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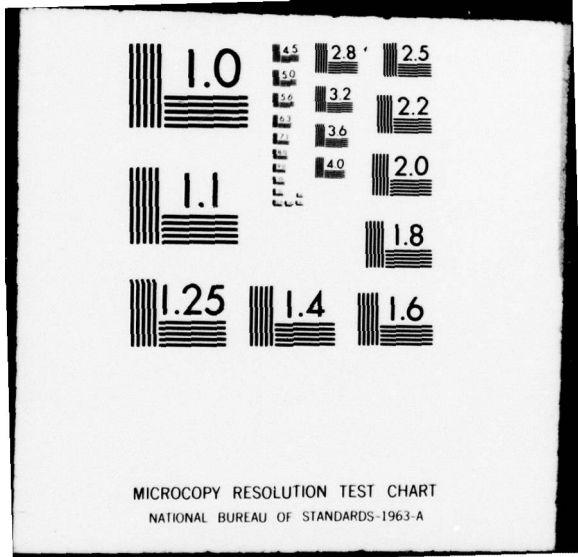
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Report No. FAA-RD-78-142

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**EXHAUST EMISSIONS CHARACTERISTICS
FOR A GENERAL AVIATION LIGHT-AIRCRAFT
AVCO LYCOMING IO-360-A1B6D PISTON ENGINE**

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Eric E. Becker



FEBRUARY 1979

FINAL REPORT

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Springfield, Virginia 22161.

Prepared for

**U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590**

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NOTICE

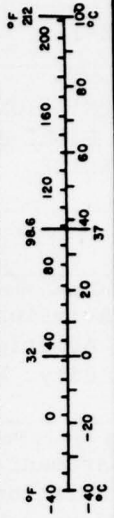
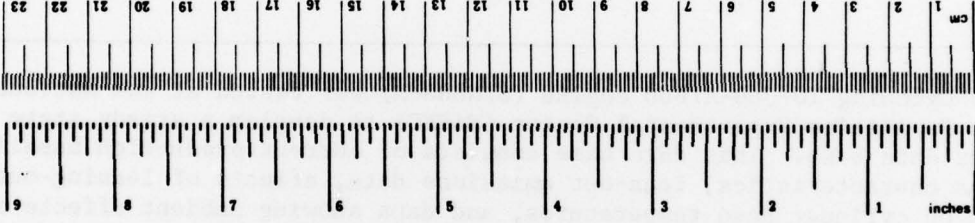
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Technical Report Documentation Page

| | | | |
|--|--|---|---|
| <p>1. Report No. 19 18 FAA-RD-78-142</p> | <p>2. Government Accession No.</p> | <p>3. Recipient's Catalog No.</p> | |
| <p>4. Title and Subtitle 6 EXHAUST EMISSIONS CHARACTERISTICS FOR A GENERAL AVIATION LIGHT-AIRCRAFT AVCO LYCOMING IO-360-A1B6D PISTON ENGINE</p> | | <p>5. Report Date 11 February 1979</p> | <p>6. Performing Organization Code</p> |
| <p>7. Author(s) 10 Eric E./Becker</p> | <p>8. Performing Organization Report No. 14 FAA-NA-78-49</p> | | <p>10. Work Unit No. (TRAVIS) 12 95p</p> |
| <p>9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405</p> | | <p>11. Contract or Grant No. 201-521-100</p> | |
| <p>12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590</p> | | <p>13. Type of Report and Period Covered 9 Final report</p> | |
| <p>15. Supplementary Notes</p> | | | |
| <p>6. Abstract The Avco Lycoming IO-360-A1B6D engine (S/N888-X) was tested at the National Aviation Facilities Experimental Center (NAFEC) to develop a steady state exhaust emissions data base. This data base consists of current production baseline emissions characteristics, lean-out emissions data, effects of leaning-out the fuel schedule on cylinder head temperatures, and data showing ambient effects on exhaust emissions and cylinder head temperatures. The engine operating with its current full-rich production fuel schedule could not meet the proposed Environmental Protection Agency (EPA) standard for carbon monoxide (CO) under sea level, standard-day conditions. The engine did, however, meet the proposed EPA standards for unburned hydrocarbons (HC) and oxides of nitrogen (NO_x) under the same sea level test conditions. The results of testing the engine under different ambient conditions (hot day) are also presented, and these results show a trend toward higher levels of emissions output for CO and HC while producing slightly lower levels of NO_x.</p> | | | |
| <p>17. Key Words General Aviation Piston Engines Oxides of Nitrogen Carbon Monoxide Emissions (Pollution) Unburned Hydrocarbons</p> | | <p>18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161</p> | |
| <p>19. Security Classif. (of this report) Unclassified</p> | <p>20. Security Classif. (of this page) Unclassified</p> | <p>21. No. of Pages 81</p> | <p>22. Price</p> |

METRIC CONVERSION FACTORS

| Approximate Conversions to Metric Measures | | | Approximate Conversions from Metric Measures | | | | | |
|--|------------------------|----------------------------|--|-----------------|-----------------------------------|---------------------|------------------------|-----------------|
| Symbol | When You Know | Multiply by | To Find | Symbol | When You Know | Multiply by | To Find | Symbol |
| LENGTH | | | | | | | | |
| in | inches | 2.5 | centimeters | cm | millimeters | 0.04 | inches | in |
| ft | feet | 30 | centimeters | cm | inches | 0.4 | inches | in |
| yd | yards | 0.9 | meters | m | feet | 3.3 | feet | ft |
| mi | miles | 1.6 | kilometers | km | meters | 1.1 | yards | yd |
| | | | | | kilometers | 0.6 | miles | mi |
| AREA | | | | | | | | |
| in ² | square inches | 6.5 | square centimeters | cm ² | square centimeters | 0.16 | square inches | in ² |
| ft ² | square feet | 0.09 | square meters | m ² | square meters | 1.2 | square yards | yd ² |
| yd ² | square yards | 0.8 | square meters | m ² | square kilometers | 0.4 | square miles | mi ² |
| mi ² | square miles | 2.6 | square kilometers | km ² | hectares (10,000 m ²) | 2.5 | acres | ac |
| | acres | 0.4 | hectares | ha | | | | |
| MASS (weight) | | | | | | | | |
| oz | ounces | 28 | grams | g | grams | 0.035 | ounces | oz |
| lb | pounds | 0.45 | kilograms | kg | kilograms | 2.2 | pounds | lb |
| | short tons (2000 lb) | 0.9 | tonnes | t | tonnes (1000 kg) | 1.1 | short tons | st |
| VOLUME | | | | | | | | |
| teaspoon | teaspoons | 5 | milliliters | ml | milliliters | 0.03 | fluid ounces | fl oz |
| Tablespoon | tablespoons | 15 | milliliters | ml | liters | 2.1 | pints | pt |
| fl oz | fluid ounces | 30 | milliliters | ml | liters | 1.06 | quarts | qt |
| c | cup | 0.24 | liters | l | liters | 0.26 | gallons | gal |
| pt | pint | 0.47 | liters | l | cubic meters | 35 | cubic feet | ft ³ |
| qt | quart | 0.96 | liters | l | cubic meters | 1.3 | cubic yards | yd ³ |
| gal | gallon | 3.8 | liters | l | | | | |
| ft ³ | cubic feet | 0.03 | cubic meters | m ³ | | | | |
| yd ³ | cubic yards | 0.76 | cubic meters | m ³ | | | | |
| TEMPERATURE (exact) | | | | | | | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C | °C | Celsius temperature | Fahrenheit temperature | °F |



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10-286.

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INTRODUCTION

PURPOSE.

General aviation piston engine exhaust emission tests were conducted at the National Aviation Facility Experimental Center (NAFEC) for the following reasons:

1. Determine and establish total exhaust emissions characteristics for a representative group of current production general aviation piston engines.
2. Determine the effects of leaning-out of the fuel metering system on exhaust emissions.
3. Verify the acceptability of test procedures, testing techniques, instrumentation, etc.
4. Determine reductions in operating limits and safety margins resulting from fuel system adjustments/modifications evaluated for improved piston engine exhaust emissions characteristics.

BACKGROUND.

Beginning in 1967, Congress enacted a series of laws which added environmental considerations to the civil aviation safety, control, and promotional functions of the Federal Aviation Administration (FAA). This legislation was in response to the growing public concern over environmental degradation. Thus, the FAA was committed to the development, evaluation, and execution of programs designed to identify and minimize the undesirable environmental effects attributable to aviation.

In accordance with the Clean Air Act Amendments of 1970, the Environmental Protection Agency (EPA) established emission standards and outlined test procedures when it issued EPA rule part 87 in January 1973. The Secretary of Transportation, and therefore the FAA was charged with the responsibility for issuing regulations to implement this rule and enforcing these standards.

Implementation of this rule was contingent on the FAA's finding that safety was not impaired by whatever means was employed to achieve the standards. For this reason, the FAA undertook a program, subsequent to the issuance of the EPA emission standards in July 1973, to determine the feasibility of implementation, verify test procedures, and validate test results.

There was concern on the part of the FAA that the actions indicated as necessary in order to comply with the EPA emission standards, such as operating engines at leaner mixture settings during landing and takeoff cycles, might compromise safety and/or significantly reduce engine operating margins. Therefore, the FAA contracted with Avco Lycoming and Teledyne Continental Motors to select engines that they considered typical of their production, test these

engines as normally produced to establish a baseline emissions data base, and then alter (by lean-out adjustments) the fuel schedule and ignition timing to demonstrate methods by which the proposed EPA limits could be reached.

In the event that hazardous operating conditions were indicated by the manufacturer's tests, independent verification of data would be necessary. Therefore, it was decided that duplication of the tests be undertaken at NAFEC to provide the needed verification. This report presents the NAFEC test results for the Avco Lycoming IO-360-A1B6D piston engine (S/N888-X). It should be noted that since the time of these tests, the EPA has rescinded the promulgated piston engine standards (reference 1). This work is reported upon herein in the same light as it would have been if the requirements were still in effect.

DISCUSSION

DESCRIPTION OF AVCO LYCOMING IO-360-A1B6D ENGINE.

The IO-360-A1B6D engine tested at NAFEC is a fuel-injected, horizontally opposed engine with a nominal 360 cubic inch displacement (cid) rated at 200 brake horsepower (bhp) for a nominal brake specific fuel consumption (bsfc) of 0.50. This engine is designed to operate on 100/130 octane aviation gasoline (appendix A - Fuel Sample Analysis of NAFEC Test Fuel). The vital statistics for this engine are provided in table 1.

TABLE 1. AVCO LYCOMING IO-360-A1B6D ENGINE

| | |
|---|---------------|
| No. of Cylinders | 4 |
| Cylinder Arrangement | HO |
| Max. Engine Takeoff Power (HP, RPM) | 200, 2700 |
| Bore and Stroke (in.) | 5.125 x 4.375 |
| Displacement (cu. in.) | 361 |
| Weight, Dry (lbs)--Basic Engine | 330 |
| Prop. Drive | Direct |
| Fuel Grade | 100/130 |
| Compression Ratio | 8.7:1 |
| Max. Cylinder Head Temperature Limit (°F) | 475 |

DESCRIPTION OF TEST SETUP AND BASIC FACILITIES.

For the NAFEC sea level static tests, the engines were installed in the propeller test stand shown in figures 1 and 2. This test stand was located in the NAFEC General Aviation Piston Engine Test Facility (building 211). The test facility provided the following capabilities for testing light aircraft piston engines:

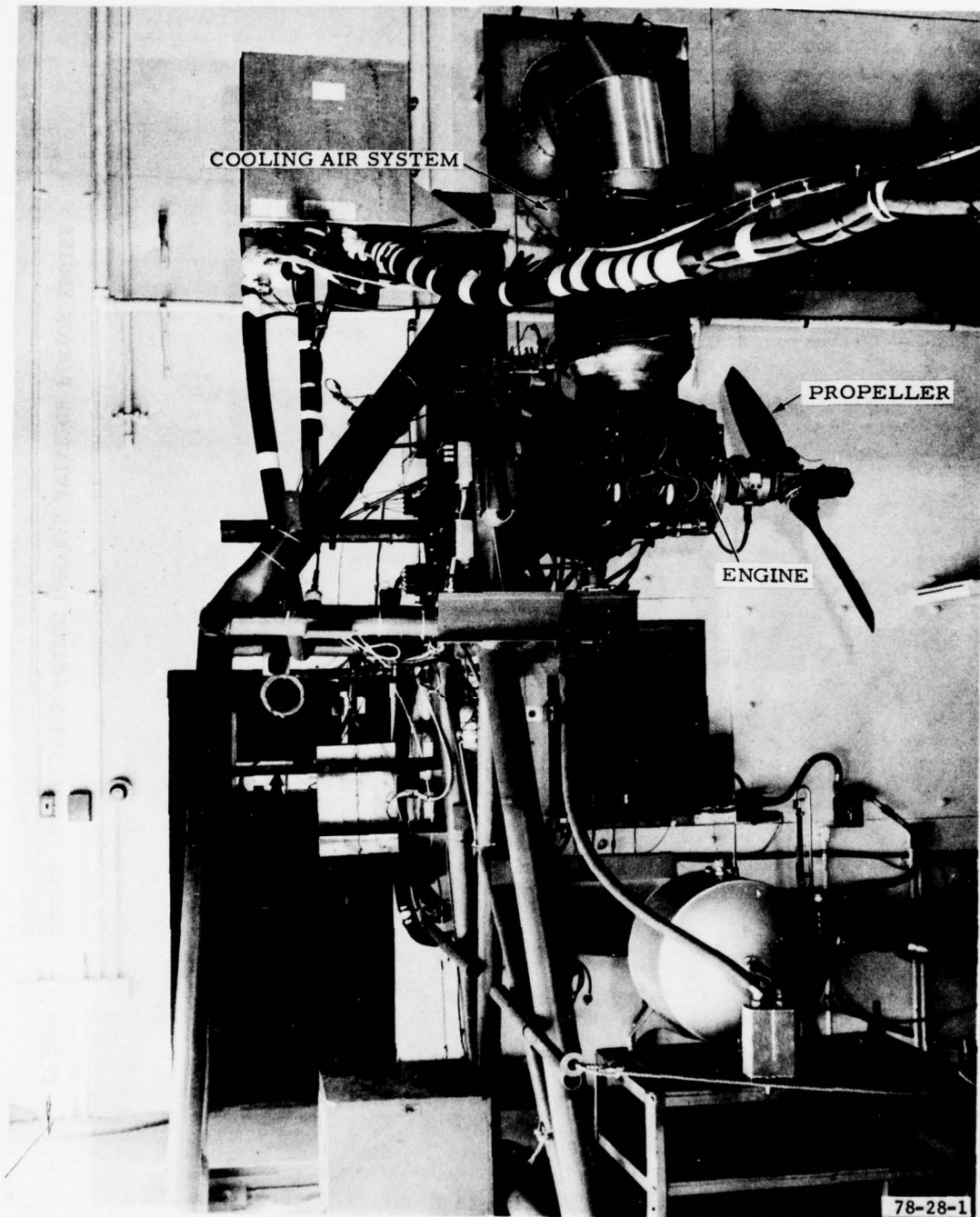


FIGURE 1. TYPICAL SEA LEVEL PROPELLER TEST STAND--PISTON ENGINE
INSTALLATION--EMISSIONS TESTING

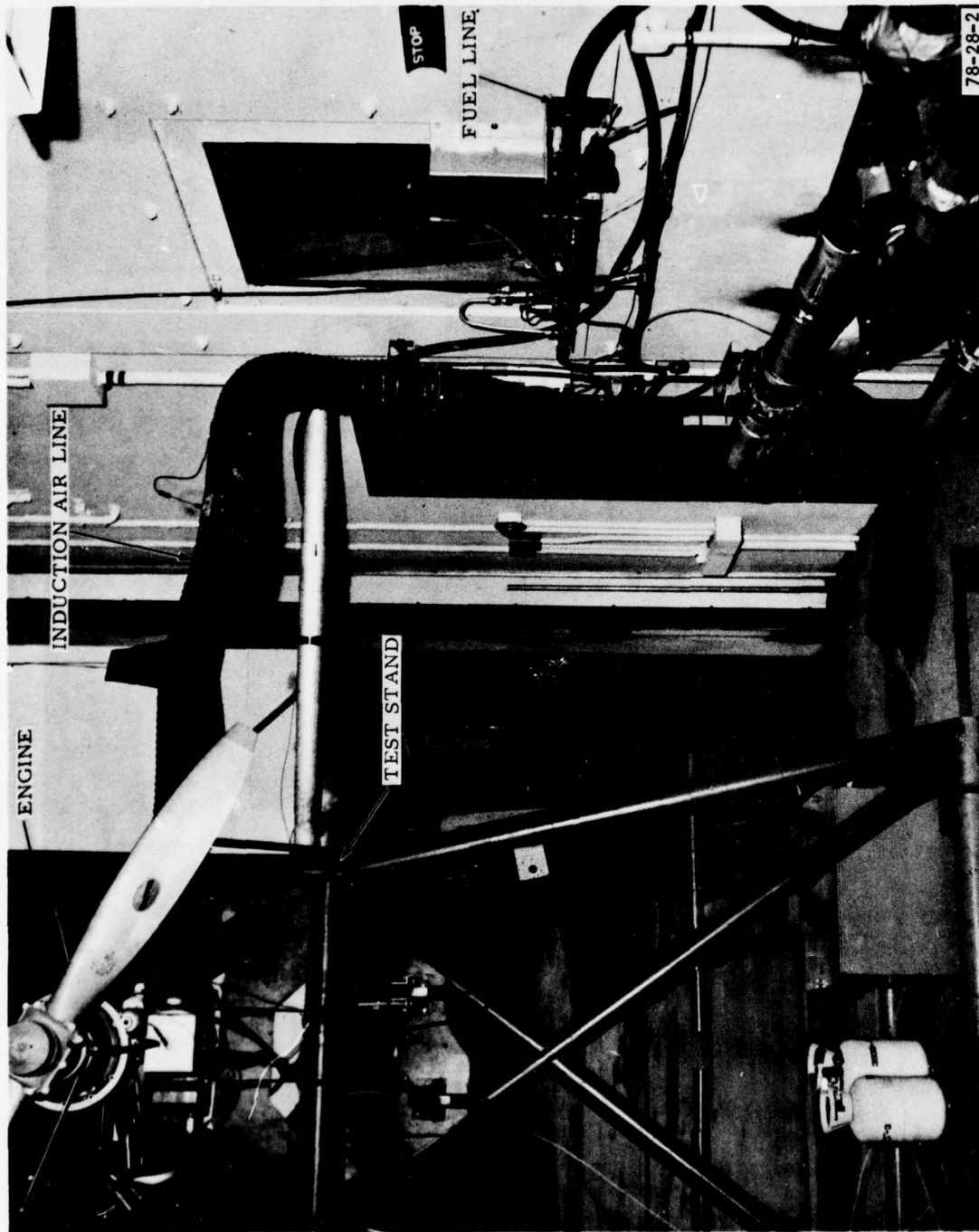


FIGURE 2. ENGINE INSTALLATION--NAFEC GENERAL AVIATION PISTON ENGINE TEST FACILITY

- (1) Two basic air sources--dry bottles and ambient air
- (2) Ambient temperatures (20 to 140 degrees Fahrenheit (°F))
- (3) Nominal sea level pressures (29.50 to 30.50 inches of mercury absolute (inHgA))
- (4) Humidity (specific humidity--0 to 0.020 lb water (H₂O) vapor/lb dry air)
- (5) Fuel (100/130 octane aviation gasoline--a dedicated 5,000 gallon tank)

