

# **Investigation of Subterranean Fuel Vapor Extraction and Destruction Using a Diesel Engine: Phase II**

**INTERIM REPORT  
TFLRF No. 366**

by

**Matthew E. Schulman**

**Karl E. Stoecklein**

**U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI)  
Southwest Research Institute  
San Antonio, TX**

for

**U.S. Air Force Center for Environmental Excellence  
Installation Excellence Worldwide Directorate  
Brooks City-Base  
San Antonio, TX**

Under Contract to

**U.S. Army TARDEC  
Petroleum and Water Business Area  
Warren, MI**

Contract No. DAAE-07-99-C-L053

Approved for public release; distribution unlimited

**June 2003**

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Edwin C. Owens, Director  
U.S. Army TARDEC Fuels and Lubricants  
Research Facility (SwRI)

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## EXECUTIVE SUMMARY

**Problems and Objectives:** Environmental and health hazards posed by soil contamination resulting from underground fuel tank leakage and spillage at U.S. Air Force bases have created a need for cost-effective methods of removing volatile and combustible compounds from subterranean soil. Following removal of as much liquid-state contaminant as possible from a site, the next step in the clean-up process is further removal of contaminant in gaseous form as it evaporates from the saturated soil. One method employed is to bore a well, insert a pipe into the contaminated soil and route the vapors into the intake of a running engine for combustion.

Current engines used for this task are spark-ignited automotive models using propane or natural gas as supplemental fuel during startup and lean vapor conditions. The purpose of this project is to investigate whether a compression-ignition (CI) diesel engine could perform the same function, perhaps increasing efficiency, durability and reliability.

**Importance of Project:** Continuous operation of an engine for this purpose can result in significant maintenance cost over time. The inherently sturdier design of compression-ignition engines predicts greater durability and a longer life cycle between rebuilds. Other important advantages that a CI engine may offer in this application are the capability to operate at leaner air-fuel ratios and the ability to use readily available JP-8 as a supplemental fuel instead of bottled gases. Using a liquid fuel could also reduce the requirement for refueling, since a larger tank could be used, thereby reducing the associated labor costs.

**Technical Approach:** A small diesel engine obtained from Air Force surplus inventory was equipped for operation as a pre-mixed vapor dual-fuel test platform. Propane, butane and pentane in various concentrations were used as surrogate gases to simulate fuel vapors found in a typical well site. The engine was operated at various steady state speed and load conditions while the gas to air ratio in the intake air stream was incrementally increased. At each test point, the cylinder pressure was monitored for indications of potentially damaging knock, and parameters such as fuel and air consumption rates and engine temperatures were recorded.

**Accomplishments:** Data was acquired at a wide range of engine speed and load conditions, using different concentrations of the hydrocarbon gases, to investigate and describe how the engine will operate in actual use at a well site. Further testing examined how the engine would operate with the intake throttled, to simulate the pumping work required to extract the gases from a well. The operating conditions were defined, in preparation for a field test in the following project phase.

**Military Impact:** The results of this limited study show promise for the possibility of using diesel engines in the task of removing and destroying fuel vapors from underground contamination sites. If the concept ultimately proves practicable through further investigation, it could potentially increase the effectiveness and reliability of engine-based ground vapor removal systems while simultaneously reducing the maintenance costs associated with them.

## **FOREWORD/ACKNOWLEDGMENTS**

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## ACRONYMS & ABBREVIATIONS

|                    |                                                             |
|--------------------|-------------------------------------------------------------|
| AFCEE              | U. S. Air Force Center for Environmental Excellence         |
| bhp                | Brake Horsepower                                            |
| CI                 | Compression Ignition                                        |
| CO                 | Carbon Monoxide                                             |
| CO <sub>2</sub>    | Carbon Dioxide                                              |
| ERT                | Environmental Restoration Team                              |
| ft-lb <sub>f</sub> | Foot-pound(s) (force)                                       |
| GC                 | Gas Chromatograph                                           |
| HC                 | Hydrocarbons(s)                                             |
| kPaa               | Kilopascals (absolute)                                      |
| lbm                | Pound mass                                                  |
| LFE                | Laminar Flow Element                                        |
| ppt                | parts per thousand                                          |
| psig               | Pound(s) per square inch (gauge)                            |
| PPM                | Parts Per Million                                           |
| RPM                | Rotation(s) per minute                                      |
| SI                 | Spark Ignited                                               |
| SwRI               | Southwest Research Institute                                |
| TARDEC             | Tank-Automotive Research Development and Engineering Center |
| TACOM              | Tank-Automotive Armaments Command                           |
| TFLRF              | U.S. Army TARDEC Fuels and Lubricants Research Facility     |
| T/p                | Torque/pressure                                             |
| TVH                | Total Volatile Hydrocarbons                                 |

## **1.0 BACKGROUND**

Over a period of many years, leakage from underground fuel storage tanks and other sources has contaminated the ground soil sites at many US Air Force bases worldwide. The common technique used for cleanup at these locations is to drill into the contaminated soil and extract as much liquid waste as possible. Following removal of the majority of the liquid fuel, the remainder is extracted in vapor form with the aid of an internal combustion engine adapted to burn the vapors as fuel. The extraction unit currently in use has a spark-ignited (SI) automobile engine that serves as both a vapor “pump” and a means of vapor destruction, with propane or natural gas serving as a supplemental fuel during startup and lean conditions.

In order to obtain increased efficiency, durability and reliability in these engine-based extraction units, the Air Force has contracted Southwest Research Institute (SwRI) to investigate the feasibility of using compression-ignition (CI) engines in place of the SI automobile engines now employed. An engine utilized in this role would operate similarly to a dual-fuel natural gas/diesel unit, using distillate fuel as a pilot to ignite the extracted gas charge.

## **2.0 OBJECTIVES**

The initial phase of testing demonstrated that the basic concept of burning pre-mixed gaseous fuel vapors in a diesel engine using liquid fuel as an ignition pilot is indeed feasible. It has been shown that the combustion of a gaseous fuel increases as engine load increases. It was found that under significant loading conditions, the pilot fuel amount can be reduced to approximately 20% of the total fuel requirement, assuming the fuel vapors are of high enough concentration to sustain engine operation.

For reasons of practicality and availability, first phase testing used propane gas as a surrogate to simulate well vapors. With the knowledge gained from that testing, the

second project year seeks to develop the concept using gases that more closely approximate the molecular weight and composition of typical well vapors.

Work performed in Phase II incorporates the following additional items to further determine concept feasibility:

- Measurement of engine load at test points to better facilitate duplication of laboratory conditions in future field experiments.
- Exhaust emissions analysis, including evaluation of hydrocarbons, smoke, CO and CO<sub>2</sub> concentrations.
- Mapping of quantitative gas consumption rates and efficiencies.
- A throttling experiment to examine the effects of engine intake air restriction, as would be seen when installed at a well site.

### **3.0 EXPERIMENTAL APPROACH**

#### **3.1 Setup Modifications**

In order to determine the load applied to the engine during testing, a novel torque-sensing instrument was installed in the coupling between the engine and the roots blower. Figure 1 below shows the coupling that was on the cabin pressurization unit when received at SwRI. Figure 2 below shows the torque-sensing coupling installed in its place. Comparing the two views reveals that it was necessary to remount the blower farther from the engine in order to accommodate the additional equipment. Installation of the instrument included design and fabrication of flanges to mate to the flywheel and blower, careful shaft alignment of the components, and integration into the cell's data acquisition system.



**Figure 1. Original Coupling**  
(top view)

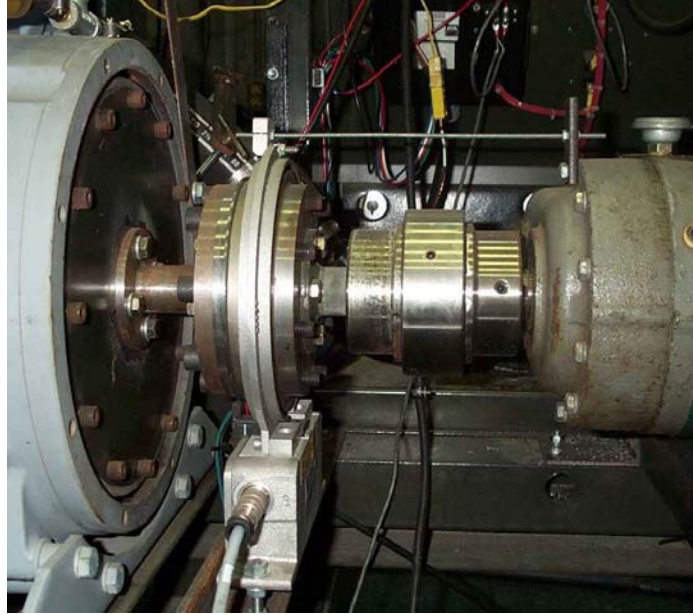


**Figure 2. Torque-Sensing Coupling**  
(side view)

The device is an HBM T10F Flange Torque Sensor. It uses shear stress to measure torque instead of torsional stress. The measurement signal telemetry and the coupling of excitation voltage are carried out inductively via antenna segments that enclose the flange in a ring shape. This makes the instrument compact, and the lack of physical contact allows it to provide very high accuracy.

Figure 3 shows another view of the coupling. In Figure 3, the Roots blower is in the foreground and the flywheel end of the Hatz engine is in the background. The device closest to the flywheel is the torque sensor. The middle portion, out to the maroon-colored ring, rotates within the silver-colored stator. The enclosure below the stator houses the excitation and sensing parts of the instrument. A rod extends from the blower housing to the top of the stator ring, to stabilize the structure (thus the signal) during operation. A coupling to absorb torsional vibrations is in place on the shaft between the torque sensor and the blower.

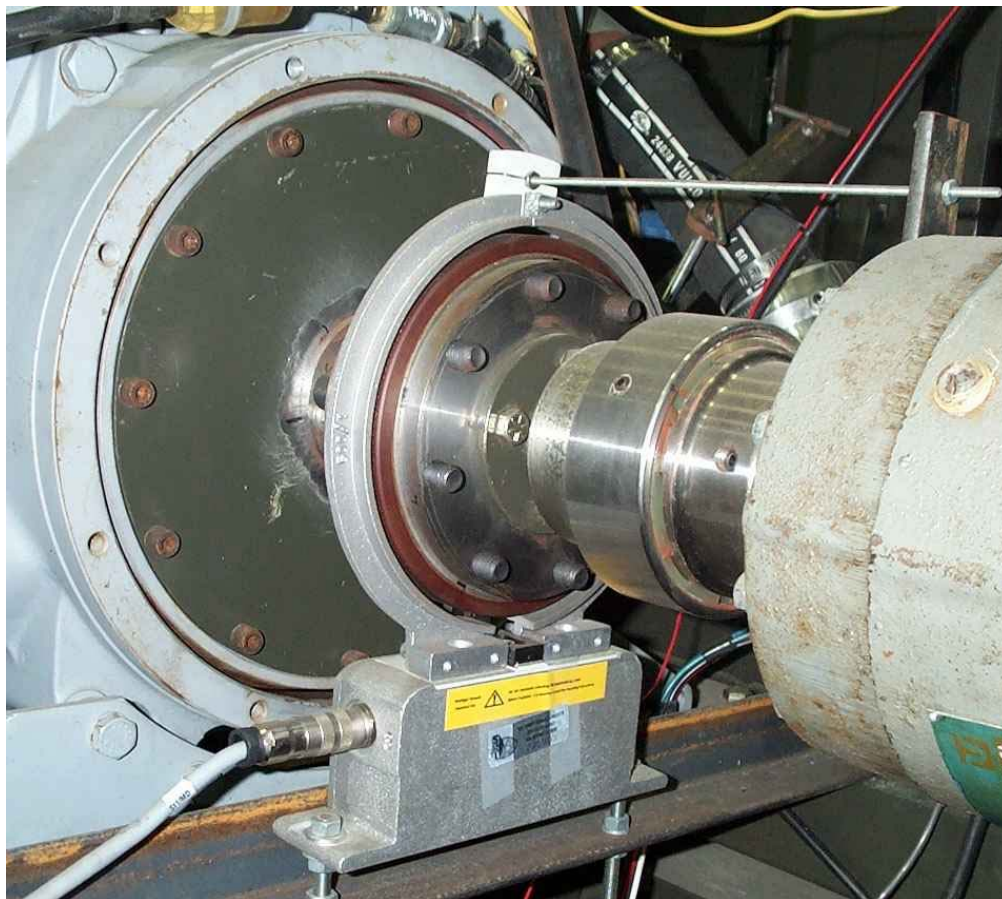


**Figure 3. Detail of Torque Sensor**

Lacking this torque sensor, the initial testing was performed by setting blower pressures to obtain different levels of load. "Light" load used a setting of 2 psig, "Intermediate" load used 8 psig, and "Heavy" load used 11 psig. To compare these load levels with data taken later, a load curve was measured, correlating blower pressure with engine torque. Figure 4 is a plot of this data. All data was acquired at 2000 rpm.

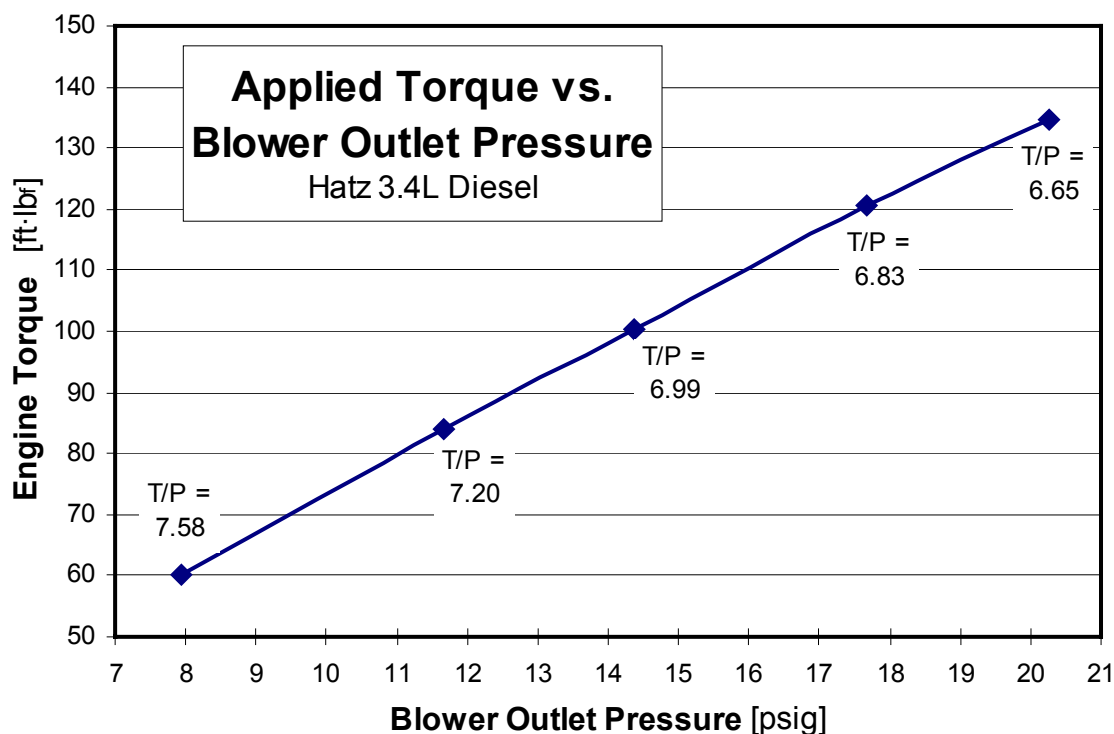


**Figure 4. Blower Outlet Pressure correlated to Engine Torque**

In order to counteract the low vapor pressure of pentane gas at ambient conditions, a simple water-immersion bottle heater was constructed and installed. This is necessary to provide sufficient in-cylinder vapor pressure to achieve gas flow rates that will allow the desired ratios of gas to liquid fuel to be attained. The pentane tank in the immersion heater is shown in Figure 5. The temperature control for the electric heater is visible at the lower-left of the tank.

