implies that either technique would provide an indication of the onset of vapor formation long before vapor lock occurred.

An attempt was made to induce detonation while using the same batch of 100LL avgas as was used in the two tasks above. It was unsuccessful even though the cylinder head temperatures (CHT's) and the oil temperature were at the limits for this engine, the carburetor inlet air temperature was above 100° F and the power and mixture controls were adjusted to obtain the most severe condition possible. This was expected since the engine was designed to operate on 91/96 octane avgas.

Two runs were conducted in order to establish a performance table and to see if there were any differences in the power output as the fuel supply variables were altered. These tests were run using a fresh batch of Gulf 100LL avgas purchased from the fixed base operator at Atlantic City International Airport. During this sequence, the power settings were varied from normal cruise to takeoff power.

Figure 5 shows the data from the first of these runs. In figure 5A, the engine speed and manifold pressure are shown and figure 5B shows the calculated and corrected horsepower. The ambient pressure was 30.47 inHg and the ambient temperature varied from 15° to 18° C (59° to 65° F). The cylinder head temperatures were maintained at 177° C (350° F); the oil temperature was maintained at 82° C (180° F) and the temperature of the carburetor inlet air was used to calculate the corrected horsepower. No significant differences in the horsepower developed were measured as a consequence of running on either hot or cool avgas. In addition, there were

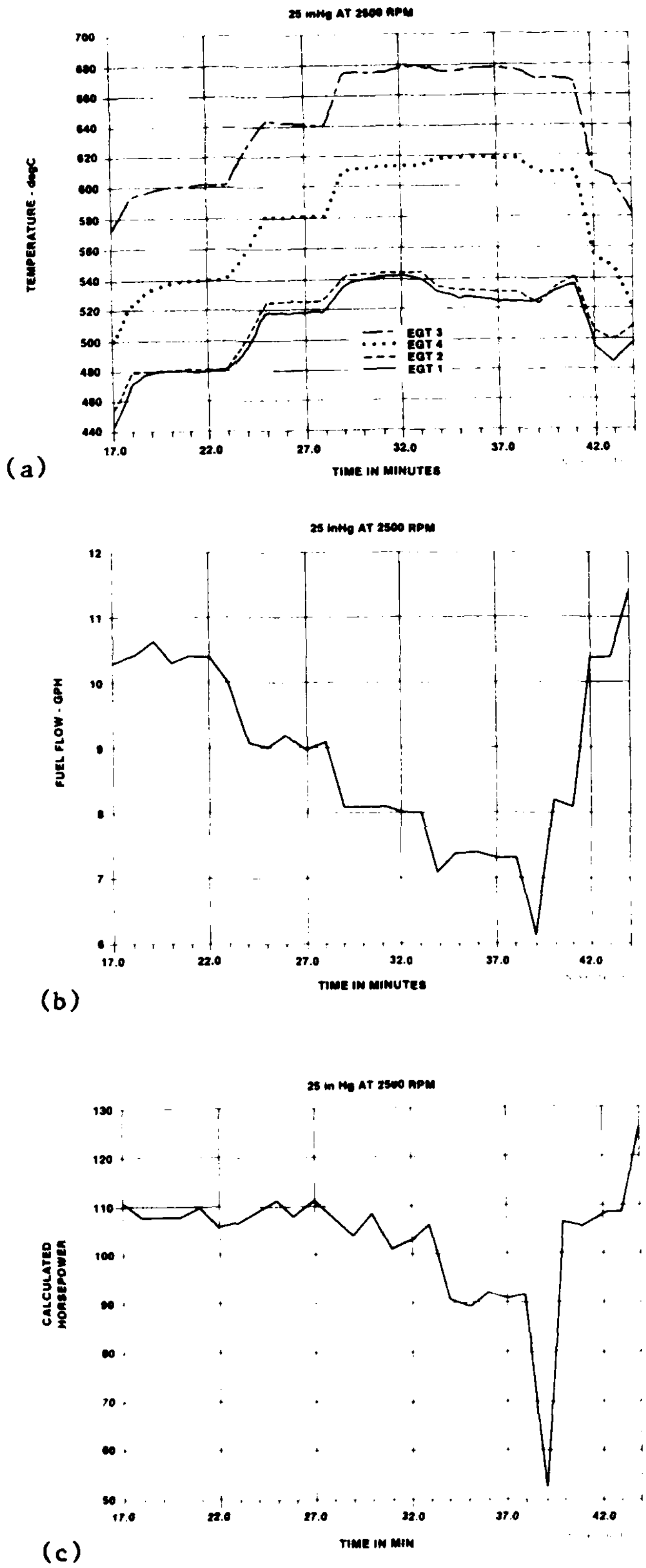
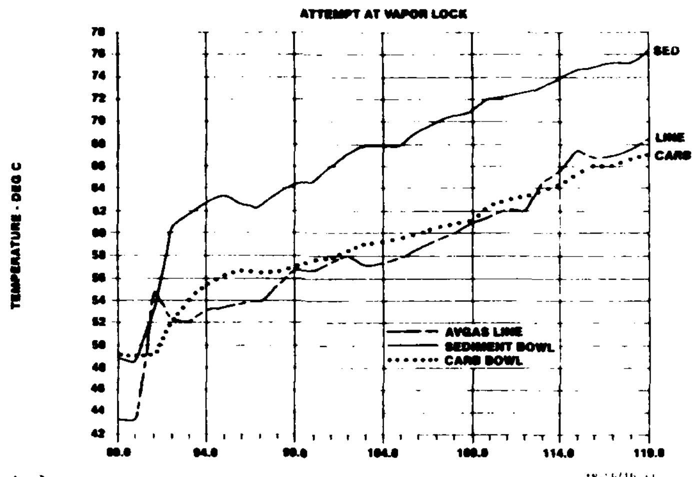
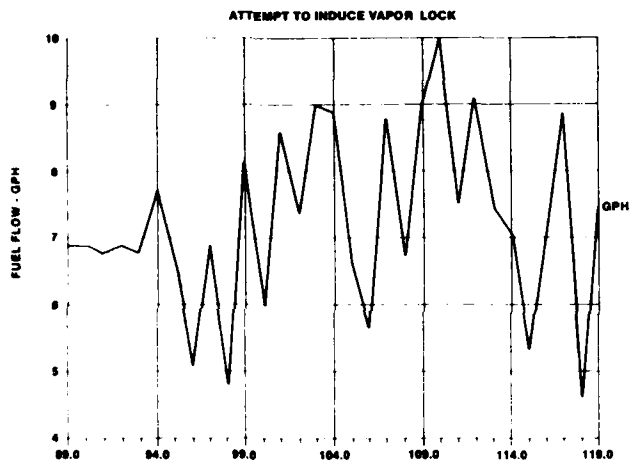


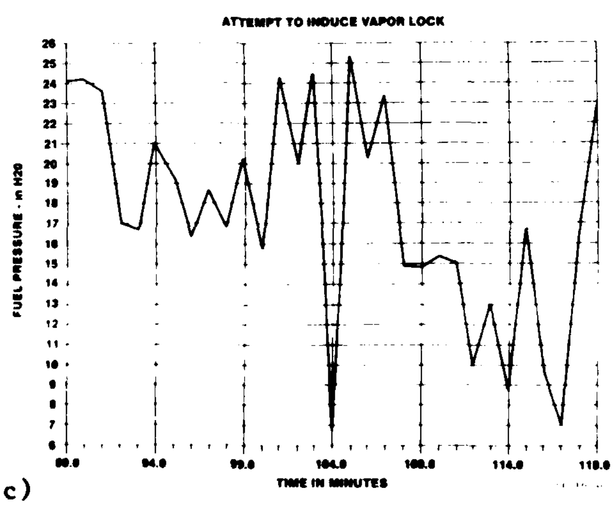
FIGURE 3. LEANEST CYLINDER DETERMINATION USING EGT CROSSOVER



(a)

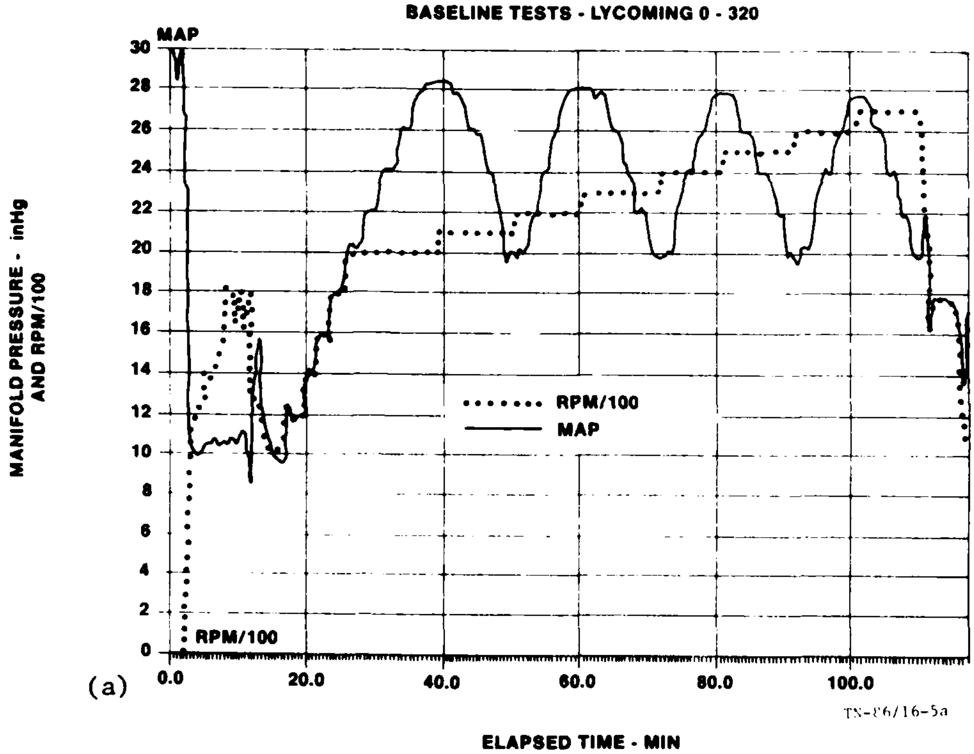


(b)

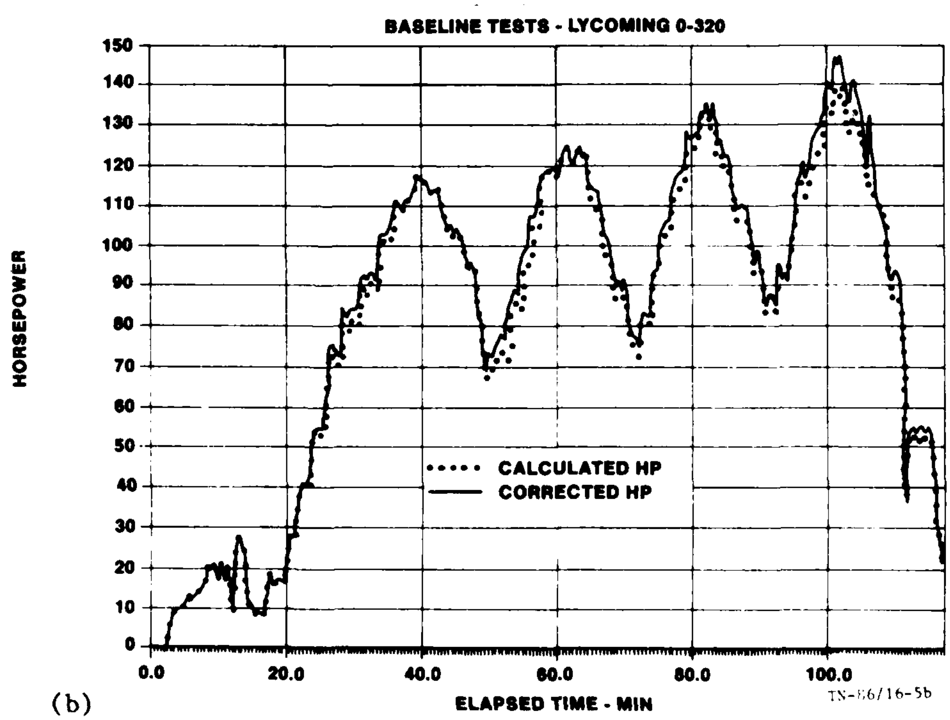


(c)

FIGURE 4. FUEL SYSTEM TEMPERATURES, FUEL FLOW AND PRESSURE DURING AN ATTEMPT TO INDUCE VAPOR LOCK WITH AVGAS



(a)



(b)

FIGURE 5. KEY CONTROL VARIABLES, CALCULATED AND CORRECTED HORSEPOWER DURING THE BASELINE TESTS

no significant variations in fuel pressure or fuel flow as a consequence of operating the engine on either fuel tank.

Figure 6 shows the horsepower as a function of both manifold pressure and engine speed for this engine and figure 7 shows the corresponding fuel flow with the mixture in the full rich position. The brake specific fuel consumption was calculated for these settings (see table 3) and the values are in the normal range for this engine. The full throttle curve in figure 6 collapses onto the 28 inHg curve. This is a consequence of the ducting losses which occur in this installation. The discontinuity in figure 7 for the full throttle curve is due to the power enrichment valve becoming operational.

TABLE 3. BRAKE SPECIFIC FUEL CONSUMPTION FOR VARIOUS MANIFOLD PRESSURES AND ENGINE SPEEDS

(Mixture at full rich; the brake specific fuel consumption is in lbm/hp-hr)

Manifold Pressure	Engine Speed - RPM							
inHg	2000	2100	2200	2300	2400	2500	2600	2700
20	0.57	0.59	0.56	0.56	0.58	0.56	0.55	0.57
22	0.53	0.52	0.53	0.55	0.55	0.54	0.54	0.54
24	0.51	0.51	0.53	0.52	0.53	0.53	0.54	0.54
26	0.51	0.51	0.53	0.53	0.53	0.53	0.54	0.54
28	0.52	0.53	0.52	0.52	0.58	--	--	--
FT*	0.54	0.53	0.53	0.52	0.58	0.57	0.54	0.55

*FT is the full throttle condition.

Figure 8 shows the torque as a function of engine speed and manifold pressure. As can be seen, the torque is higher at lower engine speeds for the same manifold pressure. This means the brake mean effective pressure (BMEP) is higher at lower engine speeds. Since detonation is more probable, the higher the BMEP (all else considered), it is important that an aircraft engine with a variable pitch propeller not be operated at full throttle with the propeller set at coarse pitch (lower engine speeds).

An abbreviated version of the above run was conducted later that day. The results of this test (see figure 9) show that the system is stable and repeatable results can be obtained, given the same operating conditions.