DESCRIPTION OF AIR INDUCTION SYSTEM AND AIRFLOW COMPUTATIONS.

The airflow system (induction system) utilized at NAFEC for testing light-aircraft piston engines is illustrated in schematic form in figure 3. This system incorporated a redundant airflow measuring system for accuracy and reliability. In the high-flow measuring section, NAFEC utilized a 3.0 inch orifice and an Autronics air meter (model No. 100-750S). The capability of this high-flow system ranged from 400 to 2000 pounds per hour (lb/h) with an estimated reading tolerance in flow accuracy of +2 percent. The low-flow measuring section utilized a small 1.0 inch orifice and an Autronics air meter (model No. 100-100S). The capability of this system ranged from 40 to 400 lb/h with an estimated reading tolerance in flow accuracy of +3 percent. The size of the basic air duct was 8.0 inches (inside diameter) for the high-flow system and 2.0 inches (inside diameter) for the low-flow system.

The airflow was computed from the orifice differential pressure and induction air density using the following equation:

$$W_a = (1891) (C_f) (d_o)^2 \left[(.03609) \Delta P_\rho \right]^{1/2} \quad (\text{reference 2})$$

ΔP = inH₂O (differential air pressure)

ρ = lb/ft³ (induction air density)

d_o = inches (inside diameter (i.d.) of orifice)

C_f = flow coefficient for orifice (nondimensional)

1891 = conversion constant for airflow in pounds per hour.

For the 3.0-inch orifice this equation simplifies to:

$$W_a = (10,381.6) \left[(.03609) \Delta P_\rho \right]^{1/2} = 1972.23 (\Delta P_\rho)^{1/2}$$

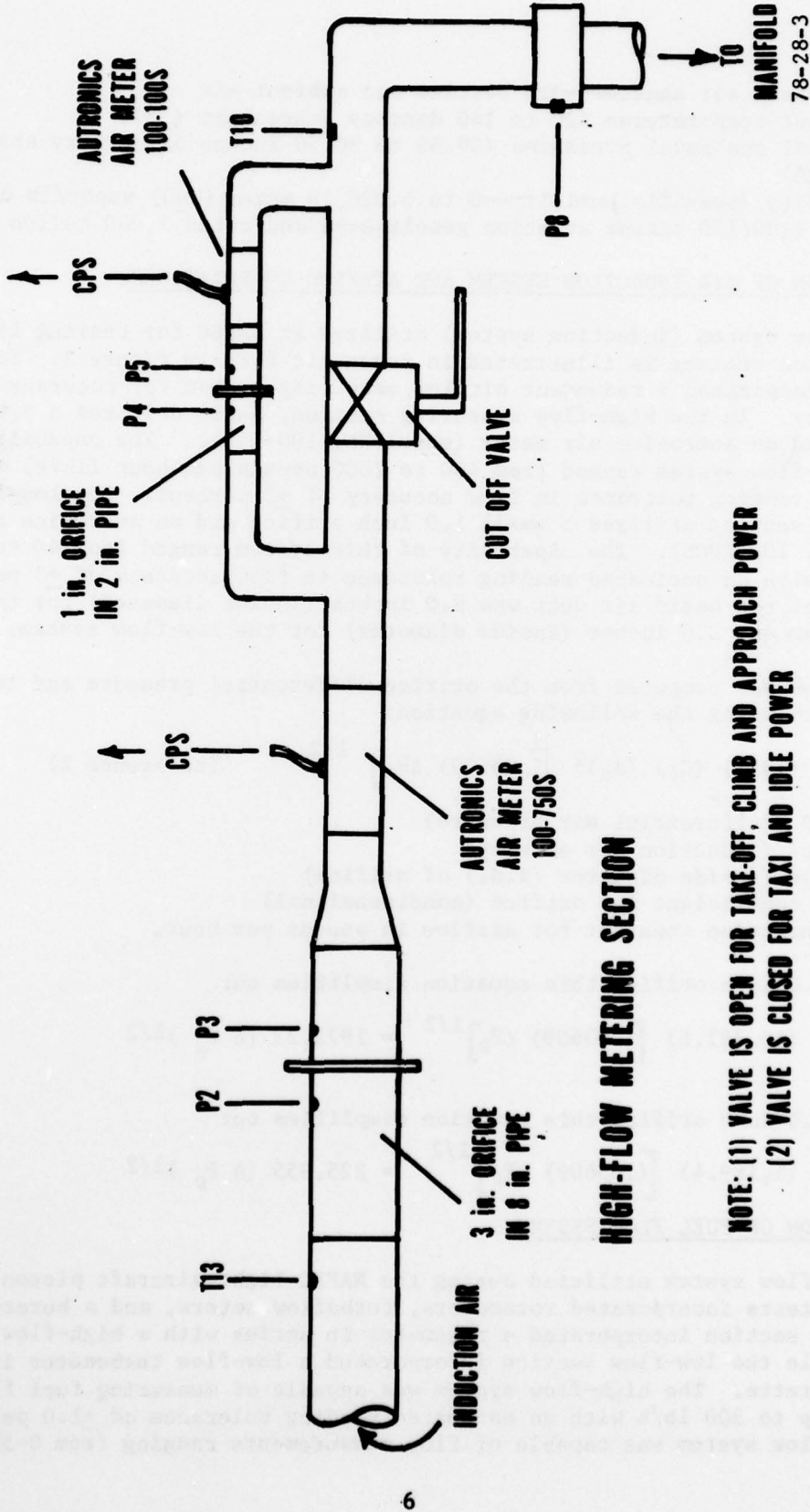
For the 1.0-inch orifice this equation simplifies to:

$$W_a = (1,189.4) \left[(.03609) \Delta P_\rho \right]^{1/2} = 225.955 (\Delta P_\rho)^{1/2}$$

DESCRIPTION OF FUEL FLOW SYSTEM.

The fuel flow system utilized during the NAFEC light-aircraft piston engine emission tests incorporated rotameters, turboflow meters, and a burette. The high-flow section incorporated a rotameter in series with a high-flow turbometer while the low-flow section incorporated a low-flow turbometer in series with a burette. The high-flow system was capable of measuring fuel flows from 50 lb/h up to 300 lb/h with an estimated reading tolerance of +1.0 percent. The low-flow system was capable of flow measurements ranging from 0-50 lb/h

LOW-FLOW METERING SECTION



**NOTE: (1) VALVE IS OPEN FOR TAKE-OFF, CLIMB AND APPROACH POWER
 (2) VALVE IS CLOSED FOR TAXI AND IDLE POWER**

FIGURE 3. NAPEC AIR INDUCTION (AIRFLOW MEASUREMENT) SYSTEM FOR LIGHT-AIRCRAFT PISTON ENGINE EMISSION TESTS

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with an estimated reading tolerance of ± 2.0 percent. Figure 4 illustrates the NAFEC fuel flow system in schematic form.

DESCRIPTION OF COOLING AIR SYSTEM.

The NAFEC piston engine test facility also incorporated a system which provided cooling air (see figure 1) to the engine cylinders. The engine mounted in the test stand was enclosed in a simulated nacelle and cooling air was provided to this enclosure from an external source. The cooling air temperature was maintained within $\pm 10^{\circ}$ F of the induction air supply temperature for any specified set of test conditions. This not only minimized variations in temperature but also minimized variations in the specific weight of air for all test conditions. All of the basic cooling air tests with the IO-360-11B6D engine were conducted with differential cooling air pressures of 3.0 inH₂O. A range of differential cooling air pressures from 1.0 to 6.0 inH₂O were evaluated using the IO-360-11BD engine to determine the effects of variable cooling air conditions on maximum cylinder head temperatures (see page 29).

DESCRIPTION OF TEST PROCEDURES AND EPA STANDARDS.

The data presented in this report were measured while conducting tests in accordance with specific landing and takeoff cycles (LTO) and by modal lean-out tests. The basic EPA LTO cycle is defined in table 2.

The FAA/NAFEC contract and inhouse test programs utilized an LTO cycle which was a modification of the table 2 test cycle. Table 3 defines this modified LTO cycle which was used to evaluate the total full-rich emission characteristics of light-aircraft piston engines.

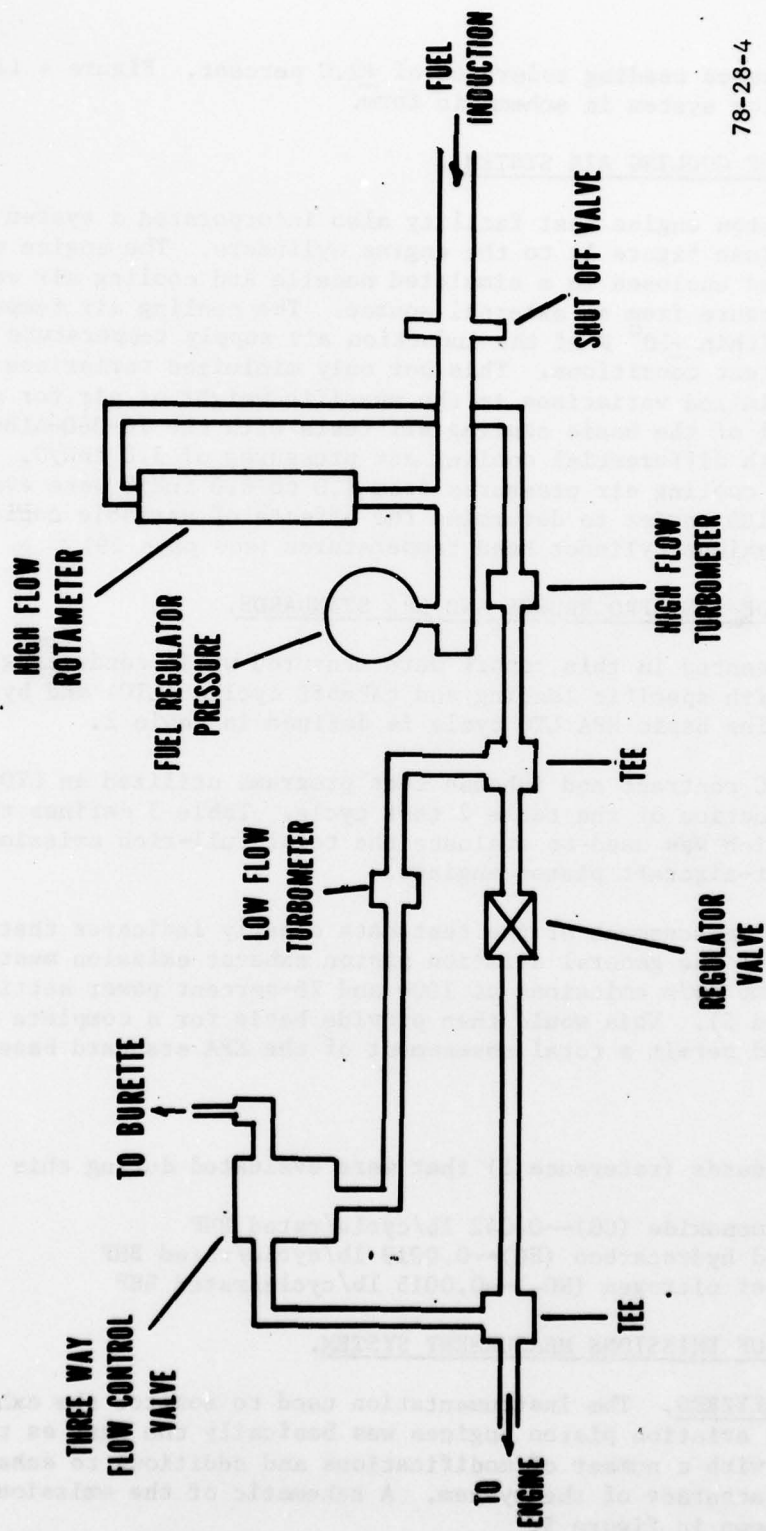
An additional assessment of the test data clearly indicates that further evaluations of the general aviation piston exhaust emission must be analyzed with the climb mode emissions at 100- and 75-percent power settings (tables 4 and 5). This would then provide basis for a complete evaluation of test data and permit a total assessment of the EPA standard based on LTO cyclic tolerances.

The EPA Standards (reference 1) that were evaluated during this program were:

Carbon monoxide (CO)--0.042 lb/cycle/rated BHP
Unburned hydrocarbon (HC)--0.0019 lb/cycle/rated BHP
Oxides of nitrogen (NO_x)--0.0015 lb/cycle/rated BHP

DESCRIPTION OF EMISSIONS MEASUREMENT SYSTEM.

EMISSION ANALYZERS. The instrumentation used to monitor the exhaust emissions from general aviation piston engines was basically the same as that recommended by EPA, but with a number of modifications and additions to enhance the reliability and accuracy of the system. A schematic of the emissions measurement system is shown in figure 5.



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FIGURE 4. NAFEC FUEL FLOW SYSTEM FOR LIGHT-AIRCRAFT PISTON ENGINE EMISSION TESTS

TABLE 2. EPA FIVE-MODE LTO CYCLE

| <u>Mode No.</u> | <u>Mode Name</u> | <u>Time-In-Mode (Min.)</u> | <u>Power (%)</u> | <u>Engine Speed (%)</u> |
|-----------------|------------------|----------------------------|------------------|-------------------------|
| 1 | Taxi/idle (out) | 12.0 | * | * |
| 2 | Takeoff | 0.3 | 100 | 100 |
| 3 | Climb | 5.0 | 75-100 | * |
| 4 | Approach | 6.0 | 40 | * |
| 5 | Taxi/idle (in) | 4.0 | * | * |

*Manufacturer's Recommendation

TABLE 3. FAA/NAFEC SEVEN-MODE LTO CYCLE

| <u>Mode No.</u> | <u>Mode Name</u> | <u>Time-In-Mode (Min.)</u> | <u>Power (%)</u> | <u>Engine Speed (%)</u> |
|-----------------|------------------|----------------------------|------------------|-------------------------|
| 1 | Idle (out) | 1.0 | * | * |
| 2 | Taxi (out) | 11.0 | * | * |
| 3 | Takeoff | 0.3 | 100 | 100 |
| 4 | Climb | 5.0 | 80 | * |
| 5 | Approach | 6.0 | 40 | * |
| 6 | Taxi (in) | 3.0 | * | * |
| 7 | Idle (in) | 1.0 | * | * |

*Manufacturer's Recommendation

TABLE 4. MAXIMUM FIVE-MODE LTO CYCLE

| <u>Mode No.</u> | <u>Mode Name</u> | <u>Time-In-Mode (Min.)</u> | <u>Power (%)</u> | <u>Engine Speed (%)</u> |
|-----------------|------------------|----------------------------|------------------|-------------------------|
| 1 | Taxi (out) | 12.0 | * | * |
| 2 | Takeoff | 0.3 | 100 | 100 |
| 3 | Climb | 5.0 | 100 | 100 |
| 4 | Approach | 6.0 | 40 | * |
| 5 | Taxi (in) | 4.0 | * | * |

*Manufacturer's Recommended

TABLE 5. MINIMUM FIVE-MODE LTO CYCLE

| <u>Mode No.</u> | <u>Mode Name</u> | <u>Time-In-Mode (Min)</u> | <u>Power (%)</u> | <u>Engine Speed (%)</u> |
|-----------------|------------------|---------------------------|------------------|-------------------------|
| 1 | Taxi (out) | 12.0 | * | * |
| 2 | Takeoff | 0.3 | 100 | 100 |
| 3 | Climb | 5.0 | 75 | * |
| 4 | Approach | 6.0 | 40 | * |
| 5 | Taxi (in) | 4.0 | * | * |

*Manufacturer's Recommended

EMISSION INSTRUMENTATION ACCURACY/MODIFICATIONS. The basic analysis instrumentation utilized for this system, which is summarized in figure 5, is explained in the following paragraphs.