For this same purpose, piping carrying the gaseous fuel was wrapped with insulation. Heating wraps were installed on some lines.



**Figure 5. Immersion Heater**

The air pressure regulating system of the cabin pressurization unit was removed and replaced with a manually controlled butterfly valve to simplify operation. Controls for engine throttle, gas flow and blower backpressure were relocated to the operator console.

Emissions measuring equipment was installed in the test cell to measure exhaust concentration of hydrocarbons at each test point and condition, as well as hydrocarbon content in the inlet air stream — with or without added gaseous fuel.

### **3.2 Testing Procedures**

Similar to the procedure followed in Phase I, tests were conducted according to a matrix involving variations in engine speed, engine load and pilot fuel percentage to map characteristics at steady-state operating conditions. Performance measurements include a range of pertinent temperatures, pressures, flow rates and engine operating parameters, as well as emissions as previously described.

The testing commenced using propane [ $C_3H_8$ ] as the surrogate well vapor to establish baseline performance parameters. This strategy was employed because it was anticipated that the lighter hydrocarbons would present the greatest challenge to the feasibility of the concept. The high octane rating, therefore low cetane rating, of the propane was expected to be a problem for a diesel engine. The testing did indicate some limitations on safe engine conditions, but overall proved that the use of a diesel engine for vapor destruction was feasible. Following successful completion of testing using propane, the test matrix was repeated with butane [ $C_4H_{10}$ ] gas, then with pentane [ $C_5H_{12}$ ] gas. Progressing by steps higher in carbon number was to provide an indication of how a heavier molecular weight gas affects the combustion characteristics of the engine.

The carbon content of pentane is representative of the majority of hydrocarbons found in the vapor sample extracted at Kelley AFB, and results obtained with pentane should be a good indicator of prospective performance at a well site. Pentane will provide the closest approximation of actual well vapors for laboratory testing.

The engine was tested at four load levels, at 2000 rpm under all conditions. At each load level, data acquisition commenced without gaseous fuel. Gaseous fuel was then introduced, and the JP-8 fuel flow rate correspondingly reduced, until a desired proportional mixture was achieved, at the previously set engine speed and load. Data was acquired, then the procedure was repeated to further reduce the JP-8 fuel proportion of the total fuel. This procedure was repeated until the JP-8 fuel was only 10% of the total, or until misfire, knock or other combustion problem occurred. Finally, the gaseous fuel was shut off and the JP-8 flow returned to the original rate to repeat the initial condition, to ensure that nothing had changed during testing.

With all data acquired for a given load level, this procedure was repeated for the next-higher load until all conditions had been tested. This matrix is summarized in Table 1:

**Table 1. Test Conditions**

| Designation | Engine Speed | Engine Load            | JP-8 % of Total |
|-------------|--------------|------------------------|-----------------|
| 1A1         | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 100 %           |
| 1B          | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 80 %            |
| 1C          | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 60 %            |
| 1D          | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 40 %            |
| 1E          | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 20 %            |
| 1F          | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 10 %            |
| 1A2         | 2000 rpm     | 60 ft·lb <sub>f</sub>  | 100 %           |
| 2A1         | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 100 %           |
| 2B          | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 80 %            |
| 2C          | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 60 %            |
| 2D          | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 40 %            |
| 2E          | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 20 %            |
| 2F          | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 10 %            |
| 2A2         | 2000 rpm     | 80 ft·lb <sub>f</sub>  | 100 %           |
| 3A1         | 2000 rpm     | 100 ft·lb <sub>f</sub> | 100 %           |
| 3B          | 2000 rpm     | 100 ft·lb <sub>f</sub> | 80 %            |
| 3C          | 2000 rpm     | 100 ft·lb <sub>f</sub> | 60 %            |
| 3D          | 2000 rpm     | 100 ft·lb <sub>f</sub> | 40 %            |
| 3E          | 2000 rpm     | 100 ft·lb <sub>f</sub> | 20 %            |
| 3F          | 2000 rpm     | 100 ft·lb <sub>f</sub> | 10 %            |
| 3A2         | 2000 rpm     | 100 ft·lb <sub>f</sub> | 100 %           |
| 4A1         | 2000 rpm     | 120 ft·lb <sub>f</sub> | 100 %           |
| 4B          | 2000 rpm     | 120 ft·lb <sub>f</sub> | 80 %            |
| 4C          | 2000 rpm     | 120 ft·lb <sub>f</sub> | 60 %            |
| 4D          | 2000 rpm     | 120 ft·lb <sub>f</sub> | 40 %            |
| 4E          | 2000 rpm     | 120 ft·lb <sub>f</sub> | 20 %            |
| 4F          | 2000 rpm     | 120 ft·lb <sub>f</sub> | 10 %            |
| 4A2         | 2000 rpm     | 120 ft·lb <sub>f</sub> | 100 %           |

### 3.3 Problems Encountered

A malfunctioning fuel shutoff solenoid on the Hatz engine had to be corrected. The solenoid prevented the engine from starting for more than a few seconds at a time. A solution was found to circumvent the problem and allow the engine to run normally, but only after approximately a week of investigation and repair.

Utilization of pentane as a surrogate test gas proved to be a challenge. During testing, an error in dispenser configuration resulted in liquid pentane being introduced into the engine air stream. The surge in available energy caused a very rapid rise in engine speed and cylinder pressure along with likely detonation that destroyed the cylinder pressure transducer. Upon receiving the properly packaged pentane, and installation of another transducer, another attempt was made at running the test matrix. During execution of the test, another problem was encountered with pentane condensing in the supply lines, resulting in a second surge event and a second transducer failure. Following removal of an in-line pressure regulator that was contributing to the condensation problem, and the installation of additional heat tapes, the condensation problem was solved. Testing was then resumed, with the full test matrix being completed on pentane fuel.

Upon start of the engine for the next test session, a pronounced audible knock was detected. Investigation and disassembly showed that the piston and bore of cylinder 1 were damaged. It appears that debris from one of the failed pressure transducers lodged between the piston and cylinder wall resulting in broken rings and a damaged piston. The engine was repaired and a new pressure transducer was installed.

The intake piping as originally installed sloped steeply downward, and the "gas ring" where the gaseous fuel was introduced was very close physically to the engine. This arrangement is shown in Figure 6 on the left below.

Figure 7 on the right shows the new arrangement of the piping. In order to prevent recurrence of this problem, the air intake piping was reconfigured to prevent liquid fuel,

even if it does reach the intake piping, from entering the engine. Bright green lines have been added to the picture to indicate the position of the pipes in places where they are concealed behind the engine or other equipment. Note that the gas ring is now much farther from the engine, and lower than before. Should liquid fuel ever again reach the intake air stream, it would have to flow uphill through nearly two meters of piping, while being evaporated by the inlet air flow, before reaching the engine. The focus will remain on preventing liquid fuel from being introduced at all, but this added safeguard should prevent further engine damage.



**Figure 6. Original Setup**

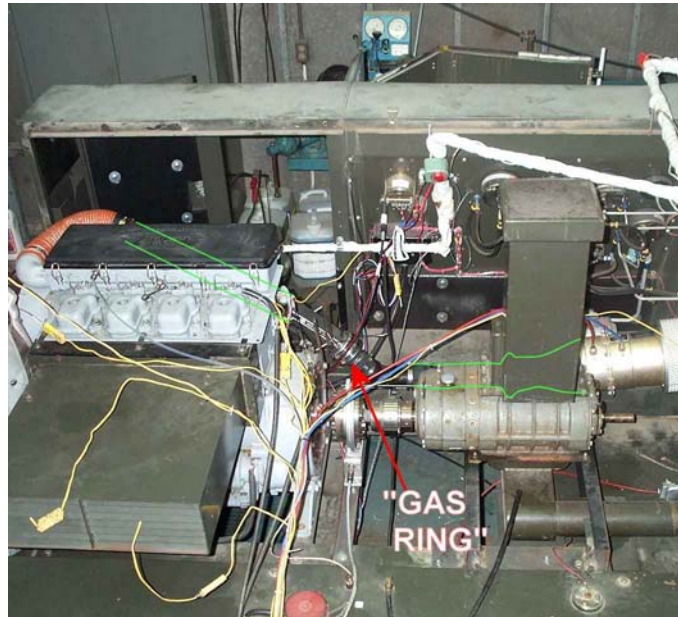


**Figure 7. Revised Intake Piping**

## **4.0 RESULTS**

A complete set of tabulated test data is attached as Appendix A. A summary of the pertinent test data for discussion is shown in Table 2. All of this data was acquired using pentane as the gaseous fuel, at an engine speed of 2000 rpm. The shaded rows in Table 2 indicate the test condition for each torque setting which used the highest proportion of gaseous fuel without evidencing audible knock.

As previously noted, the pentane used in these experiments as a well gas surrogate most closely approximates the sample collected at Kelly AFB. As this data is therefore expected to most closely predict the operation of the unit in actual use at a well site, this analysis will discuss only the results obtained using pentane.

### **4.1 Upper Limit of Gaseous Fuel Ingestion**

The first effect visible in these data is an apparent limit of the gaseous fuel flow rate without inviting knock. In all but the lowest-load data ( $60 \text{ ft}\cdot\text{lb}_f$ ), more than  $7 \text{ lb}_m/\text{hr}$  of pentane invited knock. This exception likely resulted from the lower cylinder temperatures associated with the lower engine load. It should be noted that this inference depends on perceptible monitoring for knock as the cylinder pressure instrumentation was inoperative.

**Table 2. Vapor Destruction Data Using Pentane**

| Test<br>Desig. | Engine<br>Power | Torque             | Air Flow LFE<br>Dry | JP-8 Fuel<br>Flow   | Gaseous Fuel<br>Flow | Total Fuel<br>Flow  | Air / JP-8<br>Ratio | Air / Gaseous<br>Fuel Ratio | Air / Total<br>Fuel Ratio | BSFC                    | Exhaust HC | Intake HC | HC<br>Reduction |
|----------------|-----------------|--------------------|---------------------|---------------------|----------------------|---------------------|---------------------|-----------------------------|---------------------------|-------------------------|------------|-----------|-----------------|
| -              | bhp             | ft-lb <sub>f</sub> | lb <sub>m</sub> /hr | lb <sub>m</sub> /hr | lb <sub>m</sub> /hr  | lb <sub>m</sub> /hr |                     |                             |                           | lb <sub>m</sub> /bhp-hr | ppm        | ppm       | %               |
| 1A1            | 23.2            | 61.0               | 391.69              | 10.017              | 0                    | 10.02               | 39.10               | -                           | 39.10                     | 0.431                   | 638        | 4         |                 |
| 1B             | 23.2            | 60.9               | 388.01              | 7.893               | 2.048                | 9.94                | 49.16               | 189.5                       | 39.03                     | 0.428                   | 1591       | 11194     | 85.8            |
| 1C             | 23.1            | 60.8               | 387.58              | 6.083               | 4.033                | 10.12               | 63.71               | 96.1                        | 38.31                     | 0.437                   | 2296       | 20365     | 88.7            |
| 1B2            | 23.3            | 61.1               | 389.00              | 8.024               | 1.938                | 9.96                | 48.48               | 200.8                       | 39.05                     | 0.427                   | 1702       | 10723     | 84.1            |
| 1D             | 23.3            | 61.1               | 386.38              | 4.099               | 6.139                | 10.24               | 94.25               | 62.9                        | 37.74                     | 0.440                   | 2660       | 30072     | 91.2            |
| 1E             | 23.1            | 60.5               | 383.89              | 1.825               | 7.821                | 9.65                | 210.30              | 49.1                        | 39.80                     | 0.418                   | 2751       | 37461     | 92.7            |
| 1A2            | 23.2            | 60.8               | 387.79              | 9.982               | 0                    | 9.98                | 38.85               | -                           | 38.85                     | 0.431                   | 697        | 5         |                 |
| 2A1            | 30.6            | 80.3               | 385.01              | 12.181              | 0                    | 12.18               | 31.61               | -                           | 31.61                     | 0.398                   | 668        | 2         |                 |
| 2B             | 30.5            | 80.0               | 383.12              | 9.531               | 2.394                | 11.93               | 40.20               | 160.0                       | 32.13                     | 0.391                   | 1471       | 12918     | 88.6            |
| 2C             | 30.2            | 79.5               | 380.98              | 7.136               | 4.717                | 11.85               | 53.39               | 80.8                        | 32.14                     | 0.392                   | 1913       | 24038     | 92.0            |
| 2D             | 30.6            | 80.1               | 379.51              | 4.791               | 7.062                | 11.85               | 79.21               | 53.7                        | 32.02                     | 0.388                   | 2335       | 35343     | 93.4            |
| 2E             | 29.6            | 77.7               | 345.46              | 3.259               | 11.520               | 14.78               | 106.01              | 30.0                        | 23.37                     | 0.499                   | 1117       | 56357     | 98.0            |
| 2A2            | 30.7            | 80.4               | 378.67              | 12.316              | 0                    | 12.32               | 30.75               | -                           | 30.75                     | 0.402                   | 678        | 3         |                 |
| 3A1            | 38.5            | 100.9              | 376.86              | 15.024              | 0                    | 15.02               | 25.08               | -                           | 25.08                     | 0.391                   | 667        | 2         |                 |
| 3B             | 38.1            | 99.8               | 375.17              | 11.350              | 2.920                | 14.27               | 33.06               | 128.5                       | 26.29                     | 0.375                   | 1402       | 17297     | 91.9            |
| 3C             | 39.0            | 102.3              | 372.56              | 8.919               | 5.763                | 14.68               | 41.77               | 64.7                        | 25.38                     | 0.376                   | 1566       | 30193     | 94.8            |
| 3D             | 37.9            | 99.3               | 350.89              | 6.548               | 9.668                | 16.22               | 53.59               | 36.3                        | 21.64                     | 0.428                   | 668        | 51027     | 98.7            |
| 3C+            | 38.5            | 100.9              | 363.03              | 7.011               | 7.556                | 14.57               | 51.78               | 48.1                        | 24.92                     | 0.379                   | 1036       | 39954     | 97.4            |
| 3A2            | 39.0            | 102.4              | 371.59              | 15.301              | 0                    | 15.30               | 24.28               | -                           | 24.28                     | 0.392                   | 785        | 1         |                 |
| 4A1            | 45.6            | 119.6              | 371.07              | 17.948              | 0                    | 17.95               | 20.67               | -                           | 20.67                     | 0.393                   | 501        | 1         |                 |
| 4B             | 45.8            | 120.0              | 370.28              | 13.203              | 3.637                | 16.84               | 28.05               | 101.8                       | 21.99                     | 0.368                   | 1330       | 20670     | 93.6            |
| 4C             | 45.9            | 120.4              | 360.46              | 10.250              | 7.568                | 17.82               | 35.17               | 47.6                        | 20.23                     | 0.389                   | 1051       | 40139     | 97.4            |
| 4A2            | 47.2            | 123.7              | 355.05              | 19.817              | 0                    | 19.82               | 17.92               | -                           | 17.92                     | 0.420                   | 492        | 397       |                 |

## 4.2 Destruction Efficiency

For this discussion, "destruction efficiency" is defined as the percentage of the inducted hydrocarbons that are destroyed during combustion. For each condition, the concentration of hydrocarbons is measured in the intake and exhaust gases, and compared to a reference measurement with no inducted hydrocarbons:

$$\text{destruction efficiency} = \frac{\text{Intake HC} - (\text{Exhaust HC (measured)} - \text{Exhaust HC (reference)})}{\text{Intake HC}} \times 100\%$$

To examine the effect of engine load on hydrocarbon destruction efficiency given a certain concentration of gaseous fuel available, Figure 8 presents the destruction efficiency data acquired relative to the gaseous fuel flow rate for the four engine load ranges tested. Predictably, the proportion of hydrocarbons in the inlet air stream burned increases with increasing engine load. The useable range is limited by engine knock, which starts to occur in the light blue region indicated. The region is bounded at the lower-left by points where no knock occurred, and at the top by points where knock was detected. No destruction efficiency targets have been identified, but the figure outlines possible operational regions.