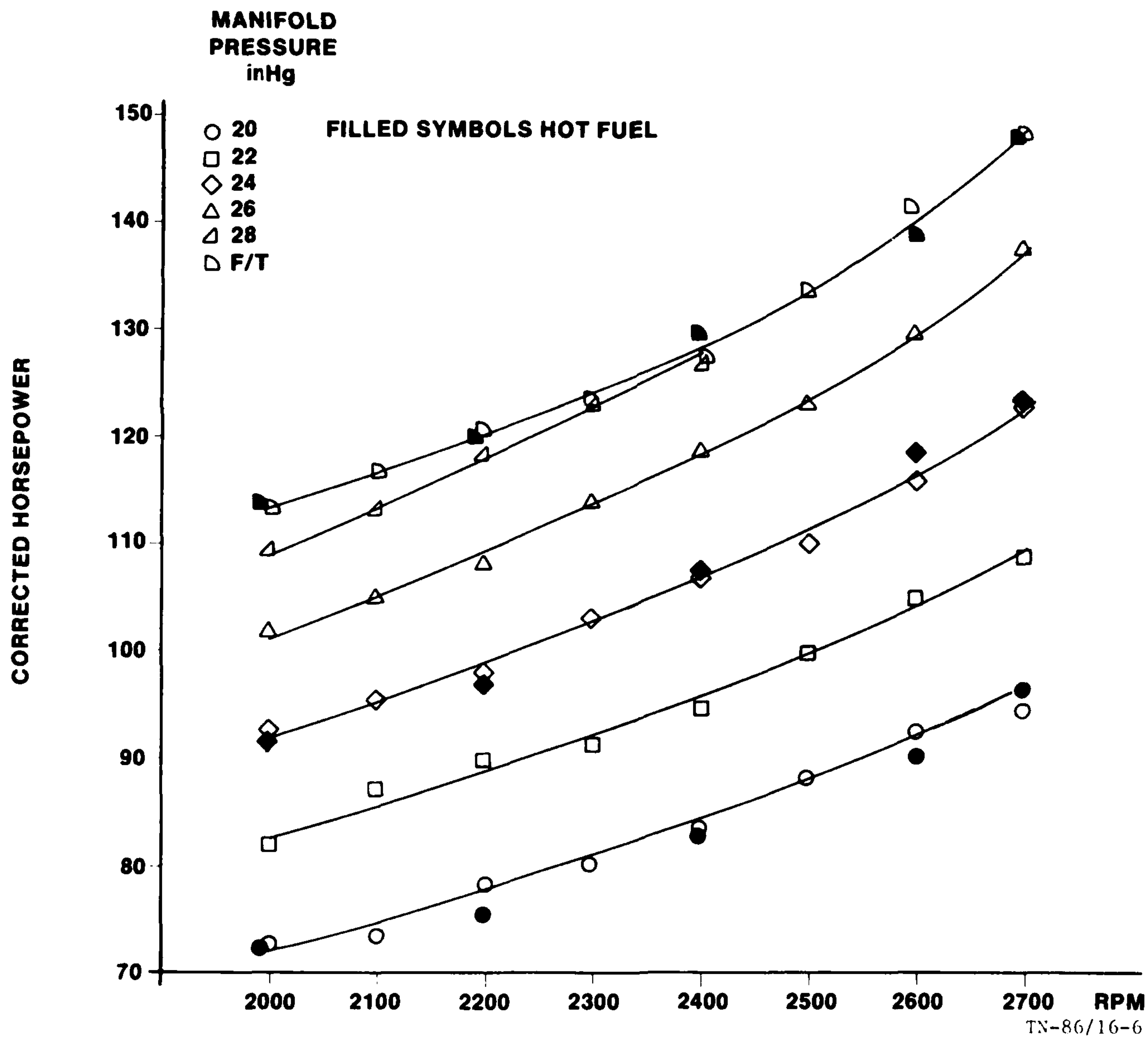


FIGURE 6. CORRECTED HORSEPOWER AS A FUNCTION OF MANIFOLD PRESSURE AND ENGINE SPEED

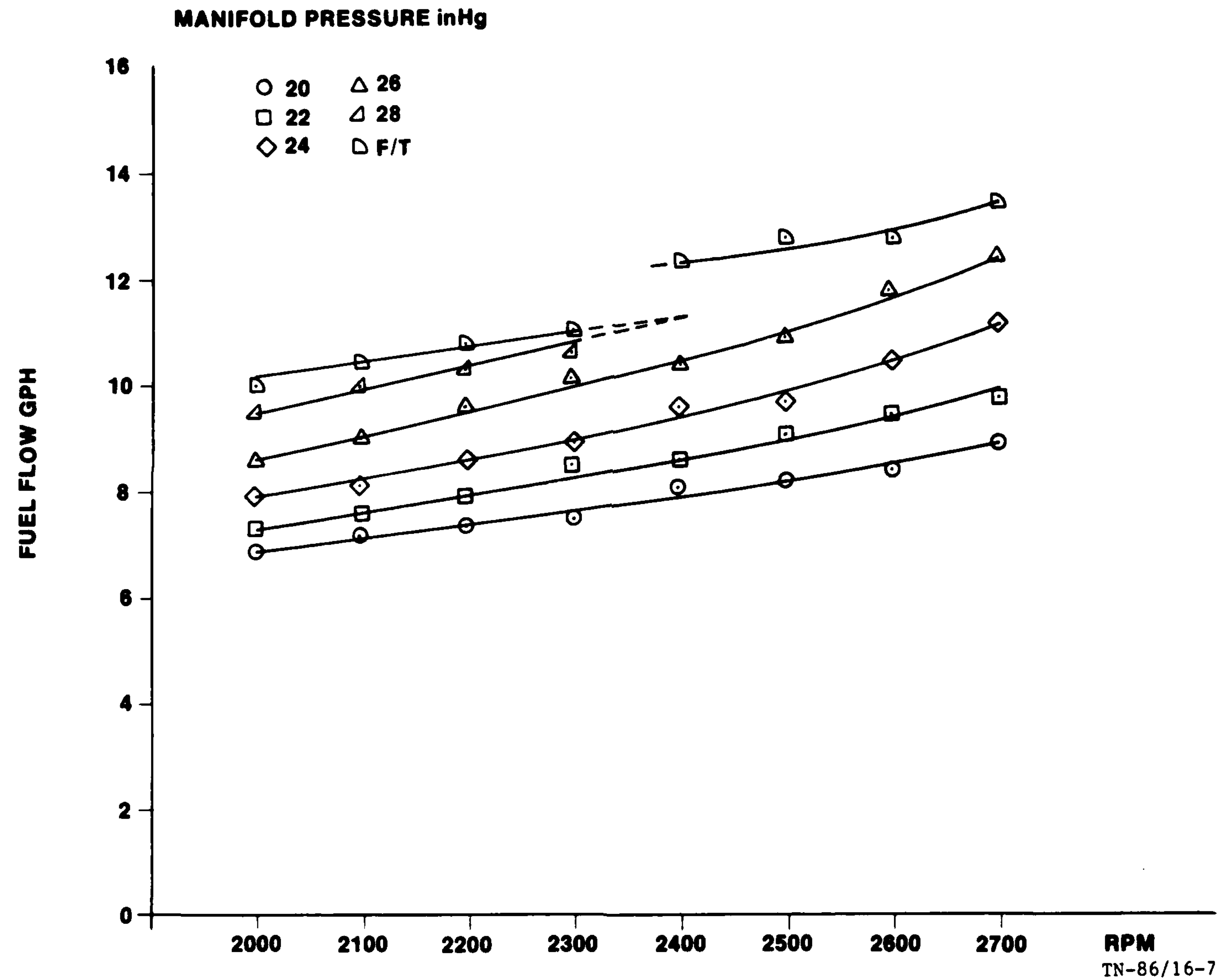


FIGURE 7. FUEL FLOW AS A FUNCTION OF MANIFOLD PRESSURE AND ENGINE SPEED

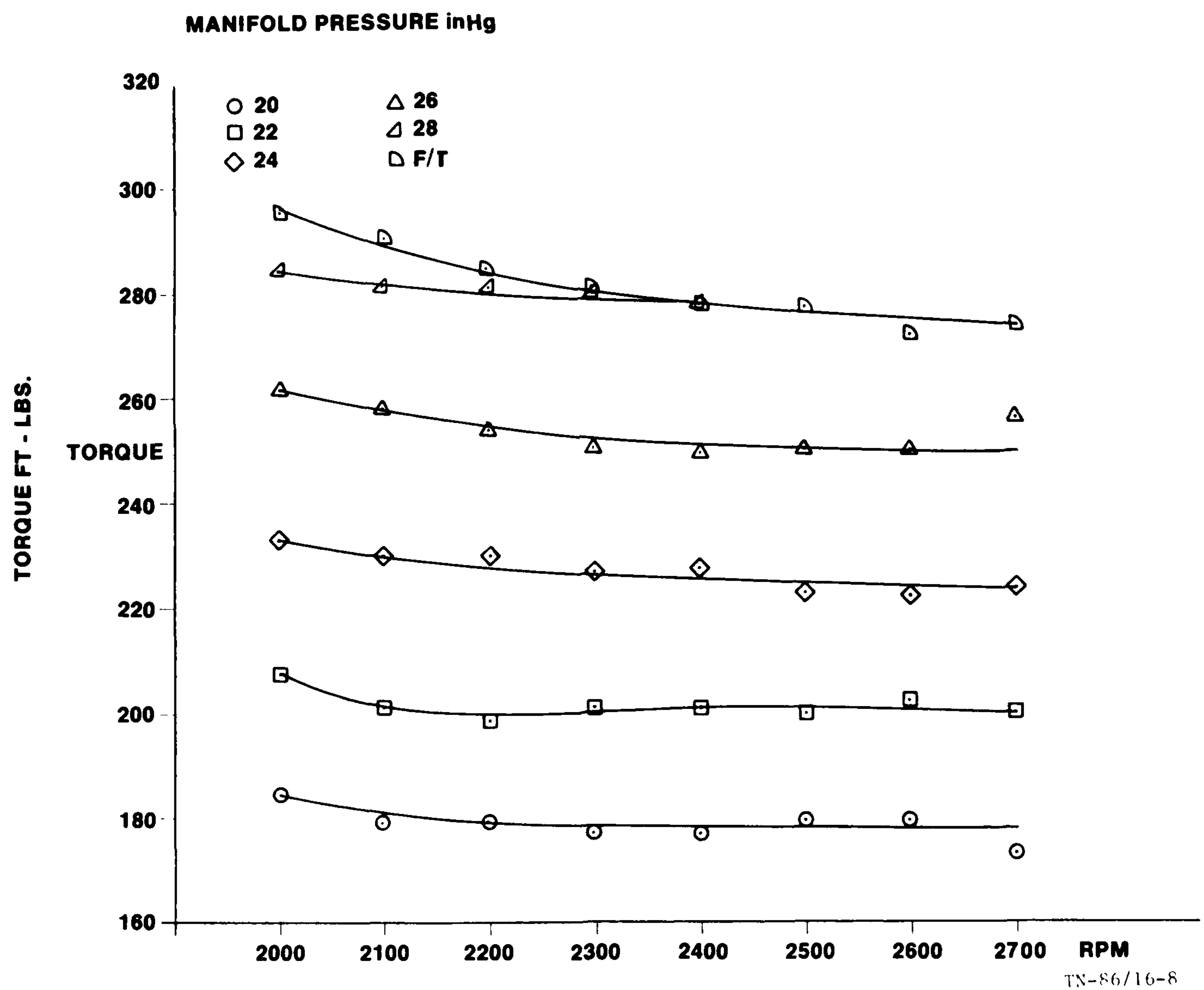
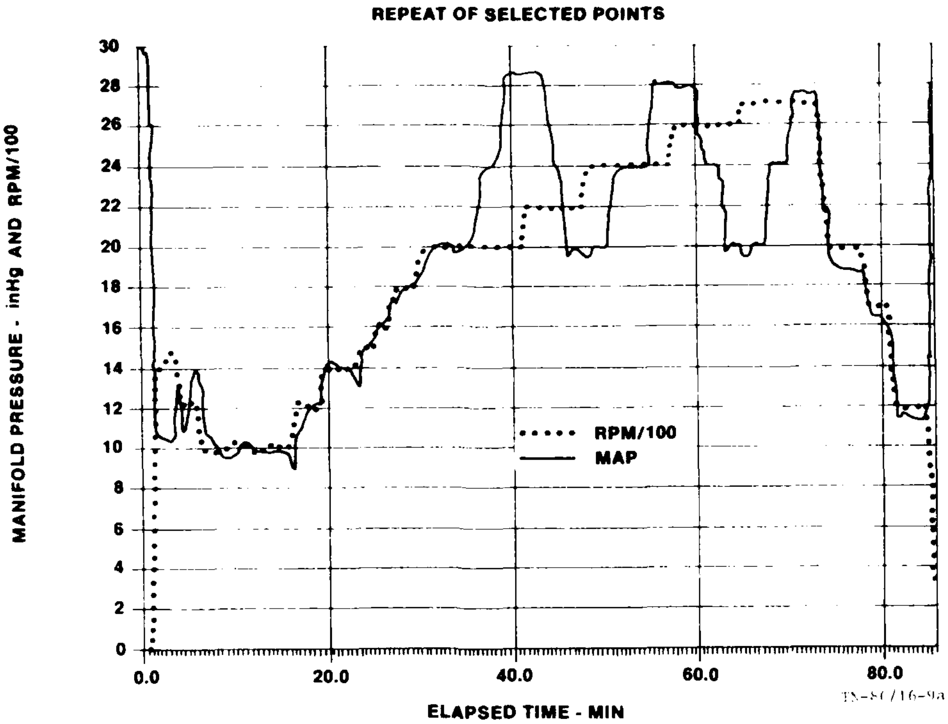


FIGURE 8. TORQUE DURING THE BASELINE RUNS AS A FUNCTION OF ENGINE SPEED AND MANIFOLD PRESSURE



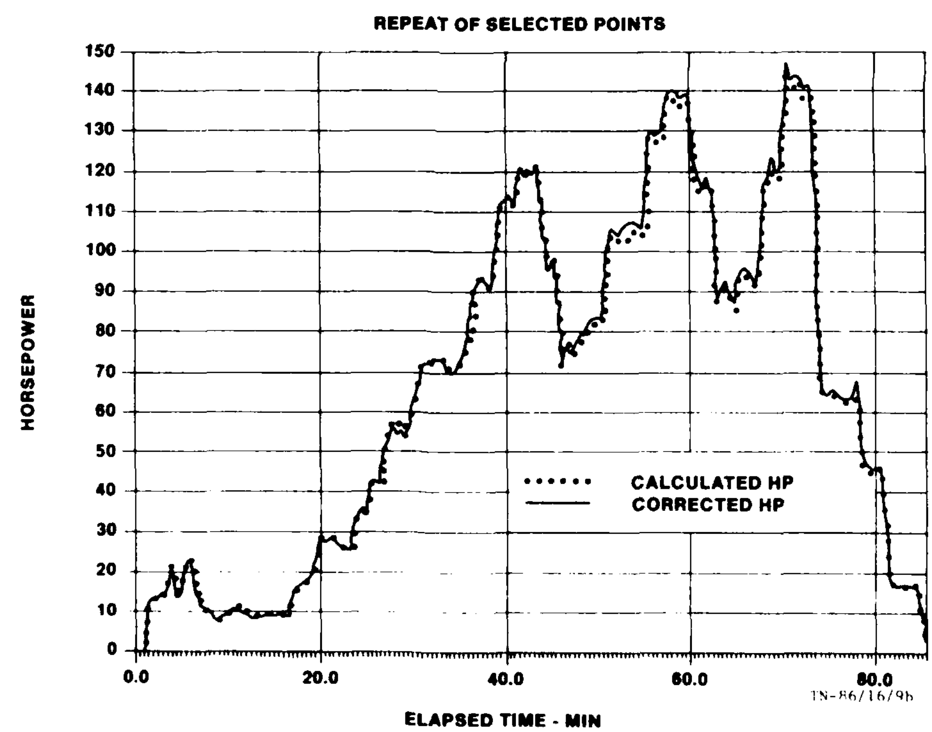


FIGURE 9. KEY CONTROL VARIABLES, CALCULATED AND CORRECTED HORSEPOWER DURING A REPEAT OF SELECTED POWER SETTINGS FOUND IN FIGURE 5

VAPOR LOCK TESTS - AUTOGAS.

