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Determination of Emissions from Gas Turbine Powered Light Duty Surface Vehicles—SAE J1130

SAE Recommended Practice
Approved April 1976

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Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

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DETERMINATION OF EMISSIONS FROM GAS TURBINE POWERED LIGHT DUTY SURFACE VEHICLES—SAE J1130

SAE Recommended Practice

Report of Automotive Emissions Committee approved April 1976

Purpose—This is an SAE recommended procedure for determining the hydrocarbon, carbon monoxide, and oxides of nitrogen emissions of a gas turbine powered light duty surface vehicle operated over the EPA Urban Dynamometer Driving Schedule specified for Federal certification of vehicle exhaust emissions of light duty vehicles. This procedure, which is performed on a chassis dynamometer, is designed to yield accurate values of grams per mile (g/km) for the three pollutants.

Introduction—The Environmental Protection Agency has defined the test procedures for vehicle exhaust emissions of gasoline fueled and diesel powered light duty vehicles in the Federal Register (1-4). These procedures must be rigidly adhered to when new motor vehicles are certified to have emissions below the established standards prior to the sale of these vehicles to the public. Since these procedures are not applicable to gas turbine powered light duty vehicles, a procedure which is applicable for engine and vehicle development purposes has been defined and is presented.

The recommended procedure is defined as a "fuel based continuous technique." In this procedure, the undiluted exhaust pollutant species and the engine fuel flow are measured continuously throughout the test driving schedule. By using the carbon balance technique, the instantaneous pollutant concentrations can be expressed as an instantaneous "grams of pollutant per kilogram of fuel burned" (commonly referred to as Emission-Index). Multiplying this value by the measured instantaneous fuel flow and summing these values for the entire test will give the total grams of pollutants. Dividing by the total mileage of the test will give the desired grams per mile (g/km) value. In addition to grams per mile (g/km) values, this procedure provides instantaneous emission information which can be used for diagnostic and developmental purposes.

Background—Since gas turbine powered cars are not currently offered for sale to the public, there is no requirement for EPA to certify the emissions of a gas turbine powered light duty vehicle. For this reason, no test procedure for gas turbine powered light duty vehicles has been issued by EPA.

The EPA procedures referred to earlier are unable to accommodate a gas turbine since these procedures specify the processing and handling of the total dilute exhaust flow of the test vehicle. In all cases covered by these procedures, the total exhaust flow is significantly below the 350 ft^3/min (0.165 m^3/s) capacity of the equipment in use. Since turbine exhaust flows can be 10 times this value, the existing equipment for processing the total exhaust flow is inadequate. Although a scaled-up version of the equipment specified by the EPA procedure could be recommended, the committee decided that this recommendation could not be justified at this time because of technical uncertainty, very low dilute concentrations, cost, size, and lack of incentives for implementation of such a procedure. The committee, therefore, decided to recommend a procedure which would provide for an accurate determination of the three pollutant emissions for making engineering comparisons. However, the procedure was required to be reasonably simple and inexpensive as well as being suitable as a development technique.

This recommended procedure can provide data that can be used for development and comparison purposes. An attractive feature of this procedure is that it is applicable to any type of engine regardless of the exhaust flow rate, provided its instantaneous fuel flow can be measured. Therefore, this procedure is equally applicable not only to gas turbines, but also to other engines, such as spark ignition engines, diesel engines, steam engines, and Stirling engines.

This universal applicability permits a determination of the accuracy of the procedure. The fuel based continuous procedure can be used for measuring piston engine emissions in parallel with the conventional Federally specified procedure. Results of such tests by the committee as well as those reported in the literature (5,6) establish the good correlation between the fuel based continuous procedure and the Federally specified procedure for piston engines. Although a similar parallel test is not available for a gas turbine, it is reasonable to assume that the turbine results from the fuel based procedure should be as accurate as those from the piston engine.

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1. Definitions of Terms and Abbreviations

1.1 Terms

1.1.1 Exhaust Emission—Any substance emitted into the atmosphere from any opening downstream from the combustion chamber. Exhaust emission shall also include oil sump breather emissions.

1.1.2 Gas Turbine Engine—Any engine using the basic gas turbine or Brayton cycle consisting of adiabatic compression, constant pressure heating, and adiabatic expansion.

1.1.3 Calibrating Gas—Gas of known concentration used to establish instrument response.

1.1.4 Span Gas—A calibrating gas used routinely to check instrument response.

1.1.5 Zero Gas—A calibrating gas used routinely to check instrument zero.

1.1.6 Concentration—The volume fraction of the component of interest in the gas mixture—expressed as volume percentage or as parts per million (ppm).

1.1.7 Total Hydrocarbons—The total of hydrocarbon compounds of all classes and molecular weights.

1.1.8 Flame Ionization Detector—A hydrogen-air diffusion flame detector that produces a signal nominally proportional to the mass flow rate of hydrocarbons entering the flame per unit of time—generally assumed responsive to the number of carbon atoms entering the flame.

1.1.9 Non-dispersive Infrared Analyzer—An instrument that, by absorption of infrared energy, selectively measures specific components.

1.1.10 Chemiluminescent Analyzer—An instrument in which the intensity of light produced by the chemiluminescence of the reaction of nitric oxide with ozone is proportional to the concentration of nitric oxide. Conversion of NO_2 to NO prior to entering the analyzer permits the determination of both species with this analyzer.

1.1.11 Interference—Instrument response due to the presence of components other than the gas that is to be measured.

1.2 Abbreviations and Symbols

(CO) = concentration of carbon monoxide
(CO_2) = concentration of carbon dioxide
(HC) = concentration of unburned hydrocarbon as equivalent carbon (for example, ppm C)
(H_2) = concentration of hydrogen
(NO) = concentration of nitric oxide
(NO_2) = concentration of nitrogen dioxide
(NO_x) = sum of (NO) + (NO_2)
(TC) = total carbon in exhaust, (HC) + (CO) + (CO_2)
(BG) = concentration of background pollutant
( ) = molar percent except as noted
y = atomic hydrogen/carbon ratio of fuel
COEI = CO emission index—g CO/kg fuel
HCEI = HC emission index—g HC/kg fuel
BGEI = BG emission index—g BG/kg fuel
NOXEI = NO_x emission index—g NO_2/kg fuel
EFF = combustion efficiency
FV = fuel volume associated with combustion during a time increment