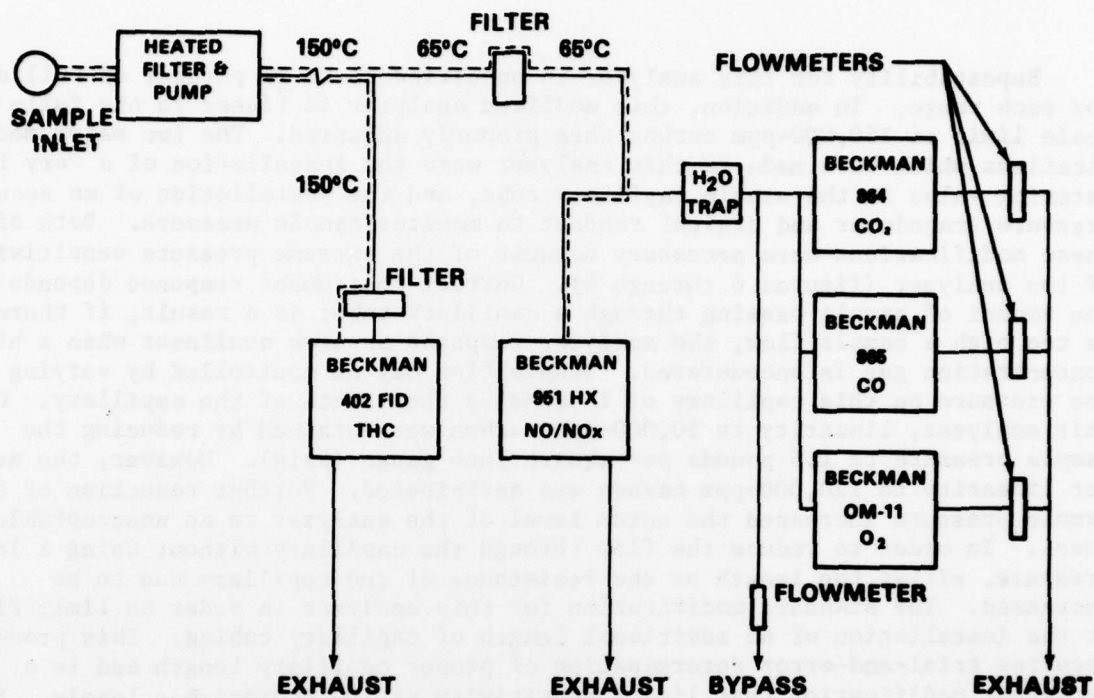
Carbon Dioxide. The carbon dioxide (CO)₂ subsystem is constructed around a Beckman model 864-23-2-4 nondispersive infrared analyzer (NDIR). This analyzer has a specified repeatability of +1 percent of full scale for each operating range. The calibration ranges on this particular unit are: Range 1, 0 to 20 percent; Range 3, 0 to 5 percent. Stated accuracy for each range is, therefore, +0.2 and +0.05 percent respectively.

Carbon Monoxide. The subsystem used to measure carbon monoxide (CO) is constructed around a Beckman model 865-X-4-4-4 NIDR. This analyzer has a specified repeatability of +1 percent of full scale for ranges 1 and 2 and +2 percent of full scale for range 3.

Range 1 has been calibrated for 0 to 20 percent by volume, range 2 for 0 to 1,000 parts per million (ppm) and range 3 for 0 to 100 ppm. The wide range capability of this analyzer is made possible by using stacked sample cells which in effect give this analyzer six usable ranges when completely calibrated.

Effects of interfering gases, such as CO₂ and water vapor, were determined and reported by the factory. Interferences from 10-percent CO₂ were determined to be 12-ppm equivalent CO, and interferences from 4-percent water vapor were determined to be 6-ppm CO equivalent. Even though the interference from water vapor is negligible, a condenser is used in the CO/CO₂ subsystem to eliminate condensed water in the lines, analyzers, and flowmeters. This condensation would have decreased analyzer sensitivity and necessitated more frequent maintenance if it had been eliminated.

Total Hydrocarbons. The system that is used to measure total hydrocarbons is a modified Beckman model 402 heated flame ionization detector. This analyzer has a full-scale sensitivity that is adjustable to 150,000-ppm carbon with intermediate range multipliers 0.5, 0.1, 0.05, 0.01, 0.005, and 0.001 times full scale.



• CARBON DIOXIDE - CO₂

- NONDISPERSIVE INFRARED (NDIR)
- RANGE 0-20%
- REPEATABILITY ± 0.2% CO₂

• CARBON MONOXIDE - CO

- NDIR
- RANGE 0-20%
- REPEATABILITY ± 0.2% CO

• TOTAL HYDROCARBONS - THC

- FLAME IONIZATION DETECTOR (FID)
- RANGE 0-150,000 ppm_c
- MINIMUM SENSITIVITY 1.5 ppm_c
- LINEAR TO 180,000 ppm_c

• OXIDES OF NITROGEN - NO_x

- CHEMILUMINESCENT (CL)
- RANGE 0-10,000 ppm
- MINIMUM SENSITIVITY 0.1 ppm

• OXYGEN - O₂

- POLAROGRAPHIC
- RANGE 0-100%
- REPEATABILITY 0.1% O₂
- RESPONSE 200 ms

78-28-5

FIGURE 5. SCHEMATIC OF EMISSIONS MEASUREMENT SYSTEM AND ITS MEASUREMENT CHARACTERISTICS

Repeatability for this analyzer is specified to be ± 1 percent of full scale for each range. In addition, this modified analyzer is linear to the full-scale limit of 150,000-ppm carbon when properly adjusted. The two major modifications which were made to this analyzer were the installation of a very fine metering valve in the sample capillary tube, and the installation of an accurate pressure transducer and digital readout to monitor sample pressure. Both of these modifications were necessary because of the extreme pressure sensitivity of the analyzer (figures 6 through 8). Correct instrument response depends on the amount of sample passing through a capillary tube; as a result, if there is too high a sample flow, the analyzer response becomes nonlinear when a high concentration gas is encountered. Sample flow may be controlled by varying the pressure on this capillary or increasing the length of the capillary. On this analyzer, linearity to 50,000-ppm carbon was obtained by reducing the sample pressure to 1.5 pounds per square inch gauge (psig). However, the need for linearity to 120,000-ppm carbon was anticipated. Further reduction of the sample pressure increased the noise level of the analyzer to an unacceptable level. In order to reduce the flow through the capillary without using a lower pressure, either the length or the resistance of the capillary had to be increased. The standard modification for this analyzer in order to limit flow is the installation of an additional length of capillary tubing. This procedure requires trial-and-error determination of proper capillary length and is a permanent modification that limits sensitivity at low hydrocarbon levels. By installing a metering valve in the capillary, flow could be selectively set at either low flow for linearity at high concentrations or high flow for greater sensitivity at low concentrations. Installation time was reduced by eliminating the cut-and-try procedure for determining capillary length.

The addition of a sensitive pressure transducer and digital readout to monitor sample pressure was needed since the pressure regulator and gauge supplied with the analyzer would not maintain the pressure setting accurately at low pressures. Using the digital pressure readout, the sample pressure could be monitored and easily maintained to within 0.05 inH₂O.

Oxides of Nitrogen. Oxides of nitrogen (NO_x) are measured by a modified Beckman model 951H atmospheric pressure, heated, chemiluminescent analyzer (CL). This analyzer has a full-scale range of 10,000 ppm with six intermediate ranges. Nominal minimum sensitivity is 0.1 ppm on the 10-ppm full-scale range.

The atmospheric pressure analyzer was chosen because of its simplicity, ease of maintenance, and compactness. Anticipated water vapor problems in the atmospheric pressure unit were to be handled by the heating of the internal sample train. Interference from CO₂ quenching, common in the atmospheric pressure type CL analyzer, was checked and found to be nonexistent.

A series of major modifications were performed by the manufacturer on this analyzer to insure compliance with specifications. One such modification was installed in order to maintain the temperature of the sample stream above the dew point of the sample gas. Originally, this analyzer was specified to maintain a temperature of 140° F at all points in contact with the sample. After a survey of the 951H analyzers in use on FAA projects, it was determined that

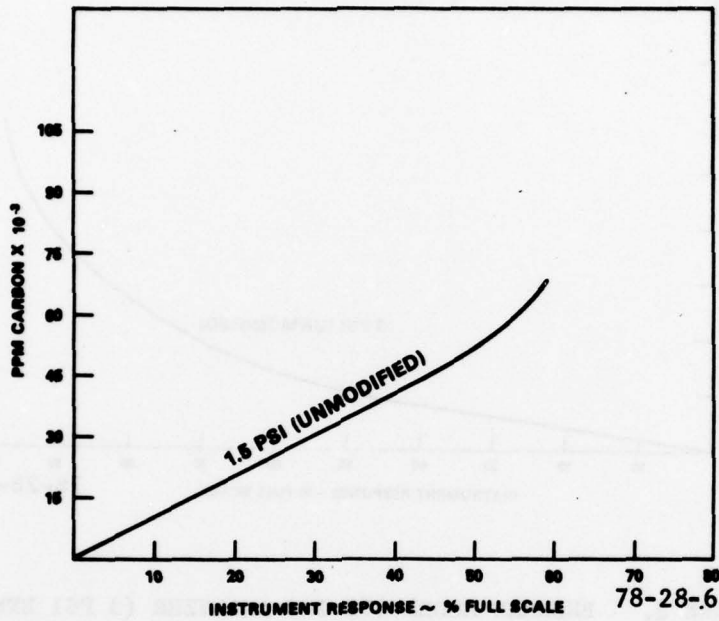


FIGURE 6. BECKMAN MODEL 402 THC ANALYZER (1.5 PSI UNMODIFIED)

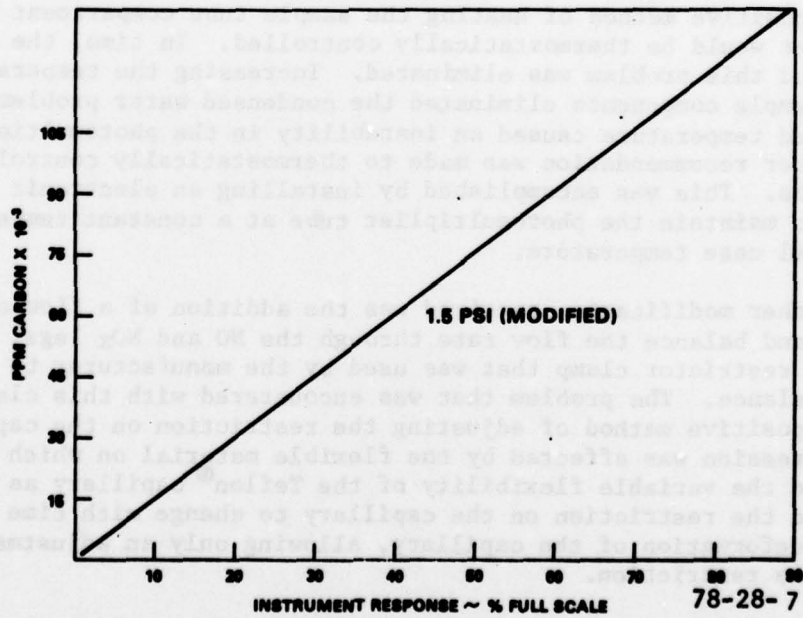


FIGURE 7. BECKMAN MODEL 402 THC ANALYZER (1.5 PSI MODIFIED)

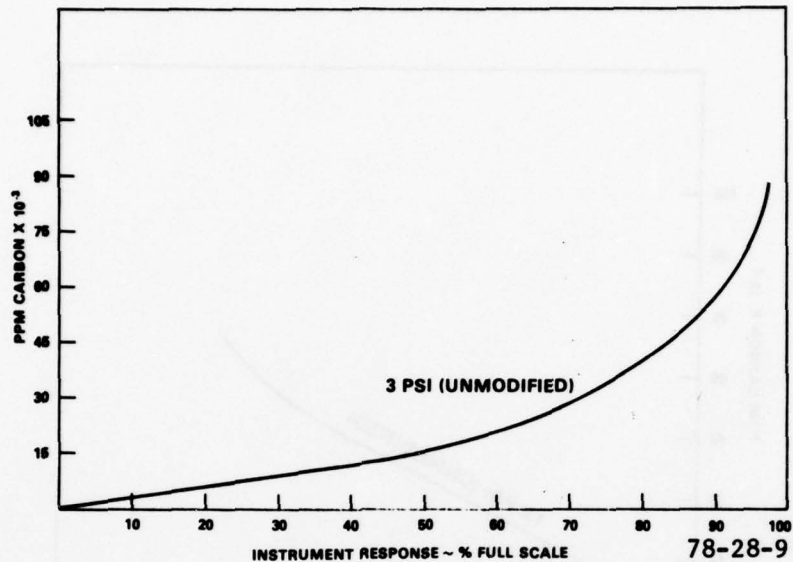


FIGURE 8. BECKMAN MODEL 402 THC ANALYZER (3 PSI UNMODIFIED)

this temperature was not being achieved because the method used to heat the components was inadequate. A recommendation was made to the manufacturer to install a positive method of heating the sample tube compartment and reaction chamber that would be thermostatically controlled. In time, the modification was made and this problem was eliminated. Increasing the temperature of the internal sample components eliminated the condensed water problem; however, the elevated temperature caused an instability in the photomultiplier tube output. Another recommendation was made to thermostatically control the temperature of this tube. This was accomplished by installing an electronic cooling jacket designed to maintain the photomultiplier tube at a constant temperature below the internal case temperature.

A further modification required was the addition of a flow control valve to adjust and balance the flow rate through the NO and NO_x legs. This valve replaced a restrictor clamp that was used by the manufacturer to set the NO to NO_x flow balance. The problem that was encountered with this clamp was that it was not a positive method of adjusting the restriction on the capillary. The clamp compression was affected by the flexible material on which the clamp was mounted and the variable flexibility of the Teflon[®] capillary as it was heated. This caused the restriction on the capillary to change with time and caused permanent deformation of the capillary, allowing only an adjustment that would increase the restriction.

Oxygen Measurement. Oxygen (O₂) was measured by a Beckman model OM-11 oxygen analyzer. This analyzer uses a polarographic-type sensor unit to measure

oxygen concentration. An advanced sensor and amplification system combine to give an extremely fast response and high accuracy. Specified response for 90 percent of final reading is less than 200 milliseconds (ms) with an accuracy of less than ± 0.1 -percent O₂. The range of this unit is a fixed 0 to 100 percent O₂ concentration.

EMISSIONS INSTRUMENTATION MODIFICATION STATUS DURING THE TESTING OF THE IO-360-ALB6D ENGINE. The tests conducted with the Avco Lycoming IO-360-ALB6D engine utilized the model 742 oxygen (O₂) analyzer and a prototype Beckman model 951H oxides of nitrogen (NO_x) analyzer.

The model 742 oxygen (O₂) analyzer did not have the extremely fast response rate of the Beckman model OM-11 analyzer, and it was not as accurate. The data recorded with this analyzer reflects these deficiencies.

DESCRIPTION OF SAMPLE HANDLING SYSTEM.

Exhaust samples are transported to the analysis instrumentation under pressure through a 35-foot-long, 3/8-inch o.d., heated, stainless steel sample line. The gas is first filtered and then pumped through this line by a heated Metal Bellows model MB-158 high temperature stainless steel sample pump. The pump, filter, and line are maintained at a temperature of 300° \pm 4° F to prevent condensation of water vapor and hydrocarbons. At the instrument console, the sample is split to feed the hydrocarbon, oxides of nitrogen, and CO/CO₂/O₂ subsystems which require different temperature conditioning. The sample gas to the total hydrocarbon subsystem is maintained at 300° F while the temperature of remaining sample gas to the NO_x and CO/CO₂/O₂ system is allowed to drop to 150° F. Gas routed to the oxides of nitrogen subsystem is then maintained at 150° F, while the gas to the CO/CO₂/O₂ subsystem is passed through a 32° F condenser to remove any water vapor present in the sample. Flow rates to each analyzer are controlled by a fine-metering valve and are maintained at predetermined values to minimize sample transport and system response time. Flow is monitored at the exhaust of each analyzer by three 15-centimeter (cm) rotameters. Two bypasses are incorporated into the system to keep sample transport time through the lines and condenser to a minimum without causing adverse pressure effects in the analyzers.