Seven fuels were tested for vapor lock. Six of these fuels were gasolines purchased from retailers in the vicinity of the FAA Technical Center and the seventh was a special blend of leaded automobile gasoline. Three of the commercial gasolines were unleaded regular gasolines and the remaining three were were unleaded premium gasolines. Four of the six commercial gasolines were volatility class E fuels (winter blends) and two were volatility class D fuels (one a regular unleaded and one a premium unleaded). The six commercial fuels were sent to Sun Refining and Marketing Company in Marcus Hook, Pennsylvaina, to be tested for the Research and the Motor Octane Numbers and the RVP. The RON and MON values were used in conjunction with the detonation studies conducted along with the vapor lock studies and the RVP's were used as a cross check for the values obtained at the Technical Center. The results of these tests are listed in table 4. It is interesting to note that there was not a significant difference in the RVP between the two classes of fuel.

TABLE 4. PROPERTIES OF THE AUTOMOBILE GASOLINES TESTED BY SUN REFINING AND MARKETING COMPANY

		Tech Center		Sun Refining and Marketing Data				
Fuel ID	Volatility Class	IBP (degC)	RVP (psi)	RVP (psi)	RVP (psi)	RON	MON	R+M/2
HPU	E	25	12.2	12.7	12.8	97.9	87.0	92.5
HRU	E	25	12.4	13.3	13.3	91.6	83.5	87.5
CPU	E	25	13.3	13.6	N/A	96.4	87.5	92.2
CRU	E	26	11.8	13.1	N/A	91.4	83.2	87.3
EPU	D	26	12.7	12.5	12.6	98.0	86.9	92.5
ERU	D	25	14.1	14.0	14.0	94.0	82.5	88.3
SBL	-	30	13.6	-	-	-	-	-

A special blend of leaded gasoline was prepared for the Technical Center approximately two years prior to being tested (sample SBL in table 4). This fuel originally had a RVP of 15 psi and it was stored in a sealed drum. When the fuel was first used, the RVP had decayed to 13.6 psi and the RVP continued to decay for the subsequent runs. Originally this fuel was used to develop expertise when conducting the tests, but since the data is consistent with the following runs, it is included in this report.

The RVP and the distillation was measured prior to each test and a sample was tested after the test to measure any changes in the RVP and distillation. For the most part, the changes were insignificant and they were masked by the normal variation in the respective tests. The only exception was the special blend of leaded gasoline and because of the age of the fuel, the data from these tests were inconclusive. However, they do imply that once the RVP begins to decay, the decay is rapid. An attempt was made to correlate either the initial boiling point of the fuel or temperature at which a certain percent of the fuel was distilled with the fuel temperature at which vapor locked occurred. These results were also inconclusive. The pre- and post-test RVP's can be found in appendix D as can the initial boiling points of the fuel.

For each test, the fuel was placed in the C-172 fuel tanks and heated to the desired temperature. For this program the range of temperatures was from 21° C (70° F) to 49° C (120° F). The range of initial tank temperatures can be found in appendix D. Typically, a fuel would be tested with a 21, 32, and 43° C (70, 90, and 110° F) initial tank temperature and if sufficient sample remained, it would be tested with either an 27, 38, or 49° C (80, 100, or 120° F) initial tank temperature. Two fuels were tested with the tank temperature set at their initial boiling point.

For each tank temperature a fuel was tested at a number of fuel flows. A typical series would include 2.5, 5.0, 7.5, 10.0, 12.5, 13.5 (full throttle) gph. At the end of the sequence, one of the above points would be repeated to see if changes were apparent in either the temperature at which vapor lock occurred or the period of time it took to reach vapor lock.

With the exception of the 2.5 and 5.0 gph settings, there were no significant differences between the initial data point and the repeated data point: the temperatures were typically within a couple of degrees of each other; there was no trend toward higher temperatures at the end of the run and vapor lock occurred within the same time frame for both the initial data point and the repeated data point. For the 2.5 and 5.0 gph settings, fuel would percolate in the fuel system and this percolation was of a random nature. As best as can be determined, fuel would boil in the system, the vapor would return to the tank via the forward fuel line and cooler fuel would flow down the fuel line which runs from the rear of the tank. Under these conditions, vapor lock could occur at a relatively low temperature and at other times it would not occur at all.

For this fuel system, the occurrence of vapor lock depends on two variables. The primary variable is the initial fuel temperature in the tank and the secondary variable is the fuel flow rate. As the initial tank temperature increases, the temperature at which vapor lock occurs increases. On the surface this would imply that increasing the tank temperature decreases the probability of vapor lock, but the opposite is true. Since the fuel is closer to the temperature at which vapor lock occurs less heat must be added to the fuel system to induce vapor lock. As the fuel flow rate is increased two phenomena occur which combine to create a more severe environment for vapor lock. Viscous losses in the fuel system decrease the pressure at the lowest point of the system, in this case the sediment bowl, and more heat is generated causing an increase in the operating temperatures. The combination of hot fuel and high fuel flows makes the takeoff fuel flow with fuel at an elevated temperature a severe condition indeed.

There is a limit to how hot the fuel can be made before the loss of the volatile components begins to lessen the severity of vapor lock. When the fuel is below it's initial boiling point it is difficult, at best, to add sufficient heat to cause vapor lock. As the fuel in the tank is heated to the initial boiling point, it becomes progressively easier to induce vapor lock, but this is by no means the worse case. As the fuel is heated still further, vapor lock begins to occur at the higher fuel flows without the addition of supplemental heat to the fuel system (i.e., without turning the electric line heaters on). Typically a tank temperature of 38 to 43° C (100 to 110° F) was the most severe for this fuel system and the fuels tested. When the fuel in the tank is heated to 49° C (120° F, vapor lock is not as severe as with 32° C (90° F) fuel. This is probably a consequence of the loss of the more volatile components in the fuel.

It is significant that there is not a large drop in the RVP when a post-test sample is drawn following a test at 49° C. This phenomena appears to be tied to the results from a study conducted at the National Institute of Petroleum and Energy Resources (NIPER). In this study, reference 1, a number of samples were heated in a sealed tank and allowed to vent for a limited period of time. The RVP was tracked for these fuels and the results indicated that there would be no significant change for the duration studied (up to 24 hours) with the exception of fuels which had a high RVP and were kept at elevated temperatures. This may also tie in with the unusually large changes in RVP associated with the 2-year-old special blend. It is possible that a percentage of the volatile components can be lost, yet enough remain to affect the total vapor pressure of the fuel. As the fuel continues to age, more of the volatile components are lost until there is an insufficient amount remaining to affect the vapor pressure and the vapor pressure begins to fall rapidly. If this is true, then it should be possible to have a fuel with the same vapor pressure exhibit an entirely different vapor lock behavior.

Two tests were conducted with fuel which had been allowed to age and repeat tests were conducted with fuel fresh from a sealed container. One of these tests used the special blend of leaded autogas (SBL in appendix D) and the other was conducted using a regular unleaded gasoline (HRU in appendix D). The tests using the SBL sample were conducted at 43° C and the tests with the HRU sample were conducted at 49° C. In both cases, the sample which was allowed to age overnight exhibited a less severe vapor lock behavior than the samples which were heated then tested immediately. The SBL sample which had already been aged showed a small but significant drop in RVP but the HRU sample did not. In light of these results, it is imperative that the fuel used for vapor lock studies be as fresh as possible.

The RVP for the two class D fuels (ERU and EPU in appendix D) were of the same magnitude as the class E fuels. For both of these fuels, the Technical Center was unable to induce vapor lock at the 2.5 gph setting. In addition, these fuels would exhibit all of the symptoms of vapor lock (such as reduced fuel pressure, zero fuel flows, rising EGT's and rough running) and then recover only to repeat the sequence until supplemental heat was added. This behavior was in sharp contrast to the class E fuels which would quit once the fuel pressure fell to 5 inH_2O or lower. Despite these differences, an initial tank temperature of 38° to 43° C was still the worse case as far as vapor lock was concerned.

It was observed that when the engine began to run rough during the above tests, advancing the throttle or increasing the engine speed would invariably result in an engine stoppage. Likewise, setting the mixture to full rich would not improve engine performance since the fuel flow was being restricted by vapor formation and not by the mixture adjustment. Reducing the throttle to improve the smoothness of engine operation would not necessarily result in more power being developed but it typically did not reduce the power being developed. There is a chance that periods of extended rough running would not occur in an aircraft since turbulence and aircraft vibration would probably aggravate vapor formation and result in an engine stoppage.

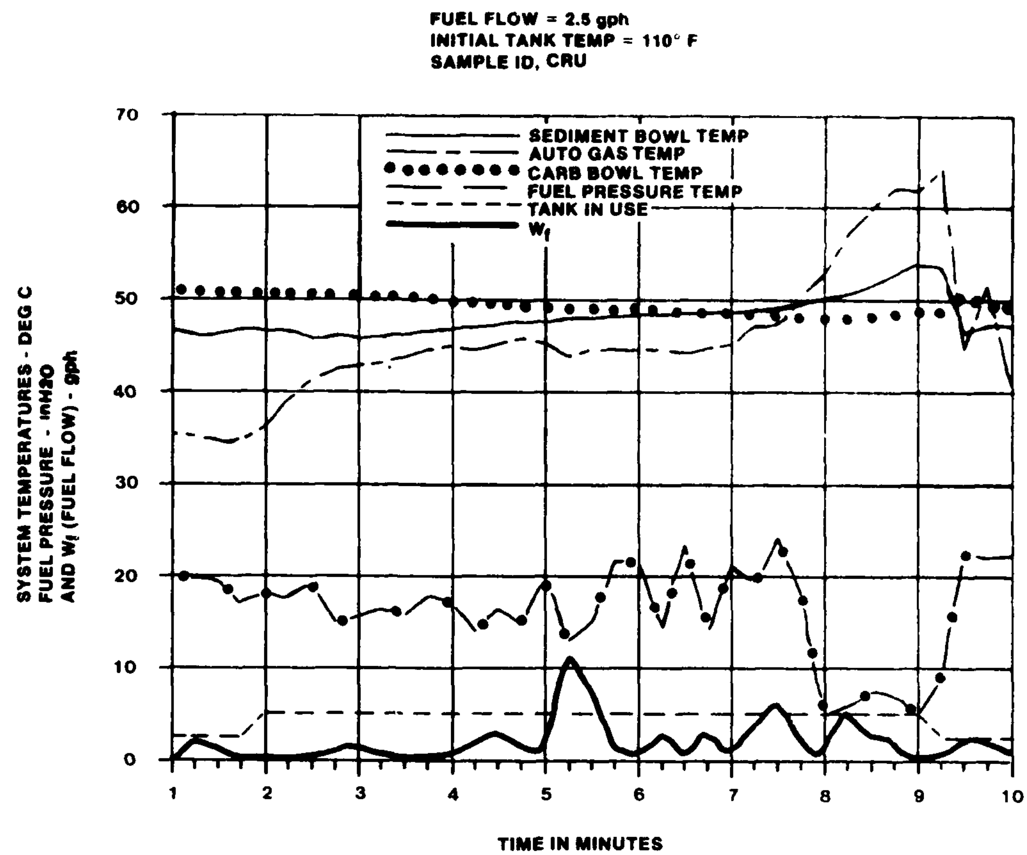
For all of the above runs, the engine cooling air temperature was kept at 38° C ±2° C. To see if the cooling air temperature would have an effect several points were conducted with the cooling air temperature at 29° C (85° F). These tests were not exhaustive but they demonstrated that vapor lock would occur without supplemental heat being added whenever the fuel in the tank was at 38° to 43° C and the fuel flows were above 10 gph. Since the engine would run just long enough to exhaust the supply of fuel in the carburetor bowl at these settings, this result is not surprising. An attempt was made to see if there was any difference at other fuel flow rates and the results were inconclusive.

As the fuel-to-air ratio leans during vapor lock, lean misfire can occur. This is typically accompanied by loud popping noises as the unburned fuel is ignited in the exhaust system. Some observers thought the engine was detonating when this phenomena was first observed. The Technical Center's experience during these runs was that detonation is not normally observed as the engine leans during vapor lock unless the fuel would have detonated with the mixture at full rich. Indeed, there were points where detonation was expected but the fuel-to-air ratio leaned so rapidly no detonation was observed.

As vapor lock occurs, the EGT rises and this can be a useful indicator of vapor lock as long as the limitations of the particular installation are understood. The EGT system in the Technical Center's installation had too slow a response time to provide any warning when vapor lock occurred at the higher fuel flow rates. (Note the general trend for shorter run times as the fuel flow rate increases in figure 10.) Also, there is a chance that the changes observed would be masked by the scaling of the instrumentation in the aircraft. The display used in these tests had a digital readout and even small changes were evident. When vapor lock occurred at the 2.5 gph setting, the engine would continue to run for well over a minute (see the 2.5 gph curve in figure 10) and for this condition the EGT provided a good indication that vapor lock had occurred.

Very small differences in EGT were noticed when switching between avgas and autogas and a drop of about 5 percent in fuel flow was noted when switching from avgas to autogas. The EGT changes may be caused by a number of factors such as a change in the distribution due to volatility changes or changes in the combustion process. The latter is probably an instrumentation error caused by the difference in the density between the avgas and the autogas.

As with avgas, large instrumentation errors are evident whenever the fuel in the system is above it's initial boiling point. This phenomena is aggravated by the lower IBP and higher RVP typically found in autogas. Figure 11 clearly shows this effect. (The abrupt rise in the line temperature at 9 minutes is caused by switching on the supplemental heaters.) The IBP for this fuel is 26° C (79° F) and as the temperature of the sediment bowl, which is directly upstream of the fuel flow meter, climbs above 26° C, the fuel flow becomes unreliable due to vapor formation. The fuel pressure also becomes unreliable as vapor displaces the fuel in the system. In this particular case, the periodic percolation that was mentioned earlier is shown by the cyclic rise and fall of the line temperature and the pressure variations. This means the fuel flow indicators currently found in general aviation aircraft can be used as an early warning device for the onset of vapor lock. Indeed some of the service difficulty reports on these systems, where they are unreliable in flight yet bench check OK, are probably a result of vapor formation in that particular installation.