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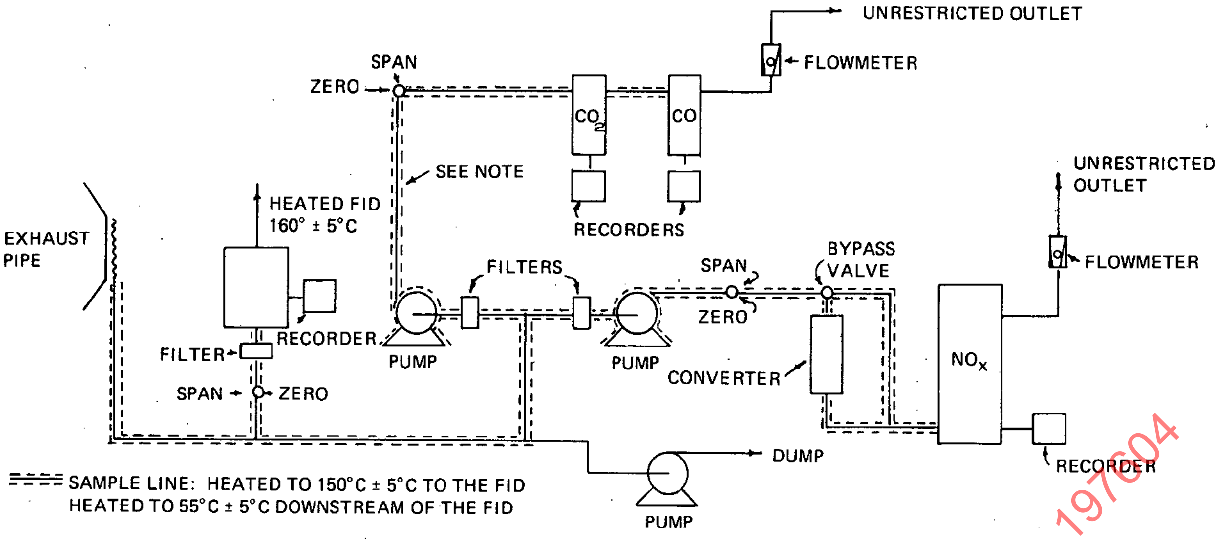

NOTE: HEATED LINE DOWNSTREAM OF PUMP OPTIONAL. IF NOT USED ADDITION OF COLD TRAP, DESICANT COLUMN, AND ASCARITE COLUMN MAY BE REQUIRED TO ELIMINATE CONDENSATION AND INTERFERENCES

FIG. 1—EXHAUST GAS ANALYSIS SYSTEM

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FM = fuel mass associated with combustion during a time increment
FVT = total fuel volume during driving mode
FMT = total g fuel consumed during driving mode
SG = specific gravity of fuel
M = molecular weight
CT = cold transient modes
CS = cold stabilized modes
HT = hot transient modes
BG = background
B = beginning of period
E = end of period
N = total number of time increments during driving mode
T = temperature—F (C)

2. *Instrumentation*

2.1 Exhaust Gas Analytical System—Fig. 1 is a schematic drawing of a typical exhaust gas sampling and analytical system for the continuous measurement of exhaust gas products emitted from the exhaust pipe of a gas turbine engine. Additional components such as instruments, valves, solenoids, pumps, and switches may be added to provide additional information and facilitate the operation of the component systems.

2.1.1 Arrangement of Analytical System—The following components are recommended for use in the exhaust sampling system.

(a) Water Removal Devices—No desicants, dryers, water traps or related equipment should be used to treat the exhaust sample flowing to the HC and NO_x analysis instrumentation. Use of such devices is optional for the CO and CO_2 analyzers.

(b) Particulate Filter—Borosilicate glass fiber filters approximately 7 cm in diameter with appropriate holding fixture of low internal volume should be used (one in each leg of the sample system) to remove any particulate matter which may be present. Contaminated filters can result in excessive hang-up and should be changed frequently (as often as each test).

(c) Pumps—A positive displacement pump (typically 20 l/min with pump inlet and outlet at atmospheric pressure) should be used in each leg of the analysis system to pull the sample from the probe to the pump and then to push the sample through the analyzer. It is recommended that a diaphragm type pump with a Teflon diaphragm and stainless steel chamber be used to minimize hang-up. Carbon vane or piston pumps which may introduce a hydrocarbon lubricant into the sample gas are to be avoided. The pump should supply a non-varying flow rate. The pump and its motor should be mounted in such a manner as to minimize the transmission of mechanical vibration to the system as such vibration may affect the output of the analyzers.

(d) Flow Control and Measurement—Sample flow or pressure in each of the analyzers must be held constant and may be regulated either with an automatic flow regulator or manually by adjustable needle valves, and should then be monitored by a rotameter with an inert material float. The range of the rotameter should be consistent with the required analyzer flow.

(e) Auxiliary Heating—All specified sample lines, filters, pumps, and control valves should be heated to such a temperature that no water vapor in the exhaust sample will condense. A temperature of 55 ± 5°C should meet this requirement.

2.1.2 Hydrocarbon Analyzers—Hydrocarbon measurements should be made with a heated flame ionization detector (HFID) type analyzer. This analyzer should be fitted within a constant-temperature chamber housing the detector and sample handling components. This chamber should maintain a temperature within the range of 155°C–165°C. The analyzer should be capable of meeting the following specifications:

(a) Response Time (Electrical)—90% of full scale in 0.5 s or less.
(b) Noise—±1% of full scale on most sensitive range.
(c) Repeatability—±1% of full scale on all ranges.
(d) Zero Drift—Less than ±1% of full scale in 2 h on all ranges.
(e) Span Drift—Less than ±1% of full scale in 2 h on all ranges.
(f) Linearity—Response with propane in air should be ±2% over the range of 0–2000 ppm C.
(g) Oxygen Effect—The response to propane in air shall not differ by more than 3% from the response to propane in a 10% O_2/90% N_2 mixture, nor differ by more than 5% from the response to propane in nitrogen.
(h) Range and Accuracy

0–10 ppm C	±5% of full scale
0–100 ppm C	±2% of full scale
All higher ranges	±1% of full scale

(i) Flame ionization type hydrocarbon analyzers are affected by the oxygen content of the sample gas. This is normally not a problem with turbine exhaust, since the oxygen content of the exhaust does not vary greatly from that of air (which is the recommended diluent for the calibration gases). Should oxygen synergism become a problem, it should be determined and corrected for as described in Ref. 7.

2.1.3 (NDIR) Analyzers—Non-dispersive infrared analyzers should be used for the monitoring of carbon monoxide and carbon dioxide. These instruments may be installed either in series or in parallel. They should meet the following specifications:

(a) Response Time (Electrical)—90% full scale in 0.5 s or less.
(b) Zero Drift—Less than ±1% of full scale in 2 h on most sensitive range.
(c) Span Drift—Less than ±1% of full scale in 2 h.
(d) Repeatability—±1% of full scale.
(e) Noise—Less than 1% of full scale on the most sensitive range.
(f) Range and Accuracy (excluding interferences)

Carbon Monoxide	
0–100 ppm	±2% of full scale
All higher ranges	±1% of full scale
Carbon Dioxide	
0 - 2%	±1% of full scale
All higher ranges	±1% of full scale

(g) All NDIR instruments should be equipped with cells of suitable length to measure exhaust concentrations within the ranges necessary to the above accuracies. Range changes may be accomplished either by use of stacked cells or changes in electronic circuitry.

(h) Interferences—The NDIR instruments used to measure CO and CO_2 may be heated or unheated. In either configuration they must be free from significant interferences from other gases found in the exhaust stream. The extent of water vapor and carbon dioxide interference on the carbon monoxide analyzer shall be determined by passing a range of anticipated concentrations of carbon dioxide and water vapor through the instrument and observing the response. If the effect is greater than 2% of measured CO levels, all subsequent measurements shall be corrected for these interferences. The extent of water vapor interference on the carbon dioxide analyzer shall be determined by passing a range of anticipated concentrations of water vapor through the instrument and observing the response. If the effect is greater than 2% of measured CO_2 levels, all subsequent measurements shall be corrected for this interference.