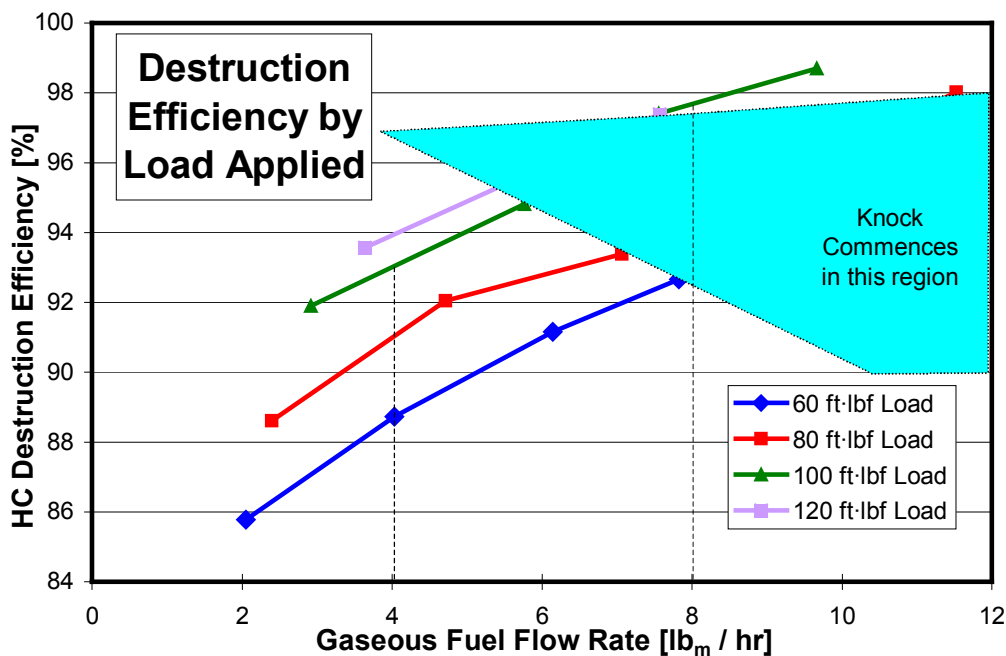


Figure 8. HC Destruction Efficiency by Load Applied

### 4.3 Fuel Required

The cost of the higher engine load required to realize the higher destruction efficiency for a given intake concentration of gaseous fuel is increased use of added liquid fuel. Figure 9 quantifies the distillate fuel flow rates required for these same conditions. The dashed lines on Figures 8 and 9 indicate that, with 4 lb<sub>m</sub>/hr of gaseous fuel entering the engine, increasing the destruction efficiency from 88.7% to 93.0%, a 4.9% improvement, demands a 70.5% increase in added liquid fuel, from 6.1 lb<sub>m</sub>/hr to 10.4 lb<sub>m</sub>/hr. Similarly, with 8 lb<sub>m</sub>/hr of gaseous fuel entering the engine, increasing the destruction efficiency from 92.8% to 97.7%, a 5.2% improvement, demands a 337% increase in added liquid fuel, from 1.6 lb<sub>m</sub>/hr to 6.9 lb<sub>m</sub>/hr.

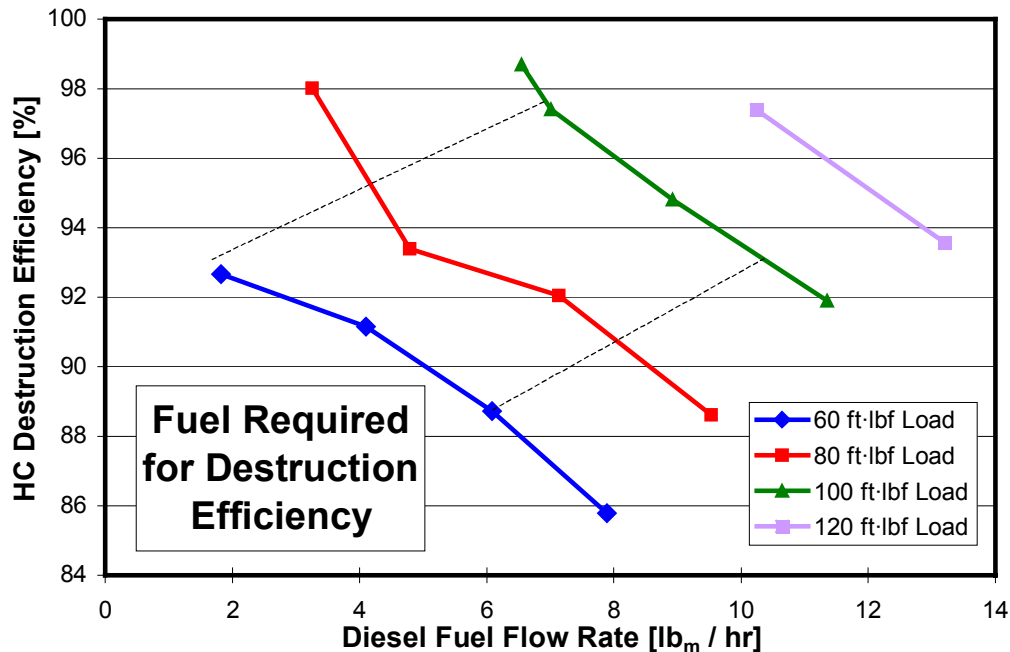


Figure 9. Additional Liquid Fuel Required for Destruction Efficiency

### 4.4 Throttled Operation

In order to characterize the operation of the engine under the high intake vacuum conditions required to produce well suction, a series of test data was acquired with the engine intake throttled. A manually-operated butterfly valve was added to the intake

tract, downstream of the "gas ring" so that the throttled flow would be a mixture of intake air and gaseous fuel.

Figure 10 is a plot of some of these data, showing the effect on mass air flow of various intake manifold pressure conditions. The tightly-clustered blue lines indicate that the gas concentration of the intake air flow has little effect on the total mass flow at 1550 rpm. The effect is repeated for the testing at 2000 rpm. Another effect shown in the data is that the air flow is a strong function of engine speed. Predictably, for comparable engine vacuum conditions, the 1/3 increase in speed from 1550 rpm to 2000 rpm results in approximately 1/3 more mass air flow. Both sets of lines, if extrapolated to reach the point at which air flow reaches zero, would do so at approximately 50 kPaa. This indicates the engine would cease to operate, for lack of air, at a vacuum of less than 50 kPaa. In fact, the points at the lower-right ends of the curves shown are those at which the engine approached a condition where it would begin to misfire, lacking sufficient air for good combustion. Finally, the one line of data shown at a higher load verifies that engine load has no effect on intake air flow for a given set of intake conditions.

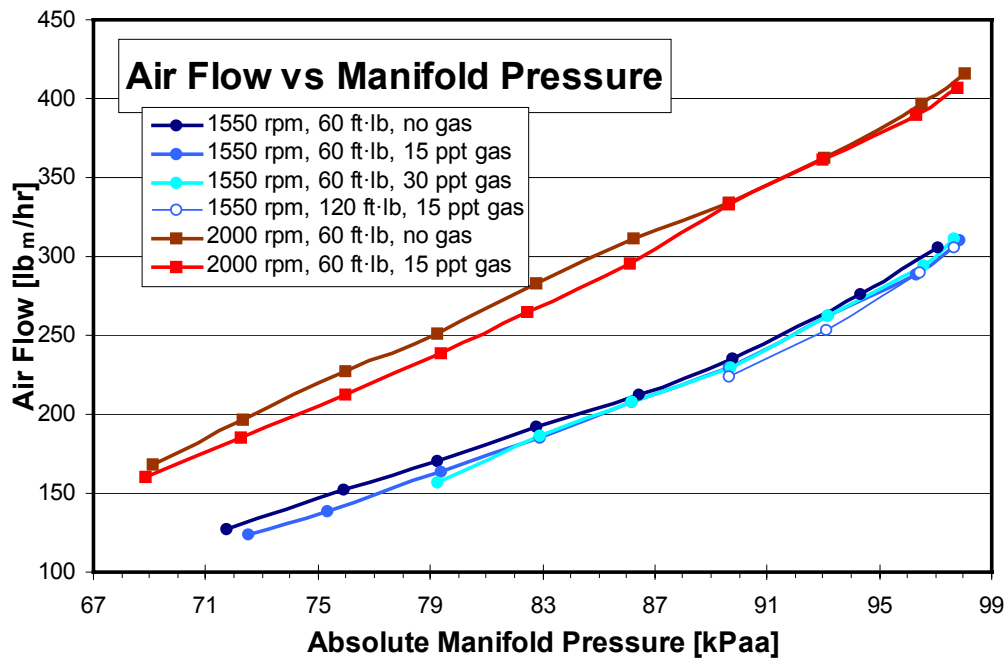


Figure 10. Air Flow vs. Intake Manifold Pressure, Engine Throttled

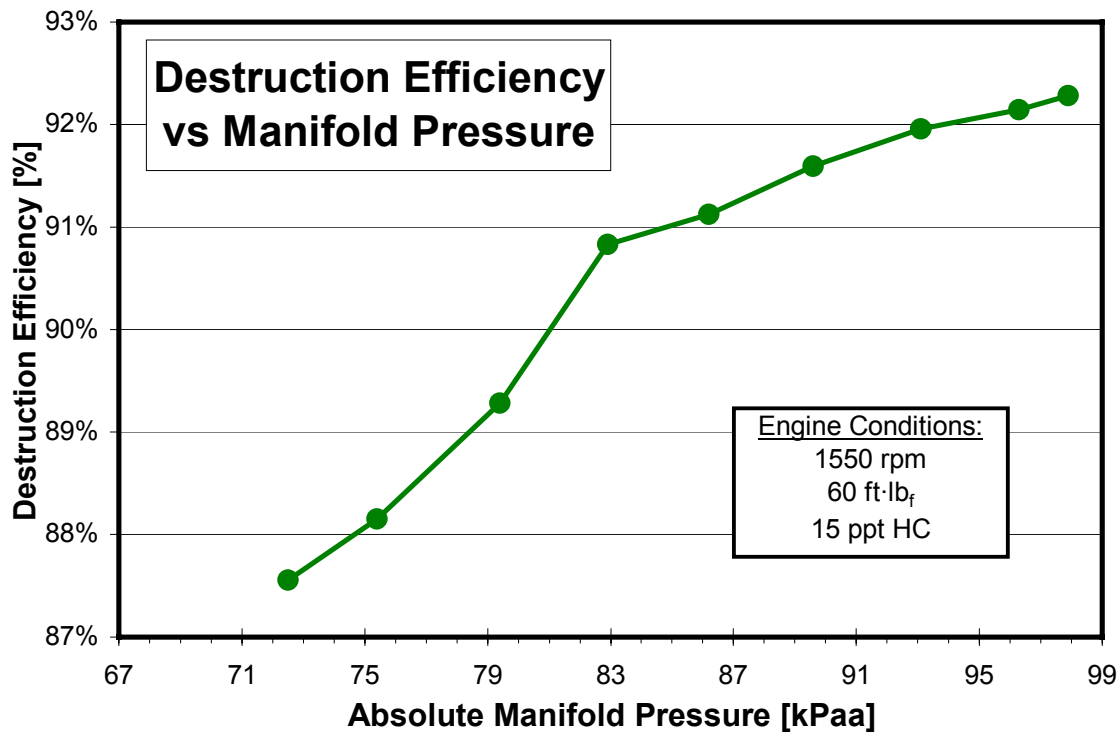


**Figure 11. HC Destruction Efficiency vs. Intake Manifold Pressure**

A number of engine characteristics that might have become problematic with reduced air flow were monitored, but none in fact reached unacceptable conditions. Temperatures of exhaust, cooling air and oil all stayed within acceptable limits, given that the engine inducted sufficient air for good combustion. Even good hydrocarbon destruction efficiency was maintained, as shown in Figure 11, though it did start to fall off as manifold vacuum increased.

The result of the testing is simply that the engine will continue to operate, and will continue to destroy inducted hydrocarbons, so long as the engine has sufficient air — and the air contains sufficient oxygen — for good combustion. If enough oxygen can not be extracted from the well, outside air must be added to the intake stream, thereby reducing the flow from the well.

## **5.0 CONCLUSIONS**

First and foremost, the diesel engine system is capable of performing the hydrocarbon vapor destruction task. Its success with a variety of hydrocarbon gases bodes well for the unknown conditions it will encounter at various well sites.

The system does have some characteristics that will limit its operation in actual use. The engine must have sufficient oxygen for good combustion. If the well gas hydrocarbon concentration is too high, its flow must be limited to the point that some liquid fuel is still needed by the engine. Finally, if high destruction efficiency is desired, additional fuel will be required.

The engine damage that occurred in the test cell resulted from conditions unlikely to be experienced at a field test site. Proper configuration of the engine system, and possibly some adsorption system or dryer, should avoid a recurrence of the problem.

## **6.0 RECOMMENDATIONS**

Having proved the concept under laboratory conditions, the test rig should proceed to a field test, under appropriate conditions. The field test site should be one in reasonable proximity to Southwest Research, with a well or wells of known concentration and composition. The field test should last long enough to quantify vapor destruction and fuel use, and to experience any conditions that will have to be dealt with at field sites.

At sites where it is needed, an adsorption device should be prepared or purchased and added to the engine system. The adsorber should mitigate large peaks in hydrocarbon concentration from dense wells, and remove excess water from the intake stream.

The project should consider using a different engine for this purpose. Much of the hydrocarbons in the exhaust is created by incomplete combustion of the added liquid fuel. In short, the engine technology is old, making the engine's exhaust unnecessarily dirty.

An engine with electronically-controlled unit injectors will emit an order of magnitude less hydrocarbons and will be more fuel-efficient.

An exhaust catalyst, likely a diesel oxidation catalyst, could be added to the device, further reducing exhaust hydrocarbons by 90-98%.

A device other than an air compressor would offer the opportunity to harness the energy created by the engine system for useful work. If a diesel-driven electrical generator were employed, the electricity generated could be used, for instance, to pump the gases out of the ground; to blow air, perhaps heated air, into the ground to accelerate recovery; or to operate some sort of catalytic aftertreatment. Any remaining available electrical energy could be fed to a local power grid, or used for constructive purposes in the vicinity of the well.