DESCRIPTION OF FILTRATION SYSTEM.

Particulates are removed from the sample at three locations in the system thereby minimizing downtime due to contaminated sample lines and analyzers (figure 5). Upstream of the main sample pump is a heated clamshell-type stainless steel filter body fitted with a Whatman GF/C glass fibre paper filter element capable of retaining particles in the 0.1-micron range. A similar filter is located in the total hydrocarbon analyzer upstream of the sample capillary. A Mine Safety Appliances (MSA) type H Ultra Filter capable of retaining 0.3-micron particles is located at the inlet to the oxides of nitrogen and CO/CO₂/O₂ subsystems.

COMPUTATION PROCEDURES.

The calculations required to convert exhaust emission measurements into mass emissions are the subject of this section.

Exhaust emission tests were designed to measure CO₂, CO, unburned hydrocarbons (HC), NO_x, and exhaust excess O₂ concentrations in percent or ppm by volume. Mass emissions were determined through calculations utilizing the data obtained during the simulation of the aircraft LTO cycle and from modal lean-out data.

COMBUSTION EQUATION. The basic combustion equation can be expressed very simply:



An initial examination of the problem requires the following simplifying assumptions:

1. The fuel consists solely of compounds of carbon and hydrogen.
2. The air is a mixture of oxygen and inert nitrogen in the volumetric ratio of 3.764 parts apparent nitrogen to 1.0-part oxygen (see appendix B for additional details).
3. If a stoichiometric combustion process exists, the fuel and air are supplied in chemically correct proportions.
4. The fuel (which consists usually of a complex mixture of hydrocarbons) can be represented by a single hydrocarbon having the same carbon-hydrogen ratio and molecular weight as the fuel; usually C₈H₁₇ as an average fuel.

Applying the above assumptions for stoichiometric conditions, a useful general reaction equation for hydrocarbon fuel is:



Where

| | |
|-------------|--|
| M_f | = Moles of Fuel |
| M_a | = Moles of Air or Oxygen |
| M_1 | = Moles of Carbon Dioxide (CO ₂) |
| M_3 | = Moles of Condensed Water (H ₂ O) |
| M_5 | = Moles of Nitrogen (N ₂)--Exhaust |
| $3.764 M_a$ | = Moles of Nitrogen (N ₂)--In Air |
| $M_a M_w$ | = Moles of Humidity (H ₂ O)--In Air |

The above equation is applicable to dry air when M_w is equal to zero.

From equation (1), and assuming dry air with one mole of fuel ($M_f=1.0$), the stoichiometric fuel-air ratio may be expressed as:

$$(F/A)_s = \frac{\text{Wt. Fuel}}{\text{Wt. Air Required}} = \frac{12.011 (8) + 1.008 (17)}{12.25 [32.000 + 3.764(28.161)]} \quad (2)$$

$$(F/A)_s = \frac{113.224}{12.25(137.998)} = 0.067$$

The mass carbon-hydrogen ratio of the fuel may be expressed as follows:

$$C/H = \frac{12.011(8)}{1.008(17)} = \frac{96.088}{17.136} = 5.607 \quad (3)$$

The atomic hydrogen-carbon ratio is:

$$17/8 = 2.125 \quad (4)$$

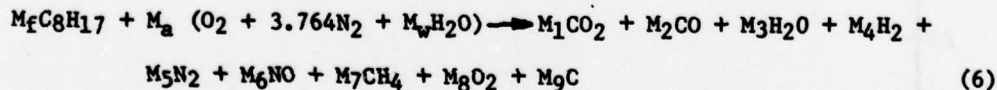
The stoichiometric fuel-air ratio may be expressed as a function of the mass hydrogen-carbon ratio of the fuel. The derivation of this equation is presented in reference 3.

$$(F/A)_s = \frac{C/H + 1}{11.5(C/H+3)} \quad (5)$$

$$(F/A)_s = 0.067 \text{ for a mass hydrogen-carbon ratio of } 5.607$$

With rich (excess fuel) mixtures, which are typical for general aviation piston engines, some of the chemical energy will not be liberated because there is not enough air to permit complete oxidation of the fuel. Combustion under such conditions is an involved process. By making certain simplifying assumptions based on test results, the effect of rich mixtures may be calculated with reasonable accuracy.

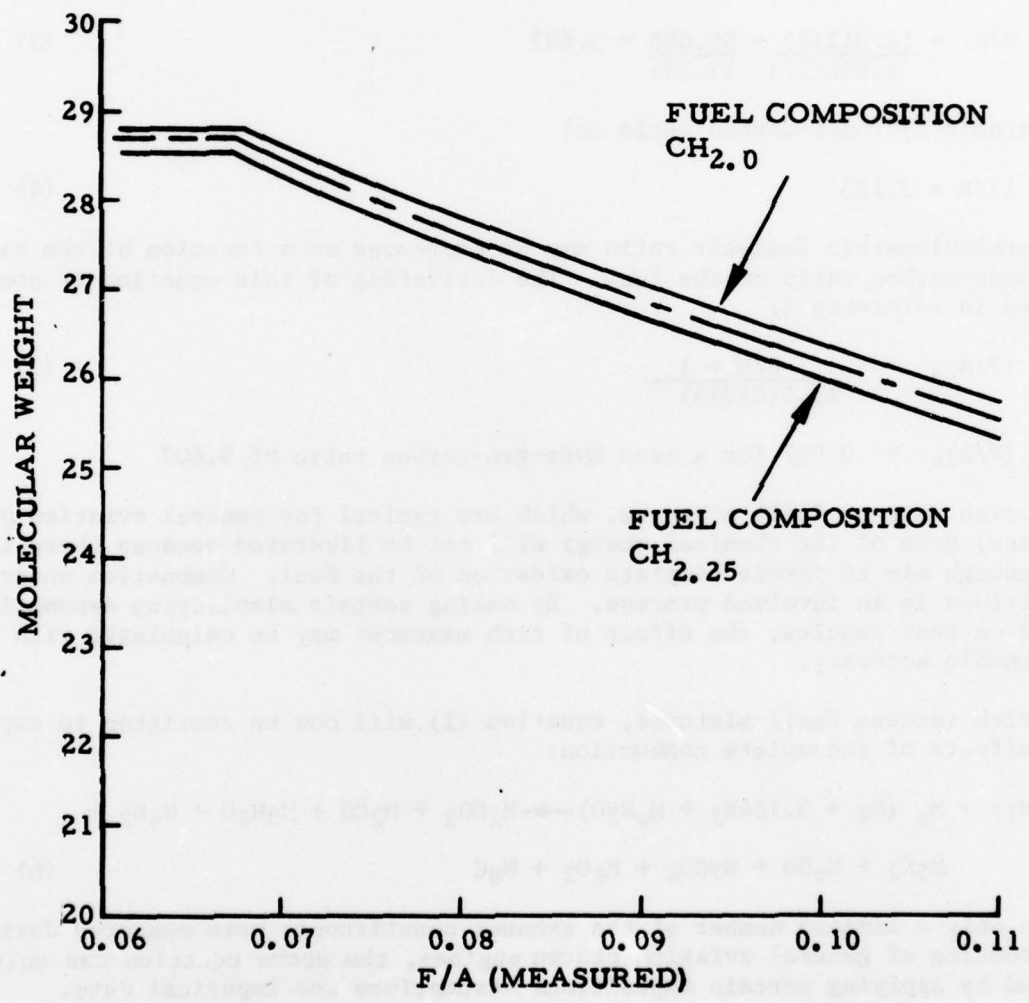
For rich (excess fuel) mixtures, equation (1) will now be rewritten to express the effects of incomplete combustion:



Since only a limited number of the exhaust constituents were measured during the testing of general aviation piston engines, the above equation can only be solved by applying certain expeditious assumptions and imperical data.

An important requirement of the FAA/NAFEC General Aviation Piston Engine Emissions Test Program was the accurate measurement of air and fuel flows. These parameters provide the data for determining engine mass flow (W_m) and with the aid of figure 9 (developed from reference 5) it is a simple computation to calculate the total moles (M_{tp}) of exhaust products being expelled by general aviation piston engines.

$$(M_{tp}) = W_m (\text{engine mass flow}) \div (\text{exh. mol. wt}) \quad (7)$$



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FIGURE 9. EXHAUST GAS MOLECULAR WEIGHTS

Since the unburned hydrocarbons (HC) and oxides of nitrogen (NO_x) are measured wet, it becomes a very simple matter to compute the moles of HC and NO_x that are produced by light-aircraft piston engines.

$$M_7 \text{ (Moles of HC)} = (\text{ppm} + 10^6) \times M_{\text{tp}} \quad (8)$$

$$M_6 \text{ (Moles of } \text{NO}_x) = (\text{ppm} + 10^6) \times M_{\text{tp}} \quad (9)$$

If the dry products (M_{dp}) of combustion are separated from the total exhaust products (M_{tp}) it is possible to develop a partial solution for five of the products specified in equation 6.

This can be accomplished as follows:

The summation of the mole fractions (MF)_d for dry products is

$$m_1 + m_2 + m_4 + m_5 + m_8 = 1.0000 \quad (10)$$

$$m_1 = \text{MF}(\text{CO}_2) = \% \text{CO}_2 \text{ (measured dry), expressed as a fraction}$$

$$m_2 = \text{MF}(\text{CO}) = \% \text{CO (measured dry), expressed as a fraction}$$

$$m_4 = \text{MF}(\text{H}_2) = K_4 (\% \text{CO}) \text{ (see figure 10, also references 4, 5, and 6), expressed as a fraction}$$

$$m_8 = \text{MF}(\text{O}_2) = \% \text{O}_2 \text{ (measured dry), expressed as a fraction}$$

$$m_5 = 1.0000 - (m_1 + m_2 + m_4 + m_8) = \% \text{N}_2 \text{ (dry), expressed as a fraction} \quad (11)$$

Utilizing the nitrogen balance equation, it is now possible to determine the moles of nitrogen that are being exhausted from the engine.

$$M_5 = 3.764 M_a - (M_6 + 2); M_6 = \text{moles (NO)} \quad (12)$$

The moles of exhaust dry products (M_{dp}) may now be determined by dividing equation 12 by equation 11.

$$M_{\text{dp}} = M_5 + m_5 \quad (13)$$

Using all the information available from equations (7), (8), (9), (10), (11), (12), and (13), it is now possible to determine the molar quantities for seven exhaust products specified in equation 6.

$$\text{Moles (CO}_2) = M_1 = m_1 \times M_{\text{dp}} \quad (14)$$

$$\text{Moles (CO)} = M_2 = m_2 \times M_{\text{dp}} \quad (15)$$

$$\text{Moles (H}_2) = M_4 = m_4 \times M_{\text{dp}} \quad (16)$$

$$\text{Moles (N}_2) = M_5 = m_5 \times M_{\text{dp}} \quad (17)$$

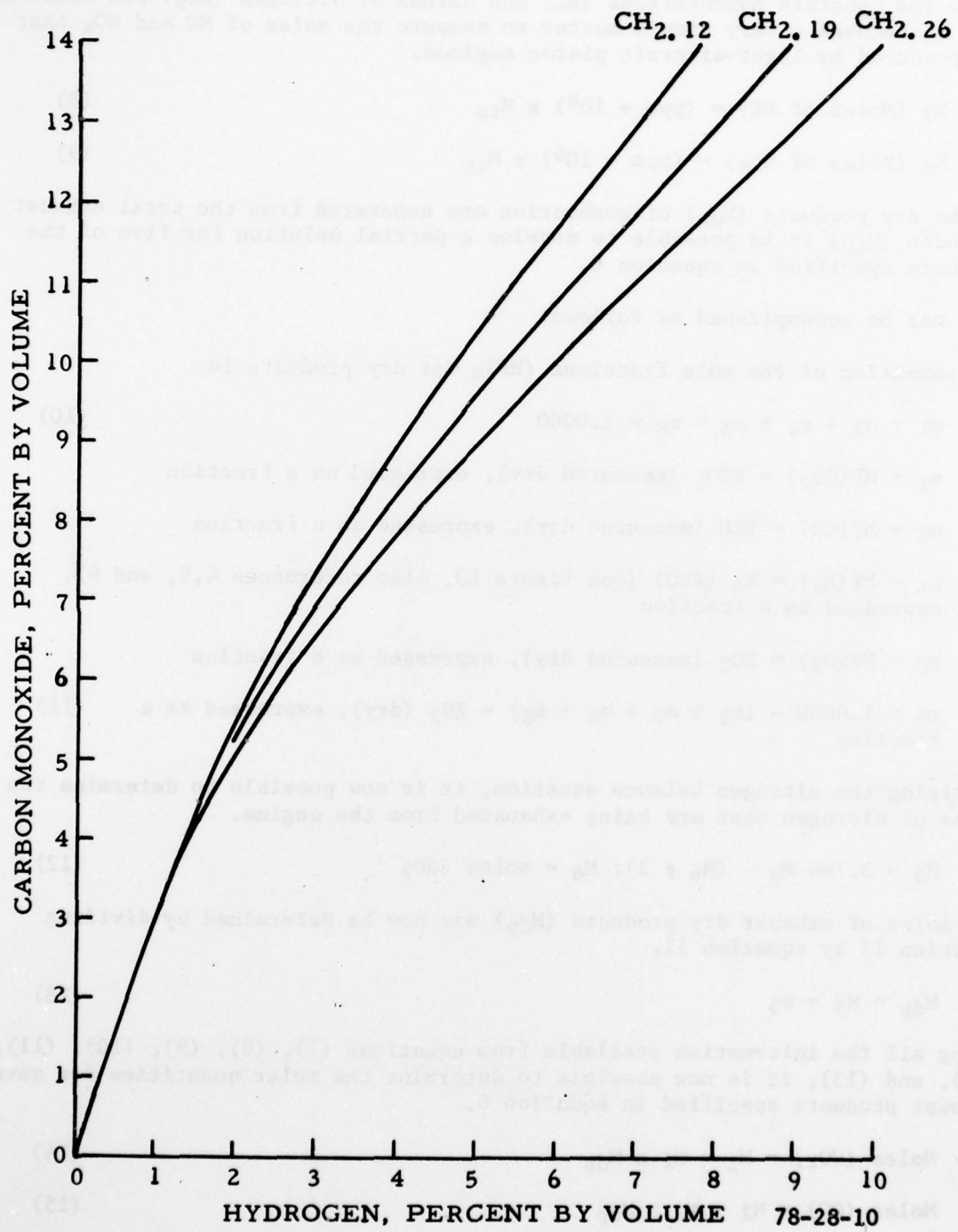


FIGURE 10. RELATION OF CARBON MONOXIDE AND HYDROGEN

$$\text{Moles (O}_2\text{)} = M_8 = m_8 \times M_{dp} \quad (18)$$

$$\text{Moles (CH}_4\text{)} = M_7 = (\text{ppm} + 10^6) \times M_{tp} \quad (19)$$

$$\text{Moles (NO)} = M_6 = (\text{ppm} + 10^6) \times M_{tp} \quad (20)$$

To determine M_3 (Moles of condensed H_2O), it is now appropriate to apply the oxygen balance equation.

$$M_3 = M_a (2 + M_w) - (2M_1 + M_2 + M_6 + 2M_8) = \text{Moles (H}_2\text{O)} \quad (21)$$

The remaining constituent specified in equation 6 may now be determined from the carbon balance equation 22.

$$M_9 = 8M_f - (M_1 + M_2 + M_7) \quad (22)$$

A check for the total number of exhaust moles (M_{tp}) calculated from equation 9 may now be determined from equation 23.

$$M_{tp} = M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 + M_8 + M_9 \quad (23)$$

$$\dot{m}_1 + \dot{m}_2 + \dot{m}_3 + \dot{m}_4 + \dot{m}_5 + \dot{m}_6 + \dot{m}_7 + \dot{m}_8 + \dot{m}_9 = 1.0000 \quad (24)$$

$$\dot{m}_1 = \text{MF}(\text{CO}_2) = M_1 + M_{tp}$$

$$\dot{m}_2 = \text{MF}(\text{CO}) = M_2 + M_{tp}$$

$$\dot{m}_3 = \text{MF}(\text{H}_2\text{O}) = M_3 + M_{tp}$$

$$\dot{m}_4 = \text{MF}(\text{H}_2) = M_4 + M_{tp}$$

$$\dot{m}_5 = \text{MF}(\text{N}_2) = M_5 + M_{tp}$$

$$\dot{m}_6 = \text{MF}(\text{NO}) = M_6 + M_{tp}$$

$$\dot{m}_7 = \text{MF}(\text{CH}_4) = M_7 + M_{tp}$$

$$\dot{m}_8 = \text{MF}(\text{O}_2) = M_8 + M_{tp}$$

$$\dot{m}_9 = \text{MF}(\text{C}) = M_9 + M_{tp}$$

The exhaust constituent mass flow rates may be computed in the following manner using each exhaust constituent's molar constant with the appropriate molecular weight.

$$M_1 \times 44.011 = \text{CO}_2 \text{ in lb/h} \quad (25)$$

$$M_2 \times 28.011 = \text{CO in lb/h} \quad (26)$$

$$M_3 \times 18.016 = \text{H}_2\text{O in lb/h} \quad (27)$$

$$M_4 \times 2.016 = \text{H}_2 \text{ in lb/h} \quad (28)$$

$$M_5 \times 28.161 = \text{N}_2 \text{ in lb/h} \quad (29)$$

$$M_6 \times 30.008 = \text{NO in lb/h} \quad (30)$$

$$M_7 \times 16.043 = \text{CH}_4 \text{ in lb/h} \quad (31)$$

$$M_8 \times 32.000 = \text{O}_2 \text{ in lb/h} \quad (32)$$

$$M_9 \times 12.011 = \text{C in lb/h} \quad (33)$$

The exhaust fuel flow (W_{fe}), base on exhaust constituents, can now be calculated on a constituent by constituents basis as follows:

$$(M_1 + M_2 + M_9) \times 12.011 = \text{lb/h} \quad (34)$$

$$M_7 \times 16.043 = \text{lb/h} \quad (35)$$

$$[(M_3 - M_a M_w) + M_4] \times 2.016 = \text{lb/h} \quad (36)$$

$$W_{fe} = (34) + (35) + (36) = \text{lb/h} \quad (37)$$

In a similar manner the exhaust airflow (W_{ae}) can also be calculated on a constituent by constituent basis:

$$M_1 \times 32.000 = \text{lb/h} \quad (38)$$

$$M_2 \times 16.000 = \text{lb/h} \quad (39)$$

$$(M_3 \times 16.000) + M_a M_w \times 18.016 = \text{lb/h} \quad (40)$$

$$M_5 \times 28.161 = \text{lb/h} \quad (41)$$

$$M_6 \times 30.008 = \text{lb/h} \quad (42)$$

$$M_8 \times 32.000 = \text{lb/h} \quad (43)$$

$$W_{ae} = \Sigma (38) \rightarrow (45) = \text{lb/h} \quad (44)$$

Using equations (37) and (44) it is now possible to determine a calculated fuel-air ratio on the basis of total exhaust constituents.

$$(F/A)_{\text{calculated}} = (37) \div (44) \quad (45)$$

RESULTS

GENERAL COMMENTS.