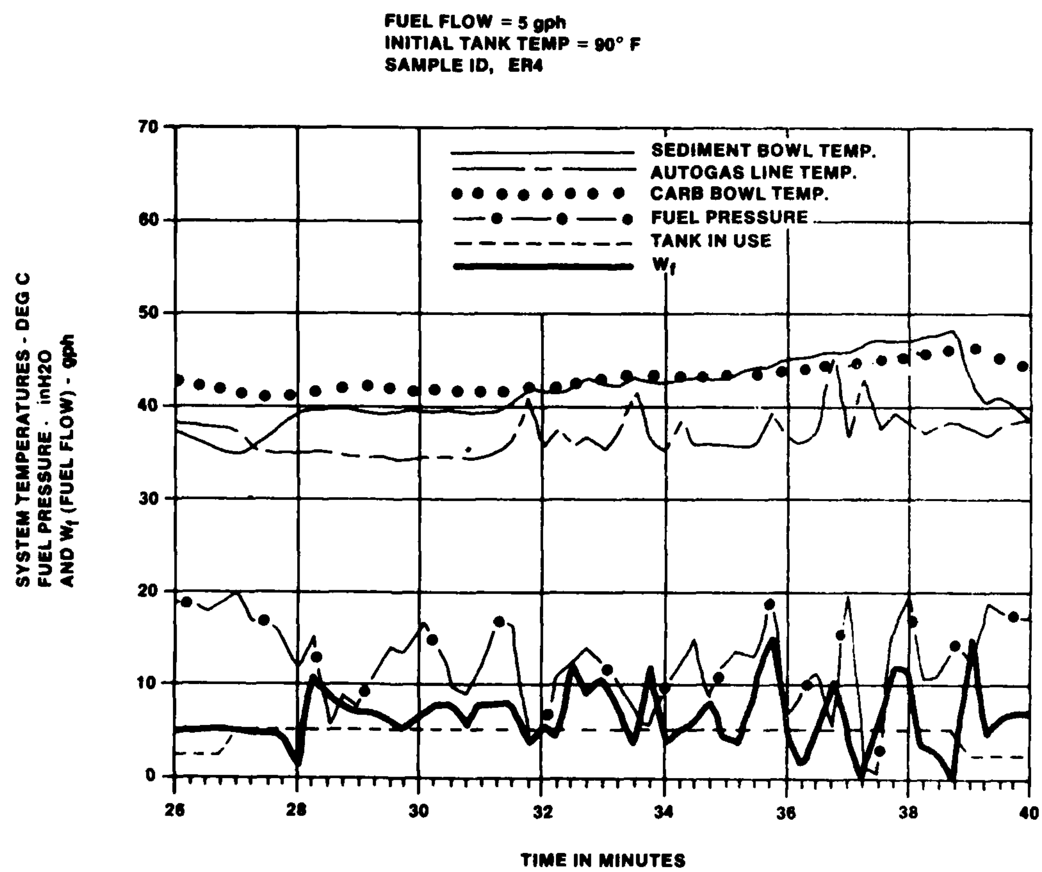
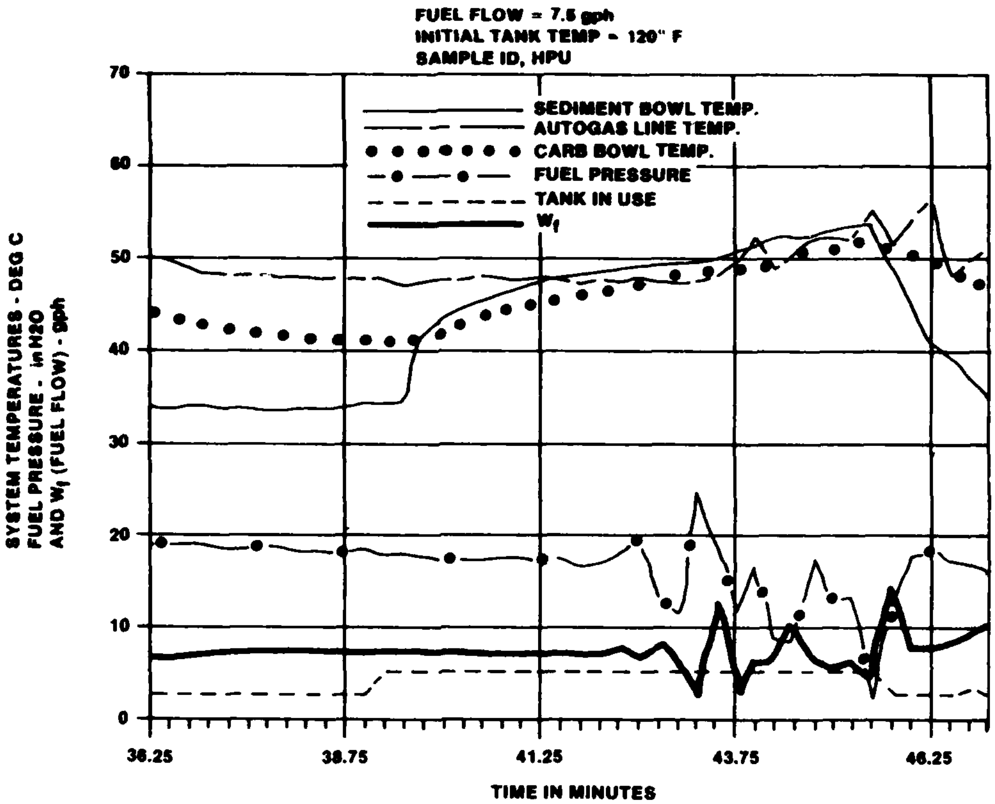


FIGURE 10. SELECT VAPOR LOCK SEQUENCES FOR VARIOUS FUEL FLOWS AND TANK TEMPERATURES (1 of 3 Sheets)



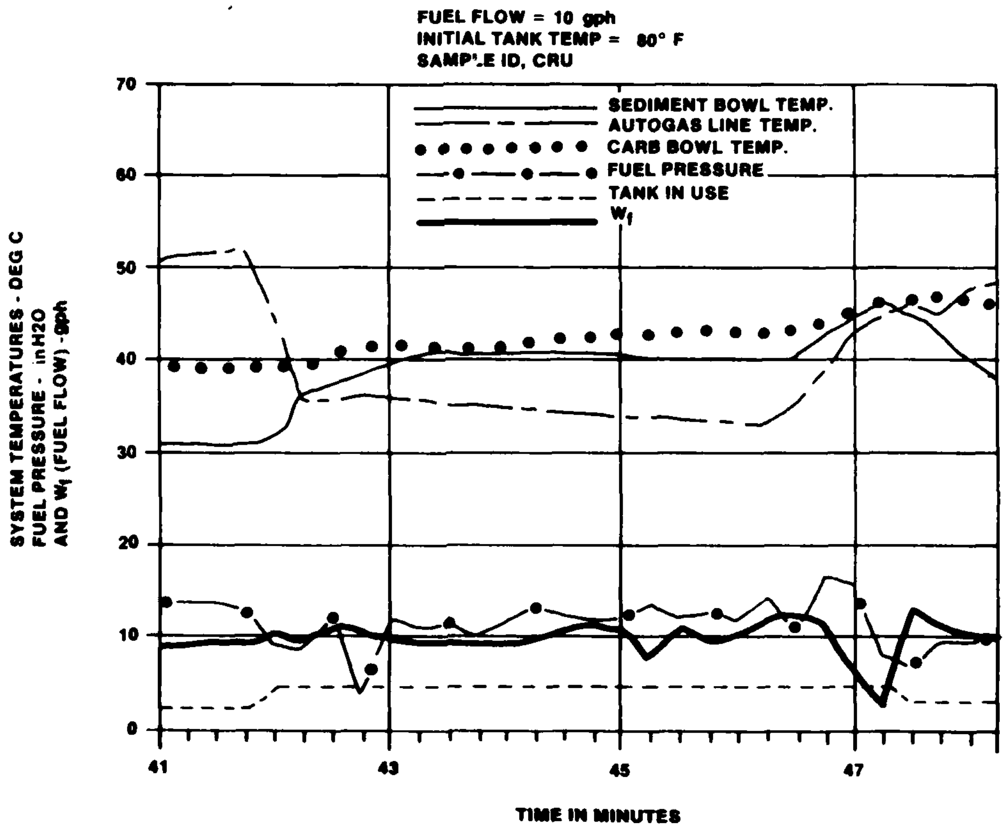


FIGURE 10. SELECT VAPOR LOCK SEQUENCES FOR VARIOUS FUEL FLOWS AND TANK TEMPERATURES (2 of 3 Sheets)

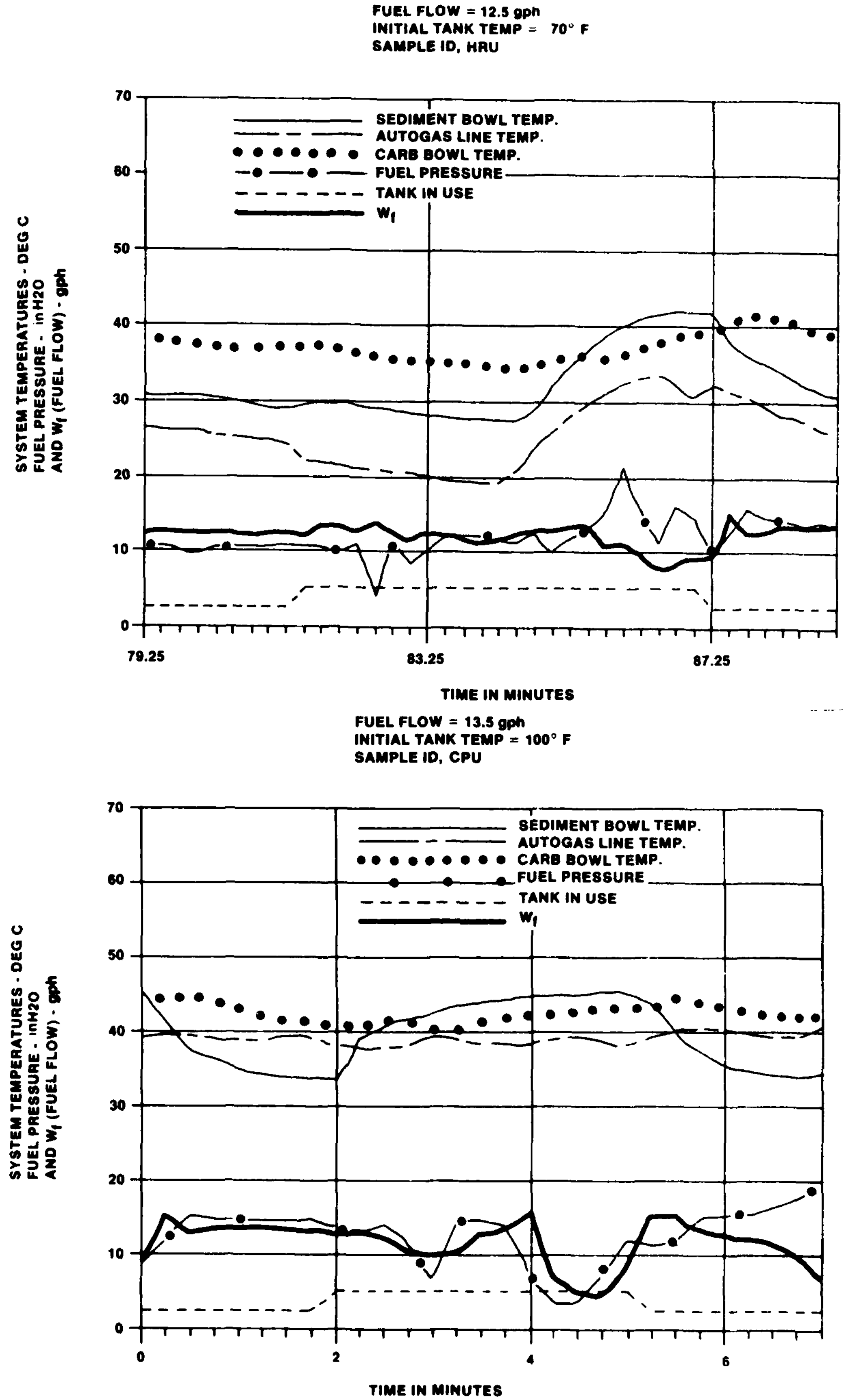


FIGURE 10. SELECT VAPOR LOCK SEQUENCES FOR VARIOUS FUEL FLOWS AND TANK TEMPERATURES (3 of 3 Sheets)

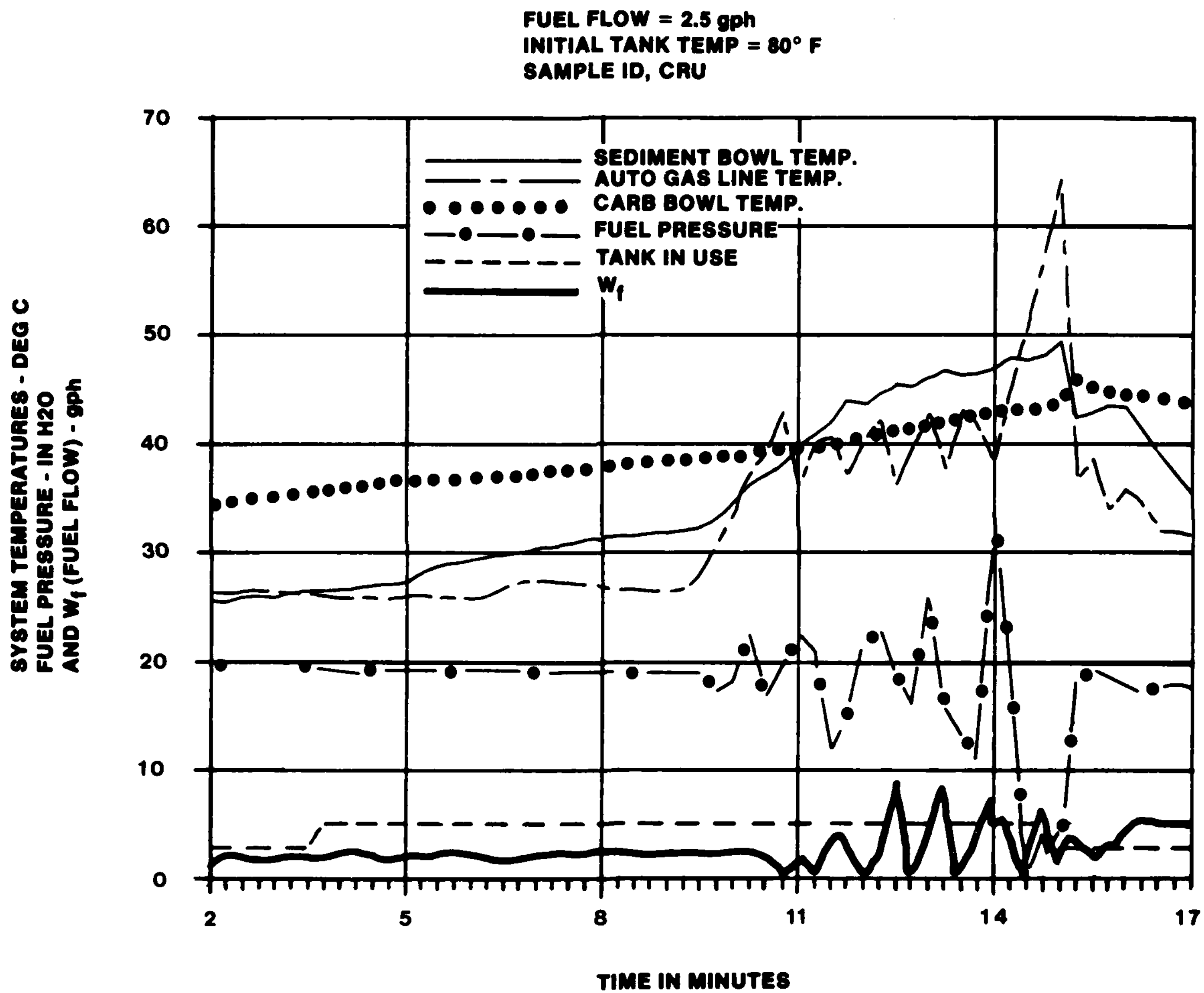


FIGURE 11. A VAPOR LOCK SEQUENCE SHOWING THE EFFECT OF THE IBP ON THE FUEL FLOW RATE AND FUEL PRESSURE

At this point, one should keep in mind that heating the lines, as was done during this sequence of tests, would not occur in an aircraft. This was done to insure the fuel system would vapor lock and give us a point for comparison. Likewise, a C-172 fuel system would not normally be operated at takeoff on one tank, but this procedure enabled the Technical Center to recover from vapor lock without restarting the engine.