**APPENDIX A**  
**RAW DATA**

| Run #                             | Date      | Time     | Test Comment | Temp-RH °F | Relative Humidity % | JP-8 Fuel In °F | Pentane Fuel In °F | Inlet Air (LFE) °F | Intake Manifold Air °F | Oil Sump °F | Engine Cooling Air In °F | Engine Cooling Air Out °F | Exhaust Cylinder #1 °F | Exhaust Stack °F | Engine Power bhp | BSFC lb/bhp-hr | A/F Ratio LFE Total :1 | Total Fuel Flow lb/hr | % Pilot JP-8 % | Air Flow LFE Dry | Air Flow LFE Wet | A/F Ratio LFE JP-8 only :1 | Air Flow LFE acfm | Air / Gaseous Fuel Ratio :1 | Engine Speed rpm | LFE ΔP "H <sub>2</sub> O | Intake Manif Press psia | Baro Press psia | JP-8 Fuel Flow lb/hr | Gaseous Fuel Flow lb/hr | Torque ft-lb | Exhaust HC ppm | Intake HC ppm | Dew Point °F | LFE Air Density lb/ft³ |  |  |  |
|-----------------------------------|-----------|----------|--------------|------------|---------------------|-----------------|--------------------|--------------------|------------------------|-------------|--------------------------|---------------------------|------------------------|------------------|------------------|----------------|------------------------|-----------------------|----------------|------------------|------------------|----------------------------|-------------------|-----------------------------|------------------|--------------------------|-------------------------|-----------------|----------------------|-------------------------|--------------|----------------|---------------|--------------|------------------------|--|--|--|
| Propane, Test Condition 1         |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 1                                 | 19 Jan 02 | 12:03:05 | TC1A1        | 77.1       | 21.8                | 88.1            | 71.3               | 74.0               | 76.6                   | 178.0       | 70.1                     | 136.7                     | 535.5                  | 509.0            | 23.1             | 0.469          | 37.68                  | 10.81                 | 91.6           | 402.64           | 404.39           | 40.66                      | 93.25             | 444.59                      | 2001.0           | 1.719                    | 14.12                   | 14.41           | 9.904                | 0.906                   | 60.5         | 2              | 2             | 35.1         | 0.073                  |  |  |  |
| 2                                 | 19 Jan 02 | 12:27:46 | TC1B         | 77.6       | 21.3                | 91.6            | 71.6               | 74.2               | 77.1                   | 186.1       | 70.1                     | 138.5                     | 538.5                  | 511.3            | 22.9             | 0.458          | 38.72                  | 10.48                 | 79.3           | 401.05           | 402.79           | 48.23                      | 93.00             | 184.90                      | 2001.9           | 1.715                    | 14.11                   | 14.40           | 8.315                | 2.169                   | 60.1         | 2              | 2             | 34.9         | 0.073                  |  |  |  |
| 3                                 | 19 Jan 02 | 12:51:45 | TC1C         | 78.1       | 22.2                | 92.4            | 72.2               | 76.0               | 78.0                   | 186.3       | 70.8                     | 139.4                     | 557.1                  | 528.4            | 23.3             | 0.456          | 38.01                  | 10.61                 | 62.9           | 399.38           | 401.21           | 59.78                      | 92.78             | 101.56                      | 2002.0           | 1.715                    | 14.10                   | 14.40           | 6.680                | 3.932                   | 61.1         | 2              | 2             | 36.4         | 0.073                  |  |  |  |
| 4                                 | 19 Jan 02 | 13:26:06 | TC1D         | 78.0       | 20.3                | 93.8            | 73.6               | 78.8               | 79.7                   | 186.1       | 71.3                     | 139.4                     | 583.3                  | 554.8            | 22.9             | 0.534          | 32.85                  | 12.19                 | 40.5           | 398.79           | 400.46           | 80.70                      | 92.59             | 55.00                       | 2002.9           | 1.718                    | 14.10                   | 14.39           | 4.942                | 7.251                   | 59.9         | 2              | 2             | 34.0         | 0.072                  |  |  |  |
| 5                                 | 19 Jan 02 | 13:39:57 | TC1E         | 78.0       | 20.3                | 94.3            | 73.9               | 77.2               | 79.5                   | 186.7       | 72.1                     | 139.7                     | 647.7                  | 602.5            | 22.6             | 0.652          | 26.94                  | 14.74                 | 21.1           | 394.09           | 395.74           | 126.74                     | 91.53             | 33.90                       | 2002.1           | 1.695                    | 14.10                   | 14.39           | 3.110                | 11.626                  | 59.3         | 2              | 2             | 34.0         | 0.072                  |  |  |  |
| 6                                 | 19 Jan 02 | 14:02:05 | TC1A2        | 78.2       | 19.9                | 93.5            | 72.0               | 74.9               | 78.2                   | 189.1       | 71.4                     | 141.2                     | 531.7                  | 505.3            | 22.8             | 0.428          | 41.62                  | 9.75                  | 100.0          | 401.15           | 402.81           | 41.13                      | 93.20             | -                           | 2002.3           | 1.721                    | 14.10                   | 14.39           | 9.753                | -0.107                  | 59.8         | 2              | 2             | 33.7         | 0.073                  |  |  |  |
| Propane, Test Condition 2         |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 1                                 | 19 Jan 02 | 15:43:22 | TC2A1        | 78.5       | 20.3                | 83.8            | 68.8               | 70.7               | 74.0                   | 174.7       | 67.1                     | 138.4                     | 657.5                  | 617.0            | 30.6             | 0.400          | 33.19                  | 12.26                 | 100.0          | 398.81           | 400.51           | 32.52                      | 92.73             | -                           | 2001.6           | 1.702                    | 14.10                   | 14.39           | 12.262               | -0.626                  | 80.3         | 2              | 2             | 34.4         | 0.073                  |  |  |  |
| 2                                 | 19 Jan 02 | 16:23:32 | TC2B         | 78.5       | 19.8                | 90.3            | 68.9               | 71.2               | 74.5                   | 194.9       | 66.8                     | 143.9                     | 670.5                  | 632.1            | 31.7             | 0.399          | 32.08                  | 12.61                 | 80.8           | 396.98           | 398.62           | 38.95                      | 92.26             | 163.82                      | 2006.3           | 1.694                    | 14.10                   | 14.39           | 10.192               | 2.423                   | 82.9         | 2              | 2             | 33.8         | 0.073                  |  |  |  |
| 3                                 | 19 Jan 02 | 16:49:42 | TC2C         | 78.5       | 19.6                | 92.3            | 68.9               | 73.1               | 76.6                   | 196.2       | 69.2                     | 146.0                     | 694.5                  | 650.8            | 32.7             | 0.415          | 29.51                  | 13.56                 | 59.1           | 394.01           | 395.62           | 49.16                      | 91.55             | 71.04                       | 2000.9           | 1.686                    | 14.11                   | 14.39           | 8.015                | 5.547                   | 85.8         | 2              | 2             | 33.6         | 0.073                  |  |  |  |
| 4                                 | 19 Jan 02 | 17:08:46 | TC2D         | 78.4       | 19.5                | 92.2            | 68.5               | 72.8               | 76.0                   | 194.8       | 68.7                     | 146.1                     | 722.6                  | 678.9            | 32.6             | 0.410          | 29.91                  | 13.36                 | 41.8           | 393.25           | 394.85           | 70.38                      | 91.37             | 50.58                       | 2002.1           | 1.682                    | 14.11                   | 14.39           | 5.587                | 7.775                   | 85.6         | 2              | 2             | 33.4         | 0.073                  |  |  |  |
| 5                                 | 19 Jan 02 | 17:19:09 | TC2E         | 78.3       | 19.4                | 92.6            | 69.1               | 73.2               | 76.5                   | 195.0       | 69.0                     | 151.5                     | 738.6                  | 697.9            | 32.1             | 0.547          | 22.49                  | 17.58                 | 23.5           | 369.50           | 391.08           | 94.08                      | 90.46             | 28.97                       | 2004.0           | 1.666                    | 14.11                   | 14.39           | 4.140                | 13.443                  | 84.2         | 2              | 2             | 33.2         | 0.073                  |  |  |  |
| 6                                 | 19 Jan 02 | 17:27:41 | TC2A2        | 78.1       | 19.2                | 92.5            | 68.8               | 72.8               | 76.6                   | 196.0       | 68.5                     | 147.4                     | 694.7                  | 653.8            | 32.3             | 0.447          | 27.88                  | 14.45                 | 100.0          | 396.65           | 398.22           | 27.46                      | 92.07             | -                           | 2000.6           | 1.695                    | 14.12                   | 14.39           | 14.445               | -0.130                  | 84.9         | 2              | 2             | 32.7         | 0.073                  |  |  |  |
| Propane, Test Condition 3         |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 1                                 | 21 Jan 02 | 16:26:48 | TC3A1        | 74.7       | 18.7                | 93.8            | 73.7               | 76.5               | 80.8                   | 197.6       | 78.8                     | 154.5                     | 825.1                  | 772.0            | 38.2             | 0.392          | 26.46                  | 14.97                 | 99.2           | 395.69           | 397.06           | 26.63                      | 91.37             | 3385.25                     | 2001.0           | 1.691                    | 14.09                   | 14.37           | 14.857               | 0.117                   | 100.3        | 3              | 3             | 29.3         | 0.072                  |  |  |  |
| 2                                 | 21 Jan 02 | 16:47:39 | TC3B         | 74.9       | 19.0                | 98.1            | 74.2               | 77.1               | 81.3                   | 207.8       | 79.2                     | 157.4                     | 802.0                  | 749.1            | 38.2             | 0.389          | 26.45                  | 14.86                 | 80.0           | 392.88           | 394.27           | 33.03                      | 90.79             | 132.25                      | 2001.1           | 1.681                    | 14.09                   | 14.36           | 11.894               | 2.971                   | 100.4        | 3              | 3             | 29.9         | 0.072                  |  |  |  |
| 3                                 | 21 Jan 02 | 17:04:39 | TC3C         | 74.9       | 19.5                | 99.0            | 74.6               | 77.0               | 81.2                   | 208.8       | 78.2                     | 156.0                     | 794.2                  | 741.7            | 38.3             | 0.384          | 26.60                  | 14.72                 | 60.6           | 391.05           | 392.47           | 43.85                      | 90.38             | 67.42                       | 2001.5           | 1.674                    | 14.09                   | 14.36           | 8.918                | 5.800                   | 100.5        | 3              | 3             | 30.5         | 0.072                  |  |  |  |
| 4                                 | 21 Jan 02 | 17:28:57 | TC3D         | 75.6       | 20.3                | 99.2            | 75.1               | 77.0               | 81.0                   | 207.0       | 78.4                     | 155.4                     | 802.2                  | 751.4            | 38.2             | 0.391          | 26.15                  | 14.93                 | 40.5           | 389.26           | 390.77           | 64.44                      | 90.12             | 43.81                       | 2001.4           | 1.668                    | 14.09                   | 14.36           | 6.040                | 8.886                   | 100.2        | 3              | 3             | 32.1         | 0.072                  |  |  |  |
| 5                                 | 21 Jan 02 | 17:52:08 | TC3E         | 76.4       | 20.5                | 100.0           | 75.0               | 77.0               | 81.2                   | 205.8       | 78.8                     | 155.3                     | 883.6                  | 828.4            | 38.4             | 0.430          | 23.50                  | 16.50                 | 19.9           | 386.16           | 387.71           | 117.76                     | 89.54             | 29.20                       | 2002.4           | 1.658                    | 14.09                   | 14.36           | 3.279                | 13.223                  | 100.6        | 3              | 3             | 33.0         | 0.072                  |  |  |  |
| 6                                 | 21 Jan 02 | 18:08:57 | TC3A2        | 76.7       | 20.4                | 97.3            | 74.0               | 76.6               | 81.0                   | 209.2       | 78.8                     | 158.0                     | 829.5                  | 775.7            | 38.4             | 0.390          | 26.34                  | 14.98                 | 99.9           | 392.35           | 393.94           | 26.22                      | 91.05             | 28100.62                    | 2002.3           | 1.685                    | 14.08                   | 14.36           | 14.966               | 0.014                   | 100.8        | 3              | 3             | 33.1         | 0.072                  |  |  |  |
| Propane, Test Condition 4         |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 1                                 | 21 Jan 02 | 21:18:03 | TC4A1        | 76.9       | 21.5                | 96.6            | 73.6               | 76.6               | 81.5                   | 223.8       | 77.5                     | 169.8                     | 1019.0                 | 959.5            | 46.0             | 0.405          | 20.87                  | 18.62                 | 98.0           | 386.08           | 387.73           | 21.15                      | 89.58             | 1052.85                     | 2000.3           | 1.657                    | 14.11                   | 14.38           | 18.251               | 0.367                   | 120.8        | 3              | 3             | 34.6         | 0.072                  |  |  |  |
| 2                                 | 21 Jan 02 | 21:34:09 | TC4B         | 76.8       | 21.6                | 97.8            | 73.0               | 76.0               | 80.6                   | 221.6       | 75.5                     | 166.9                     | 956.7                  | 898.4            | 45.9             | 0.386          | 21.87                  | 17.71                 | 80.9           | 384.59           | 386.23           | 26.85                      | 89.21             | 113.57                      | 2002.3           | 1.649                    | 14.10                   | 14.38           | 14.325               | 3.386                   | 120.5        | 3              | 3             | 34.6         | 0.072                  |  |  |  |
| 3                                 | 21 Jan 02 | 21:54:55 | TC4C         | 76.8       | 21.7                | 97.8            | 72.8               | 75.3               | 79.9                   | 219.8       | 76.2                     | 166.0                     | 918.7                  | 860.1            | 45.9             | 0.367          | 22.89                  | 16.86                 | 60.3           | 382.63           | 384.29           | 37.63                      | 88.78             | 57.18                       | 2001.8           | 1.640                    | 14.11                   | 14.38           | 10.168               | 6.691                   | 120.6        | 3              | 3             | 34.8         | 0.073                  |  |  |  |
| 4                                 | 21 Jan 02 | 22:13:08 | TC4D         | 76.9       | 21.8                | 98.5            | 72.8               | 75.1               | 79.4                   | 217.7       | 75.2                     | 164.0                     | 903.2                  | 844.8            | 46.0             | 0.363          | 23.06                  | 16.72                 | 40.7           | 381.90           | 383.56           | 56.10                      | 88.60             | 38.54                       | 2002.4           | 1.636                    | 14.11                   | 14.38           | 6.807                | 9.908                   | 120.6        | 3              | 3             | 34.9         | 0.073                  |  |  |  |
| 5                                 | 21 Jan 02 | 22:48:39 | TC4E         | 76.9       | 23.1                | 98.3            | 72.6               | 75.3               | 79.4                   | 209.4       | 76.2                     | 160.1                     | 945.3                  | 886.5            | 45.8             | 0.360          | 23.34                  | 16.49                 | 20.8           | 381.50           | 383.26           | 111.26                     | 88.53             | 29.21                       | 2000.7           | 1.635                    | 14.11                   | 14.38           | 3.429                | 13.060                  | 120.2        | 3              | 3             | 36.4         | 0.073                  |  |  |  |
| 6                                 | 21 Jan 02 | 23:19:45 | TC4A2        | 76.9       | 24.2                | 95.7            | 72.5               | 75.8               | 80.6                   | 216.8       | 76.4                     | 166.8                     | 1023.4                 | 961.0            | 45.9             | 0.398          | 21.30                  | 18.28                 | 99.5           | 386.22           | 388.08           | 21.23                      | 89.69             | 4315.94                     | 2001.8           | 1.658                    | 14.11                   | 14.38           | 18.192               | 0.089                   | 120.5        | 3              | 3             | 37.6         | 0.072                  |  |  |  |
| Propane, Max Torque at 2000 & hot |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 37                                | 21 Jan 02 | 23:41:36 | maxTQ        | 76.9       | 24.2                | 95.8            | 72.9               | 76.7               | 81.8                   | 223.9       | 77.8                     | 180.4                     | 1220.2                 | 1157.9           | 51.4             | 0.428          | 17.46                  | 21.99                 | 99.3           | 381.53           | 383.37           | 17.48                      | 88.62             | 2376.79                     | 2004.2           | 1.640                    | 14.11                   | 14.37           | 21.833               | 0.161                   | 134.8        | 4              | 4             | 37.6         | 0.072                  |  |  |  |
| Butane, Test Condition 1          |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 44                                | 23 Jan 02 | 18:23:57 | TC1A1        | 80.2       | 50.9                | 97.2            | 79.0               | 80.6               | 84.1                   | 183.8       | 82.1                     | 143.3                     | 551.1                  | 522.2            | 22.9             | 0.436          | 39.27                  | 9.98                  | 97.4           | 388.68           | 393.16           | 39.97                      | 92.68             | 1507.10                     | 2000.8           | 1.722                    | 13.96                   | 14.24           | 9.725                | 0.258                   | 60.1         | 2              | 2             | 60.3         | 0.071                  |  |  |  |
| 45                                | 23 Jan 02 | 18:45:10 | TC1B         | 80.1       | 51.0                | 100.1           | 79.0               | 80.6               | 84.1                   | 192.2       | 80.8                     | 145.0                     | 551.7                  | 523.2            | 23.0             | 0.451          | 37.80                  | 10.35                 | 80.4           | 388.09           | 392.56           | 46.62                      | 92.51             | 191.40                      | 2002.5           | 1.719                    | 13.96                   | 14.24           | 8.325                | 2.028                   | 60.2         | 2              | 2             | 60.3         | 0.071                  |  |  |  |
| 46                                | 23 Jan 02 | 18:58:34 | TC1C         | 80.0       | 50.9                | 100.2           | 78.7               | 80.2               | 83.7                   | 192.1       | 80.9                     | 143.4                     | 560.6                  | 530.7            | 23.0             | 0.469          | 36.29                  | 10.76                 | 60.2           | 387.24           | 391.68           | 59.73                      | 92.27             | 90.46                       | 2002.0           | 1.714                    | 13.96                   | 14.24           | 6.484                | 4.281                   | 60.2         | 2              | 2             | 60.2         | 0.071                  |  |  |  |
| 47                                | 23 Jan 02 | 19:12:45 | TC1D         | 79.9       | 51.2                | 100.0           | 78.7               | 79.9               | 83.3                   | 191.2       | 80.0                     | 141.8                     | 573.8                  | 544.8            | 23.0             | 0.510          | 33.30                  | 11.73                 | 40.2           | 387.14           | 391.59           | 82.09                      | 92.23             | 55.18                       | 2004.3           | 1.712                    | 13.96                   | 14.24           | 4.716                | 7.016                   | 60.3         | 2              | 2             | 60.2         | 0.071                  |  |  |  |
| 48                                | 23 Jan 02 | 19:25:16 | TC1E         | 79.9       | 52.3                | 100.3           | 78.5               | 79.5               | 82.8                   | 191.2       | 79.8                     | 143.0                     | 611.5                  | 574.3            | 22.9             | 0.624          | 27.21                  | 14.27                 | 19.9           | 384.59           | 389.10           | 135.31                     | 91.62             | 33.65                       | 2002.0           | 1.700                    | 13.97                   | 14.25           | 2.842                | 11.431                  | 60.1         | 2              | 2             | 60.8         | 0.071                  |  |  |  |
| 49                                | 23 Jan 02 | 19:46:05 | TC1A2        | 79.9       | 54.2                | 99.7            | 77.6               | 79.5               | 83.0                   | 193.2       | 79.9                     | 144.6                     | 549.5                  | 519.9            | 23.0             | 0.436          | 39.16                  | 10.22                 | 97.8           | 388.50           | 393.22           | 39.67                      | 92.61             | 1727.33                     | 2001.3           | 1.718                    | 13.97                   | 14.25           | 9.794                | 0.225                   | 60.3         | 2              | 2             | 61.8         | 0.071                  |  |  |  |
| Butane, Test Condition 2          |           |          |              |            |                     |                 |                    |                    |                        |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |
| 53                                | 23 Jan 02 | 20:37:13 | TC2A1        | 79.2       | 51.6                | 96.7            | 76.4               | 78.5               | 82.2                   | 191.9       | 77.9                     | 148.8                     | 678.0                  | 637.8            | 30.6             | 0.405          | 31.46                  | 12.41                 | 98.0           | 386.37           | 390.74           | 31.76                      | 91.86             | 1582.84                     | 2001.0           | 1.702                    | 13.97                   | 14.25           | 12.165               | 0.244                   | 80.4         | 2              | 2             | 59.8         | 0.071                  |  |  |  |
| 54                                | 23 Jan 02 | 20:51:39 | TC2B         | 79.4       | 53.1                | 98.8            | 76.3               | 78.5               | 82.2                   |             |                          |                           |                        |                  |                  |                |                        |                       |                |                  |                  |                            |                   |                             |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |  |