General aviation piston engine emission tests were conducted to provide the following categories of data:

1. Full-rich (or production fuel schedule) baseline data for each power mode specified in the LTO test cycle.
2. Lean-out data for each power mode specified in the LTO test cycle.
3. Data for the above categories at different spark settings.
4. Data for each power mode specified in the LTO test cycle utilizing different quantities of cooling air.

RESULTS OF BASELINE TESTS (LANDING-TAKEOFF CYCLE EFFECTS).

Based on an analysis of the factors affecting piston engine emissions, it can be shown that the mode conditions having the greatest influence on the gross pollutant levels produced by the combustion process are taxi, approach, and climb when using the LTO cycle defined in tables 3, 4, and 5. The five-mode LTO cycle shows that approximately 99 percent of the total cycle time (27.3 min) is attributed to these three modal conditions. Furthermore, the taxi modes (both out and in) account for slightly less than 59 percent of the total cycle time. The remainder of the time is almost equally apportioned to the approach and climb modes (22 and 18 percent, respectively).

As a result of these time apportionments, it was decided that an investigation and evaluation of the data should be undertaken to determine which mode(s) has the greatest influence on improving general aviation piston engine emissions. The subsequent sections of this report will show the exhaust emissions characteristics for an Avco Lycoming IO-360-A1B6D engine (S/N 888-X) and what improvements are technically feasible within the limits of safe aircraft/engine operational requirements based on sea level propeller test stand evaluations conducted at NAFEC.

The first set of data to be presented and evaluated is the five-mode baseline runs conducted to establish the current production full-rich exhaust emissions characteristics of the IO-360-A1B6D engine. These are summarized in tabular form in appendix C (see tables C-1 through C-17) and includes data that were obtained for a range of sea level, ambient conditions specified as follows:

Induction air temperature (T_1) = 50° F to 115° F
Cooling air temperature (T_c) = $T_1 \pm 10^\circ$ F
Induction air pressure (P_1) = 29.20 to 30.50 inHgA
Induction air density (ρ) = 0.0680 to 0.0790 lb/ft³

Figure 11 presents five-mode baseline data in bargraph form (for different sea level ambient conditions). It also compares the total emissions characteristics of the IO-360-1B6D engine (current production configuration) with the proposed EPA standards as a function of percent of standard. The data that were utilized to develop figure 11 are tabulated in appendix C and plotted in various forms for analysis and evaluation in figures C-1 through C-19. Tables C-15 and C-16 provide the data tabulation that was used to construct the bargraphs for $T_1 = 60^\circ \text{ F}$ and 95° F .

RESULTS OF LEAN-OUT TESTS.

In the subsequent sections of this report it will be shown what improvements can be achieved as a result of making lean-out adjustments to the fuel metering device: (1) taxi mode only, (2) taxi and approach modes combined, and (3) leaning-out the climb mode to "best power" in combination with taxi and approach mode leaning.

EFFECTS OF LEANING-OUT ON CO EMISSIONS. The test data obtained as a result of NAFEC testing the Avco Lycoming IO-360-1B6D have been evaluated on the basis of leaning-out the taxi, approach, and climb modes while continuing the operation of the test engine at the production rich and lean limits in the takeoff mode. The results of leaning-out under this procedure are shown in bargraph form in figure 12.

When the taxi modes (out and in) were leaned-out from the production rich or lean limits to a fuel-air ratio of 0.075 or lower, but not lower than stoichiometric ($F/A = 0.067$) (see figure 12), CO emissions were reduced approximately 20 percent. However, adjustments to the taxi mode fuel schedule alone are not sufficient to bring the total five-mode LTO cycle CO emission level below the proposed federal standard.

Simultaneously, leaning-out both the taxi and approach modes to fuel-air ratios between 0.067 to 0.075 will result in additional improvements in CO emissions. In the case of operating the engine at production rich limits for takeoff and climb while operating taxi and approach at $F/A = 0.075$, the total five-mode LTO cycle CO emission level will be reduced approximately 50 percent as shown in figure 12.

Additional improvements in the total five-mode LTO cycle for CO emissions can be achieved, as shown in figure 12, if the engine is adjusted to operate at "best power" fuel-air ratios in the climb mode while operating the approach and taxi modes at $F/A = 0.075$ or lower (not lower than fuel-air ratio = 0.067.)

The preceding evaluation of CO emissions characteristics was based on the LTO cycle defined by table 5. However, the EPA five-mode LTO cycle defined by table 2 implies that the climb mode power levels can range from 75 to 100 percent. The exhaust emissions produced will be drastically affected. A further examination of the measured data produced at NAFEC show that there is a significant difference in each engine's total LTO cycle emissions output when climbing at 100-percent power compared to climbing at 75-percent power. This

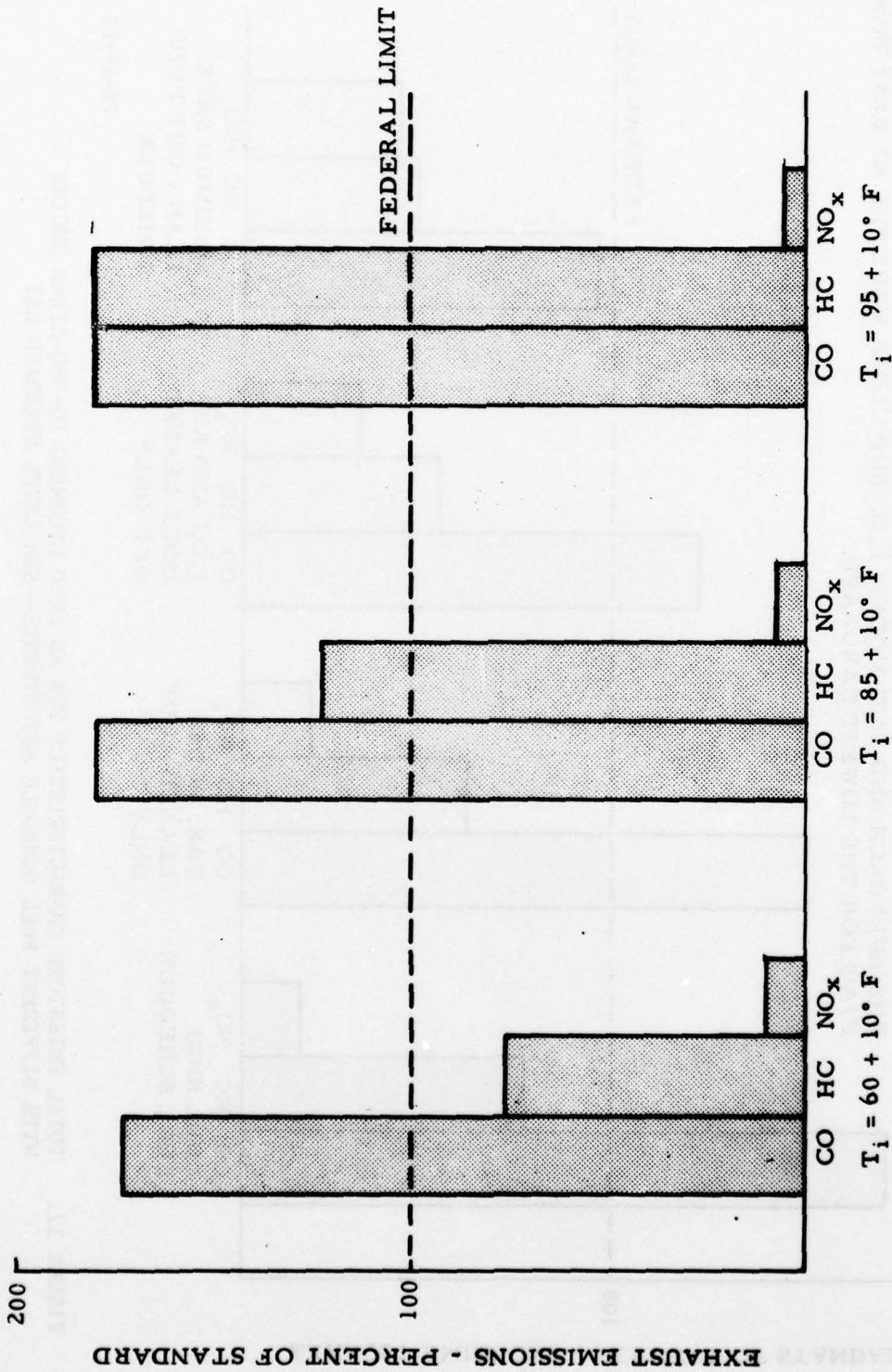


FIGURE 11. AVERAGE TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING 10-360-A1B6D ENGINE OPERATING UNDER VARYING SEA LEVEL INDUCTION AIR TEMPERATURES--TABLE 5 MINIMUM FIVE-MODE LTO CYCLE

78-49-11

NOTE:
 1. THIS FIGURE IS BASED ON THE TABLE 5 LTO CYCLE WITH THE CLIMB MODE AT APPROXIMATELY 75-80 PERCENT POWER.
 2. THE MINIMUM F/A RATIO SETTING FOR THIS FIGURE IS 0.075 FOR THE APPROACH AND TAXI MODES; T. O. AND CLIMB WERE SET AT BEST POWER F/A'S FOR THE LOWEST BARGRAPH.

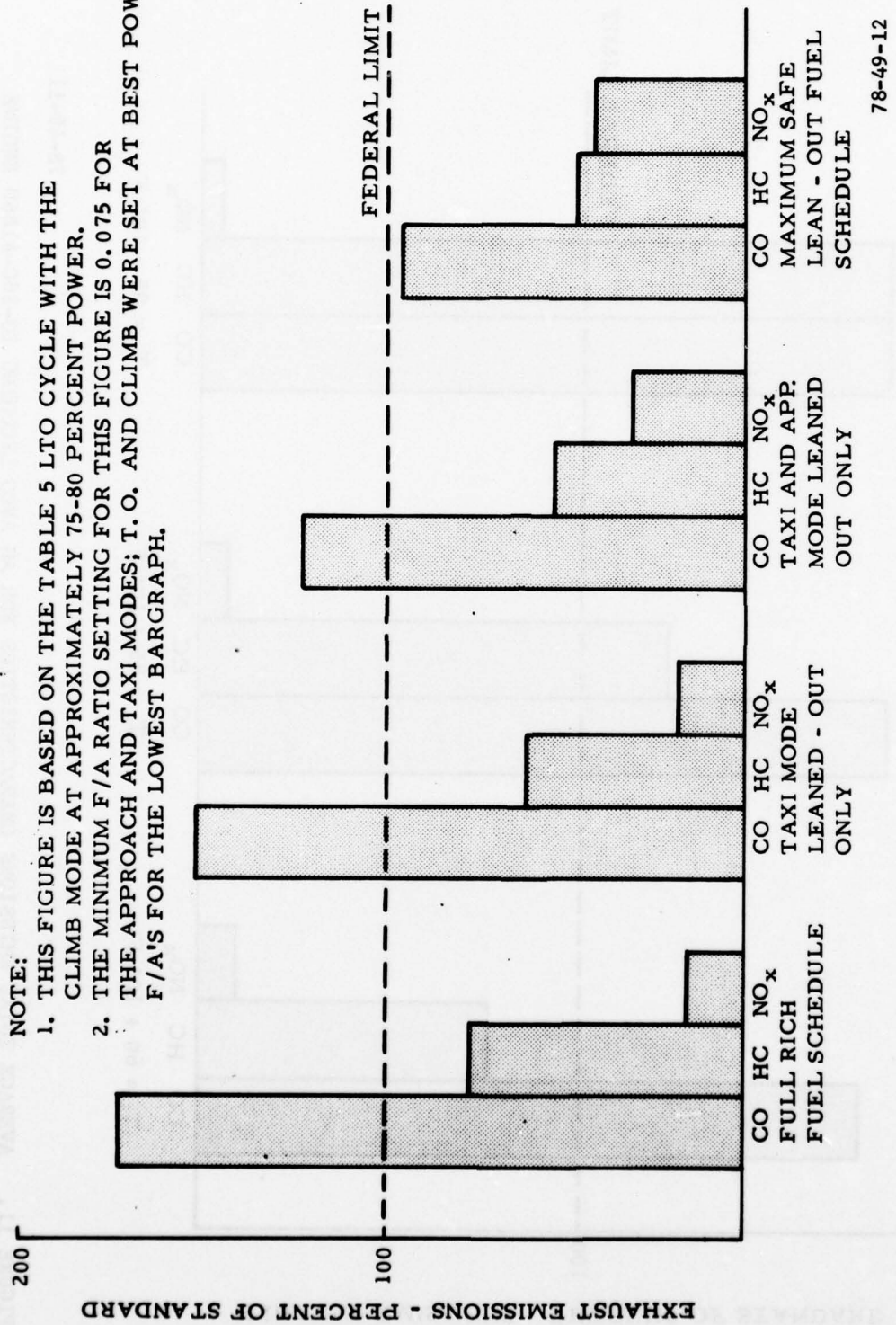


FIGURE 12. TOTAL EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE WITH DIFFERENT FUEL SCHEDULE ADJUSTMENTS--SEA LEVEL STANDARD DAY

78-49-12

data evaluation also show that whereas a CO limit of 0.042 pounds per cycle per rated brake horsepower may be achievable as described previously by using the LTO cycle defined by table 5; it is not achievable using an LTO cycle defined by table 4. When one considers the following safety considerations: (1) sea level, hot-day takeoff requirements with an aircraft at heavy gross weight and (2) altitude takeoff requirements with an aircraft at heavy gross weight, it would appear that the EPA 0.042 limit for CO is not realistic and cannot be complied with, unless engine operational and safety limits are totally ignored.

Table 6 provides a summary of the NAFEC data which indicate what levels of improvement in CO emissions can be achieved by applying simple fuel management techniques (leaning-out by mixture control manipulations), albeit with drastically reduced margins between actual measured maximum cylinder head temperature (CHT) and the maximum CHT limit.