There is some evidence that for this particular fuel system, the sediment bowl is where vapor lock actually occurs. In general, the temperatures at vapor lock are more consistent for the sediment bowl than for either the carburetor bowl or the line temperature; the fuel pressure and fuel flow indications become erratic when the temperature of the sediment bowl exceeds the IBP and the sediment bowl is the lowest point in the system.

There is strong evidence that foaming occurs in the carburetor bowl prior to the onset of vapor lock. This was particularly evident when testing fuels with cool (27° C or cooler) tank temperatures and at low fuel flow rates. As the temperature in the carburetor bowl increased the fuel would begin to boil and the EGT would begin to drop. Eventually, the power developed would begin to fall but conditions would not decay to the point of the engine running roughly. The existence of foaming also supports the notion that vapor lock occurs in the sediment bowl since the excess vapor in the carburetor bowl is apparently ingested into the engine.

DETONATION SURVEYS - AUTOGAS.

All six commercially available fuels were tested for detonation. Samples of these fuels were then taken and placed in wing tanks set up at the Technical Center. After the fuel ages, these fuels will be tested at the same points to determine if there is a significant shift in the octane rating as a consequence of aging.

During these tests, the engine was set at a specific power setting using avgas before switching to the autogas being tested. The horsepower developed on either fuel was compared and, unless there was detonation, there was no significant difference. Light detonation (5 flashes per minute or less) could occur without noticeably affecting either the horsepower, the EGT or the CHT which was unexpected. Unless the detonation was severe, the EGT, and CHT would show only slight changes which could go unnoticed if the operator did not expect detonation was occurring. Not only was light to moderate detonation difficult to detect using the instrumentation available to most pilots but, even in the test cell environment, detonation was inaudible unless it was severe. In the nosier aircraft environment, one could not be expected to detect detonation. As with the onset of vapor lock, the EGT probes in this installation were slow to respond to onset of severe detonation.

All six commercially available fuels detonated at one or more power settings, whereas, the 100LL avgas used to set the data points did not exhibit a tendency to detonate. There was one exception, and that particular sample was 2-year-old avgas that was being used during some maintenance runs early in the program. The Technical Center was unable to repeat this point and it is inconclusive as to whether the age of the fuel was the cause of the detonation.

Occasionally during switchover from avgas to autogas, a brief period of detonation was detected. It appeared to be associated with the mixing of the two fuels. A number of samples were prepared where different percentages of avgas were mixed with a regular unleaded autogas. These samples were tested to determine the octane rating of the blend and the results are listed in table 5. As can be seen, mixing avgas and autogas results in a higher octane number than the autogas alone so a reduction in either octane number is not the cause of detonation. One possible explanation for this phenomena is maldistribution during the switchover from avgas to autogas.

TABLE 5. PROPERTIES OF SEVERAL MIXTURES OF AVGAS IN REGULAR UNLEADED AUTOGAS

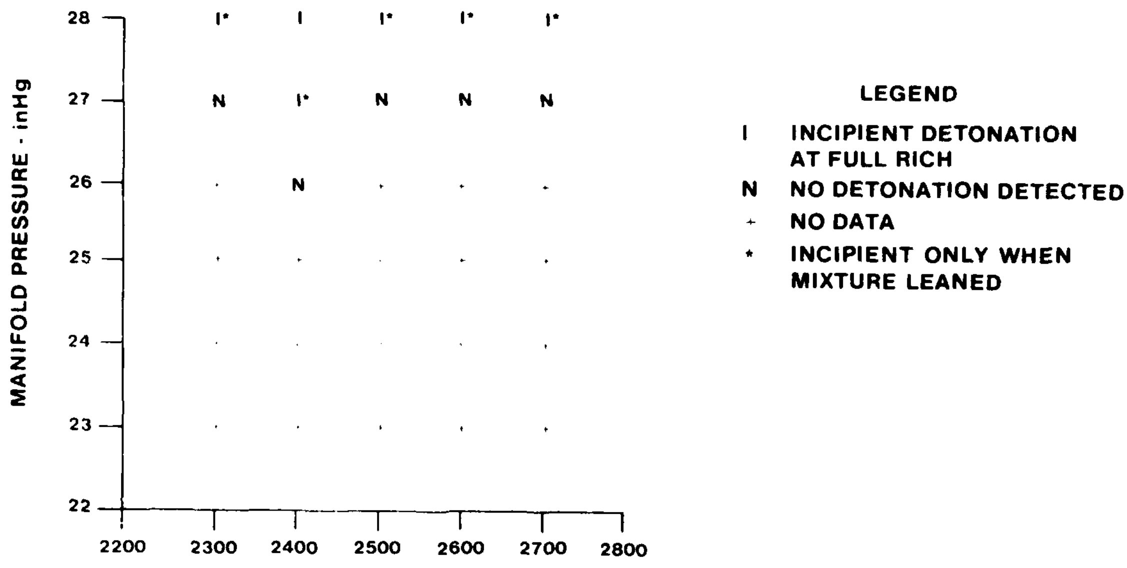
Sample ID	Percent Avgas	RVP (psi)	RVP (psi)	RON	MON	R+M/2
ERU	0	14.0	14.0	94.0	82.5	88.3
SM1	10	9.0	9.1	96.0	84.3	90.2
SM2	20	8.8	8.8	97.8	87.0	92.4
SM3	33	8.6	8.6	98.0	87.1	92.6
SM5	50	7.9	7.8	100.1	91.1	95.6

The design of the detonation experiments called for the engine cooling air temperature to be at 38° C. While testing sample EPU (see figure 12) the boiler in the cooling air blower failed. A repeat of several of the data points where detonation had occurred resulted in only incipient detonation. This demonstrated that the engine cooling air temperature has a significant effect on detonation. It was also observed that the humidity of the carburetor inlet air has an effect on the occurrence of detonation.

Figure 12 shows the results of the detonation series as a function of engine speed and manifold pressure. These figures are arranged in the order of descending MON. As can be seen there is a strong relationship between the MON and the occurrence of detonation. The RON is also listed to show that while there is a general trend it is not as definite as the relationship with the MON. This shows that the design of the different octane tests is applicable to the type of application in which the fuel will be used. The Aviation Supercharge Octane Number was not determined for these fuels since it would not normally be available to an individual purchasing autogas for use in a general aviation aircraft.

There appeared to be a hysteresis effect when doing the detonation series of tests. Detonation was more likely to occur at a given power setting if it followed a higher power setting as opposed to a lower power setting. This is probably due to elevated internal temperatures which are not reflected in either the CHT or oil temperature, which were monitored to determine if the engine had stabilized at a given data point prior to switching to autogas. This could explain why, on occasion, the 2400 RPM data points were more severe than for both the 2300 and 2500 RPM points since the 2400 RPM points were typically the last points conducted during a run.

SAMPLE CPU, MON 87.5, RON 96.4



SAMPLE HPU, MON=87.0, RON=97.9

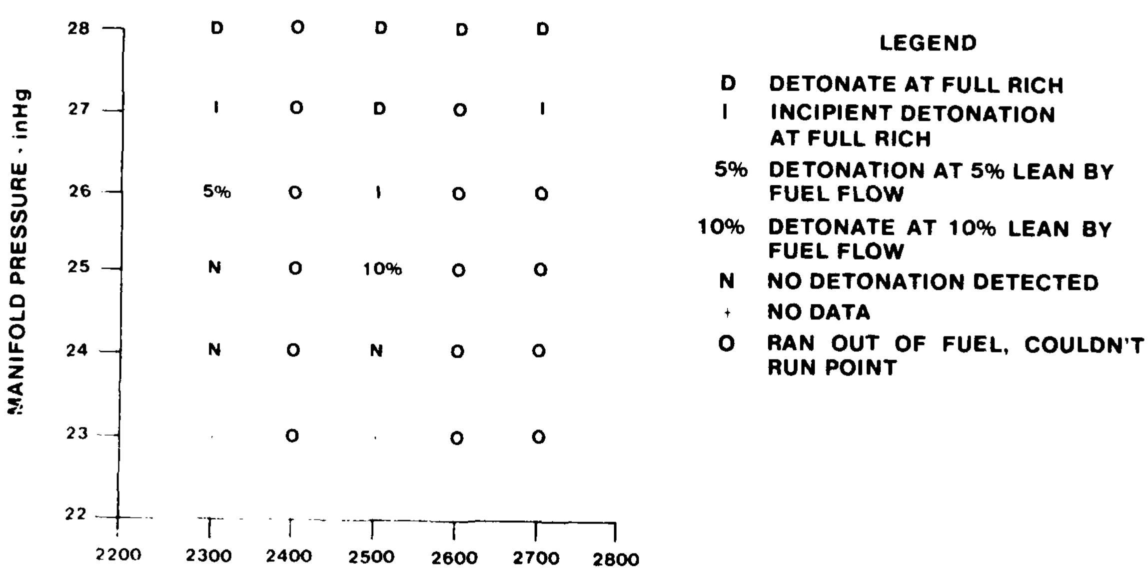
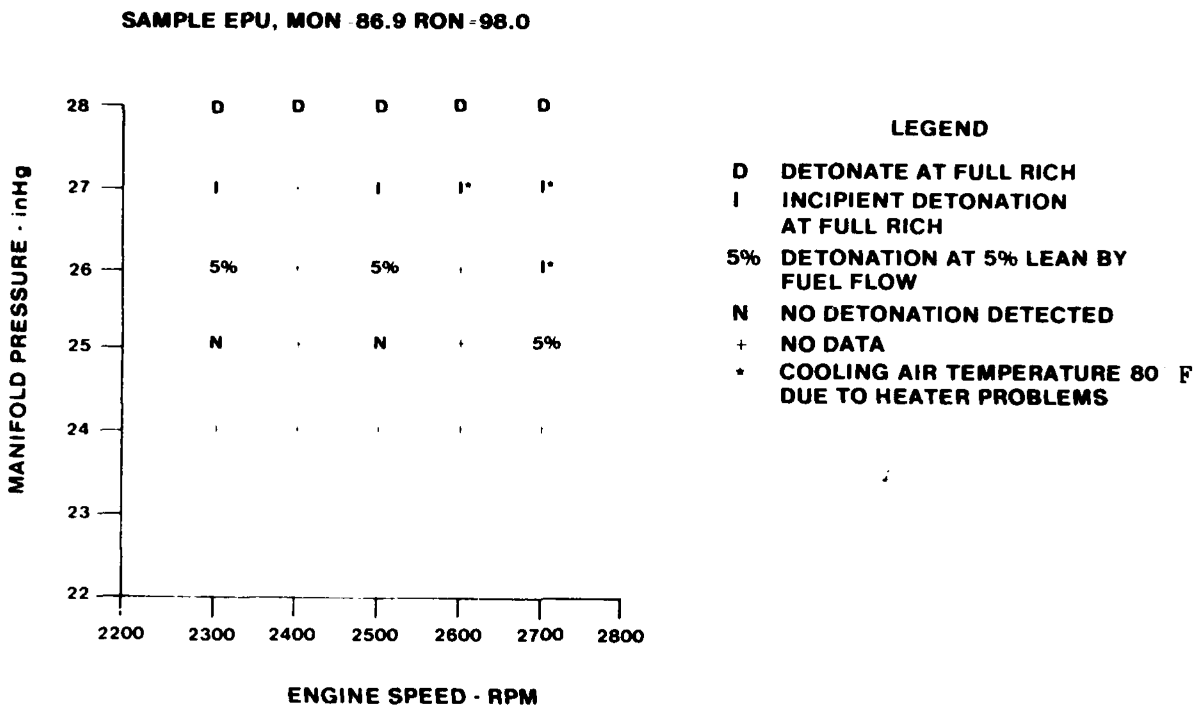


FIGURE 12. RESULTS FROM THE DETONATION SURVEYS SHOWING THE THE EFFECT OF THE MON AND RON RATINGS (1 of 3 Sheets)