2.1.4 NO_x Analyzers—Oxides of nitrogen measurements should be made with a chemiluminescent type instrument. Since this type of instrument is sensitive to only nitric oxide (NO), it is necessary that the instrument be equipped with a high efficiency thermal converter which will convert any nitrogen dioxide (NO_2) to nitric oxide prior to analysis. This instrument should be capable of meeting the following specifications:

(a) Response Time (Electrical)—90% of full scale in 0.5 s or less.
(b) Noise—Less than 1% of full scale.
(c) Repeatability—±1% of full scale.
(d) Zero Drift—Less than ±1% of full scale in 2 h.
(e) Span Drift—Less than ±1% of full scale in 2 h.
(f) Linearity—Linear to ±2% of full scale on all ranges.
(g) Range and Accuracy

0-10 ppm	±1% of full scale
All higher ranges	±1% of full scale

(h) Converter Efficiency—Should be greater than 90%.

Note: There may be problems in achieving the specified noise and response specifications simultaneously. If these problems are encountered and a specification must be relaxed, it is most important that the response times of all analyzers be balanced.

2.2 Exhaust Gas Sampling System

2.2.1 Sampling Probe—The exhaust gas sampling probe/or probes shall be designed to provide a continuous representative sample of the engine exhaust gas. To minimize any change in the chemical composition of the exhaust gas sample, the probe shall be made of stainless steel, or other inert material. It should be ascertained that no catalytic action occurs in the probe. Prior to testing under this procedure, it shall be determined that the sampling probe provides an adequate representative sample of the exhaust gas. In general, a mixing probe of the following design has been shown to provide a representative sample. The probe may be fabricated from a 3/8 in (9.5 mm) stainless steel tube which is sealed at one end. Sampling holes of equal diameter (1/16 in [1.6 mm] is commonly used) shall be spaced at 1 in (25.4 mm) intervals along the portion of the tube which is inserted inside the exhaust duct. The sampling holes shall be sized so that the major pressure drop through the probe assembly shall be taken at the holes or orifices. When the probe is inserted in the exhaust duct, the sampling holes shall face upstream (analogous to a total pressure probe).

Generally, one sampling probe per exhaust duct is adequate. When the vehicle has two exhaust ducts, connection of the two sampling probes with a minimum restriction "Tee" will usually provide a single representative sample for the emission analyzers. The exhaust sampling probes shall be located a minimum of 2 exhaust duct diameters downstream from the engine exhaust flange.

The emissions from an oil sump breather system must be included in this procedure. Therefore, it must be ascertained that the breather emissions are either directly or indirectly (through an internal venting system analogous to a PCV valve system in a piston engine) included in the exhaust gas sample provided by the sampling probe.

2.2.2 Sample Transfer—The continuous exhaust sample shall be transferred from the sampling probe to the analytical instruments through a sample line of either stainless steel or other inert material. Total sample flow rate should be adjusted so that a fresh charge of sample gas will be transported from the sampling probe entrance to the inlet of each analyzer within 6 s. Sample line length should be as short as possible and sample bypass flow should be maintained as required.

2.3 Fuel Flow Instrumentation—The measurement of fuel flow shall be made using either an integrating, volumetric, positive-displacement meter or a flow rate meter of the rotor or turbine type. Other meter types may also be employed provided their performance conforms to the general specifications outlined herein.

Performance specifications for the integral, volumetric fuel meter are as follows:

Flow Rate Range:	0.5 gal/h (1.89 l/h) to 125% of highest flow rate expected during test.
Resolution:	0.0003 gal (1.14 ml) or less.
Accuracy:	±0.5% of reading[1] or ±0.0003 gal (1.14 ml) whichever is greater for 2-20 gal/h (7.57-75.7 l/h). ±1.0% of reading[1] or ±0.0003 gal (1.14 ml) whichever is greater for 0.5-2.0 gal/h (1.89-7.57 l/h) and 20 gal/h (75.7 l/h) to max. flow.
Repeatability:	±0.3% of reading or ±0.0003 gal (1.14 ml) whichever is greater.
Temperature range:	60°F (15.5°C)-150°F (65.6°C) ambient.

Performance specifications for the fuel flow rate meter are as follows:

Flow Range:	0.5 gal/h (1.89 l/h) to 125% of highest flow rate expected during test.
Resolution:	0.5% of full scale.
Accuracy:	±0.5% of full scale.
Zero Drift:	Less than 0.5% of full scale in 2 h.
Span Drift:	Less than 0.5% of full scale in 2 h.
Repeatability:	±1.0% of reading.
Temperature Range:	60°F (15.5°C)-150°F (65.6°C) ambient.
Response:	90% of final reading for 0 to maximum fuel flow in less than 0.5 s.

Although specifications for both fuel meter types are presented, it is recommended that the generally more accurate integral, volumetric fuel meter be used.

2.4 Data Recording—The fuel-based mass emission measurement system requires continuous and accurate recording and processing of highly transient data. An acceptable data recording system shall provide for the following two functions:

(a) The continuous, permanent, real-time test site display of all test variables required and listed in Section 5.2 of this recommendation.

(b) Computerized data reduction.

Function (a) shall be implemented by utilizing devices such as multichannel oscillographs or strip chart recorders to provide gross verification of the data being processed. The data handling error incurred from pick-up of the emission analyzer signals and fuel meter signal through the real-time display of these signals shall be less than ±5% of the full scale signal for each range of each instrument. Function (b) shall be implemented with devices commonly used to prepare data for entry into digital computing systems in either a real-time or post-test mode. Included are devices such as FM magnetic tape recorders, analog-to-digital converters, multiplexers, and associated signal conditioning equipment. The data acquisition error for each channel into the computing system, exclusive of measurement errors and computer data reduction errors (that is, the data handling error incurred from pick-up of the emission analyzer signals and fuel meter signal through digitization of all data channels), shall be less than ±2% of the full scale signal for each range of each instrument. Figs. 2 and 3 illustrate schematically data recording systems which adhere to the above recommendations. However, these example systems should not be construed as required systems for compliance with this recommended practice.

2.5 Chassis Dynamometer—A chassis dynamometer shall be used for testing the vehicle on the EPA Urban Dynamometer Driving Schedule (Appendix I, Ref. 1). The dynamometer must employ a power absorber to simulate road load conditions and a method of simulating inertia (either mechanical or electrical).

Specifications—Chassis Dynamometer	
Absorber Range	0-20 hp (14.9 kw)
Hp Accuracy	±2% of full scale
Hp Repeatability	±2% of reading
Speed Range	0-60 mph (96.5 km/h)
Speed Accuracy	±2% of full scale
Speed Repeatability	±2% of reading
Equivalent Inertia	1000-5500 lb (453.6-2495 kg)

3. *Instrumentation Routines*

3.1 Exhaust Gas Analytical System Procedures—The following procedures are recommended for the proper utilization of the exhaust analysis instruments.

3.1.1 Reference and Calibration Gases—Each of the analysis instruments requires a specific complement of gases for proper operation. These are:

(a) Hydrocarbon Analyzer—The heated flame ionization detector instrument requires zero gas, fuel, and calibration gases. These gases should meet the following specifications:

[1] The readout of an integral, volumetric fuel meter normally displays the cumulative fuel volume measured (for example, in gal [l]) from reset of the readout to zero. It does not display a fuel flow rate (for example, in gal/h [l/h]). The use of the expression "% of reading" for the integral, volumetric fuel meter, therefore, refers to a percentage of the total fuel volume measured (and displayed) and not to a percentage of some fuel flow rate.