Example: Consider the engine installed in a sea level propeller stand and operating with cooling air at a $\Delta P = 3.0$ inH₂O and the following critical test conditions:

1. Ambient conditions (pressure, temperature, and density)--sea level standard day
2. Fuel schedule--production rich setting
3. Power setting--100%
4. Measured max. CHT--440° F
5. Max. CHT limit--475° F
6. Margin-- (5) minus (4) --35° F

If this engine fuel schedule setting is adjusted to best power (all other parameters constant based on above conditions), the following changes take place:

1. CO emissions are improved by 87% (nominal)
2. Measured max. CHT increases 6.8% (from 440° F to 470° F)
3. Max. CHT limit--475° F
4. Margin-- (3) minus (2) = 5° F
5. Reduction in margin (max. CHT)-- $(30 + 35) \times 100 = 85.7\%$

Now, if we apply the above results to a sea level hot-day condition, we arrive at the following results:

Production Rich Limit Schedule (100% power)

1. Ambient conditions--sea level hot day
2. Fuel schedule--production rich setting
3. Power setting--100% (nominal)
4. Measured max. CHT--445° F
5. Max. CHT limit--475° F
6. Margin-- (5) minus (4) = 30° F

TABLE 6. SUMMARY OF EXHAUST EMISSIONS (CO) REDUCTION POSSIBILITIES FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE--SEA LEVEL STANDARD DAY (EXCEPT AS NOTED)--COOLING AIR $\Delta P=3.0$ inH₂O

| Modes | F/A | CO lb/Mode | Max. CHT-°F | F/A | CO lb/Mode | Max. CHT-°F | Max. CHT-°F | Max. Limit CHT-°F |
|---|--------|------------|----------------------------------|--------|------------|----------------------------------|-----------------------------|-------------------|
| 1 Taxi | 0.0950 | 2.827 | 345 | 0.0750 | 1.067 | - | - | - |
| 2 Takeoff (100%) | 0.0960 | 0.550 | 440 | 0.0850 | 0.375 | 470 | 475 | 475 |
| 3 Climb (100%) | 0.0960 | 9.167 | 440 | 0.0850 | 6.250 | 470 | 475 | 475 |
| 4 Approach | 0.0905 | 4.480 | 345 | 0.0750 | 9.742 | 350 | 355 | 475 |
| 5 lb/Cycle | | 17.024 | | | 0.0487 | | | |
| 6 lb/Cycle/RBHP | | 0.0851 | | | 0.042 | | | |
| 7 Federal Limit | | 0.042 | | | 0.0067 | | | |
| 8 Diff. = $\frac{6}{7} \times 100$ | | 0.0431 | | | 15.0 | | | |
| 9 $\frac{8}{7} \times 100$ | | 102.7 | | | 116.0 | | | |
| 10 % of STD = $\frac{9}{9} + 100$ | | 202.7 | | | | | | |
| | | | This Column For SL. Standard Day | | | This Column For SL. Standard Day | This Column For SL. Hot Day | |
| 11 Taxi | 0.0950 | 2.827 | 345 | 0.0750 | 1.067 | - | - | 475 |
| 12 Takeoff (100%) | 0.0960 | 0.550 | 440 | 0.0850 | 0.375 | 470 | 475 | 475 |
| 13 Climb (75-80%) | 0.0920 | 6.667 | 425 | 0.0725 | 4.417 | 440 | 435 | 475 |
| 14 Approach | 0.0905 | 4.480 | 345 | 0.0750 | 2.050 | 350 | 355 | 475 |
| 15 lb/Cycle | | 14.524 | | | 7.909 | | | |
| 16 lb/Cycle/RBHP | | 0.0726 | | | 0.0395 | | | |
| 17 Federal Limit | | 0.042 | | | 0.042 | | | |
| 18 Diff. = $\frac{16}{17} - \frac{17}{17} \times 100$ | | 0.0306 | | | -0.0025 | | | |
| 19 $\frac{18}{17} + \frac{17}{17} \times 100$ | | 72.6 | | | -5.8 | | | |
| 20 % of STD = $\frac{19}{19} + 100$ | | 172.6 | | | 94.2 | | | |

Best Power Fuel Schedule (100% Power)

1. Ambient conditions--sea level hot day
2. Fuel schedule--best power fuel schedule
3. Power setting--100% (nominal)
4. Measured max. CHT--475° F
5. Max. CHT limit--475° F
6. Margin--(5) minus (4) = 0° F
7. Reduction in margin (max. CHT)-- $(30 + 30) \times 100 = 100.0\%$

EFFECTS OF LEANING-OUT ON HC EMISSIONS. The test data show that the Lycoming engine met the proposed federal standard for a sea level standard day when operating full rich. Leaning-out in the taxi, approach, and climb modes provides added improvements, but is not required to produce HC emission levels below the federal standard (see figure 12). However, it should be noted here that this satisfactory hydrocarbon condition may have been the result of a procedural effect; that is, the engine was cleared out prior to running most of the taxi-out modal tests.

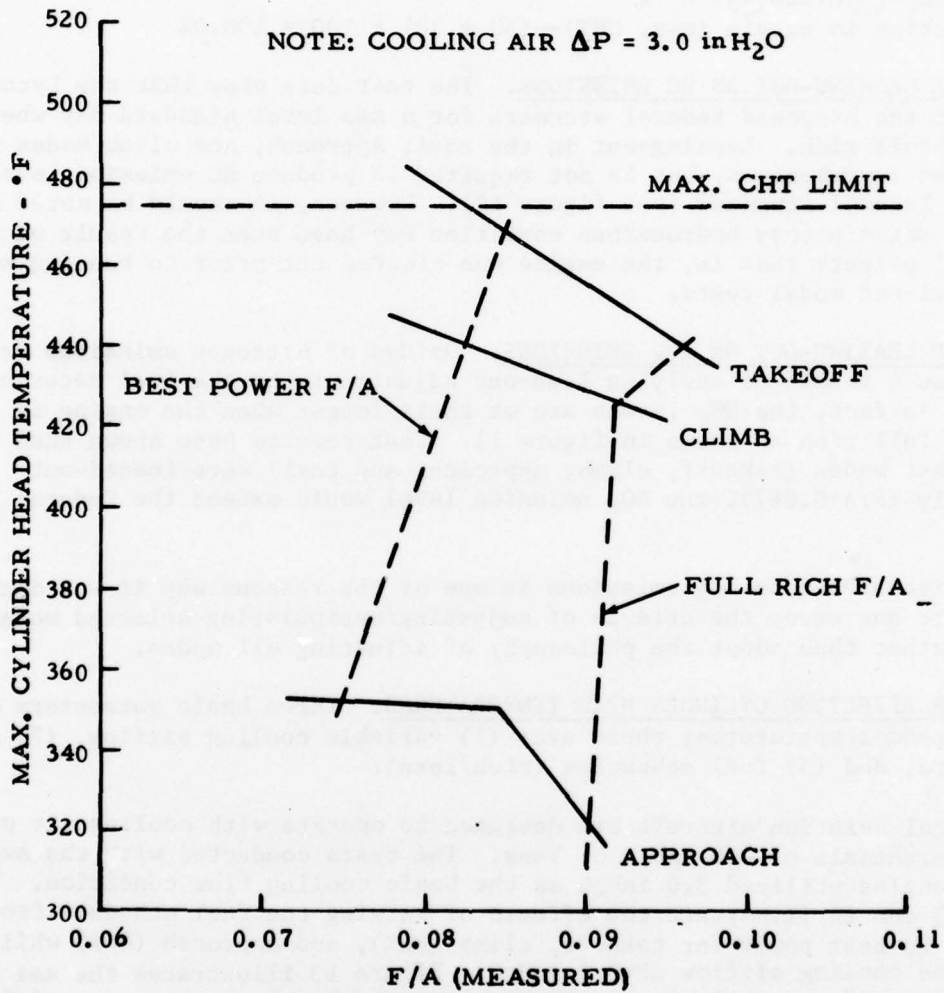
EFFECTS OF LEANING-OUT ON NO_x EMISSIONS. Oxides of nitrogen emissions are not improved as a result of applying lean-out adjustments to the fuel metering devices. In fact, the NO_x levels are at their lowest when the engine is operating full rich as shown in figure 11. Test results have shown that if all the test modes (takeoff, climb, approach, and taxi) were leaned-out excessively (F/A=0.067), the NO_x emission level would exceed the federal standard.

The negative effect on NO_x emissions is one of the reasons why it was decided to evaluate and study the effects of adjusting/manipulating selected mode conditions rather than adopt the philosophy of adjusting all modes.

PARAMETERS EFFECTING CYLINDER HEAD TEMPERATURES. Three basic parameters effect cylinder head temperatures; these are: (1) variable cooling airflow, (2) air temperature, and (3) fuel schedules (rich/lean).

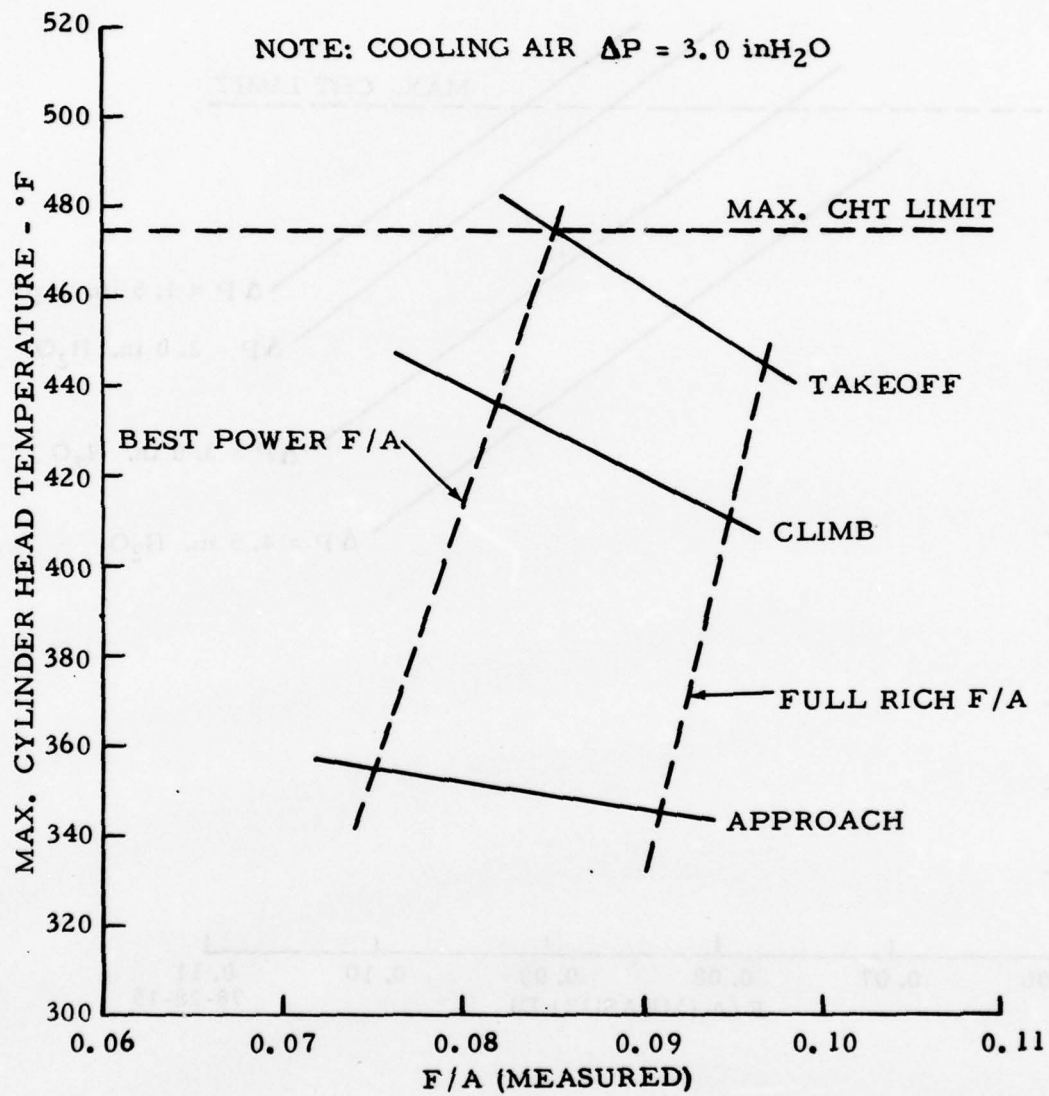
Most general aviation aircraft are designed to operate with cooling air pressure differentials of 4.0 inH₂O or less. The tests conducted with the Avco Lycoming engine utilized 3.0 inH₂O as the basic cooling flow condition. Figures 13 and 14 illustrate the effects of varying the fuel schedule from full rich to best power for takeoff, climb (80%), and approach (40%) while holding the cooling airflow $\Delta P=3.0$ inH₂O. Figure 13 illustrates the sea level, standard-day effects while figure 14 presents the sea level, hot-day (95° F) results.

No tests were conducted with the IO-360-A1B6D engine to investigate the effects of varying the cooling airflow. Therefore, figure 15 (which was extracted from reference 11) was included in this report to illustrate the relative effects that can be achieved when varying the cooling airflow. This figure clearly shows that any attempt to lean-out current production fuel schedules for general aviation piston engines without giving proper priority consideration to the nacelle cooling requirements can result in drastic reductions in cylinder head temperature margins for safe aircraft operation.



78-49-13

FIGURE 13. SEA LEVEL STANDARD-DAY MAXIMUM CYLINDER HEAD TEMPERATURES FOR DIFFERENT POWER MODE CONDITIONS AND VARYING FUEL-AIR RATIOS—AVCO LYCOMING IO-360-A1B6D ENGINE



78-49-14

FIGURE 14. SEA LEVEL HOT-DAY ($T_1=95^\circ \text{ F}$) MAXIMUM CYLINDER HEAD TEMPERATURE FOR DIFFERENT POWER MODE CONDITIONS AND VARYING FUEL-AIR RATIOS--AVCO LYCOMING IO-360-1B6D ENGINE

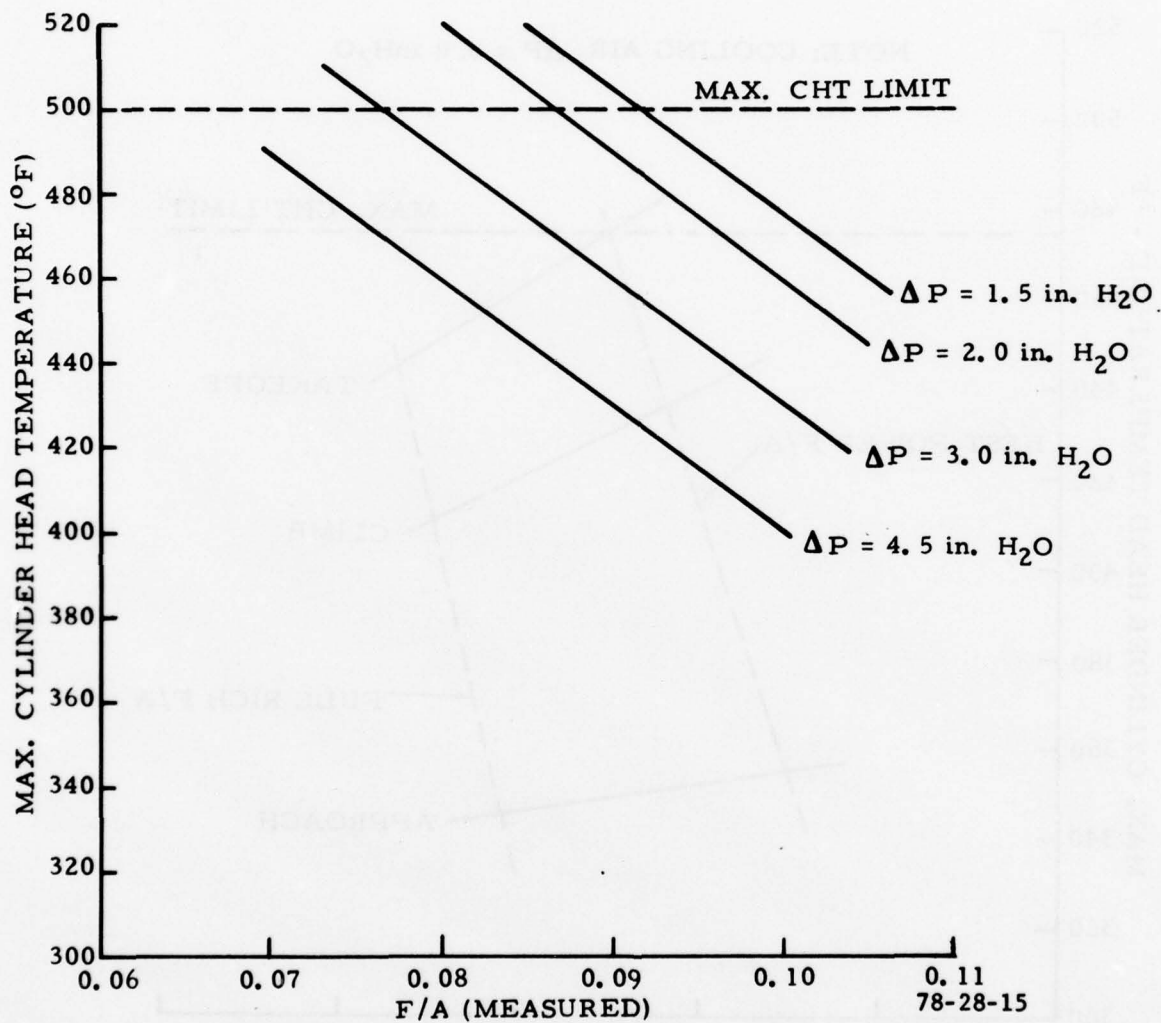


FIGURE 15. SEA LEVEL MAXIMUM CYLINDER HEAD TEMPERATURE VARIATIONS FOR DIFFERENT COOLING AIR DIFFERENTIAL PRESSURE CONDITIONS AND VARYING FUEL-AIR RATIOS--AVCO LYCOMING IO-360-B1BD ENGINE--TAKEOFF MODE

RESULTS OF TESTS WITH VARYING SPARK SETTINGS.