|                                        |           |          | Butane, Test Condition 1, HC Sampling |          |                   |             |                |               |                       |            |                      |                          | Butane, Test Condition 2, HC Sampling |                 |                  |                |                      |                       |                |                    |                    |                          | Butane, Test Condition 3, HC Sampling |                          |                  |                          |                  |                 |                      |                         |              |                | Butane, Test Condition 4, HC Sampling |              |                        |  |  |  |  |  |  |  | Pentane, Test Condition 1, HC Sampling |  |  |  |  |  |  |  |  |  | Pentane, Test Condition 2, HC Sampling |  |  |  |  |  |  |  |  |  | Pentane, Test Condition 3, HC Sampling |  |  |  |  |  |  |  |  |  | Pentane, Test Condition 4, HC Sampling |  |  |  |  |  |  |  |  |  | No Gas, Engine Check Runs |  |  |  |  |  |  |  |  |  |
|----------------------------------------|-----------|----------|---------------------------------------|----------|-------------------|-------------|----------------|---------------|-----------------------|------------|----------------------|--------------------------|---------------------------------------|-----------------|------------------|----------------|----------------------|-----------------------|----------------|--------------------|--------------------|--------------------------|---------------------------------------|--------------------------|------------------|--------------------------|------------------|-----------------|----------------------|-------------------------|--------------|----------------|---------------------------------------|--------------|------------------------|--|--|--|--|--|--|--|----------------------------------------|--|--|--|--|--|--|--|--|--|----------------------------------------|--|--|--|--|--|--|--|--|--|----------------------------------------|--|--|--|--|--|--|--|--|--|----------------------------------------|--|--|--|--|--|--|--|--|--|---------------------------|--|--|--|--|--|--|--|--|--|
| Run #                                  | Date      | Time     | Test Comment                          | Temp- RH | Relative Humidity | JP-8 Fuel % | Pentane Fuel % | Inlet (LFE) % | Intake Manifold Air % | Oil Sump % | Engine Cooling Air % | Engine Cooling Air Out % | Exhaust Cylind #1 %                   | Exhaust Stack % | Engine Power bhp | BSFC lb/bhp-hr | A/F Ratio Total Fuel | Total Fuel Flow lb/hr | % Pilot JP-8 % | Air Flow Dry lb/hr | Air Flow Wet lb/hr | A/F Ratio LFE, JP-8 only | Air Flow LFE acfm                     | Air / Gaseous Fuel Ratio | Engine Speed rpm | LFE ΔP "H <sub>2</sub> O | Manif Press psia | Baro Press psia | JP-8 Fuel Flow lb/hr | Gaseous Fuel Flow lb/hr | Torque ft-lb | Exhaust HC ppm | Intake HC ppm                         | Dew Point °F | LFE Air Density lb/ft³ |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Butane, Test Condition 1, HC Sampling  |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 83                                     | 12 Feb 02 | 10:54:21 | TC1A - HC                             | 71.2     | 19.1              | 81.7        | 61.7           | 64.4          | 67.5                  | 171.5      | 64.6                 | 128.0                    | 521.6                                 | 494.8           | 22.9             | 0.437          | 41.94                | 9.99                  | 98.2           | 411.64             | 412.93             | 41.96                    | 93.82                                 | 2353.76                  | 2000.7           | 1.706                    | 14.16            | 14.45           | 9.811                | 0.175                   | 60.1         | 650            | 24                                    | 27.0         | 0.074                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 84                                     | 12 Feb 02 | 13:56:57 | TC1A1 - HC                            | 74.4     | 16.5              | 86.9        | 67.5           | 69.4          | 72.9                  | 173.7      | 69.9                 | 132.6                    | 531.8                                 | 505.2           | 22.8             | 0.428          | 41.99                | 9.78                  | 100.0          | 405.13             | 406.35             | 41.42                    | 93.21                                 | -                        | 2001.0           | 1.708                    | 14.11            | 14.40           | 9.782                | -0.017                  | 59.9         | 639            | 41                                    | 26.0         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 85                                     | 12 Feb 02 | 14:08:16 | TC1B - HC                             | 74.8     | 16.2              | 90.4        | 67.8           | 69.9          | 73.3                  | 181.0      | 70.2                 | 134.7                    | 531.8                                 | 504.8           | 22.8             | 0.445          | 40.36                | 10.13                 | 82.6           | 403.51             | 404.72             | 41.22                    | 92.92                                 | 228.43                   | 2001.1           | 1.703                    | 14.12            | 14.40           | 8.968                | 1.766                   | 59.8         | 1882           | 11187                                 | 25.9         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 86                                     | 12 Feb 02 | 14:11:26 | TC1B - HC                             | 74.8     | 16.2              | 90.9        | 67.8           | 69.8          | 73.4                  | 182.0      | 70.5                 | 135.1                    | 531.7                                 | 504.2           | 22.8             | 0.453          | 39.67                | 10.33                 | 81.1           | 404.32             | 405.54             | 41.28                    | 93.10                                 | 206.54                   | 2001.0           | 1.707                    | 14.12            | 14.40           | 8.374                | 1.958                   | 59.9         | 1874           | 11022                                 | 25.9         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 87                                     | 12 Feb 02 | 14:22:09 | TC1C - HC                             | 75.1     | 16.4              | 92.1        | 68.4           | 70.4          | 73.7                  | 183.4      | 70.2                 | 134.3                    | 542.9                                 | 514.2           | 22.9             | 0.493          | 36.18                | 11.27                 | 58.1           | 402.44             | 403.67             | 41.48                    | 92.74                                 | 85.16                    | 2002.3           | 1.701                    | 14.12            | 14.40           | 6.546                | 4.726                   | 60.0         | 2669           | 26223                                 | 26.4         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 88                                     | 12 Feb 02 | 14:27:42 | TC1C - HC                             | 75.1     | 16.4              | 92.4        | 68.5           | 70.1          | 73.7                  | 183.9      | 69.8                 | 135.0                    | 539.5                                 | 511.8           | 22.9             | 0.481          | 37.18                | 10.99                 | 62.9           | 403.04             | 404.28             | 41.58                    | 92.89                                 | 89.73                    | 2002.3           | 1.703                    | 14.11            | 14.40           | 6.908                | 4.082                   | 60.0         | 2681           | 22648                                 | 26.4         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 89                                     | 12 Feb 02 | 14:31:23 | TC1C - HC                             | 75.1     | 16.4              | 92.5        | 68.3           | 69.9          | 73.5                  | 183.9      | 70.9                 | 135.1                    | 540.0                                 | 512.4           | 22.9             | 0.493          | 36.12                | 11.31                 | 60.1           | 402.62             | 403.85             | 41.59                    | 92.99                                 | 89.15                    | 2003.7           | 1.701                    | 14.12            | 14.40           | 6.790                | 4.516                   | 60.1         | 2670           | 25680                                 | 26.4         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 90                                     | 12 Feb 02 | 14:39:45 | TC1D - HC                             | 75.4     | 15.7              | 92.7        | 68.6           | 70.3          | 73.7                  | 183.6      | 69.8                 | 133.2                    | 553.5                                 | 526.0           | 22.8             | 0.516          | 34.68                | 11.76                 | 40.6           | 402.33             | 403.52             | 41.21                    | 92.78                                 | 57.59                    | 2002.0           | 1.702                    | 14.11            | 14.39           | 4.778                | 6.986                   | 59.8         | 2662           | 35392                                 | 25.6         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Butane, Test Condition 2, HC Sampling  |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 94                                     | 12 Feb 02 | 15:17:41 | TC2A1 - HC                            | 76.1     | 15.9              | 95.6        | 69.8           | 71.8          | 76.0                  | 197.3      | 71.0                 | 146.4                    | 659.5                                 | 622.5           | 30.6             | 0.401          | 32.82                | 12.26                 | 100.0          | 397.60             | 398.83             | 32.42                    | 91.84                                 | -                        | 2000.8           | 1.688                    | 14.11            | 14.39           | 12.265               | -0.676                  | 80.3         | 605            | 42                                    | 26.5         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 95                                     | 12 Feb 02 | 15:44:23 | TC2B - HC                             | 76.8     | 16.1              | 96.2        | 70.0           | 71.8          | 75.9                  | 196.6      | 73.9                 | 146.0                    | 656.3                                 | 617.9           | 30.9             | 0.406          | 32.17                | 12.52                 | 80.1           | 397.31             | 398.58             | 39.60                    | 91.92                                 | 159.52                   | 2003.3           | 1.690                    | 14.11            | 14.39           | 10.033               | 2.491                   | 81.0         | 1577           | 15900                                 | 27.4         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 96                                     | 12 Feb 02 | 15:57:23 | TC2C - HC                             | 77.4     | 15.0              | 96.4        | 70.2           | 72.3          | 76.0                  | 195.9      | 71.6                 | 144.9                    | 651.5                                 | 613.7           | 30.8             | 0.412          | 31.59                | 12.71                 | 59.8           | 396.33             | 397.23             | 52.08                    | 91.72                                 | 77.52                    | 2002.9           | 1.687                    | 14.11            | 14.39           | 7.604                | 5.109                   | 80.9         | 2660           | 33804                                 | 26.1         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Butane, Test Condition 3, HC Sampling  |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 100                                    | 12 Feb 02 | 16:13:45 | TC3D - HC                             | 77.7     | 14.6              | 97.4        | 71.1           | 72.7          | 77.1                  | 203.5      | 73.4                 | 153.5                    | 760.2                                 | 713.5           | 38.2             | 0.389          | 26.75                | 14.83                 | 59.9           | 391.30             | 392.46             | 44.20                    | 90.68                                 | 65.47                    | 2002.2           | 1.669                    | 14.11            | 14.38           | 8.853                | 5.977                   | 100.1        | 1959           | 35414                                 | 25.7         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 101                                    | 12 Feb 02 | 16:24:11 | TC3D - HC                             | 78.0     | 15.3              | 98.0        | 71.1           | 72.8          | 77.0                  | 204.2      | 73.6                 | 153.2                    | 752.3                                 | 706.9           | 38.3             | 0.383          | 26.97                | 14.69                 | 42.3           | 390.48             | 391.71             | 62.90                    | 90.55                                 | 46.06                    | 2002.5           | 1.667                    | 14.11            | 14.39           | 6.208                | 8.477                   | 100.5        | 2606           | 35135                                 | 27.1         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Butane, Test Condition 4, HC Sampling  |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 105                                    | 12 Feb 02 | 16:35:44 | TC4C - HC                             | 78.0     | 14.2              | 99.5        | 72.0           | 73.5          | 78.5                  | 213.6      | 75.3                 | 167.8                    | 814.0                                 | 855.6           | 46.8             | 0.381          | 21.81                | 17.82                 | 56.1           | 393.72             | 394.85             | 38.36                    | 88.96                                 | 49.08                    | 2003.4           | 1.639                    | 14.12            | 14.39           | 10.003               | 7.818                   | 122.7        | 1386           | 35200                                 | 25.3         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 106                                    | 12 Feb 02 | 16:50:28 | TC4E - HC                             | 78.0     | 14.5              | 101.9       | 71.2           | 73.5          | 78.6                  | 223.0      | 74.5                 | 176.0                    | 862.0                                 | 810.3           | 46.0             | 0.436          | 18.43                | 20.07                 | 29.8           | 365.17             | 366.26             | 60.98                    | 84.67                                 | 25.94                    | 2003.5           | 1.560                    | 14.13            | 14.39           | 5.988                | 14.079                  | 120.5        | 604            | 35118                                 | 25.8         | 0.073                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Pentane, Test Condition 1, HC Sampling |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 110                                    | 1 Mar 02  | 