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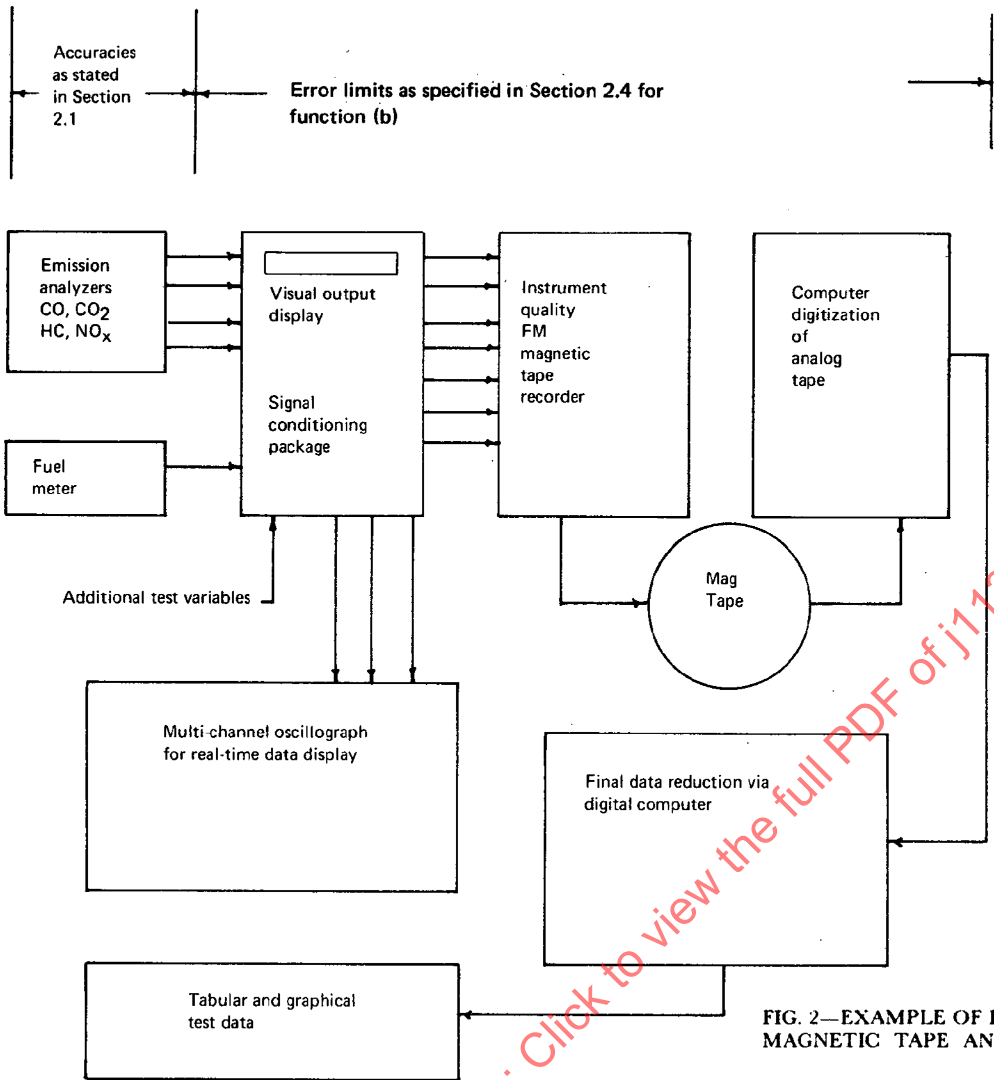

FIG. 2—EXAMPLE OF DATA RECORDING SYSTEM UTILIZING FM MAGNETIC TAPE AND COMPUTER FACILITY ANALOG TAPE DIGITIZATION

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Zero Gas—Hydrocarbon free air with impurities not exceeding 0.1 ppm C.

Fuel—60% helium, 40% hydrogen containing less than 1 ppm C hydrocarbon.

Calibration Gases—Propane in air mixtures having nominal concentrations of 50–95% of full scale of each range used. The actual concentrations should be known to ±2% of the true values. Calibration gases of this accuracy are available from many gas suppliers and ±1% calibrations gases are available from the National Bureau of Standards.

(b) Carbon Monoxide Analyzer—The NDIR used to measure carbon monoxide concentration requires zero gas and calibration gases. These gases should meet the following specifications:

Zero Gas—Zero grade nitrogen having less than 1 ppm carbon monoxide.

Calibration Gases—Carbon monoxide in nitrogen having nominal concentrations of 30, 60, and 90% of full scale of each range used. The actual concentration should be known to ±2% of the true value.

(c) Carbon Dioxide Analyzer—The NDIR used to measure carbon dioxide requires zero gas and calibration gases. These gases should meet the following specifications:

Zero Gas—Zero grade nitrogen having less than 350 ppm carbon dioxide.

Calibration Gases—Carbon dioxide in nitrogen having nominal concentrations of 30, 60, and 90% of full scale of each range used. The actual concentration should be known to ±2% of the true value.

(d) Oxides of Nitrogen Analyzer—The chemiluminescent instrument used to measure NO_x requires zero gas, calibration gas and converter efficiency evaluation gases.

Zero Gas—Zero grade nitrogen having less than 0.1 ppm NO.

Calibration Gases—Nitric oxide in nitrogen having nominal concentrations of 50 and 95% of full scale of each range used. The actual concentration should be known to ±2% of the true value.

Converter Efficiency Gases—The instrument manufacturer will specify the gases necessary to perform a converter efficiency check. Where specific concentrations are required, these concentrations should be known to ±2% of their true value.

3.1.2 CALIBRATION PROCEDURE—The analytical system should be calibrated at least once every 30 days. It is important that when calibrating, the same flow rates are used as when analyzing samples.

(a) Zero the hydrocarbon, carbon monoxide, carbon dioxide, and oxides of nitrogen analyzers with the zero gases specified above.

(b) Set the CO and CO_2 analyzer gains to give the desired range. Select the desired attenuation scale on the HC analyzer and adjust the electronic gain control to give the desired range. Select the desired range of the NO_x analyzer and adjust the phototube high voltage supply or amplifier gain to give the desired range.

(c) Calibrate each analyzer with the appropriate calibration gases specified above.

(d) Compare the values obtained on the CO and CO_2 analyzers with previous calibration curves. Any significant changes reflect some problem in the system which must be corrected. If necessary, locate and correct the problem and recalibrate. For the HC and NO_x analyzers, the calibration data must be linear through zero (within the tolerances allowed by linearity specifications and calibration gas accuracy). Deviation from a straight line indicates instrument problems which must be corrected before recalibration.

(e) Check the efficiency of the NO_x to NO converter at least once per week by the procedure recommended by the instrument manufacturer. If no such procedure is recommended, the procedure outlined in Ref. 8 may be used. The efficiency of the converter should be virtually 100%. Efficiency checks should be made on each appropriate analyzer range. If the efficiency is not greater than 90%, the cause of the inefficiency must be corrected, and the efficiency check performed again.