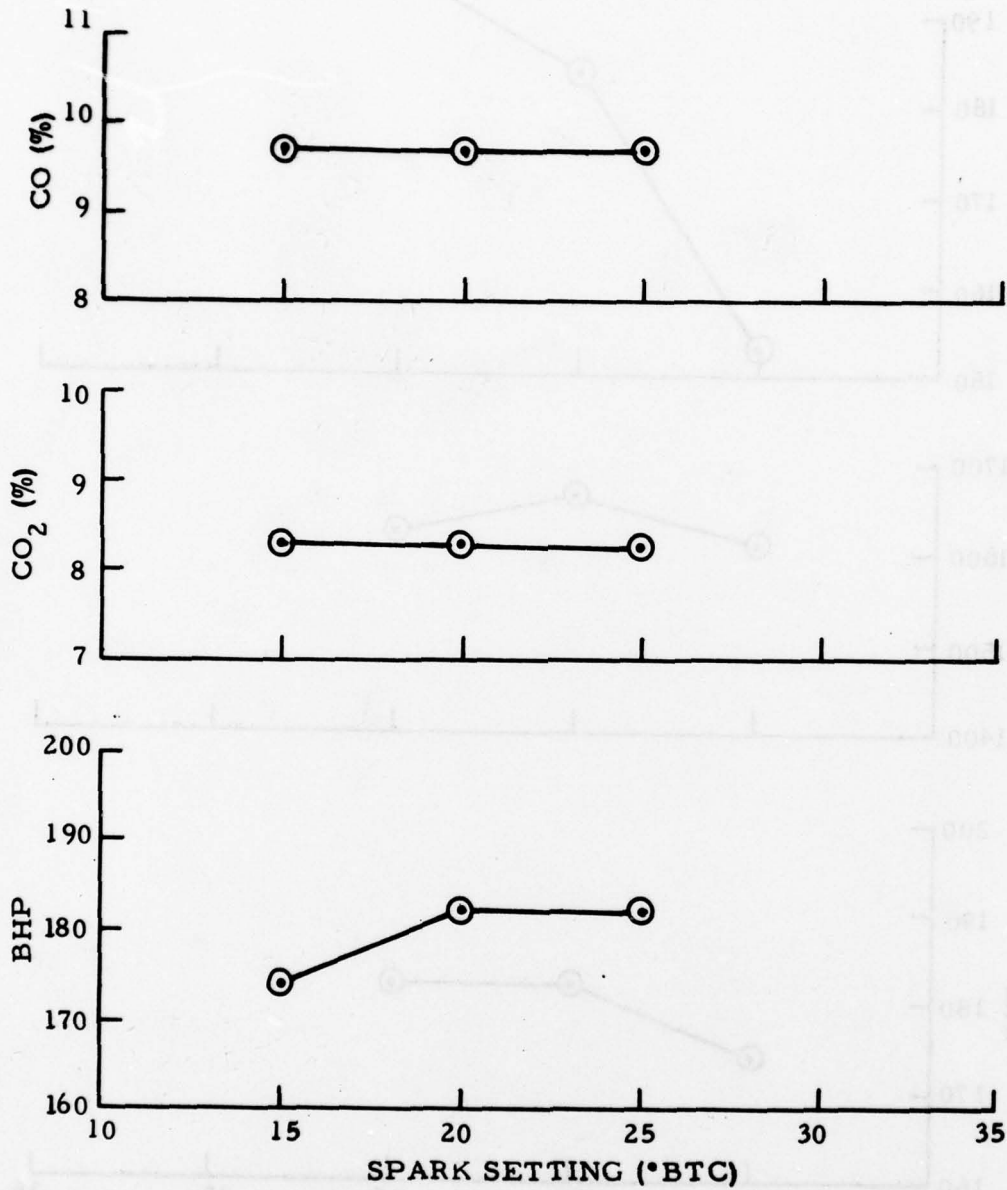
This engine was also evaluated with different spark settings. The basic production setting is 25° before top dead center (BTC). Two other settings were evaluated: 20° BTC and 15° BTC. Table 7 summarizes the results of all the tests conducted and presents the data on an average basis. The three basic power modes (takeoff, climb, and approach—100, 75-80, and 40 percent, respectively) are tabulated using average data based on a minimum of three test runs for each power mode condition and each spark setting.

The results of these tests and the percent changes in emission output are also shown in table 7. For a change in the spark setting from 25° BTC to 20° BTC it may be noted that the CO change is negligible in the takeoff and climb modes for a negligible change in power and a nominal 2.76-percent reduction in maximum CHT. Even though the percent changes in unburned HC and NO_x appear to be significant, it should be noted that both of these pollutants are being measured on a fraction of a percent basis. Changing the spark setting from 25° BTC to 15° BTC shows that the CO emissions increase (0.03 to 1.68 for takeoff, climb, and approach modes respectively) with a nominal 4.5-percent reduction in power and a 8.0-percent reduction in maximum CHT.

The data presented in table 7 and the plotted results in figures 16 through 21, for the various power conditions and spark setting indicate that the most optimum condition(s) for the IO-360-1B6D engine is the 20-25° BTC spark settings if it is important not to compromise the available power at the significant modal conditions (takeoff, climb, and approach).

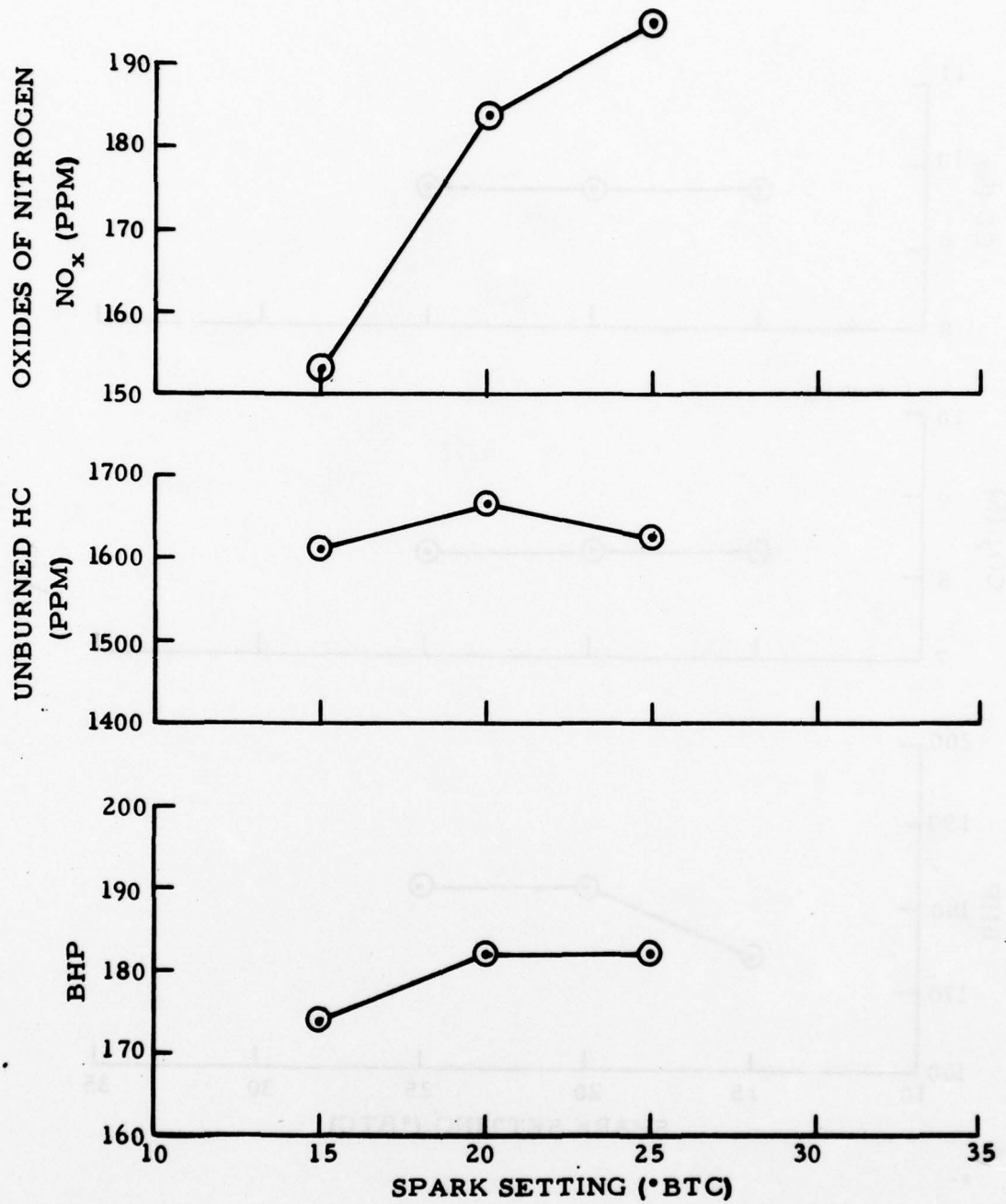
TABLE 7. SUMMARY OF ENGINE PERFORMANCE AND EXHAUST EMISSIONS CHARACTERISTICS FOR THREE DIFFERENT SPARK SETTINGS (°BTC)---FULL-RICH FUEL SCHEDULE

| Mode Cond. | RPM | Torque | | Ind. Air Temp. (°F) | Wf lb/h | Wa lb/h | F/A | ZCO ₂ | ZCO | HC-PPM | NO _x -PPM | Max. CHT (°F) | Run No. |
|------------------------------|-------------|------------------|----------------|------------------------|-------------|------------|--------------------|------------------|----------|-----------------------|----------------------|------------------|---------------|
| | | lb-ft 25° BTC | BHP 25° BTC | | | | | | | | | | |
| Takeoff Climb Approach | 2700 | 354 | 182 | 79 | 112.8 | 1173.6 | 0.0961 | 8.24 | 9.74 | 1625 | 195 | 435 | 16,30,910,924 |
| | 2430 | 311 | 144 | 80 | 86.5 | 926.0 | 0.0934 | 8.24 | 8.95 | 1500 | 230 | 427 | 20,31,911,925 |
| | 2350 | 152 | 68 | 81 | 45.4 | 501.4 | 0.0905 | 8.33 | 9.40 | 1990 | 232 | 356 | 24,32,912,926 |
| | | Torque | | Ind. Air Temp. (°F) | | | | | | | | | |
| | | lb-ft 20° BTC | BHP 20° BTC | | | | | | | | | | |
| Takeoff Climb Approach | 2700 | 354 | 182 | 78 | 113.3 | 1184.8 | 0.0958 | 8.30 | 0.67 | 1665 | 184 | 423 | 37,50,64 |
| | 2430 | 311 | 144 | 77 | 88.5 | 943.9 | 0.0938 | 8.20 | 8.95 | 1500 | 210 | 402 | 38,54,65 |
| | 2350 | 152 | 68 | 78 | 46.5 | 514.7 | 0.0903 | 8.15 | 9.25 | 1935 | 185 | 343 | 39,58,66 |
| | | Torque | | Ind. Air Temp. (°F) | | | | | | | | | |
| | | lb-ft 15° BTC | BHP 15° BTC | | | | | | | | | | |
| Takeoff Climb Approach | 2700 | 338 | 174 | 74 | 114.3 | 1188.4 | 0.0962 | 8.30 | 9.71 | 1615 | 153 | 399 | 71,84,98 |
| | 2430 | 303 | 140 | 72 | 90.0 | 966.0 | 0.0932 | 8.07 | 8.30 | 1395 | 180 | 388 | 72,88,99 |
| | 2300 | 146 | 64 | 70 | 45.8 | 515.8 | 0.0868 | 8.00 | 7.72 | 1686 | 158 | 332 | 92,100 |
| | | Nominal | | Ind. Air Temp. (°F) | | | | | | | | | |
| | | Δ Torq. | Δ BHP | | Δ CHT (Max) | ZΔ BHP | Δ ZCO ₂ | Δ ZCO | Δ HC (Z) | Δ NO _x (Z) | Z Δ CHT (Max) | | |
| Takeoff Climb Approach | 25°-20° BTC | 0 | 0 | -12 | 78.5 | 0 | +0.06 | -0.07 | +2.46 | -5.64 | -2.76 | | |
| | 25°-20° BTC | 0 | 0 | -25 | 78.5 | 0 | -0.04 | 0 | -8.70 | -5.85 | | | |
| | 25°-20° BTC | 0 | 0 | -13 | 79.5 | 0 | -0.18 | -0.15 | -2.76 | -20.26 | -3.65 | | |
| Takeoff Climb Approach | 25°-15° BTC | -16 | -8 | -36 | 76.5 | -4.40 | +0.06 | -0.03 | -0.62 | -21.54 | -8.28 | | |
| | 25°-15° BTC | -8 | -4 | -39 | 76.0 | -2.78 | -0.17 | -0.65 | -7.00 | -21.74 | -9.13 | | |
| | 25°-15° BTC | -6 | -4 | -24 | 75.5 | -5.88 | -0.33 | -1.68 | -15.23 | -31.90 | -6.74 | | |



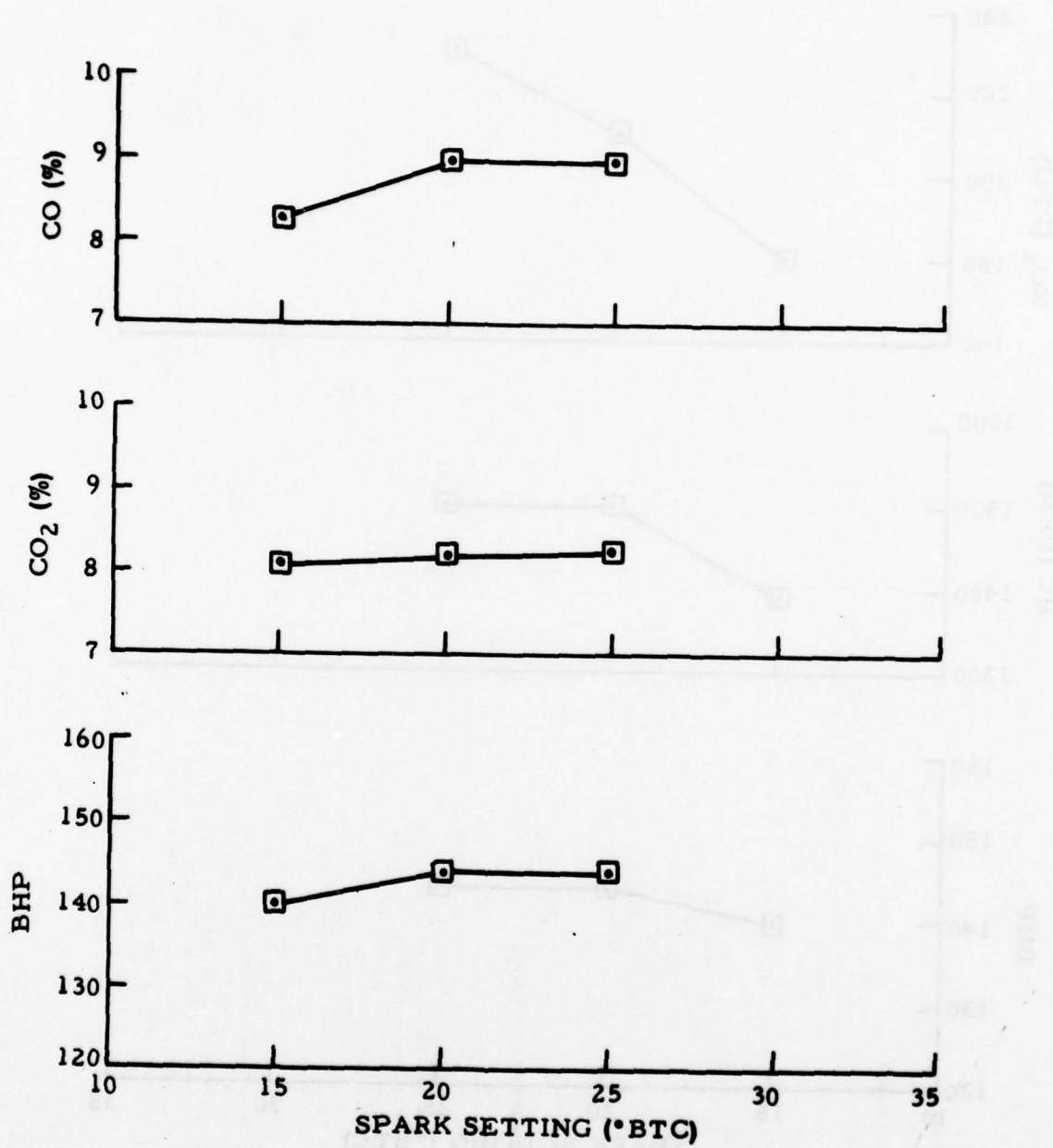
78-49-16

FIGURE 16. EFFECT OF VARYING SPARK SETTING ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS--TAKEOFF MODE (CO AND CO₂)