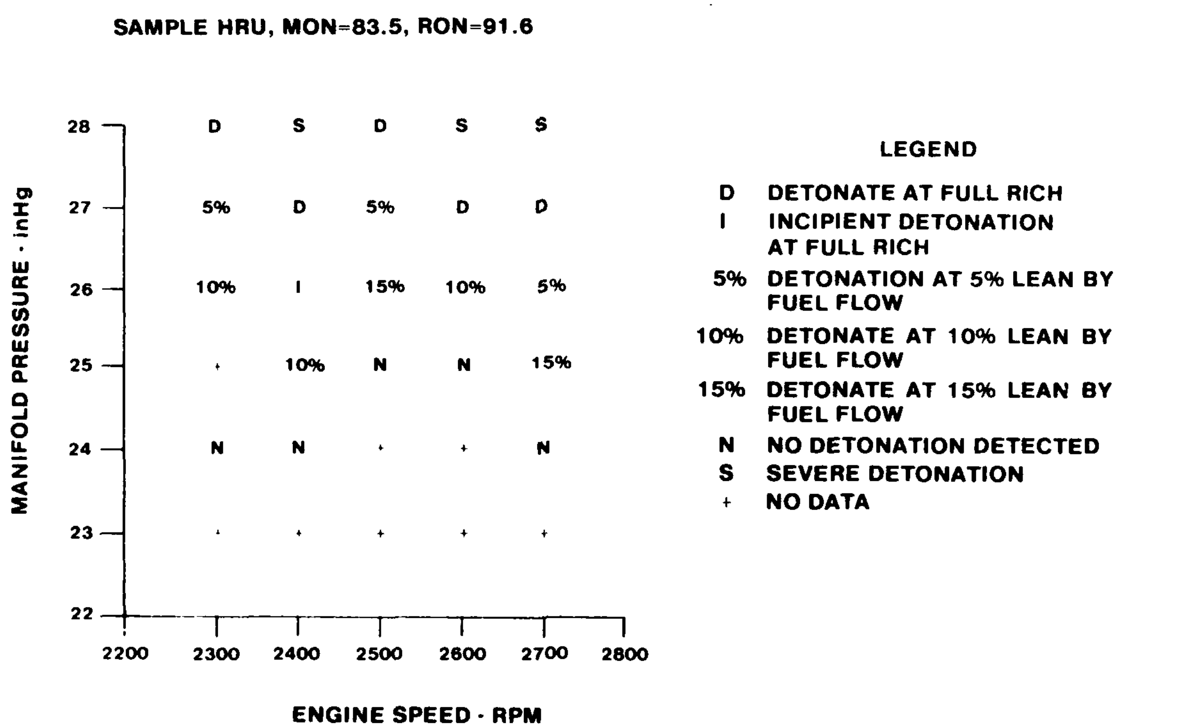
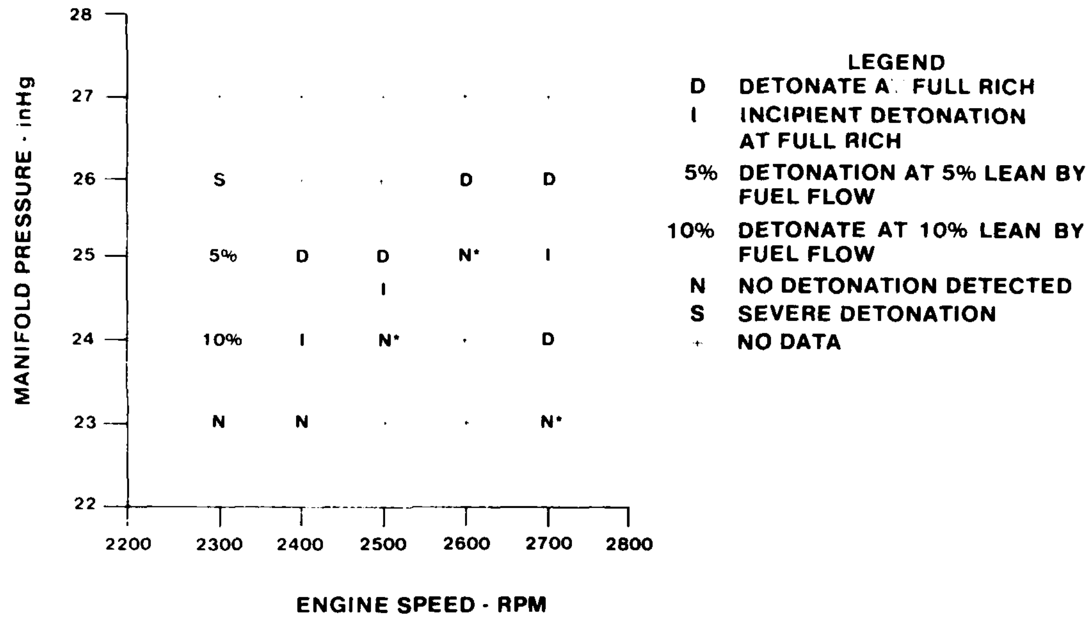


FIGURE 12. RESULTS FROM THE DETONATION SURVEYS SHOWING THE THE EFFECT OF THE MON AND RON RATINGS (2 of 3 Sheets)

SAMPLE CRU, MON 83.2, RON 91.4



*FUEL FLOW METER UNRELIABLE DUE TO VAPOR FORMATION, THEREFORE NO LEAN SETTINGS ABOVE 2400 RPM.

IT IS POSSIBLE THAT DETONATION WOULD HAVE OCCURRED AT THESE POINTS IF THE OPERATORS COULD HAVE LEARNED THE MIXTURE AT THESE POINTS.

ERU, MON 82.5, RON 94.0

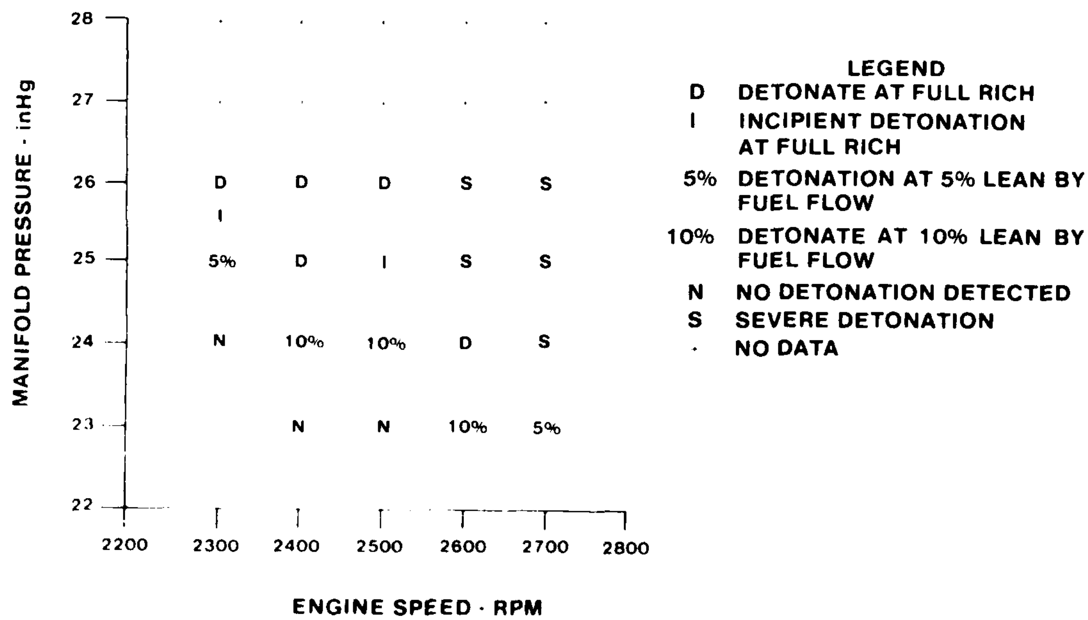


FIGURE 12. RESULTS FROM THE DETONATION SURVEYS SHOWING THE THE EFFECT OF THE MON AND RON RATINGS (3 of 3 Sheets)

MISCELLANEOUS - AUTOGAS.

There was a compatibility problem with autogas in the fuel system used for these tests. The tank selector used is the same as the selector found in the C-172 but it is operated remotely with a pneumatic actuator. When a test was terminated on autogas the seals in the selector valve would swell and the pneumatic operator was not strong enough to overcome the additional resistance. If the engine was shut down on avgas following a shutdown on autogas the problem would not occur. There did not seem to be a correlation with the sample of autogas used and it may not be a problem for systems which are manually operated.

During the vapor lock tests, a large amount of vapor and fuel would be vented. This occurred even though the tanks were usually less than half full during the vapor lock tests. Up to 7 percent of the initial volume of fuel was collected during a typical run. An individual using autogas should be aware of this and allow for extra reserve when planning an extended flight.

CONCLUSIONS

For Autogas, the fuel temperature at which vapor lock testing is conducted is critical. The most severe case occurs when the temperature of the fuel in the tank is between 100 and 110° F. Heating the fuel to 120° F greatly reduces the potential for vapor lock occurring. In addition, leaving the fuel in a vented container overnight greatly reduces the tendency to vapor lock even though the RVP does not change dramatically.

For the C-172 fuel system, the onset of vapor lock depended on the fuel flow rate. The existence of percolation in the system implies that the fuel system design can have a dramatic effect. This needs to be investigated further.

The engine cooling air temperature did not have a significant effect on the tendency to vapor lock but flight tests should be conducted on as hot a day as possible to avoid cooling the fuel in the tanks.

Reducing the throttle may result in smoother operation at the onset of vapor lock but does not necessarily increase the power developed. Any abrupt throttle movements can result in the engine quitting.

Whenever the fuel temperature in the system exceeds the initial boiling point of the fuel, there is vapor in the system. This vapor affects both the fuel flow meter and the fuel pressure. For a gravity feed fuel system such as is found on the C-172, either fuel flow or fuel pressure is a useful indicator of the onset of vapor lock. The fuel pressure may be more difficult to interpret since it is affected by fuel flow and atmospheric turbulence.

All the autogas samples detonated to some extent. The Motor Octane Number (MON) for a particular sample is more useful in predicting detonation than the Research Octane Number (RON).

Light detonation may not be detectable with the instrumentation currently found in general aviation aircraft.

All else being equal, the engine cooling air temperature and the humidity of the carburetor inlet air affects the onset of detonation. Detonation is more severe with low humidty carburetor inlet air and high engine cooling air temperatures.

Carburetor foaming occurs when operating at low power settings with relatively cool (27° C or below) autogas. For the Lycoming 0-320 used in these tests it did not cause an operational problem but it deserves further investigation.

For this fuel system, which is a relatively simple design, there was a slight material compatibility problem with autogas. This problem needs further investigation.

The horsepower does not vary significantly between avgas and autogas unless detonation is occurring.

Detonation could not be induced in this engine with 100LL avgas. Likewise, vapor lock was not observed in this fuel system when testing with 100LL avgas.

There is insufficient data to correlate the RVP with the onset of vapor lock. This effort will require testing with fuels whose RVP is significantly different from the samples tested.

REFERENCES

1. Wares, Richard N. and Allsup, Jerry R., Weathering Effects on Autogas, DOT/FAA/CT-TN85/54, National Institute for Petroleum and Energy Research, Bartlesville, Oklahoma, October 1985.

2. 1983 Annual Book of ASTM Standards, Section 5, "Petroleum Products, Lubricants, and Fossil Fuels," Volumes 1 - 4, The American Society for Testing and Materials, Philadelphia, Pennsylvania.

3. Code of Federal Regulations, Volume 14, "Aeronautics and Space", Part 23, Airworthiness Standards; Normal Utility and Acrobatic Catagory Airplanes.

APPENDIX A

ENGINEER'S CHECKLIST

The checklist on the following pages is used by the project engineer prior to each run. The objective sheets referred to in item one in the checklist are the same as the test proceedures listed earlier in this report.

1. Prepare the run objectives and sequence.

2. Prepare the run sheet; record the following:

Test #	Run #
Date	P_{bar}
T_{amb}	T_{dew}
Avgas ID	Autogas ID

The headings on the run sheet should be as follows:

Time	Torque	Tach	MAP	Oil Temp. and Pressure	Cooling Air Temp. and Pressure	Fuel Pressure

Changes to the above headings can be made from the list of parameters in table 2 of the text.

3. Enter the following into the automatic data acquisition system:

Test #	Run #
Date	Time
Number of Scans (NSCAN)	Period

4. Put a tape on line with the write ring in place.

5. Assure the CRT displays the same parameters as on the run sheet.

6. Assure the fuel in the tanks is heated to the desired temperature.

7. Type GOGO.

8. Type LIST and make sure the computer is in the run mode.

9. Type in DISP (display).

10. Start the O-320 per the operators check list.

11. Record the start time.

12. Conduct the test according to the run objective.

13. At the end of the test type NSCAN=1.

14. Type LIST. Make sure the computer is in the WAIT mode. If not, repeat as necessary.

15. Remove the write ring from the tape and put the tape back on line.

16. Type in headings per the attached list then type:

REVIEW,1,1,N
where N is the number of scans.

17. Repeat item 16 until all of the parameters are listed.

18. Save the tape if desired; otherwise return the write ring and put the tape back on line.

APPENDIX B

SYSTEM CHECKLIST

The following check list is used by the technician prior to each run.

1. Turn on 28 VDC.
2. Turn on 115 VAC.
3. Reset temperature controllers on the dynamometer control module.
4. Assure all dynamometer control switches are off.
5. Assure fuel heater switch is off.
6. Turn on Supply Air System, start switch. (Engine cooling air)
7. Turn on Rotating Beacon switch.
8. Plug in battery charger.
9. Assure oil cooler water is on.
10. Turn on Dyno Cooling Water Supply valve.
11. Pull Dyno Safety switch. (Small red light should illuminate.)
12. Assure Dyno Control Box is plugged into 115 VAC.
13. Turn on top and bottom air conditioners.
14. Turn on dyno air control valve (for pneumatic actuators).
15. Assure proper type and amount of fuel in tanks.
16. Check Engine Oil quantity. (5 1/2 qts. min. with cold engine.)
17. Perform wet and dry reading.
18. Take barometer reading.
19. Make entries in Engine Run Log.
20. Open test cell doors if necessary.
21. Sound Klaxon three times.
22. Start engine:
    a. Pull Emergency Stop switch.
    b. Turn on fuel and ignition switches.

c. Hold Fault Mode Reset Switch. (Master light should be out)

d. Assure Command Selector on Manual, Control Selector on Load.

e. Set Condition Switches to A, Load Pot to 0, Throttle. Pot to 250, Mixture Pot to 1000.

f. Hold Start Button until engine is running.

23. Check for Oil Pressure within 30 sec. of engine start.

APPENDIX C

TANK HEATER CHECKLIST

Tne following checklist is used by the technician whenever the test requires the fuel in the C-172 tanks be heated or cooled to a desired temperature.

GENERAL INFORMATION: This system provides the temperature control of the fuel in the C-172 tanks. The system uses water heat exchangers in each tank and temperature control is provided by two Thermoelectric™ controllers linked to solenoids which regulate the flow of water through the heat exchangers. The temperature of the fuel is monitored by thermocouples (channel number 6 for avgas and number 8 for autogas). When the water heater is set at 150° F the actual water temperature varies from 135° to 155° F.

STARTUP CHECKLIST

1. Turn on the 28 volt DC and 110 volt AC power.

2. Check water level. If the system is not full:

   a. open both solenoids using the controllers.
   b. fill the system through the faucet and monitor the water level via the expansion tank.
   c. when full, turn off the faucet and partially close the cap on the expansion tank. (This provides for pressure relief.)

3. Set the temperature controllers to the temperature as desired.

4. To heat the tanks, perform the following three items:

   a. Start the pump.
   b. Plug in the heater and set the water temperature as desired.
   c. Assure flow selector on hot position.

5. To cool the tanks perform the following:

   a. Set the flow selector to the cool position.
   b. Open the faucet and adjust the flow rate as desired.

SHUT DOWN CHECKLIST

1. Turn off the heater and unplug it.

2. Shut both solenoids with the temperature controllers.

3. Turn off the pump or close the faucet.

4. Turn off the electrical power.

5. If desired, drain the water from the system by opening the drain valve and the expansion tank cap.

APPENDIX D

VAPOR LOCK TEMPERATURES AS A FUNCTION OF FUEL FLOW RATE, INITIAL TANK TEMPERATURE AND RVP

Tables D1 through D6 list the autogas line temperature, the sediment bowl temperature and the carburetor bowl temperature for each fuel flow rate, in ascending order of initial tank temperature and in ascending order of initial RVP as measured by the Technical Center. As noted on each table, all temperatures are in degrees Celsius and the RVP is reported in psi.