10:02:24 | TC1A1                                 | 79.8     | 35.0              | 95.9        | 67.3           | 69.5          | 75.4                  | 190.5      | 71.3                 | 140.6                    | 562.8                                 | 533.8           | 23.2             | 0.431          | 39.10                | 10.02                 | 100.0          | 391.69             | 393.40             | 39.10                    | 92.15                                 | -                        | 2001.7           | 1.688                    | 13.98            | 14.26           | 10.017               | -0.508                  | 61.0         | 638            | 4                                     | 34.8         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 111                                    | 1 Mar 02  | 10:22:33 | TC1B                                  | 80.0     | 34.7              | 96.3        | 92.1           | 69.1          | 75.0                  | 191.7      | 71.4                 | 140.5                    | 557.0                                 | 527.4           | 23.2             | 0.428          | 39.03                | 9.94                  | 79.4           | 388.01             | 391.02             | 49.16                    | 91.80                                 | 189.47                   | 2003.1           | 1.681                    | 13.98            | 14.26           | 7.893                | 2.048                   | 60.9         | 1591           | 11194                                 | 49.7         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 112                                    | 1 Mar 02  | 10:33:05 | TC1C                                  | 79.8     | 36                | 96.4        | 92.9           | 69.7          | 75.5                  | 191.6      | 72.5                 | 141.4                    | 549.4                                 | 520.9           | 23.1             | 0.437          | 38.31                | 10.12                 | 60.1           | 387.58             | 390.68             | 63.71                    | 91.89                                 | 96.10                    | 1999.7           | 1.680                    | 13.98            | 14.26           | 6.083                | 4.033                   | 60.8         | 2296           | 20365                                 | 50.4         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 113                                    | 1 Mar 02  | 10:41:29 | TC1B2                                 | 79.8     | 36                | 96.4        | 92.3           | 69.3          | 76.1                  | 191.6      | 73.0                 | 141.2                    | 560.4                                 | 530.2           | 23.3             | 0.427          | 39.05                | 9.96                  | 80.5           | 389.00             | 392.11             | 48.48                    | 92.04                                 | 200.76                   | 2005.0           | 1.688                    | 13.98            | 14.26           | 8.024                | 1.938                   | 61.1         | 1702           | 10723                                 | 50.4         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 114                                    | 1 Mar 02  | 10:52:27 | TC1D                                  | 79.8     | 36                | 96.9        | 95.1           | 69.7          | 76.1                  | 192.2      | 72.8                 | 143.7                    | 532.3                                 | 507.1           | 23.3             | 0.440          | 37.74                | 10.24                 | 40.0           | 386.38             | 389.47             | 94.25                    | 91.45                                 | 62.94                    | 2001.4           | 1.676                    | 13.97            | 14.25           | 4.099                | 6.139                   | 61.5         | 2660           | 30072                                 | 50.4         | 0.028                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 115                                    | 1 Mar 02  | 11:03:34 | TC1E                                  | 80.0     | 36.8              | 98.4        | 100.3          | 70.4          | 77.3                  | 195.0      | 72.8                 | 146.6                    | 511.8                                 | 487.9           | 23.1             | 0.418          | 39.80                | 9.65                  | 18.9           | 383.89             | 387.05             | 21.30                    | 90.94                                 | 49.08                    | 2002.6           | 1.668                    | 13.97            | 14.25           | 1.825                | 7.821                   | 60.5         | 2751           | 37461                                 | 51.2         | 0.028                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 116                                    | 1 Mar 02  | 11:10:54 | TC1A2                                 | 80.1     | 36.7              | 98.5        | 79.5           | 71.0          | 77.1                  | 195.2      | 71.8                 | 143.4                    | 565.0                                 | 533.4           | 23.2             | 0.431          | 38.85                | 9.98                  | 100.0          | 387.79             | 390.98             | 38.85                    | 91.87                                 | -                        | 2001.7           | 1.668                    | 13.97            | 14.25           | 9.982                | -0.411                  | 60.8         | 697            | 5                                     | 51.2         | 0.028                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Pentane, Test Condition 2, HC Sampling |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 120                                    | 1 Mar 02  | 13:38:03 | TC2A1                                 | 78.8     | 41.8              | 99.6        | 70.9           | 74.2          | 80.3                  | 201.2      | 76.7                 | 152.5                    | 691.3                                 | 651.4           | 30.6             | 0.398          | 31.61                | 12.18                 | 100.0          | 385.01             | 388.44             | 31.61                    | 91.33                                 | -                        | 2001.6           | 1.683                    | 13.94            | 14.22           | 12.181               | -0.428                  | 80.3         | 668            | 2                                     | 53.3         | 0.028                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 121                                    | 1 Mar 02  | 13:52:53 | TC2B                                  | 79.4     | 41.1              | 101.7       | 92.7           | 75.0          | 80.9                  | 204.9      | 77.8                 | 153.7                    | 683.5                                 | 644.0           | 30.5             | 0.381          | 32.13                | 11.93                 | 79.9           | 383.12             | 386.59             | 40.20                    | 91.03                                 | 160.00                   | 2002.5           | 1.680                    | 13.93            | 14.21           | 9.531                | 2.394                   | 80.0         | 1471           | 12918                                 | 53.7         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 122                                    | 1 Mar 02  | 14:01:42 | TC2C                                  | 79.4     | 41                | 102.2       | 93.3           | 74.9          | 81.4                  | 205.9      | 77.9                 | 154.6                    | 666.5                                 | 628.6           | 30.2             | 0.382          | 32.14                | 11.91                 | 60.2           | 380.58             | 384.42             | 53.39                    | 90.54                                 | 80.76                    | 1998.4           | 1.670                    | 13.93            | 14.21           | 7.136                | 4.717                   | 79.5         | 1913           | 24038                                 | 53.6         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 123                                    | 1 Mar 02  | 14:11:28 | TC2D                                  | 79.5     | 41.4              | 105.9       | 98.7           | 75.2          | 82.3                  | 207.8      | 77.5                 | 157.5                    | 642.0                                 | 607.7           | 30.6             | 0.386          | 32.02                | 11.85                 | 40.4           | 379.51             | 382.99             | 79.21                    | 90.25                                 | 53.74                    | 2004.5           | 1.666                    | 13.93            | 14.20           | 7.917                | 7.062                   | 80.1         | 2335           | 35343                                 | 50.4         | 0.028                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 124                                    | 1 Mar 02  | 14:20:04 | TC2E                                  | 79.5     | 40.9              | 105.1       | 108.3          | 75.4          | 85.7                  | 225.5      | 78.0                 | 202.3                    | 804.5                                 | 729.9           | 29.6             | 0.499          | 23.37                | 14.78                 | 22.0           | 345.46             | 348.58             | 106.01                   | 82.15                                 | 29.99                    | 2000.1           | 1.516                    | 13.96            | 14.20           | 3.259                | 11.520                  | 77.7         | 1117           | 56357                                 | 53.6         | 0.030                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 125                                    | 1 Mar 02  | 14:38:43 | TC2A2                                 | 79.3     | 41.1              | 105.9       | 74.2           | 76.6          | 83.1                  | 217.9      | 78.2                 | 160.1                    | 707.2                                 | 665.1           | 30.7             | 0.402          | 30.75                | 12.32                 | 100.0          | 378.67             | 382.09             | 30.75                    | 90.05                                 | -                        | 2003.0           | 1.665                    | 13.93            | 14.20           | 12.316               | -0.360                  | 80.4         | 678            | 3                                     | 53.6         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| Pentane, Test Condition 3, HC Sampling |           |          |                                       |          |                   |             |                |               |                       |            |                      |                          |                                       |                 |                  |                |                      |                       |                |                    |                    |                          |                                       |                          |                  |                          |                  |                 |                      |                         |              |                |                                       |              |                        |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 129                                    | 1 Mar 02  | 15:39:15 | TC3A1                                 | 80.1     | 39.8              | 103.2       | 75.3           | 79.8          | 86.2                  | 215.5      | 79.1                 | 167.6                    | 871.7                                 | 818.6           | 38.5             | 0.391          | 25.08                | 15.02                 | 100.0          | 376.86             | 380.25             | 25.08                    | 89.81                                 | -                        | 2002.4           | 1.668                    | 13.92            | 14.19           | 15.024               | -0.523                  | 100.9        | 667            | 2                                     | 53.4         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 130                                    | 1 Mar 02  | 15:50:30 | TC3B                                  | 80.1     | 39.4              | 105.9       | 93.0           | 80.3          | 86.7                  | 220.5      | 79.1                 | 169.3                    | 839.9                                 | 790.8           | 38.1             | 0.375          | 28.99                | 14.27                 | 79.5           | 375.17             | 378.50             | 33.06                    | 89.40                                 | 128.48                   | 2002.0           | 1.682                    | 13.92            | 14.19           | 11.350               | 2.920                   | 99.8         | 1402           | 17297                                 | 53.2         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 131                                    | 1 Mar 02  | 16:01:24 | TC3C                                  | 80.3     | 39                | 107.6       | 96.6           | 80.4          | 87.6                  | 223.5      | 80.9                 | 171.8                    | 823.4                                 | 774.2           | 39.0             | 0.376          | 25.38                | 14.68                 | 60.7           | 372.56             | 375.87             | 41.77                    | 88.62                                 | 64.65                    | 2002.4           | 1.651                    | 13.92            | 14.18           | 8.919                | 5.763                   | 102.3        | 1566           | 30193                                 | 53.1         | 0.029                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 132                                    | 1 Mar 02  | 16:08:28 | TC3D                                  | 80.3     | 38.7              | 109.6       | 106.2          | 81.2          | 90.2                  | 234.9      | 80.7                 | 200.9                    | 914.6                                 | 842.1           | 37.9             | 0.428          | 21.64                | 16.22                 | 40.4           | 350.89             | 353.97             | 53.59                    | 83.64                                 | 36.30                    | 2003.5           | 1.557                    | 13.94            | 14.18           | 6.548                | 9.668                   | 99.3         | 668            | 51027                                 | 52.8         | 0.030                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |
| 133                                    | 1 Mar 02  | 16:14:52 | TC3C+                                 | 80.5     | 38.4              | 111.9       | 105.1          | 81.5          | 91.1                  | 248.7      | 81.2                 | 191.9                    | 849.2                                 | 807.6           | 38.5             | 0.379          | 24.92                | 14.57                 | 48.1           | 363.03             | 366.22             | 51.78                    | 86.57                                 | 48.05                    | 2002.7           | 1.612                    | 13.92            | 14.18           | 7.011                | 7.556                   | 100.9        | 1036           | 39954                                 | 52.8         | 0.030                  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                                        |  |  |  |  |  |  |  |  |  |                           |  |  |  |  |  |  |  |  |  |