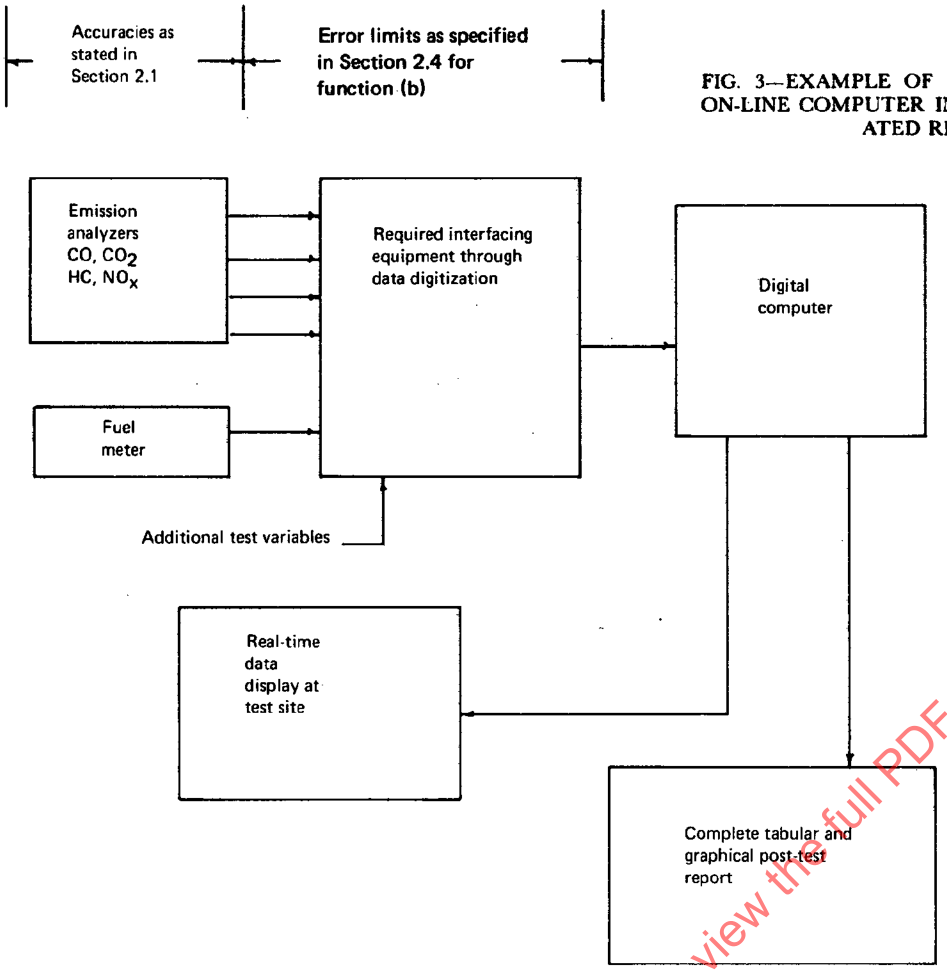

FIG. 3—EXAMPLE OF DATA RECORDING SYSTEM UTILIZING ON-LINE COMPUTER INSTALLATION AND COMPUTER GENERATED REAL-TIME INFORMATION

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3.1.3 Verification and Instrument Checks—Verification and instrument checks should be performed before and after each test, but at least once per hour.

(a) Allow a minimum of 2 h warm-up for all analyzers (power is normally left on for infrared and chemiluminescent analyzers; but when not in use, the chopper motors of infrared analyzers are turned off and the phototube high voltage supply of the chemiluminescent analyzer is placed in standby).

(b) Check the sampling system for any leaks that could dilute the exhaust gas and replace or clean the sample line filter.

(c) Introduce zero gases at the same flow rates used to analyze exhaust gas and zero the analyzers. Obtain a stable zero on each amplifier meter and recorder. Recheck after tests.

(d) Introduce span gases having concentrations of about 90–95% of full scale for each range used. In order to avoid corrections, span gases should be of the same flow rates or pressures used to analyze test samples. Set the CO and CO_2 analyzer gains, the HC analyzer sample capillary flow and electronic gain control, and the NO_x high voltage supply or amplifier gain to match the calibration curves. If gain has shifted significantly on the CO or CO_2 analyzers, check instrument tuning as per manufacturers' recommendations. If necessary, recheck calibration. Respan at end of test, but at least once per hour. Record actual concentrations and gain readings.

(e) Recheck zeros; repeat (a) and (b) above, if necessary.

(f) Check sample line temperatures.

(g) Check instrument flow rates.

(h) Recheck zero and span points at the end of each test and also at approximately 1 h intervals during a test. If either has changed by ±2% of full scale, the test should be rerun after system maintenance. Should it be impractical to repeat the test, a correction based on a linear interpolation with time is acceptable for corrections within ±4%.

(i) When the sample probe is in the exhaust stream and sampling is not in progress, a back purge with air or inert gas may be necessary to protect the probe and sample lines from build-up which could affect HC readings. Check the sample line for contamination each time the instrument zero and span points are checked. This check is performed immediately after zero and span adjustments are completed by introducing HC zero gas at the sample probe. If the instrument zero reading increases by more than 5% of the scale in use, the sample line shall be purged or cleaned as required to bring the zero within limits. Upon meeting these requirements, introduce HC span gas into the sampling system. If the instrument span reading is different by more than ±5% from the correct setting for the scale in use, further purging or cleaning must be performed to bring the span within limits.

3.2 Fuel Flow Instrumentation—The fuel meter should be isolated in a manner such that pressure drop, valving, or shuttle action have no influence on the engine fuel control. The fuel meter must be placed in the fuel system so that it measures only the fuel used by the engine. In engines with fuel control systems using an external bypass or spill line, a low pressure fuel meter must be placed in a position so that the bypass or spill line can be returned downstream of the meter without affecting the operation of the engine fuel control. A high pressure fuel meter must be placed downstream of the point where the high pressure bypass or spill line originates. Fig. 4 shows several acceptable fuel meter connections and fuel system modifications.

Similarly, fuel meters with significant pressure drop, or transient pulse effects, can be isolated from the engine fuel control by means of an accumulator downstream. Satisfactory accumulators have been fabricated from carburetor float bowls, thereby providing both pressure drop isolation and a reservoir for spill return fuel. A fuel pump may be mounted at the fuel meter inlet in such installations, provided the pump is compatible with the fuel meter.

The following fuel meter calibration procedure shall be used:

(a) The fuel meter shall be calibrated to a known volumetric standard over its entire flow range before it is placed in service.

(b) At weekly intervals, the fuel meter calibration should be verified for at least one representative flow rate.

(c) The fuel meter should be recalibrated over the entire flow range on an annual basis.

(d) The user shall ascertain that transient flow rate variations do not adversely affect calibration.

4. Test Procedure

4.1 Test Layout

(a) The vehicle shall be placed on the dynamometer. Tie downs and/or wheel chocks (if used) shall be installed.