Some special notes of interest are as follows:

a. Items marked with a (1) were from tests where the initial tank temperature was set at the initial boiling point of the fuel.

b. Items marked with a (2) have two data points listed in the last three columns. These were points where one reading was taken during the normal sequence of the test and a second was at the conclusion of the normal test sequence. Not all of the repeated data points are listed.

c. Items marked with an asterisk were from the tests where the fuel was allowed to age overnight in a vented container at room temperature. The second data points listed were from runs using identical conditions except the fuel was taken from a sealed container just prior to the test.

d. If the Technical Center was unable to induce vapor lock for that setting the notation NO VAPOR LOCK is entered in the line temperature through the carburetor bowl temperature columns.

e. The accuracy of the RVP test is considered to be ± 1 psi. As a consequence, it is possible to have a posttest reading higher than the initial reading. On the average, the posttest readings are 1.8 psi lower than the pre-test readings. As expected, larger differences occur with the higher fuel temperatures.

As mentioned in the text, the temperature at which vapor lock occurs rises with the initial tank temperature, but since the fuel is starting off at a temperature closer to the point at which vapor lock occurs increasing the tank temperature increases the severity of the vapor lock test. The most severe initial tank temperatures are 100° to 110° F.

TABLE D1. VAPOR LOCK TEST DATA - FUEL FLOW: 2.5 GPH

ALL TEMPERATURES: ^{o}C; ALL RVP: PSI
FOR POINTS REPEATED DURING RUN--LOWEST TEMPERATURE REPORTED

FUEL ID	TANK TEMP	PRETEST RVP	POST-TEST RVP	INITIAL BOILING POINT	LINE TEMP	SEDIMENT BOWL TEMP	CARB. BOWL TEMP	SUPPLEMENTAL HEAT ADDED
CRU	21	11.8	12.0	26°	35	49	35	YES
HPU	21	12.2	12.2	25°	45	48	45	YES
HRU	21	12.4	12.2	25°	35	52	45	YES
EPU	21	12.7	10.9	25°	------NO VAPOR LOCK------			YES
CPU	21	13.3	11.8	25°	34	44	42	YES
SBL	21	13.4	12.7	30°	39	45	40	YES
ERU	21	14.1	14.1	25°	------NO VAPOR LOCK------			YES
CRU	26(1)	11.8	11.2	26°	40	47	44	YES
SBL	30(1)	11.7	8.5	40°	46	61	48	YES
CRU	32	11.8	11.6	26°	39	44	42	YES
HPU	32	12.2	11.2	25°	44	45	35	YES
HRU	32	12.4	11.5	25°	42	48	45	YES
EPU	32	12.7	12.5	25°	------NO VAPOR LOCK------			YES
CPU	32	13.3	12.2	25°	39	44	39	YES
ERU	32	14.1	12.7	25°	------NO VAPOR LOCK------			YES
CRU	38	11.8	11.8	26°	------NO VAPOR LOCK------			YES
EPU	38	12.7	11.7	25°	------NO VAPOR LOCK------			YES
CPU	38	13.3	8.5	25°	47	44	39	YES
CRU	43	11.8	10.2	26°	47	44	41	YES
HPU	43	12.2	9.9	25°	45	48	46	YES
HRU	43	12.4	11.3	25°	46	48	45	YES
EPU	43	12.7	11.1	25°	------NO VAPOR LOCK------			YES
CPU	43	13.3	9.9	25°	45	44	43	YES
SBL	43	11.0*/13.0	5.9*/8.0	37°*/35°	51*/49	45*/40	37*/33	YES*/YES
ERU	43	14.1	10.9	25°	------NO VAPOR LOCK------			YES
HPU	49	12.2	8.9	25°	57	48	43	YES
HRU	49	12.4	8.6	25°	55*/52	68*/54	52*/50	YES*/YES
CPU	49	13.3	9.2	25°	51	47	44	YES

*OVERNIGHT FUEL, NO FRESH FUEL ADDED

(1) TANK TEMPERATURE AT IBP

TABLE D2. VAPOR LOCK TEST DATA - FUEL FLOW: 5.0 GPH

ALL TEMPERATURES: ^{o}C; ALL RVP: PSI
FOR POINTS REPEATED DURING RUN--LOWEST TEMPERATURE REPORTED

FUEL ID	TANK TEMP	PRETEST RVP	POST-TEST RVP	INITIAL BOILING POINT	LINE TEMP	SEDIMENT BOWL TEMP	CARB. BOWL TEMP	SUPPLEMENTAL HEAT ADDED
CRU	21	11.8	12.0	26°	44	45	46	YES
HPU	21	12.2	12.2	25°	44	55	53	YES
HRU	21	12.4	12.2	25°	33	47	46	YES
EPU	21	12.7	10.9	25°	------NO	VAPOR	LOCK------	YES
CPU	21	13.3	11.8	25°	32	43	45	YES
SBL	21	13.4	12.7	30°	46	50	46	YES
ERU	21	14.1	14.1	25°	------NO	VAPOR	LOCK------	YES
CRU	26(1)	11.8	11.2	26°	40	46	47	YES
SBL	30(1)	11.7	8.5	40°	43	55	47	YES
CRU	32	11.8	11.6	26°	46	46	46	YES
HPU	32	12.2	11.2	25°	40	48	48	YES
HRU	32	12.4	11.5	25°	40	47	47	YES
EPU	32	12.7	12.5	25°	------NO	VAPOR	LOCK------	YES
CPU	32	13.3	12.2	25°	38	42	44	YES
ERU	32	14.1	12.7	25°	38	46	44	YES
CRU	38	11.8	11.8	26°	42	52	48	YES
EPU	38	12.7	11.7	25°	42	52	50	YES
CPU	38	13.3	8.5	25°	47	48	47	YES
CRU	43	11.8	10.2	26°	47	48	47	YES
HPU	43	12.2	9.9	25°	47	48	47	YES
HRU	43	12.4	11.3	25°	46	46	44	YES
EPU	43	12.7	11.1	25°	46	50	48	YES
CPU	43	13.3	9.9	25°	53	51	48	YES
SBL	43	11.0*/13.0	5.9*/8.0	37°*/35°	49*/48	50*/45	45*/40	YES*/YES
ERU	43	14.13	10.9	25°	44	48	45	YES
HPU	49	12.2	8.9	25°	50	49	47	YES
HRU	49	12.2	N/A	25°	56*/49	56*/52	51*/50	YES*/YES
CPU	49	13.3	9.2	25°	51	50	47	YES

*OVERNIGHT FUEL, NO FRESH FUEL ADDED

(1) TANK TEMPERATURE AT IBP

TABLE D3. VAPOR LOCK TEST DATA - FUEL FLOW: 7.5 GPH

ALL TEMPERATURES: ^{o}C; ALL RVP: PSI
FOR POINTS REPEATED DURING RUN--LOWEST TEMPERATURE REPORTED

FUEL ID	TANK TEMP	PRETEST RVP	POST-TEST RVP	INITIAL BOILING POINT	LINE TEMP	SEDIMENT BOWL TEMP	CARB. BOWL TEMP	SUPPLEMENTAL HEAT ADDED
CRU	21	11.8	12.0	26^{o}	32	40	43	YES
HPU	21	12.2	12.2	25^{o}	35	43	45	YES
HRU	21	12.4	12.2	25^{o}	24	41	43	YES
EPU	21	12.7	10.9	25^{o}	23	43	44	YES
CPU	21	13.3	11.8	25^{o}	30	44	45	YES
SBL	21	13.4	12.7	30^{o}	42	44	42	YES
ERU	21	14.1	14.1	25^{o}	26	40	44	YES
CRU	26(1)	11.8	11.2	26^{o}	43	44	45	YES
SBL	30(1)	11.7	8.5	40^{o}	43	47	45	YES
CRU	32	11.8	11.6	26^{o}	43	45	45	YES
HPU	32	12.2	11.2	25^{o}	43	48	48	YES
HRU	32	12.4	11.5	25^{o}	40	46	45	YES
EPU	32	12.7	12.5	25^{o}	34	47	48	YES
CPU	32	13.3	12.2	25^{o}	37	42	44	YES
ERU	32	14.1	12.7	25^{o}	37	40	42	YES
CRU	38	12.2	11.8	26^{o}	48	47	46	YES
EPU	38	12.7	11.7	25^{o}	41	45	46	YES
CPU	38	13.3	8.5	25^{o}	43.5	46	46	YES
CRU	43	11.8	10.2	26^{o}	54	53	52	YES
HPU	43	12.2	9.4	25^{o}	48	48	48	YES
HRU	43	12.4	11.3	25^{o}	44	47.5	46	YES
EPU	43	12.7	11.1	25^{o}	50	50	48	YES
CPU	43	13.3	9.9	25^{o}	54	52	50	YES
SBL	43	11.0*/13.0	5.9*/8.0	37^{o}*/35^{o}	50*/50	51*/46	49*/44	YES*/YES
ERU	43	14.13	10.9	25^{o}	48	48	46	YES
HPU	49	12.2	8.9	25^{o}	53	53	52	YES
HRU	49	12.2	N/A	25^{o}	54*/55	62*/54	57*/51	YES**/YES
CPU	49	13.3	9.2	25^{o}	53	55	53	YES

*OVERNIGHT FUEL, NO FRESH FUEL ADDED

(1) TANK TEMPERATURE AT IBP

TABLE D4. VAPOR LOCK TEST DATA - FUEL FLOW: 10.0 GPH

ALL TEMPERATURES: ^{o}C; ALL RVP: PSI
FOR POINTS REPEATED DURING RUN--LOWEST TEMPERATURE REPORTED

FUEL ID	TANK TEMP	PRETEST RVP	POST-TEST RVP	INITIAL BOILING POINT	LINE TEMP	SEDIMENT BOWL TEMP	CARB. BOWL TEMP	SUPPLEMENTAL HEAT ADDED
CRU	21	11.8	12.0	26^{o}	31	41	43	YES
HPU	21	12.2	12.2	25^{o}	34	43	44	YES
HRU	21	12.4	12.2	25^{o}	32	43	43	YES
EPU	21	12.7	10.9	25^{o}	32	41	42	YES
CPU	21	13.3	11.8	25^{o}	35	43	42	YES
SBL	21	13.4	12.7	30^{o}	34	42	40	YES
ERU	21	14.1	14.1	25^{o}	27	38	41	YES
CRU	26(1)	11.8	11.2	26^{o}	38	43	44	YES
SBL	30(1)	11.7	8.5	40^{o}	44	54	51	YES
CRU	32	11.8	11.6	26^{o}	42	45	46	YES
HPU	32	12.2	11.2	25^{o}	46	48	44	YES
HRU	32	12.4	11.5	25^{o}	36	41	42	YES
EPU	32	12.7	12.5	25^{o}	34	44	47	YES
CPU	32	13.3	12.2	25^{o}	36	43	46	YES
ERU	32	14.1	12.7	25^{o}	38	41	43	YES
CRU	38	12.2	11.8	26^{o}	45	45	45	YES
EPU	38	12.7	11.7	25^{o}	40	45	46	YES
CPU	38	13.3	8.5	25^{o}	38	44	44	YES
CRU	43	11.8	10.2	26^{o}	44	48	47	YES
HPU	43	12.2	9.9	25^{o}	44	48	47	YES
HRU	43	12.4	11.3	25^{o}	45	48	45	YES
EPU	43	12.7	11.1	25^{o}	43	48	47	YES
CPU	43	13.3	9.9	25^{o}	53	52	51	YES
SBL	43	11.0*/13.0	5.9*/8.0	37^{o}*/35^{o}	49*/43	50*/48	46*/43	YES*/YES
ERU	43	14.13	10.9	25^{o}	45	47	42	YES
HPU	49	12.2	8.9	25^{o}	55	55	52	YES
HRU	49	12.2	N/A	25^{o}	57*/55	58*/55	53*/52	YES*/YES
CPU	49	13.3	9.2	25^{o}	57	54	52	YES

*OVERNIGHT FUEL, NO FRESH FUEL ADDED (1) TANK TEMPERATURE AT IBP

TABLE D5. VAPOR LOCK TEST DATA - FUEL FLOW: 12.5 GPH

ALL TEMPERATURES: °C; ALL RVP: PSI
FOR POINTS REPEATED DURING RUN--LOWEST TEMPERATURE REPORTED

FUEL ID	TANK TEMP	PRETEST RVP	POST-TEST RVP	INITIAL BOILING POINT	LINE TEMP	SEDIMENT BOWL TEMP	CARB. BOWL TEMP	SUPPLEMENTAL HEAT ADDED
CRU	21	11.8	12.0	26°	35	43	37	YES
HPU	21	12.2	12.2	25°	35	42	42	YES
HRU	21	12.4	12.2	25°	31	42	49	YES
EPU	21	12.7	10.9	25°	32	42	40	YES
CPU	21	13.3	11.8	25°	34	42	37	YES
SBL	21	13.4	12.7	30°	34	41	39	YES
ERU	21	14.1	14.1	25°	33	34	37	YES
CRU	26(1)	11.8	11.2	26°	37	41	40	YES
SBL	30(1)	11.7	8.5	40°	47	53	47	YES
CRU	32	11.8	11.6	26°	37	43	42	YES
HPU	32	12.2	11.2	25°	46	48	41	YES
HRU	32	12.4	11.5	25°	36	43	41	YES
EPU	32	12.7	12.5	25°	34	43	41	YES
CPU	32	13.3	12.2	25°	34	42	42	YES
ERU	32	14.1	12.7	25°	36	41	39	NO
CRU	38	12.2	11.8	26°	42	45	39	YES
EPU	38	12.7	11.7	25°	40	45	44	YES
CPU	38(2)	13.3	8.5	25°	46/39	43/45	44/44	NO/NO
CRU	43	11.8	10.2	26°	45	50	46	YES
HPU	43	12.2	9.9	25°	45	48	45	NO
HRU	43	12.4	11.3	25°	46	47	43	NO
EPU	43	12.7	11.1	25°	44	48	45	YES
CPU	43	13.3	9.9	25°	45	50	47	NO
SBL	43	11.0*/13.0	5.9*/8.0	37°*/35°	47*/42	50*/44	44*/40	YES*/NO
ERU	43	14.13	10.9	25°	44	47	42	NO
HPU	49	12.2	8.9	25°	49	53	48	YES
HRU	49	12.2	N/A	25°	54*/55	58*/54	52*/49	YES*/YES
CPU	49	13.3	9.2	25°	50	54	49	YES