| Run #                          | Date     | Time     | Test Comment  | Temp-RH | Relative Humidity | JP-8 Fuel In | Pentane Fuel In | Inlet Air (LFE) | Intake Manifold Air | Oil Sump | Engine Cooling Air In | Engine Cooling Air Out | Exhaust Cylinder #1 | Exhaust Stack | Engine Power bhp | BSFC lb/bhp-hr | A/R Ratio LFE Total | Total Fuel Flow lb/hr | % Pilot JP-8 | Air Flow LFE Dry | Air Flow LFE Wet | A/R Ratio LFE only | Air Flow LFE acfm | Air / Gaseous Fuel Ratio | Engine Speed rpm | LFE ΔP "H <sub>2</sub> O | Intake Manif Press psia | Baro Press psia | JP-8 Fuel Flow lb/hr | Gaseous Fuel Flow lb/hr | Torque ft-lb | Exhaust HC ppm | Intake HC ppm | Dew Point °F | LFE Air Density lb/ft³ |  |  |
|--------------------------------|----------|----------|---------------|---------|-------------------|--------------|-----------------|-----------------|---------------------|----------|-----------------------|------------------------|---------------------|---------------|------------------|----------------|---------------------|-----------------------|--------------|------------------|------------------|--------------------|-------------------|--------------------------|------------------|--------------------------|-------------------------|-----------------|----------------------|-------------------------|--------------|----------------|---------------|--------------|------------------------|--|--|
| Engine Check Runs with Pentane |          |          |               |         |                   |              |                 |                 |                     |          |                       |                        |                     |               |                  |                |                     |                       |              |                  |                  |                    |                   |                          |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |
| 146                            | 4 Nov 02 | 12:45:59 | 20-06-27-96.7 | 75.4    | 46.3              | 96.8         | 94.6            | 79.2            | 81.8                | 182.0    | 73.5                  | 137.0                  | 524.8               | 487.8         | 22.6             | 0.445          | 40.56               | 10.07                 | 51.6         | 408.35           | 411.00           | 78.63              | 96.26             | 83.78                    | 2001.3           | 1.785                    | 14.02                   | 14.26           | 5.194                | 4.874                   | 59.4         | 2543           | 27254         | 56.8         | 0.071                  |  |  |
| 147                            | 4 Nov 02 | 12:53:27 | 20-08-27-96.6 | 75.7    | 45.8              | 99.5         | 96.7            | 84.3            | 87.6                | 192.5    | 78.1                  | 154.4                  | 661.8               | 630.8         | 30.5             | 0.408          | 32.76               | 12.44                 | 60.7         | 407.36           | 409.04           | 54.01              | 96.59             | 83.25                    | 2002.2           | 1.805                    | 14.01                   | 14.25           | 7.543                | 4.893                   | 79.9         | 2091           | 26907         | 53.3         | 0.071                  |  |  |
| 148                            | 4 Nov 02 | 13:10:46 | 20-10-29-96.6 | 75.8    | 46.2              | 100.9        | 101.5           | 85.6            | 94.5                | 210.3    | 75.4                  | 169.9                  | 817.2               | 777.8         | 38.3             | 0.386          | 27.51               | 14.78                 | 66.5         | 406.61           | 408.26           | 41.39              | 96.73             | 82.03                    | 2002.1           | 1.811                    | 14.00                   | 14.24           | 9.825                | 4.957                   | 100.4        | 1678           | 29377         | 53.3         | 0.070                  |  |  |
| 149                            | 4 Nov 02 | 13:33:51 | 20-12-30-96.6 | 77.3    | 44.3              | 110.0        | 110.2           | 96.3            | 100.9               | 222.5    | 85.0                  | 188.5                  | 979.5               | 920.8         | 45.6             | 0.387          | 22.12               | 17.67                 | 69.2         | 390.91           | 392.53           | 31.98              | 94.80             | 71.74                    | 2001.3           | 1.798                    | 14.02                   | 14.24           | 12.225               | 5.449                   | 119.8        | 1638           | 30082         | 53.6         | 0.069                  |  |  |
| 150                            | 4 Nov 02 | 13:37:57 | 20-12-00-96.7 | 77.1    | 44.1              | 112.5        | 109.7           | 96.9            | 103.4               | 227.8    | 87.3                  | 196.8                  | 1096.5              | 1023.3        | 45.5             | 0.413          | 20.85               | 18.76                 | 100.0        | 391.19           | 392.76           | 20.85              | 94.97             | -                        | 2001.8           | 1.803                    | 14.02                   | 14.24           | 18.762               | -0.359                  | 119.3        | 750            | 36            | 53.9         | 0.069                  |  |  |
| 151                            | 4 Nov 02 | 13:42:17 | 20-10-00-96.7 | 77.2    | 43.6              | 114.0        | 108.6           | 97.0            | 103.7               | 230.6    | 87.5                  | 185.7                  | 888.4               | 857.5         | 37.7             | 0.399          | 25.96               | 15.02                 | 99.1         | 389.90           | 391.44           | 26.20              | 94.66             | -                        | 2003.0           | 1.797                    | 14.03                   | 14.24           | 14.880               | 0.139                   | 98.8         | 766            | 33            | 53.5         | 0.069                  |  |  |
| 152                            | 4 Nov 02 | 13:46:53 | 20-08-00-96.6 | 76.9    | 43.9              | 115.2        | 108.7           | 96.2            | 102.5               | 229.2    | 86.2                  | 173.5                  | 726.7               | 708.4         | 30.3             | 0.412          | 31.18               | 12.48                 | 98.2         | 389.26           | 390.77           | 31.75              | 94.38             | -                        | 2005.3           | 1.790                    | 14.02                   | 14.24           | 12.262               | 0.222                   | 79.3         | 751            | 52            | 53.3         | 0.069                  |  |  |
| 153                            | 4 Nov 02 | 13:55:22 | 20-06-00-96.6 | 77.0    | 44.1              | 114.6        | 108.0           | 89.9            | 97.4                | 221.5    | 83.6                  | 159.8                  | 587.7               | 567.3         | 23.0             | 0.450          | 37.72               | 10.34                 | 97.0         | 389.91           | 391.42           | 38.91              | 93.47             | -                        | 2001.0           | 1.759                    | 14.01                   | 14.24           | 10.022               | 0.314                   | 60.3         | 718            | 25            | 53.2         | 0.070                  |  |  |
| 154                            | 4 Nov 02 | 14:09:48 | 15-06-28-97.1 | 76.8    | 43.8              | 108.4        | 105.4           | 86.6            | 92.8                | 205.3    | 78.1                  | 157.3                  | 526.2               | 504.2         | 23.7             | 0.451          | 38.08               | 7.98                  | 54.8         | 303.76           | 304.95           | 48.41              | 72.40             | 84.32                    | 1550.9           | 1.356                    | 14.09                   | 14.23           | 4.374                | 3.603                   | 59.9         | 1986           | 27965         | 53.5         | 0.070                  |  |  |
| 155                            | 4 Nov 02 | 14:17:56 | 15-08-29-97.2 | 76.8    | 43.8              | 107.0        | 107.1           | 86.9            | 95.2                | 204.7    | 80.6                  | 173.7                  | 719.5               | 673.2         | 23.4             | 0.466          | 27.80               | 10.89                 | 65.0         | 302.72           | 303.89           | 42.78              | 72.70             | 79.37                    | 1551.2           | 1.353                    | 14.09                   | 14.23           | 7.076                | 3.814                   | 79.1         | 1852           | 28789         | 53.1         | 0.070                  |  |  |
| 156                            | 4 Nov 02 | 14:23:02 | 15-10-30-97.2 | 77.2    | 43.9              | 107.2        | 106.6           | 88.3            | 97.5                | 208.6    | 81.0                  | 186.0                  | 826.8               | 780.0         | 29.6             | 0.417          | 24.74               | 12.36                 | 68.0         | 305.73           | 306.91           | 36.38              | 73.10             | 77.30                    | 1551.7           | 1.372                    | 14.09                   | 14.23           | 8.404                | 3.965                   | 100.3        | 1650           | 29791         | 53.1         | 0.070                  |  |  |
| 157                            | 4 Nov 02 | 14:29:47 | 15-12-30-97.2 | 77.1    | 43.8              | 107.9        | 106.7           | 92.5            | 101.1               | 218.2    | 83.4                  | 203.3                  | 1009.1              | 927.7         | 35.4             | 0.422          | 20.13               | 14.96                 | 73.5         | 301.16           | 302.34           | 27.38              | 72.56             | 75.98                    | 1551.4           | 1.369                    | 14.10                   | 14.23           | 10.999               | 3.963                   | 119.9        | 1304           | 29881         | 53.5         | 0.069                  |  |  |
| 158                            | 4 Nov 02 | 14:33:03 | 15-12-00-97.2 | 77.1    | 43.7              | 107.9        | 106.7           | 92.5            | 101.1               | 218.2    | 83.4                  | 203.3                  | 1009.1              | 927.7         | 35.4             | 0.422          | 20.13               | 14.96                 | 73.5         | 301.16           | 302.34           | 27.38              | 72.56             | 75.98                    | 1551.4           | 1.369                    | 14.10                   | 14.23           | 10.999               | 3.963                   | 119.9        | 1304           | 29881         | 53.5         | 0.069                  |  |  |
| 159                            | 4 Nov 02 | 14:39:07 | 15-10-00-97.1 | 77.2    | 44.1              | 105.5        | 108.8           | 107.0           | 107.1               | 221.7    | 70.9                  | 188.0                  | 907.2               | 854.7         | 29.4             | 0.432          | 23.88               | 12.73                 | 99.3         | 304.00           | 305.18           | 24.05              | 75.18             | -                        | 1551.6           | 1.443                    | 14.09                   | 14.23           | 12.639               | 0.091                   | 99.7         | 92             | 52            | 53.3         | 0.068                  |  |  |
| 160                            | 4 Nov 02 | 14:46:40 | 15-08-00-97.1 | 77.3    | 44.0              | 103.8        | 108.1           | 103.6           | 104.0               | 215.4    | 69.4                  | 171.4                  | 733.8               | 695.2         | 23.5             | 0.448          | 29.21               | 10.50                 | 99.3         | 306.73           | 307.95           | 29.42              | 75.42             | -                        | 1554.0           | 1.442                    | 14.09                   | 14.23           | 10.427               | 0.073                   | 79.3         | 63             | 39            | 53.6         | 0.068                  |  |  |
| 161                            | 4 Nov 02 | 14:51:49 | 15-06-00-97.1 | 77.3    | 43.5              | 101.1        | 105.9           | 90.8            | 98.8                | 209.0    | 78.2                  | 158.9                  | 549.9               | 538.1         | 17.8             | 0.447          | 38.98               | 7.95                  | 96.6         | 309.70           | 310.92           | 40.35              | 74.42             | -                        | 1550.3           | 1.401                    | 14.09                   | 14.23           | 7.675                | 0.271                   | 60.2         | 78             | 20            | 53.7         | 0.070                  |  |  |
| Throttling Tests               |          |          |               |         |                   |              |                 |                 |                     |          |                       |                        |                     |               |                  |                |                     |                       |              |                  |                  |                    |                   |                          |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |
| 162                            | 6 Nov 02 | 13:50:29 | 15-06-00-98.3 | 73.0    | 27.8              | 85.4         | 78.0            | 82.6            | 83.5                | 143.1    | 78.1                  | 138.3                  | 505.4               | 478.8         | 17.6             | 0.480          | 39.00               | 8.48                  | 88.4         | 330.58           | 331.84           | 44.09              | 77.20             | -                        | 1548.6           | 1.438                    | 14.26                   | 14.42           | 7.497                | 0.980                   | 59.8         | 581            | 42            | 53.4         | 0.072                  |  |  |
| 163                            | 6 Nov 02 | 14:08:27 | 20-12-00-97.7 | 73.4    | 26                | 102.4        | 98.4            | 96.5            | 103.8               | 207.9    | 83.6                  | 191.2                  | 1084.3              | 1024.2        | 45.7             | 0.405          | 22.01               | 18.54                 | 100.0        | 408.04           | 408.59           | 22.01              | 97.40             | -                        | 1999.9           | 1.852                    | 14.17                   | 14.41           | 18.540               | -0.634                  | 120.1        | 677            | 71            | 37.8         | 0.070                  |  |  |
| 164                            | 6 Nov 02 | 14:18:03 | 20-06-00-97.7 | 73.5    | 25.9              | 105.0        | 99.1            | 85.2            | 94.8                | 211.2    | 77.5                  | 154.3                  | 575.3               | 562.4         | 23.0             | 0.431          | 41.18               | 9.91                  | 100.0        | 408.10           | 408.59           | 41.18              | 95.42             | -                        | 1998.9           | 1.787                    | 14.17                   | 14.41           | 9.910                | -0.734                  | 60.5         | 670            | 46            | 36.4         | 0.071                  |  |  |
| 165                            | 6 Nov 02 | 14:32:17 | 20-06-00-98.2 | 73.3    | 25.6              | 103.6        | 96.0            | 84.6            | 92.2                | 205.8    | 78.0                  | 151.7                  | 569.7               | 548.1         | 22.9             | 0.449          | 38.11               | 10.28                 | 96.2         | 391.72           | 392.19           | 39.62              | 91.50             | -                        | 2001.0           | 1.712                    | 13.95                   | 14.41           | 9.888                | 0.392                   | 60.0         | 718            | 44            | 36.4         | 0.071                  |  |  |
| 166                            | 6 Nov 02 | 14:40:06 | 20-12-00-96.2 | 73.6    | 25.5              | 104.4        | 98.0            | 95.9            | 99.5                | 209.4    | 82.4                  | 186.6                  | 1078.0              | 994.5         | 45.7             | 0.429          | 19.76               | 19.60                 | 95.1         | 387.24           | 387.68           | 20.78              | 92.34             | -                        | 1998.3           | 1.753                    | 13.96                   | 14.41           | 18.831               | 0.969                   | 120.2        | 750            | 49            | 35.9         | 0.070                  |  |  |
| 167                            | 6 Nov 02 | 14:46:06 | 20-10-00-96.2 | 74.0    | 25.2              | 106.6        | 102.2           | 96.1            | 102.4               | 216.6    | 81.2                  | 179.1                  | 873.1               | 835.8         | 37.9             | 0.394          | 25.91               | 14.91                 | 99.6         | 386.39           | 386.83           | 26.01              | 92.17             | -                        | 2002.2           | 1.751                    | 13.96                   | 14.41           | 14.858               | 0.052                   | 99.3         | 762            | 48            | 36.1         | 0.070                  |  |  |
| 168                            | 6 Nov 02 | 14:51:11 | 20-08-00-96.3 | 73.8    | 25.5              | 107.7        | 103.2           | 91.9            | 100.2               | 217.3    | 81.2                  | 168.7                  | 714.3               | 691.7         | 30.4             | 0.398          | 31.78               | 12.12                 | 100.0        | 385.32           | 385.76           | 31.78              | 91.22             | -                        | 1996.7           | 1.723                    | 13.96                   | 14.41           | 12.123               | -0.761                  | 80.0         | 744            | 37            | 36.1         | 0.070                  |  |  |
| 169                            | 6 Nov 02 | 14:56:29 | 20-06-00-96.2 | 74.1    | 25.1              | 107.6        | 102.3           | 89.0            | 97.4                | 214.9    | 79.9                  | 158.0                  | 585.5               | 573.6         | 22.8             | 0.430          | 39.25               | 9.83                  | 100.0        | 385.66           | 386.11           | 39.25              | 90.82             | -                        | 2000.2           | 1.709                    | 13.96                   | 14.41           | 9.826                | -0.562                  | 59.9         | 720            | 40            | 36.3         | 0.071                  |  |  |
| 170                            | 6 Nov 02 | 15:02:22 | 20-06-16-96.2 | 74.1    | 24.7              | 106.9        | 99.3            | 86.0            | 94.3                | 211.4    | 78.2                  | 153.4                  | 577.7               | 557.3         | 23.1             | 0.438          | 38.26               | 10.11                 | 79.6         | 386.74           | 387.18           | 48.06              | 90.57             | 187.48                   | 2000.6           | 1.697                    | 13.96                   | 14.41           | 8.047                | 2.063                   | 60.6         | 1649           | 15603         | 36.1         | 0.071                  |  |  |
| 171                            | 6 Nov 02 | 15:06:17 | 20-06-32-96.1 | 74.2    | 24.7              | 106.1        | 99.4            | 85.4            | 93.4                | 208.8    | 78.9                  | 151.9                  | 563.6               | 543.7         | 23.1             | 0.443          | 38.05               | 10.22                 | 58.0         | 388.81           | 389.24           | 65.64              | 90.56             | 90.52                    | 1998.2           | 1.703                    | 13.94                   | 14.41           | 5.923                | 4.295                   | 60.6         | 2184           | 31606         | 35.7         | 0.071                  |  |  |
| 172                            | 6 Nov 02 | 15:15:59 | 20-08-30-96.2 | 74.5    | 25.1              | 105.3        | 103.2           | 89.0            | 95.1                | 206.5    | 80.0                  | 159.6                  | 676.3               | 637.1         | 30.4             | 0.404          | 31.68               | 12.30                 | 65.5         | 389.66           | 390.09           | 48.41              | 91.78             | 91.71                    | 1997.6           | 1.727                    | 13.95                   | 14.40           | 8.050                | 4.249                   | 80.0         | 1914           | 29814         | 35.8         | 0.071                  |  |  |
| 173                            | 6 Nov 02 | 15:20:48 | 20-08-16-96.2 | 74.4    | 25.2              | 105.6        | 102.8           | 89.8            | 96.5                | 207.4    | 80.4                  | 162.4                  | 695.5               | 656.7         | 30.7             | 0.440          | 31.27               | 12.42                 | 81.9         | 388.32           | 388.77           | 38.20              | 91.60             | 172.28                   | 2001.1           | 1.726                    | 13.95                   | 14.40           | 10.166               | 2.254                   | 80.6         | 1385           | 16222         | 36.5         | 0.071                  |  |  |
| 174                            | 6 Nov 02 | 15:28:06 | 20-10-16-96.1 | 74.5    | 2                 |              |                 |                 |                     |          |                       |                        |                     |               |                  |                |                     |                       |              |                  |                  |                    |                   |                          |                  |                          |                         |                 |                      |                         |              |                |               |              |                        |  |  |