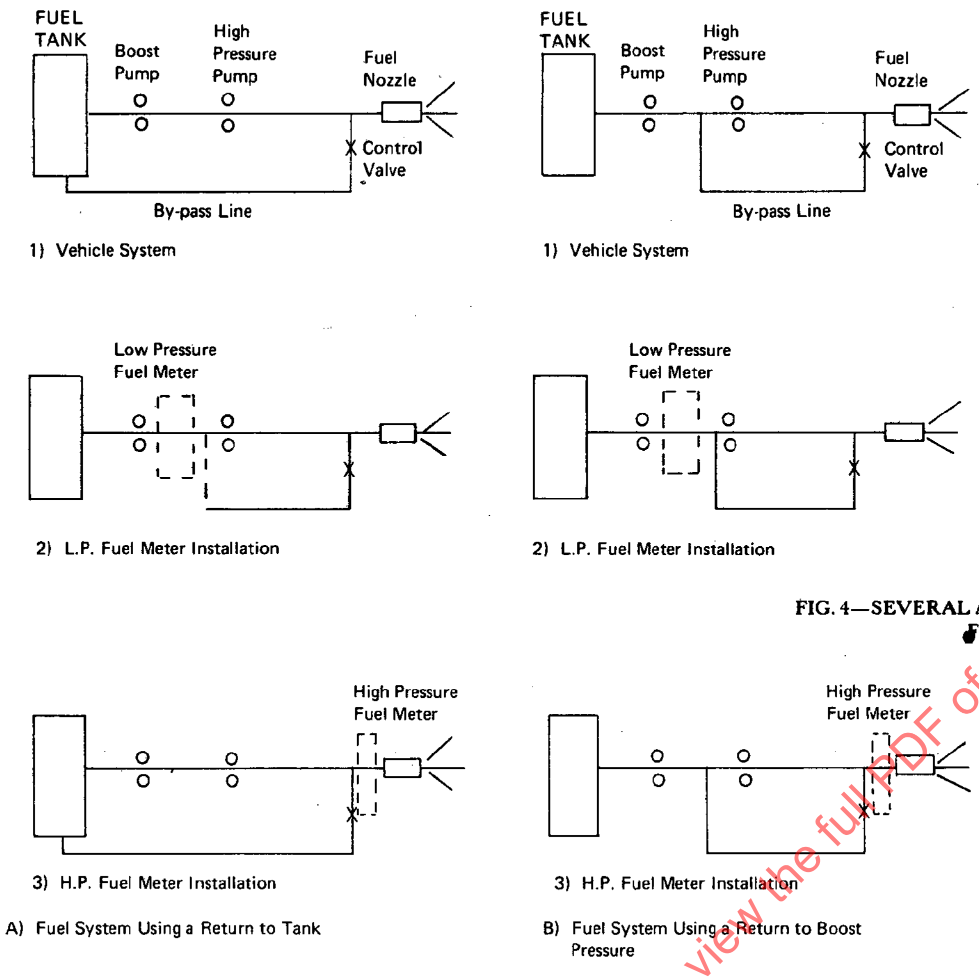

FIG. 4—SEVERAL ACCEPTABLE FUEL METER CONNECTIONS AND FUEL SYSTEM MODIFICATIONS

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NOTE: When using two-roll dynamometers a truer speed-time trace may be obtained by minimizing the rocking of the vehicle in the rolls. The rocking of the vehicle changes the tire rolling radius on each roll. The rocking may be minimized by restraining the vehicle horizontally (or nearly so) by using a cable and winch.

(b) An exhaust gas disposal system with a back pressure of ±0.5 in H_2O (gage) (0.12 kPa) at the vehicle tailpipe shall be installed. Exhaust gases shall be disposed of in such a manner that recirculation into the engine inlet during testing does not occur.

(c) A driver's aid system which measures the vehicle speed on the dynamometer rolls and plots it in comparison with the prescribed driving schedule shall be positioned in full view of the vehicle driver.

(d) The fuel meter shall be installed in the vehicle fuel system as described in Section 3.2. The fuel meter shall be connected to the readout and/or recording instrumentation for data collection. Care must be taken to purge air from the fuel system after the fuel meter is installed.

4.2 Test Conditions

4.2.1 CHASSIS DYNAMOMETER

(a) During dynamometer operation, a fixed speed cooling fan shall be positioned so as to direct sufficient cooling air to the engine compartment to maintain engine cooling.

(b) Flywheels, electrical or other means of simulating inertia shall be set for the proper equivalent inertia according to Section 85.074-15 of Ref. 1.

(c) Power absorption unit adjustment

(1) The power absorption unit shall be adjusted to reproduce road load power at 50 mph (80.5 km/h) true speed. The indicated road load power setting shall take into account the dynamometer friction. The relationship between road load (absorbed) power and indicated road load power for a particular dynamometer shall be determined by the procedure outlined in Appendix II of Ref. 1.

(2) The road load power listed in Section 85.074-15 of Ref. 1 shall be used or the vehicle manufacturer may determine the road load power by the following procedure:

a. Measure the corrected gas turbine speed and operating cycle temperatures of the representative vehicle of the same equivalent weight class when operated on a level road under balanced wind conditions at a true speed of 50 mph (80.5 km/h).

b. Note the dynamometer indicated road load horsepower setting required to reproduce that corrected gas turbine speed and operating cycle temperature when the same vehicle is operated on the dynamometer at a true speed of 50 mph (80.5 km/h). The tests on the road and on the dynamometer shall be performed with the same vehicle ambient absolute pressure (usually barometric), within ±5 mm Hg (0.67 kPa).

(3) If the vehicle being tested is equipped with air conditioning the road load power determined above shall be increased by 10%.

(d) The vehicle should be nearly level when tested in order to prevent abnormal weight or fuel distribution.

(e) The drive wheel tires shall be inflated up to 45 psig (310 kPa) in order to prevent tire damage. The drive wheel tire pressure shall be reported with the test results.

(f) If the dynamometer has not been operated during the 2 h period immediately preceding the test it shall be warmed up for 15 min by operating it at 30 mph (48.4 km/h) using a nontest vehicle. Practice runs over the prescribed driving schedule may be performed to find the minimum throttle action to maintain the proper speed-time relationship.

4.2.2 FUEL—The fuel used in exhaust emission testing shall be the same fuel specified by the engine manufacturer. Gas turbine engine fuels are typically a refined petroleum distillate, preferably of paraffin or mixed base stock, free from water, suspended matter, and foreign material. In general, it should be representative of commercial, seasonal fuels available at retail outlets. Specific gravity of the fuel shall be determined and documented as prescribed in Ref. 9. Fuel temperature shall be monitored at the fuel measuring device. The carbon/hydrogen ratio shall be determined by currently accepted procedures (10).

The emissions determined by this procedure will be a function of the type of fuel used. This procedure should not restrict or specify the type of fuel used since one of the attributes of the gas turbine is its multi-fuel capability. Emission results from this procedure should be reported with the type of fuel as an integral part of the data (see data sheet, Section 5.1).

4.2.3 VEHICLE PRE-CONDITIONING—The vehicle shall be allowed to stand with the engine turned off for a period of not less than 12 h at an ambient temperature between 60°F (15.6°C) and 86°F (30°C) prior to the cold start dynamometer testing.

4.2.4 Ambient Temperature and Pressure—The effects of ambient temperature and pressure on gas turbine emission levels are not well understood. Changes in ambient conditions can cause changes in emission levels through changes in combustion characteristics, combustor operating conditions, and engine operation caused by the control system characteristics. Because of these unknowns, the following recommendations are made.