*OVERNIGHT FUEL, NO FRESH FUEL ADDED (1) TANK TEMPERATURE AT IBP (2) DUPLICATE POINT

TABLE D6. VAPOR LOCK TEST DATA - FUEL FLOW: 13.5 GPH

ALL TEMPERATURES: ^{o}C; ALL RVP: PSI
FOR POINTS REPEATED DURING RUN--LOWEST TEMPERATURE REPORTED

FUEL ID	TANK TEMP	PRETEST RVP	POST-TEST RVP	INITIAL BOILING POINT	LINE TEMP	SEDIMENT BOWL TEMP	CARB. BOWL TEMP	SUPPLEMENTAL HEAT ADDED
CRU	21	11.8	12.0	26^{o}	36	43.5	38	YES
HPU	21	12.2	12.2	25^{o}	37	42	36	YES
HRU	21	12.4	12.2	25^{o}	29	42	48	YES
EPU	21	12.7	10.9	25^{o}	29	42	39	YES
CPU	21	13.3	11.8	25^{o}	35	42	36	YES
SBL	21	13.4	12.7	30^{o}	34	42	39	NO
ERU	21(2)	14.1	14.1	25^{o}	32/32	36/35	37/37	YES/YES
CRU	26(1)	11.8	11.2	26^{o}	36	41	39	YES
SBL	30(1)	11.7	8.5	40^{o}	43	52	44	NO
CRU	32	11.8	11.6	26^{o}	35	42	41	YES
HPU	32	12.2	11.2	25^{o}	45	47	40	YES
HRU	32	12.4	11.5	25^{o}	38	43	40	YES
EPU	32	12.7	12.5	25^{o}	34	43	41	YES
CPU	32	13.3	12.2	25^{o}	35	42	41	YES
ERU	32	14.1	12.7	25^{o}	35	39	36	NO
CRU	38	12.2	11.8	26^{o}	39	44	39	YES
EPU	38	12.7	11.7	25^{o}	40	46	43	NO
CPU	38	13.3	8.5	25^{o}	39	45	43	NO
CRU	43	11.8	10.2	26^{o}	46	49	46	NO
HPU	43	12.2	9.9	25^{o}	47	48	45	NO
HRU	43	12.4	11.3	25^{o}	46	47	43	NO
EPU	43	12.7	11.1	25^{o}	44	48	44	NO
CPU	43	13.3	9.9	25^{o}	45	51	49	NO
SBL	43	11.0*/13.0	5.9*/8.0	37^{o}*/35^{o}	47*/42	50*/45	45*/40	YES*/NO
ERU	43	14.13	10.9	26^{o}	44	47	41	NO
HPU	49	12.2	8.9	25^{o}	48	53	46	NO
HRU	49	12.2	N/A	25^{o}	58*/49	59*/54	50*/47	YES*/NO
CPU	49	13.3	9.2	25^{o}	51	55	50	YES

*OVERNIGHT FUEL, NO FRESH FUEL ADDED (1) TANK TEMPERATURE AT IBP (2) DUPLICATE POINT

APPENDIX E

STANDARD DISTRIBUTION LIST

Region Libraries

Alaska	AAL-64
Central	ACE-66
Eastern	AEA-62
Great Lakes	AGL-60
New England	ANE-40
Northwest-Mountain	ANM-60
Western-Pacific	AWP-60
Southern	ASO-63d
Southwest	ASW-40

Center Libraries

Technical Center	ACT-64
Aeronautical Center	AAC-44.4

Civil Aviation Authority
Aviation House
129 Kingsway
London WC2B 6NN England

Embassy of Australia
Civil Air Attache
1601 Mass Ave. NW
Washington, D. C. 20036

Scientific & Tech. Info FAC
Attn: NASA Rep.
P.O. Box 8757 BWI Aprt
Baltimore, Md. 21240

DOT-FAA AEU-500
American Embassy
APO New York, N. Y. 09667

Headquarters (Wash. DC)

ADL-1
ADL-32 (North)
APM-1
APM-13 (Nigro)
ALG-300
APA-300
API-19
AAT-1
AWS-1
AES-3

OST Headquarters Library

M-493.2 (Bldg. 10A)

University of California
Sers Dpt Inst of Trsp Std Lib
412 McLaughlin Hall
Berkely, CA 94720

British Embassy
Civil Air Attache ATS
3100 Mass Ave. NW
Washington, DC 20008

Dir. DuCentre Exp DE LA
Navigation Aerineene
941 Orly, France

Northwestern University
Trisnet Repository
Transportation Center Lib.
Evanston, Ill. 60201

Mr. Steve Brown (2)
AOPA
421 Aviaiton Way
Frederick, MD 21701

Mr. Richard Kirsch, AWS-120
DOT/FAA National Headquarters
800 Independence Ave., SW.
Washington, DC 20591

Mr. Dick Roemer (5)
EAA Aviation Foundation
Whitman Airfield
Oshkosh, WI 54903-2591

Mr. Jim Peterson, ACE-140W
DOT/FAA Central Region
1801 Airport Road, Room 100
Wichita, KS 67209

Mr. Richard F. Yotter, ACE-111
DOT/FAA Central Region
601 East 12th Street
Kansas City, MO 64106

Mr. Raymond V. Boice, ACE-107
DOT/FAA Central Region
601 East 12th Street
Kansas City, MO 64106

Mr. Bob Alpiser
Chicago ACO
2300 East Devon
Des Plaines, IL 60018

Mr. Roy Hettenbach, ANE-174
New York ACO
181 South Franklin Avenue
Room 202
Valley Stream, NY 11581

Mr. Richard N. Wares
National Institute for
Petroleum & Energy Research
P.O. Box 2128
Bartlesville, OK 74005

Mr. W. Locke Easton, ANE-141
DOT/FAA New England Region
12 New England Executive Park
Burlington, MA 01803

Mr. Bob Berman, AWS-110
DOT/FAA National Headquarters
800 Independence Ave., SW.
Washington, DC 20591

Mr. Augusto M. Ferrara
DOT/FAA Technical Center
Atlantic City, NJ 08405

Mr. Paul Pendleton, ACE-140W
DOT/FAA Central Region
1801 Airport Road, Room 100
Wichita, KS 67209

Mr. Oscar E. Ball, ACE-112
DOT/FAA Central Region
601 East 12th Street
Kansas City, MO 64106

Mr. Don Jacobsen, ACE-101
DOT/FAA Central Region
601 East 12th Street
Kansas City, MO 64106

Mr. Raymond Borowski, ANE-170
New York ACO
181 South Franklin Avenue
Room 202
Valley Stream, NY 11581

Mr. Jerry Allsup (3)
National Institute for
Petroleum & Energy Research
P.O. Box 2128
Bartlesville, OK 74005

Mr. William Ackerman
6B1 Adams Building
Bartlesville, OK 74004

National Business Aircraft
Association
One Farragut Square South
Washington, DC 20006

General Aviaiton
Manufacturers Association
1400 K Street, NW.
Suite 801
Washington, DC 20005

Mr. Dave Bently
Aerospace Program Manager
Society of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096

Aerospatiale Aircraft Corp.
Suite 1220
1110 Vermont Avenue, NW.
Washington, DC 20005

Aerospatiale Helicopter Corp.
2701 Forum Drive
Grand Prairie, TX 75053-4005

Agusta Aviation Corporation
Norcom and Red Lion Roads
Philadelphia, PA 19154

Air Tractor, Inc.
P.O. Box 485
Olney, TX 76374

Arctic Aircraft Company
P.O. Box 6-141
Anchorage, AK 99502

Avtek Corporation
509 Calle Carga
Camarillo, CA 93010

Ayres Corporation
P.O. Box 3090
Municipal Airport
Albany, GA 31708

Beech Aircraft Corporation
Box 85
Wichita, KS 67204

Bellanca, Inc.
P.O. Box 964
Alexandria, MN 56308

Bell Helicopter Textron
P.O. Box 482
Fort Worth, TX 76101

Boeing Commercial Airplane
Company
P.O. Box 3707
Seattle, WA 98124

British Aerospace, Inc.
P.O. Box 17414
Dulles Int'l Airport
Washington, DC 20041-0414

Canadair, Ltd.
P.O. Box 6087
Montreal H3C 3G9
CANADA

CASA Aircraft USA, Inc.
1215 Jefferson Davis Highway
Suite 404
Arlington, VA 22202

Cessna Aircraft Company
P.O. Box 1521
Wichita, KS 67201

Christen Industries, Inc.
Aircraft Manufacturing Division
P.O. Box 547
Afton, WY 83110

Falcon Jet Corporation
Teterboro Airport
Teterboro, NJ 07608

DeHavilland Aircraft of Canada
Garratt Boulevard
Downsview, Ontario M3K 1Y5
CANADA

DeVore Aviation Corporation
6104B Kircher Boulevard, NE.
Albuquerque, NM 87109

Embraer Aircraft Corporation
276 SW. 34 Street
Fort Lauderdale, FL 33315

Enstrom Helicopter Corp.
Twin County AIrport
P.O. Box 277
Menominee, MI 49858

Fairchild Aircraft Corporation
P.O. Box 32486
San Antonio, TX 78284

Fokker Aircraft USA, Inc.
1199 N. Fairfax Street
Suite 500
Alexandria, VA 22314

Gates Learjet Corporation
P.O. Box 11186
Tuscon, AZ 85734

Glaser Dirks Sailplanes, Inc.
5847 Sharpe Road
Calistoga, CA 94515

Burkhart-Grob of America
1070 Navajo Drive
Bluffton Airport Complex
Bluffton, OH 45817

Gulfstream Aerospace Corp.
Wiley Post Airport
P.O. Box 22500
Oklahoma City, OK 73123

Hynes Aviation Industries
P.O. Box 697
Frederick, OK 73542

Atlantic Aviation Corp.
Westwind Sales
Greater Wilmington Airport
P.O. Box 15000
Wilmington, DE 19850

Lake Aircraft
Laconia Airport Hangar 1
Laconia, NH 03246

Litecraft, Inc.
Route 4, Box 48
Vacherie, LA 70090

Mael Aircraft Corporation
Box 138
Portage, WI 53901

Maule Aircraft Corporation
Lake Maule
Route 5, Box 319
Moultrie, GA 31768

McDonnell Douglas Corporation
3855 Lakewood Boulevard
Long Beach, CA 90846

McDonnell Douglas Helicopter Company
Centinela and Teale Streets
Culver City, CA 90230

MBB Helicopter Corporation
900 Airport Road
P.O. Box 2349
West Chester, PA 19380

Mike Smith Aero
Box 430
Stanton County Airport
Johnson City, KS 67855

Mooney Aircraft Corporation
P.O. Box 72
Kerville, TX 78028-0072

Mudry Aviation, Ltd.
Dutchess City Airport
Route 376
Wappingers Falls, NY 12590

OMAS, Inc.
P.O. Box 3530
Albany, GA 31708

Melex USA, Inc.
1200 Front Street
Suite 101
Raleigh, NC 27609

Robinson Helicopter Company
24747 Crenshaw Boulevard
Torrance, CA 90505

SAAB Aircraft of America, Inc.
P.O. Box 17188
Dulles International Airport
Washington, DC 20041

Schleicher Sailplanes, Inc.
P.O. Box 118
Port Matilda, PA 16870

Shorts Brothers, USA, Inc.
2011 Crystal Drive
Suite 713
Arlington, VA 22202

Sikorsky Aircraft
North Main Street
Stratford, CT 06601

Skytrader Aircraft Corporation
Richards-Gebaur Air Base
P.O. Box 345
Kansas City, MO 64141

Weatherly Aviation Company
2304 San Felipe Road
Hollister, CA 95023

Morris Aviation, Ltd.
P.O. Box 718
Statesboro Airport
Statesboro, GA 30458

Jonas Aircraft and Arms
Company, Inc.
225 Broadway
New York, NY 10007

Partenavia of America
1235 Jefferson Davis Highway
#500
Arlington, VA 22202

Piper Aircraft Corporation
Box 1328
Vero Beach, FL 32961

Rogerson-Hiller Corporation
2201 Alton Avenue
Irvine, CA 92714

Graham Thomson, Ltd.
P.O. Box 1175
Pacific Palisades, CA 90272

Schweizer Aircraft Corp
P.O. Box 147
Elmira, NY 14902

Box 51, Ltd.
Municipal Airport
Route 1, Box 102
Denton, TX 76201

PIK Pacific
1231 Second Street
Manhattan Beach, CA 90266

Taylorcraft Aviation Corp.
P.O. Box 947
820 East Bald Eagle Street
Lock Haven, PA 17745

Westland, Inc.
7135 Jefferson Davis Highway
Suite 805
Arlington, VA 22202

Mr. Neils Andersen
Senior VP - Engineering
AVTEK Corporation
4680 Calle Carga
Camarillo, CA 93010

Mr. Arthur J. K. Carline
Consultant
7347 DeCelis Place
Van Nuys, CA 91406

Dean Ernest J. Cross, Jr.
College of Engineering
Old Dominion University
Norfolk, VA 23508

Mr. Robert W. Koenig
NASA Langley Reserach Center
Mail Stop 352
Hampton, VA 23665-5225

Mr. Harold C. Pierce
Honeywell, Inc.
1625 Zarthan Avenue, South
P.O. Box 312
St. Louis Park, MN 55416

Dr. Frederick O. Smetana
North Carolina State University
P.O. Box 5246
Raleigh, NC 27650

Mr. Robert J. Stewart
Program Manager
Gulfstream Aerospace Corp, B-08
P.O. Box 2206
Savannah, GA 31402

Mr. Charles M. Turrentine
Engineering Specialist
General Dynamics Corporation
P.O. Box 748, M/S 1772
Fort Worth, TX 76101

Mr. John H. Wells
Cessna Aircraft Company
Department 178
P.O. Box 7704
Wichita, KS 67277

Dr. Michael B. Bragg
Ohio State University
2300 West Case Road
Columbus, OH 43220

Mr. Everett L. Cook
Gates Learjet Corporation
P.O. Box 7707
Wichita, KS 67277

Dr. David Downing
Dept of Aerospace Engineering
The University of Kansas
2004 Learned Hall
Lawrence, KS 66045-2221

Mr. Louis J. Williams
NASA Langley Research Center
Mail Stop 286
Hampton, VA 23665-5225

Mr. Harold P. Riesen
Chief, Mech/Env. Systems, R&D
Beech Aircraft Corporation
9709 East Central
Wichita, KS 67201

Dr. Hubert C. Smith
Assistant Professor
Pennsylvania State University
233 Hammond Building
University Park, PA 16802

Mr. Fen Taylor
Chief, Aerodyanmics & Perform
Mooney Aircraft Corporation
P.O. Box 72
Kerrville, TX 78029

Dr. Donald T. Ward
Associate Professor
Aerospace Engineering Dept.
Texas A&M University
College Station, TX 77843

Dr. Edward A. Willis, Jr.
NASA Lewis Research Center
Mail Stop 77-6
21000 Brookpark Road
Cleveland, OH 44135

Mr. David C. Yeoman
Collins-Rockwell
MS 124-111
400 Collins Road, NE.
Cedar Rapids, IA 52498

Ms. Alma Ramirez, ANM-100A
ACO
701 C. Street
Box 14
Anchorage, AK 99513

Mr. Eric Jevons
Colt Industries
Control Systems Division
Charter Oak Boulevard
West Hartford, CT 06101

Mr. Russell Rogers
Aeroquip Corporation
Corporate Engineering
Jackson, MI 49203

Mr. H. Daniel Smith
Engineered Fabrics Division
Goodyear Aerospace Corporation
1210 Massillon Road
Akron, OH 44315

Mr. Peter Thomas
Sundstrand Aerospace Fluid Systems
2421 11th Street
P.O. Box 7002
Rockford, IL 61125-7002

Mr. Terence Dixon
Boeing Aerospace Corporation
P.O. Box 3999
M/S 8M-11
Seattle, WA 98124

☆U.S. GOVERNMENT PRINTING OFFICE: 1986-605-071/40134

END

12-86

DTIC