| Run # | Date      | Time     | Test Comment  | Temp-RH °F | Relative Humidity % | JP-8 Fuel In °F | Pentane Fuel In °F | Air (LFE) °F | Intake Manifold Air °F | Oil Sump °F | Engine Cooling Air In °F | Engine Cooling Air Out °F | Cylinder #1 °F | Exhaust Stack °F | Engine Power bhp | BSFC lb/bhp-hr | A/F Ratio LFE Total | Fuel Flow lb/hr | % Pilot JP-8 LFE | Air Flow LFE Wet | Air Flow LFE Dry | Air Flow LFE Wet | A/F Ratio LFE JP-8 only | Air Flow LFE acfm | Air / Gaseous Fuel Ratio | Engine Speed rpm | LFE ΔP h <sub>2</sub> O | Intake Manif Press psia | Baro Press psia | JP-8 Fuel Flow lb/hr | Gaseous Fuel Flow lb/hr | Torque ft-lb | Exhaust HC ppm | Intake HC ppm | Dew Point °F | LFE Air Density lb/ft³ |
|-------|-----------|----------|---------------|------------|---------------------|-----------------|--------------------|--------------|------------------------|-------------|--------------------------|---------------------------|----------------|------------------|------------------|----------------|---------------------|-----------------|------------------|------------------|------------------|------------------|-------------------------|-------------------|--------------------------|------------------|-------------------------|-------------------------|-----------------|----------------------|-------------------------|--------------|----------------|---------------|--------------|------------------------|
| 217   | 14 Nov 02 | 16:26:23 | 15-06-00-94.3 | 77.5       | 50.5                | 102.4           | 99.2               | 84.1         | 95.3                   | 197.6       | 81.7                     | 159.4                     | 551.2          | 536.8            | 17.7             | 0.476          | 2.24                | 8.46            | 90.9             | 276.70           | 278.16           | 35.99            | 65.85                   | -                 | 1550.0                   | 1.228            | 13.68                   | 14.22                   | 7.688           | 0.768                | 60.1                    | 574          | 2              | 57.6          | 0.070        |                        |
| 218   | 14 Nov 02 | 16:31:01 | 15-06-30-94.3 | 77.7       | 50.7                | 102.5           | 97.1               | 83.8         | 94.5                   | 196.6       | 81.9                     | 158.3                     | 516.1          | 506.7            | 17.7             | 0.450          | 2.27                | 7.95            | 35.0             | 274.20           | 275.67           | 98.58            | 65.24                   | 53.04             | 1547.3                   | 1.217            | 13.68                   | 14.22                   | 7.811           | 5.170                | 60.0                    | 2331         | 29776          | 57.9          | 0.070        |                        |
| 219   | 14 Nov 02 | 16:38:04 | 15-08-30-94.3 | 77.9       | 50.7                | 102.9           | 102.7              | 84.8         | 96.6                   | 199.6       | 82.3                     | 172.3                     | 680.3          | 635.9            | 23.5             | 0.465          | 1.69                | 10.93           | 46.7             | 278.63           | 280.13           | 54.58            | 66.41                   | 47.83             | 1548.7                   | 1.240            | 13.68                   | 14.22                   | 5.105           | 5.826                | 79.7                    | 1931         | 29679          | 58.1          | 0.070        |                        |
| 220   | 14 Nov 02 | 16:41:46 | 15-08-00-94.4 | 77.7       | 50.9                | 103.1           | 102.2              | 85.7         | 98.3                   | 202.5       | 82.7                     | 176.9                     | 760.1          | 701.0            | 23.5             | 0.485          | 1.70                | 11.37           | 92.4             | 281.09           | 282.60           | 26.76            | 67.11                   | -                 | 1549.7                   | 1.254            | 13.68                   | 14.22                   | 10.504          | 0.866                | 79.5                    | 682          | 1              | 58.1          | 0.070        |                        |
| 221   | 14 Nov 02 | 16:50:36 | 15-10-00-94.4 | 77.7       | 50.6                | 103.5           | 102.5              | 91.7         | 102.3                  | 208.9       | 86.8                     | 184.9                     | 899.7          | 843.0            | 29.6             | 0.454          | 1.44                | 13.42           | 92.4             | 281.75           | 283.25           | 22.73            | 68.03                   | -                 | 1550.5                   | 1.281            | 13.69                   | 14.22                   | 12.396          | 1.022                | 100.2                   | 632          | 2              | 57.9          | 0.069        |                        |
| 222   | 14 Nov 02 | 16:54:25 | 15-10-28-94.4 | 77.3       | 51.0                | 104.2           | 103.8              | 94.0         | 104.9                  | 209.4       | 88.1                     | 184.3                     | 816.0          | 780.2            | 29.6             | 0.271          | 1.48                | 8.03            | 100.0            | 283.11           | 284.62           | 35.26            | 68.64                   | -                 | 1551.8                   | 1.296            | 13.69                   | 14.22                   | 8.029           | -0.152               | 100.2                   | 1509         | 28361          | 57.7          | 0.069        |                        |
| 223   | 14 Nov 02 | 17:01:41 | 15-12-32-94.4 | 77.4       | 50.9                | 105.5           | 107.1              | 99.1         | 109.2                  | 215.2       | 85.5                     | 197.7                     | 975.7          | 909.2            | 35.3             | 0.491          | 2.09                | 17.34           | 59.5             | 281.70           | 283.20           | 27.32            | 68.93                   | 40.10             | 1551.8                   | 1.309            | 13.69                   | 14.21                   | 10.311          | 7.024                | 119.6                   | 1159         | 31506          | 57.8          | 0.068        |                        |
| 224   | 18 Nov 02 | 14:25:31 | 15-12-00-94.3 | 76.1       | 42.5                | 105.1           | 104.7              | 101.7        | 104.6                  | 209.8       | 79.2                     | 195.8                     | 1029.9         | 950.6            | 35.3             | 0.430          | 1.19                | 15.18           | 94.1             | 263.28           | 264.20           | 18.44            | 63.94                   | -                 | 1548.8                   | 1.220            | 13.67                   | 14.35                   | 14.280          | 0.902                | 119.6                   | 357          | -136           | 51.6          | 0.069        |                        |
| 225   | 18 Nov 02 | 14:40:15 | 15-12-00-90.9 | 75.5       | 42.3                | 105.5           | 105.6              | 92.7         | 107.3                  | 225.3       | 84.3                     | 208.0                     | 1112.4         | 1016.2           | 35.7             | 0.424          | 1.12                | 15.10           | 100.0            | 243.55           | 244.38           | 16.12            | 58.20                   | -                 | 1552.0                   | 1.099            | 13.18                   | 14.35                   | 15.105          | -0.082               | 120.7                   | 30           | -8             | 51.0          | 0.070        |                        |
| 226   | 18 Nov 02 | 15:00:36 | 15-06-00-89.7 | 75.7       | 42.8                | 104.3           | 94.7               | 84.2         | 91.9                   | 203.7       | 83.7                     | 158.2                     | 565.3          | 536.6            | 17.8             | 0.440          | 2.11                | 7.82            | 100.0            | 234.90           | 235.72           | 30.03            | 55.28                   | -                 | 1552.6                   | 1.033            | 13.02                   | 14.34                   | 7.822           | -0.148               | 60.2                    | 588          | 181            | 51.5          | 0.071        |                        |
| 227   | 18 Nov 02 | 15:05:25 | 15-06-00-86.5 | 75.7       | 42.8                | 103.3           | 92.9               | 83.6         | 90.8                   | 199.9       | 82.7                     | 157.4                     | 583.1          | 548.2            | 17.9             | 0.440          | 1.88                | 7.88            | 100.0            | 213.01           | 213.76           | 27.04            | 50.08                   | -                 | 1554.7                   | 0.936            | 12.54                   | 14.34                   | 7.877           | -0.060               | 60.4                    | 604          | 128            | 51.5          | 0.071        |                        |
| 228   | 18 Nov 02 | 15:18:54 | 15-06-00-82.8 | 76.3       | 42.4                | 101.6           | 90.4               | 83.0         | 89.7                   | 195.2       | 82.6                     | 157.3                     | 590.1          | 555.8            | 17.7             | 0.432          | 1.75                | 7.65            | 100.0            | 191.62           | 192.29           | 25.03            | 44.99                   | -                 | 1551.5                   | 0.841            | 12.01                   | 14.34                   | 7.654           | -0.091               | 60.0                    | 635          | 89             | 51.8          | 0.071        |                        |
| 229   | 18 Nov 02 | 15:26:03 | 15-06-00-79.2 | 76.6       | 42.4                | 100.4           | 87.4               | 80.3         | 86.9                   | 192.0       | 79.8                     | 156.2                     | 603.4          | 568.7            | 17.7             | 0.438          | 1.54                | 7.77            | 100.0            | 170.45           | 171.06           | 21.94            | 39.83                   | -                 | 1552.7                   | 0.743            | 11.49                   | 14.34                   | 7.770           | -0.145               | 60.0                    | 658          | 136            | 52.0          | 0.072        |                        |
| 230   | 18 Nov 02 | 15:33:49 | 15-06-00-75.9 | 76.2       | 42.5                | 99.1            | 85.0               | 79.5         | 85.3                   | 191.2       | 78.1                     | 155.9                     | 622.5          | 582.9            | 17.7             | 0.440          | 1.36                | 7.80            | 100.0            | 151.97           | 152.50           | 19.49            | 35.45                   | -                 | 1553.0                   | 0.662            | 11.01                   | 14.35                   | 7.795           | -0.093               | 60.0                    | 679          | 170            | 51.7          | 0.072        |                        |
| 231   | 18 Nov 02 | 15:41:19 | 15-06-00-71.7 | 76.3       | 42.6                | 98.8            | 84.2               | 79.5         | 85.3                   | 190.5       | 78.8                     | 157.8                     | 654.9          | 606.5            | 17.6             | 0.444          | 1.14                | 7.82            | 100.0            | 127.66           | 128.11           | 16.32            | 29.78                   | -                 | 1550.7                   | 0.557            | 10.40                   | 14.35                   | 7.820           | -0.110               | 59.7                    | 708          | 198            | 51.9          | 0.072        |                        |
| 232   | 22 Nov 02 | 15:31:06 | 15-06-30-97.9 | 75.6       | 29.7                | 94.8            | 90.6               | 89.4         | 89.3                   | 169.9       | 74.3                     | 152.3                     | 528.0          | 494.5            | 18.0             | 0.435          | 2.73                | 7.83            | 98.5             | 310.43           | 310.95           | 40.24            | 73.26                   | -                 | 1539.7                   | 1.379            | 14.20                   | 14.40                   | 7.714           | 0.120                | 61.4                    | 601          | 81             | 41.7          | 0.071        |                        |
| 233   | 22 Nov 02 | 15:40:12 | 15-06-15-97.9 | 75.8       | 28.7                | 97.3            | 95.5               | 91.1         | 91.3                   | 176.1       | 75.1                     | 143.6                     | 511.5          | 486.8            | 17.7             | 0.438          | 2.67                | 7.76            | 60.9             | 309.67           | 310.16           | 65.46            | 73.30                   | 102.17            | 1551.3                   | 1.382            | 14.19                   | 14.40                   | 4.731           | 3.031                | 60.0                    | 1720         | 15093          | 41.0          | 0.071        |                        |
| 234   | 22 Nov 02 | 15:48:36 | 15-06-15-96.3 | 76.6       | 28.6                | 98.8            | 103.3              | 90.2         | 91.8                   | 178.1       | 76.4                     | 144.8                     | 519.5          | 490.3            | 17.8             | 0.431          | 2.53                | 7.65            | 61.5             | 289.04           | 289.50           | 61.45            | 68.30                   | 98.04             | 1551.8                   | 1.287            | 13.97                   | 14.40                   | 4.704           | 2.948                | 60.1                    | 1709         | 14580          | 41.6          | 0.071        |                        |
| 235   | 22 Nov 02 | 15:54:38 | 15-06-14-93.1 | 76.4       | 28.2                | 99.4            | 105.6              | 91.3         | 92.3                   | 179.9       | 75.7                     | 145.9                     | 535.3          | 505.1            | 17.8             | 0.429          | 2.30                | 7.64            | 62.0             | 262.48           | 262.89           | 55.45            | 62.15                   | 90.33             | 1550.4                   | 1.173            | 13.51                   | 14.40                   | 4.734           | 2.906                | 60.3                    | 1727         | 14281          | 41.1          | 0.071        |                        |
| 236   | 22 Nov 02 | 16:01:46 | 15-06-14-89.6 | 76.9       | 28.3                | 99.9            | 107.0              | 92.0         | 92.0                   | 181.6       | 75.7                     | 147.0                     | 551.6          | 519.6            | 17.9             | 0.425          | 2.02                | 7.59            | 62.4             | 229.05           | 229.41           | 48.36            | 54.30                   | 80.20             | 1549.3                   | 1.026            | 13.00                   | 14.40                   | 4.736           | 2.856                | 60.5                    | 1744         | 13743          | 41.6          | 0.070        |                        |
| 237   | 22 Nov 02 | 16:07:52 | 15-06-13-86.2 | 77.1       | 28.3                | 100.8           | 107.8              | 91.5         | 91.8                   | 184.1       | 76.3                     | 148.3                     | 559.4          | 529.8            | 18.0             | 0.419          | 1.86                | 7.52            | 61.5             | 208.32           | 208.65           | 45.00            | 49.35                   | 72.01             | 1549.8                   | 0.932            | 12.50                   | 14.40                   | 4.629           | 2.893                | 60.9                    | 1796         | 13409          | 41.7          | 0.070        |                        |
| 238   | 22 Nov 02 | 16:14:23 | 15-06-13-82.9 | 76.6       | 28.2                | 101.1           | 108.3              | 91.1         | 91.1                   | 185.3       | 76.1                     | 148.4                     | 567.0          | 536.1            | 17.8             | 0.411          | 1.70                | 7.34            | 61.7             | 185.72           | 186.01           | 41.03            | 43.96                   | 65.98             | 1551.3                   | 0.831            | 12.02                   | 14.40                   | 4.526           | 2.815                | 60.4                    | 1831         | 13059          | 41.2          | 0.071        |                        |
| 239   | 22 Nov 02 | 16:19:58 | 15-06-11-79.4 | 77.8       | 27.9                | 101.3           | 108.8              | 90.7         | 91.2                   | 185.4       | 76.0                     | 149.2                     | 583.2          | 551.3            | 17.7             | 0.413          | 1.50                | 7.31            | 61.6             | 163.46           | 163.72           | 36.31            | 38.67                   | 58.18             | 1551.2                   | 0.732            | 11.51                   | 14.40                   | 4.502           | 2.809                | 59.9                    | 1878         | 11399          | 42.0          | 0.071        |                        |
| 240   | 22 Nov 02 | 16:25:22 | 15-06-10-75.4 | 77.6       | 27.9                | 101.6           | 109.2              | 90.7         | 90.8                   | 186.0       | 75.7                     | 149.9                     | 607.5          | 567.3            | 17.6             | 0.415          | 1.27                | 7.30            | 61.4             | 138.55           | 138.77           | 30.92            | 32.78                   | 49.10             | 1550.4                   | 0.622            | 10.93                   | 14.40                   | 4.481           | 2.822                | 59.6                    | 1878         | 10090          | 41.8          | 0.071        |                        |
| 241   | 22 Nov 02 | 16:32:22 | 15-06-09-72.5 | 76.4       | 32.4                | 101.6           | 109.6              | 92.0         | 90.7                   | 187.3       | 75.6                     | 152.0                     | 638.3          | 593.9            | 17.7             | 0.421          | 1.11                | 7.45            | 62.0             | 123.57           | 123.82           | 26.74            | 29.32                   | 43.65             | 1550.6                   | 0.558            | 10.51                   | 14.40                   | 4.621           | 2.831                | 60.0                    | 1844         | 9173           | 44.7          | 0.070        |                        |
| 242   | 25 Nov 02 | 14:18:10 | 15-06-30-97.6 | 70.3       | 37.6                | 88.4            | 103.2              | 82.1         | 83.4                   | 160.7       | 67.4                     | 132.9                     | 463.7          | 440.4            | 17.4             | 0.445          | 2.61                | 7.76            | 22.3             | 311.15           | 311.86           | 179.71           | 72.66                   | 51.65             | 1547.8                   | 1.353            | 14.16                   | 14.37                   | 1.731           | 6.025                | 59.1                    | 2680         | 30052          | 43.2          | 0.072        |                        |
| 243   | 25 Nov 02 | 14:23:48 | 15-06-28-96.5 | 70.4       | 37.5                | 90.8            | 106.3              | 82.8         | 84.8                   | 166.7       | 73.7                     | 137.2                     | 482.1          | 454.7            | 17.6             | 0.454          | 2.40                | 8.01            | 25.6             | 294.02           | 294.68           | 143.43           | 68.76                   | 49.33             | 1552.9                   | 1.282            | 14.00                   | 14.37                   | 2.050           | 5.960                | 59.6                    | 2692         | 27906          | 43.2          | 0.071        |                        |
| 244   | 25 Nov 02 | 14:29:17 | 15-06-25-93.1 | 70.4       | 37.7                | 96.6            | 109.5              | 87.4         | 93.0                   | 174.7       | 82.0                     | 149.9                     | 498.9          | 478.6            | 17.6             | 0.436          | 2.23                | 7.65            | 23.3             | 261.97           | 262.56           | 146.73           | 61.78                   | 44.65             | 1547.9                   | 1.159            | 13.81                   | 14.37                   | 1.785           | 5.868                | 59.6                    | 2608         | 24866          | 43.4          | 0.071        |                        |
| 245   | 25 Nov 02 | 14:34:03 | 15-06-26-89.7 | 70.5       | 37.2                | 96.6            | 111.2              | 85.6         | 88.3                   | 177.3       | 69.4                     | 141.2                     | 504.9          | 481.2            | 17.6             | 0.451          | 1.89                | 7.93            | 26.1             | 228.99           | 229.50           | 110.71           | 53.82                   | 39.08             | 1547.5                   | 1.008            | 13.01                   | 14.37                   | 2.068           | 5.859                | 59.7                    | 2762         | 25875          | 43.1          | 0.071        |                        |
| 246   | 25 Nov 02 | 14:42:38 | 15-06-22-86.2 | 70.5       | 37.3                | 99.2            | 112.6              | 87.2         | 91.8                   | 181.0       | 75.8                     | 149.5                     | 518.5          | 493.1            | 17.6             | 0.433          | 1.77                | 7.64            | 22.7             | 207.40           | 207.87           | 119.60           | 48.89                   | 35.15             | 1549.8                   | 0.918            | 12.50                   | 14.37                   | 1.734           | 5.901                | 59.7                    | 2993         | 21686          | 43.2          | 0.071        |                        |
| 247   | 25 Nov 02 | 14:46:28 | 15-06-19-82.9 | 70.5       | 37.5                | 98.8            | 113.6              | 86.3         | 88.7                   | 182.3       | 71.7                     | 145.2                     | 534.9          | 505.7            | 17.9             | 0.437          | 1.55                | 7.83            | 25.2             | 186.39           | 186.81           | 94.55            | 43.87                   | 31.81             | 1550.5                   | 0.824            | 12.03                   | 14.37                   | 1.971           | 5.937                | 60.5                    | 3035         | 28674          | 44.0          | 0.070        |                        |
| 248   | 25 Nov 02 | 14:53:19 | 15-06-29-79.3 | 70.7       | 38.3                | 103.4           | 116.1              | 91.5         | 96.8                   | 190.3       | 74.8                     | 157.6                     | 578.7          | 546.9            | 17.8             | 0.434          | 1.32                | 7.74            | 23.3             | 156.93           | 157.30           | 87.26            | 72.01                   | 51.78             | 1547.4                   | 0.706            | 11.50                   | 14.37                   | 2.201           | 5.892                | 59.6                    | 2626         | 37422          | 43.8          | 0.071        |                        |
| 249   | 25 Nov 02 | 14:59:07 | 15-06-37-97.6 | 70.7       | 37.9                | 102.0           | 116.6              | 87.8         | 91.5                   | 191.8       | 70.8                     | 147.0                     | 488.3          | 476.8            | 17.6             | 0.459          | 2.46                | 8.09            | 27.2             | 305.06           | 305.77           | 138.57           | 72.01                   | 61.97             | 1549.0                   | 1.363            | 14.16                   | 14.37                   | 11.964          | 0.493                | 121.5                   | 979          | 15422          | 43.8          |              |                        |