The EPA regulations specify an ambient temperature range of 68°F (20°C)-86°F (30°C) during piston engine emission testing. Using the SAE Engine Test Code J816a (11), it can be shown that a 2.5% variation in power output of a piston engine results over an ambient temperature range of 18°F (10°C). It can be determined that approximately a 6°F (3.3°C) ambient temperature variation will produce a similar 2.5% variation in power output of a gas turbine engine. Therefore, a 6°F (3.3°C) ambient temperature variation for a gas turbine may be roughly assumed to produce a similar variation in power and emissions as an 18°F (10°C) variation for a piston engine. Since 75°F (24°C) is a commonly available mean temperature, it is recommended that gas turbine emission tests be made within an ambient air temperature range of 72°F (22°C)-78°F (25.5°C).

Ambient pressure cannot be controlled in any practical way, although changes in ambient pressure can cause changes in emissions of a gas turbine engine. To minimize these variations, it is recommended that gas turbine emissions tests be made at an ambient pressure of 760 mm Hg ± 30 mm (101.3 ± 4.0 kPa).

Note: If tests are conducted outside of these recommended ambient temperature and pressure ranges, the results shall be qualified with a statement to this effect.

4.2.5 Ambient Humidity—Ambient absolute humidity should be maintained as close as possible to 75 grains (4.85 g) of water/lb (0.454 kg) of dry air (approximately 50-65% relative humidity at the ambient temperature level extremes of 78°F [25.5°C] and 72°F [22°C] respectively).

The EPA humidity correction factor for NO_x emissions from piston engines (1) is unity at an absolute humidity of 75 grains (4.85 g)/lb (0.454 kg) of dry air. Therefore, uncorrected gas turbine NO_x data should be directly comparable to piston engine data at this reference absolute humidity level. Minimizing the variation of absolute humidity from 75 grains (4.85 g) will minimize errors in applying to gas turbine NO_x emissions the EPA humidity correction factor which was developed for piston engines.

4.2.6 Ambient Contamination—Due to the high combustion efficiency of the gas turbine engine, the HC and CO content of the exhaust gases may be of the same magnitude or less than that of ambient engine intake air. It is also known that some percentage of the inlet HC and CO pollutants are partially consumed and HC converted to CO. NO_x passes through the engine unaffected. These phenomena suggest that determination of absolute exhaust emission levels would require that the ambient air at the testing facility be devoid of all contaminants. Since this approach is unrealistic an alternate procedure is outlined.

There is no known method to reduce the NO_x, CO, HC, and CO_2 levels in the large quantities of air consumed by the gas turbine. In the interest of accuracy, it is recommended that engine inlet NO_x levels be maintained at less than 1 ppm. Inlet CO_2 levels must be subtracted from the exhaust values in order to accurately compute the actual air/fuel ratio. Inlet CO_2 levels should be less than 500 ppm to insure valid results. In summary, it is recommended that inlet contaminants be maintained at levels less than the following values:

HC	3 ppm C
CO	5 ppm
NO_x	1 ppm
CO_2	500 ppm

Inlet contaminants shall be determined by measuring the species of pollutant in the proximity of the engine inlet with the instrumentation prescribed in Section 2.1 as follows:

(a) Less than 1 min prior to start of test.
(b) Not more than 1 min after completion of the cold stabilized test.
(c) Less than 1 min prior to the start of the hot transient test.
(d) Not more than 1 min after completion of the hot transient test.

As an optional precaution, ambient contaminants should be monitored continuously with separate instrumentation at the test facility to detect transient contamination conditions such as fuel spillage or exhaust leaks. The numerical time-average of the continuously monitored inlet contaminants should be compared to the recommended ambient levels.

Note: If tests are conducted with higher than the recommended levels of ambient contamination, the results shall be qualified with a statement to this effect.

4.3 Test Procedure

This test consists of engine start ups and vehicle operation on a chassis dynamometer over the specified driving schedule. Engine exhaust is sampled and analyzed continuously to determine hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen mass emissions over the specified driving schedule. Inlet contaminants are determined as prescribed in Section 4.2.6. NO_x is corrected for humidity (Section 4.2.5) and the results entered on the test result form (Section 7).

4.3.1 Vehicle and Test Facility Preparation—Set chassis rolls inertia and horsepower according to Section 4.2.1. Prepare car on chassis dynamometer for testing and assure that the following items are accomplished:

(a) Anchor as required.
(b) Connect exhaust gas disposal system.
(c) Connect sample probes, sample lines, analyzers, and recorders.
(d) Position fan according to manufacturer's recommendation.
(e) Hood will be closed during test.
(f) Connect fuel meter (previously installed in fuel system) to recorder and/or computer system.
(g) Obtain sample of fuel for determination of specific gravity (Section 4.2.2).

4.3.2 Instrument Calibration—Check calibration of exhaust analysis instrumentation before and after each test period (per Section 3.1.3).

4.3.3 Ambient Contamination—Record ambient contaminants (Section 4.2.6) before and after each test period using the identical instruments used for exhaust gas analysis.

4.3.4 Engine Starting and Re-Starting—Emission sampling shall begin prior to engine starting. The engine shall be started according to the manufacturer's recommended starting procedures. The initial 20 s idle period shall begin when the engine first reaches idle speed. The transmission shall be placed in drive 15 s after the engine is started. If necessary, braking may be employed to keep the drive wheels from turning.

(a) If the engine does not light off after 10 s of cranking, cranking shall cease and the reason for failure to start determined. Should the manufacturer provide a safety system which renders the start cycle inoperative for a prescribed time to permit fuel drainage from the combustor, the time required for this event shall be adhered to. Three attempts to start are allowed before aborting the test.

(b) The analyzers and sample lines shall be purged during this diagnostic period. If failure to start is an operational error, the vehicle shall be rescheduled for testing from a cold start. If failure to start is caused by vehicle malfunction, corrective action of less than 30 min duration may be taken and the test continued.

The sampling system shall be reactivated at the same time cranking is started. When the engine starts, the driving schedule timing sequence shall begin. If failure to start is caused by vehicle malfunction and the vehicle cannot be started, the test shall be voided, the vehicle removed from the dynamometer, corrective action taken, and the vehicle rescheduled for test. The reason for the malfunction (if determined) and the corrective action taken shall be reported.

(c) If the engine "false starts" (does not self sustain) the operator shall repeat the recommended starting procedure. False start emissions shall be included.

(d) If the engine stalls during some operating mode other than idle, the driving schedule indicator shall be stopped, the vehicle re-started, accelerated to the speed required at that point in the driving schedule and the test continued. Sampling shall continue throughout this period.

(e) If the vehicle will not start after three attempts, the test shall be voided, the vehicle removed from the dynamometer, corrective action taken, and the vehicle re-scheduled for test. The reason for the malfunction (if determined) and the corrective action taken shall be reported.

4.3.5 Dynamometer Driving Schedule

(a) The prescribed driving schedule to be followed consists of a nonrepetitive series of idle, acceleration, cruise, and deceleration modes of various time sequences and rates. The driving schedule is defined by a smooth transition through the speed versus time relationships listed in Appendix 1 of Ref. 1. The time sequence begins after starting the vehicle according to the start-up procedure described in Section 4.3.4.

(b) A speed tolerance of ±2 mph (3.2 km/h) and a time tolerance of ±1 s (or an algebraic combination of the two) from either the speed-time relationship prescribed in Appendix 1 or as printed on a driver's aid chart are acceptable. Speed tolerances greater than 2 mph (3.2 km/h) are acceptable provided they occur for less than 2 s on any one occasion. Speeds lower than those prescribed may be acceptable provided that the vehicle is operated at maximum available power during such occurrences. Further, speed deviations from those prescribed due to stalling are acceptable provided the provisions of Section 4.3.6 are adhered to.

(c) The dynamometer run consists of two tests, a "cold" start test after a minimum 12 h soak and a "hot" start test with a 10 min soak between the two tests. Engine start-up, operation over the driving schedule, and engine shut-

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down make a complete cold start test. Engine start up and operation over the first 505 s of the driving schedule complete the hot start test.

(d) The transmission should be placed in the park position and the sampling probes turned off upon completion of the cold transient and cold stabilized cycles. Inlet contaminants shall be measured per Section 4.2.6. After a 10 min soak period conduct a hot transient cycle identical to the cold transient procedure. The fan shall be turned off during the soak period.

(e) Disconnect sample probes, exhaust ducts and remove vehicle from chassis rolls.

4.3.6 GENERAL

(a) All test conditions shall be run with the transmission in the normal ratio for similar road driving.

(b) Idle modes shall be run with the transmission in the normal drive-away ratio, except first idle, and the wheels braked.

(c) The vehicle shall be driven with *minimum throttle movement* to maintain the desired speed and the simultaneous use of throttle and brakes shall be avoided.

(d) Acceleration modes shall be driven smoothly allowing the transmission to operate through the normal sequence of ratios. If the vehicle cannot accelerate at the specified rates, the vehicle shall be accelerated at WOT until the vehicle speed reaches the speed at which it should be at the time during the driving schedule.

(e) The deceleration modes shall be run using brakes *or* throttle as necessary to maintain the desired speed.

(f) The hood shall be closed during the 10 min hot soak period.

5. Information to be Recorded

5.1 Sample Data Sheet—See Fig. 5.

5.2 Continuous Data—The following test data shall be continuously recorded and processed through the data recording system specified in Section 2.4:

(a) CO

(b) CO_2

(c) HC

(d) NO_x

(e) Fuel Flow

(f) O_2 and additional test variables of interest as recording system capacity permits (optional).

(g) Instrument range information as specified in Section 5.2.1.

5.2.1 RANGE CHANGES—Throughout the emissions test, instrument range changes may be required to maintain a high instrument output signal-to-noise ratio. Dynamic instrument range information shall be recorded throughout the test. Range change times shall be recorded from zero time on the prescribed driving schedule with an accuracy of ±0.5 s of the true range change time. Information for determining the instrument range in use before and after the change shall be recorded. Three examples of acceptable range change techniques are presented.

Example 1—Simplified range change recording technique for use with the recording system shown in Fig. 2: A range change log for each instrument can be kept during the test noting initial range settings for all instruments, range change times for each instrument as measured from zero time on the prescribed driving schedule, and instrument range setting after range changes. Range change times can be observed from a display of cumulative time for the test. These data can later be inserted into the data reduction computer program.

Example 2—Automatic range change recording technique for use with the recording system shown in Fig. 2: All instrument range changing switches can be equipped with digital logic circuits to be used for indication of instrument range. At the time of any range change, these logic circuits would be activated and place a signal on the magnetic tape which can later be decoded by the data reduction program.

Example 3—Automatic range change recording technique for use with the recording system shown in Fig. 3: All instrument range changing switches can be equipped with digital logic circuits to be used for indication of instrument range. At the time of any range change, these logic circuits would be activated and transmit encoded information through the normal data stream to the computing facility for subsequent decoding. All required range change information could be included in the encoded data word.

5.2.2 DATA SAMPLING RATE—All continuous data specified in Section 5.2 shall be sampled (updated) at a rate of not less than 2 samples per second per channel.

5.2.3 RELATIVE INSTRUMENT LAG TIME—The relative response time differences for all the emission analyzers in the exhaust gas sampling system must be determined. The relative response time differences of the emission analyzers are unique to a particular exhaust gas sampling system and operating conditions. Sampling system line lengths, instrument cell lengths, instrument electronic response times, etc., contribute to differences in relative response time. The relative response time differences for each analyzer shall be determined as follows with reference to Fig. 6:

Vehicle Test Data

Test No. ____________ Date ____________ Time ____________

Vehicle Ident. ____________

Engine Ident. ____________

Transmission Ident. ____________

Dynamometer Ident. ____________

Date of Last Dynamometer Calibration ____________

Inertia Loading lbm (kg) ____________

Road Load Power at 50 mph (80.5 km/h) hp (kw) ____________

Drive Wheel Tire Pressure, psi (kPa) ____________

Instrumentation Ident. ____________

Fuel Specification ____________

Fuel sp. gr. (ASTM D 1298) ____________

Fuel H/C Atomic Ratio (ASTM D 1018-64) ____________

Vehicle Operator ____________ Inst. Operator ____________

	Start	End
Ambient Temp. (inlet) °F (°C)		
Wet Bulb Temp. °F (°C)		
Barometer in Hg (mm Hg)		
Fuel Temp. °F (°C)		
Sample Line Temp. °F (°C)		

No. of Abortive Starts ____________

INSTRUMENT CALIBRATION

Analyzer	Zero	Span Gases Concentration	Diluent
CO_2			
CO			
NO			
HC			

FIG. 5—DATA SHEET—GAS TURBINE VEHICLE EMISSION TEST

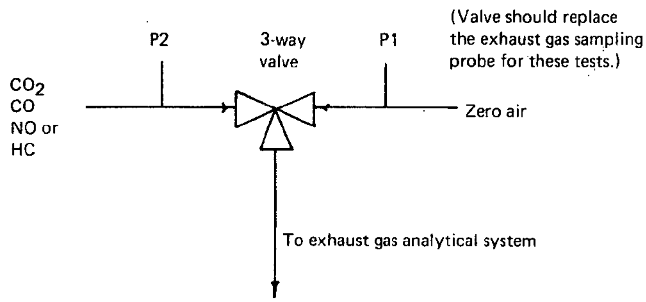

FIG. 6—TEST SYSTEM FOR THE DETERMINATION OF RELATIVE INSTRUMENT LAG TIMES

(a) With the exhaust gas sampling systems in that condition described in Section 2.1 for normal test sampling, flow zero gas through the valve shown at the flow rate to be used during testing.

(b) Connect CO_2 span gas to the test gas inlet port and adjust P2 to 0.2 ± 0.1 psig (1.4 ± 0.7 kPa).

(c) Switch the valve to allow the CO_2 span gas to flow through the exhaust gas sampling system and measure the total time within ±0.5 s from the opening of the valve to the recording of a CO_2 analyzer output signal equal to 50% of the correct value (that is, calibration value).

(d) Repeat steps a–c three times and compute the average response time for the CO_2 analyzer.

(e) Replace the CO_2 span gas in turn with CO, NO, and HC span gases and repeat steps a–d for each gas.

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