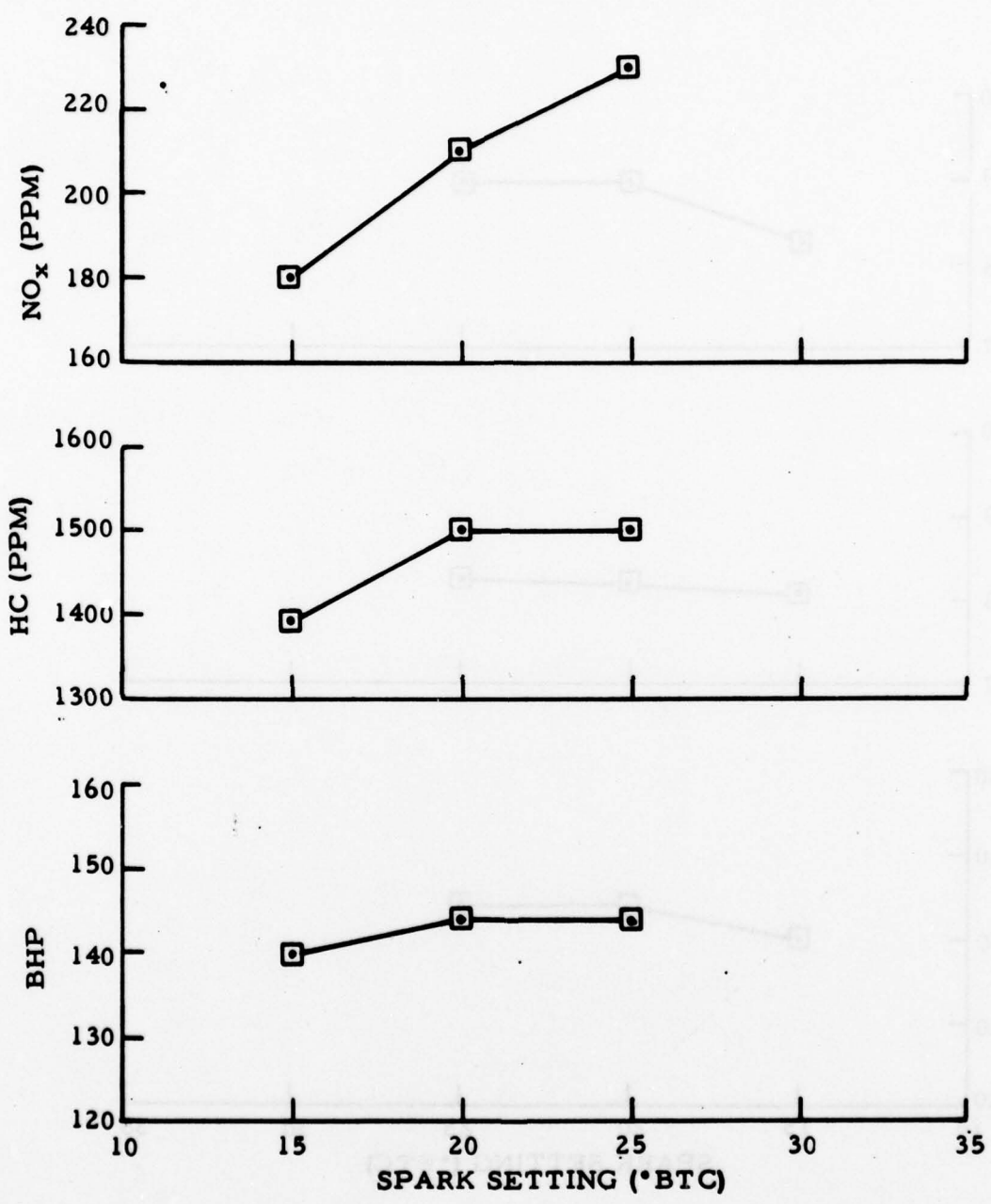
78-49-17

FIGURE 17. EFFECT OF VARYING SPARK SETTING ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS--TAKEOFF MODE (HC AND NO_x)



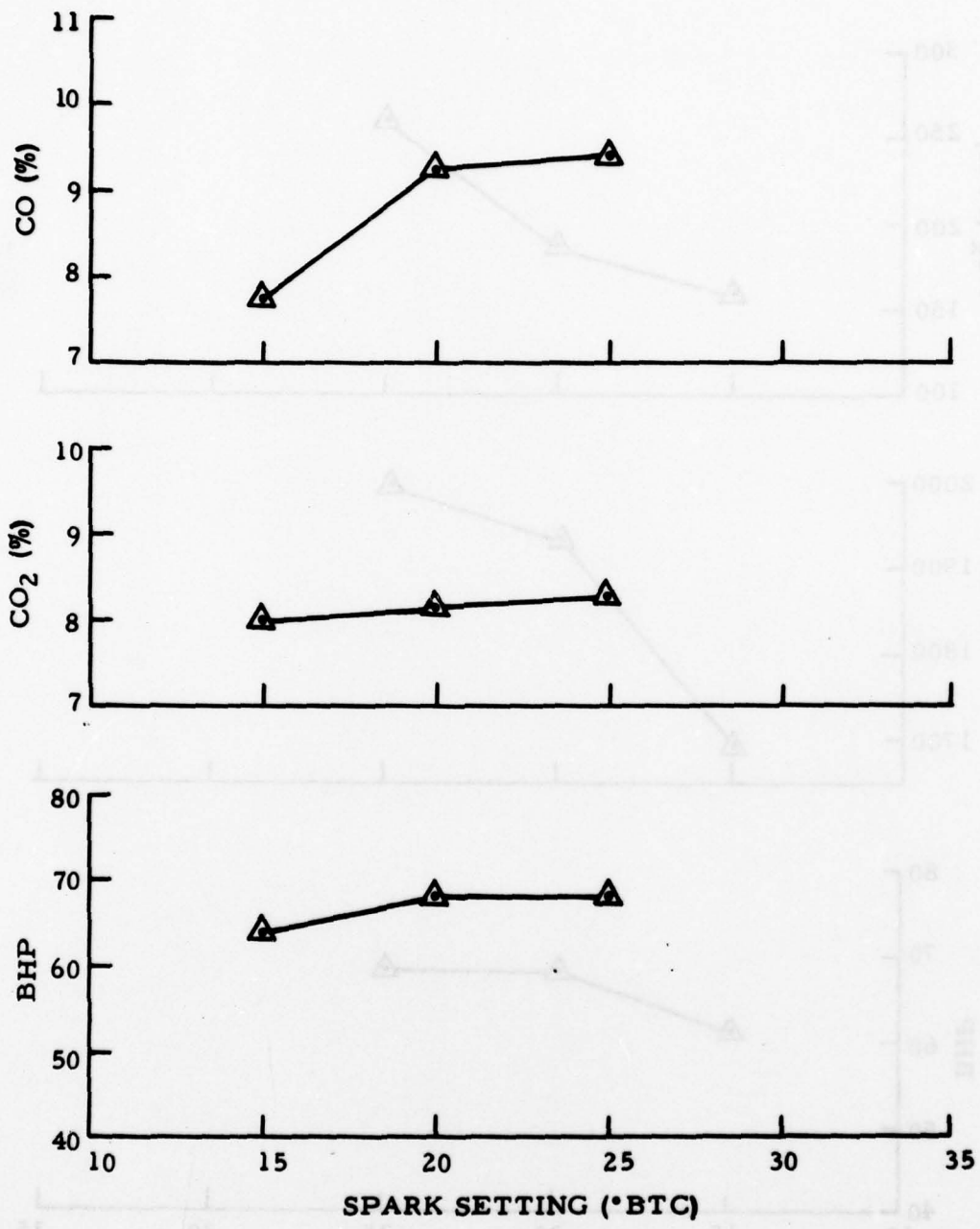
78-49-18

FIGURE 18. EFFECT OF VARYING SPARK SETTING ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS—CLIMB MODE (CO AND CO₂)



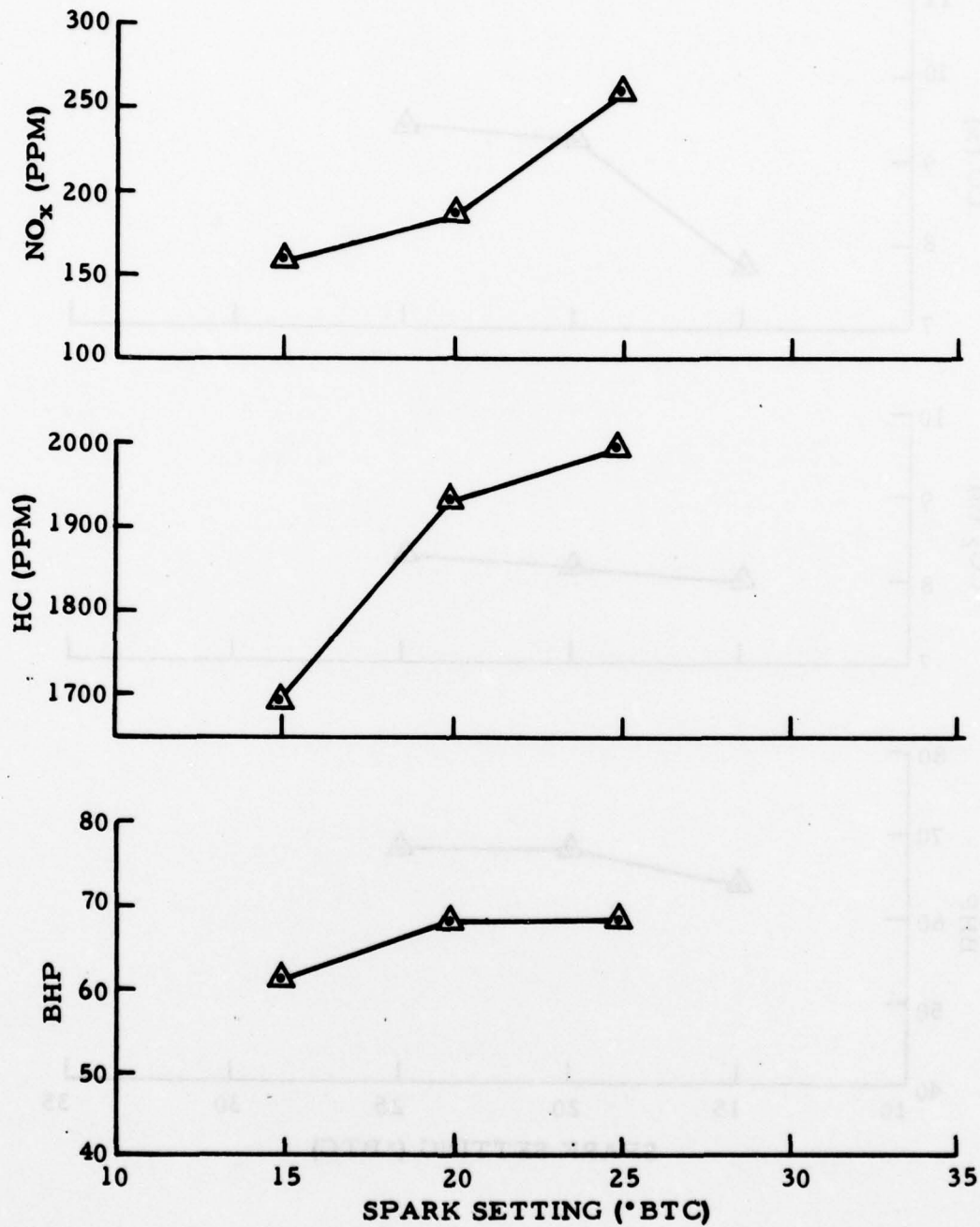
78-49-19

FIGURE 19. EFFECT OF VARYING SPARK SETTING ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS—CLIMB MODE (HC AND NO_x)



78-49-20

FIGURE 20. EFFECT OF VARYING SPARK SETTING ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS—APPROACH MODE (CO AND CO₂)



78-49-21

FIGURE 21. EFFECT OF VARYING SPARK SETTING ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS—APPROACH MODE (HC AND NO_x)

SUMMARY OF RESULTS

EXHAUST EMISSIONS.

1. The IO-360-ALB6D engine did not meet the proposed EPA carbon monoxide standard for 1979/80, under sea level standard-day conditions.
2. The IO-360-ALB6D engine meets the proposed EPA hydrocarbon and oxides of nitrogen standard for 1979/80 for sea level standard-day conditions.
3. The engine fuel metering device could be adjusted on the test stand to reduce the current CO exhaust emission level, but not to levels required by proposed EPA standards when operating under the most severe LTO cycle requirements.

MAXIMUM CYLINDER HEAD TEMPERATURES.

1. Adjusting the fuel metering device in the takeoff mode to the constant best power operation results in an increase in maximum CHT, which will exceed the engine specification limit on the test stand if cooling air $\Delta P = 3.0$ inH₂O or less.
2. Adjusting the fuel metering device in the climb mode to constant best power operation will result in an increase in maximum CHT. This latter change will necessitate an increase in cooling air flow to provide adequate temperature margins for hot-day operations. An increase in cooling air differential pressure of approximately 1.0 inH₂O may be required for certain critical installations.
3. No critical maximum CHT's result from leaning-out the approach and taxi modes.

CRITICAL LANDING AND TAKEOFF CYCLE.

1. The most critical LTO cycle is the cycle defined in this report as maximum five-mode LTO cycle (table 4). Engine operation in accordance with the maximum five-mode LTO cycle could not be adjusted to meet the proposed EPA emission standards for 1979/80 without exceeding engine maximum CHT limits.
2. Engine operation in accordance with the minimum five-mode LTO cycle (table 5) could be adjusted to meet the proposed EPA emission standards for 1979/80 without exceeding engine maximum CHT limits.

OPTIMUM SPARK SETTING.

1. The 20-25° BTC spark settings produce optimum test results:
 - a. Optimum Power
 - b. Optimum Maximum CHT
 - c. Emissions (CO, HC, and NO_x) compatible with optimum power and acceptable CHT margins.

2. The 15° BTC spark setting produced the lowest HC and NO_x emission levels. However, this setting also resulted in a nominal 4.5 percent decrease in power for the takeoff, climb, and approach modes.

CONCLUSIONS

The following conclusions are based on the testing accomplished with the Avco Lycoming IO-360-A1B6D engine.

1. Simple fuel management adjustments (altering of fuel schedule) do not appear to provide the sole capability to safely reduce light-aircraft piston engine exhaust emissions.
2. The test data indicate that fuel management adjustments must be combined with engine/nacelle cooling modifications before safe and optimum low-emission aircraft/engine combinations can be achieved.
3. Spark settings other than the 20-25° BTC settings do not appear to produce significantly beneficial improvements in exhaust emissions.
4. The EPA CO limit of 0.042 lb/cycle/rated BHP did not appear to be achievable when hot-day takeoff and climb requirements are impacted by aircraft heavy gross weight and the need to pay close attention to CHT limitations.
5. An assessment of the maximum five-mode LTO cycle (table 4) test data indicate that the following standard changes should be made to the proposed EPA emission standards:

Proposed EPA STD.

For 1979/1780

(lb/cycle/rated BHP)

Recommended Standard for 1970/80

(lb/cycle/rated BHP)

CO Standard 0.042

HC Standard 0.0019

NO_x Standard 0.0015

0.075

0.0025

0.0015

6. To avoid CHT problems in the takeoff mode (100-percent power), it is advisable not to adjust the fuel metering device. Engine operation in this mode should continue to be accomplished within current production rich/lean limits.

REFERENCES

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APPENDIX A

FUEL SAMPLE ANALYSIS

COMBUSTIBLE ELEMENTS IN FUELS (AVIATION FUEL).

1. Carbon and hydrogen are the predominant combustible elements in fuels (aviation type), with small amounts of sulphur as the only other fuel element.
2. Liquid fuels are mixtures of complex hydrocarbons.
3. For combustion calculations gasoline or fuel oil can be assumed have the average molecular formula C_8H_{17} .

Note: The Exxon® data presented in table A-1 may be found in reference 7.

TABLE A-1. TYPICAL SPECIFICATIONS FOR AVIATION FUELS

| <u>Item</u> | <u>D910-76 Grade 100/130</u> | <u>Exxon Aviation Gas 100/130</u> | <u>D910-70 Grade 115/145</u> | <u>Exxon Aviation Gas 115/145</u> |
|--------------------------------|--------------------------------------|---|--------------------------------------|---|
| Freezing Point, °F | -72 Max. | Below -76 | -76 Max. | Below -76 |
| Satd Vapor Press., PSI | 7.0 Max. | 6.8 | 7.0 Max. | 6.8 |
| Sulfur, % by Weight | 0.05 Max. | 0.02 | 0.05 Max. | 0.02 |
| Lower Heating Value, BTU/lb | 18,720 Min. | | 18,800 Min. | |
| Heat of Comb. (NET). BTU/lb | | 18,960 | | 19,050 |
| Distillation, %Evaporated | | | | |
| At 167° F (Max.) | 10 | 22 | 10 | 21 |
| At 167° F (Min.) | 40 | | 40 | |
| At 221° F (Max.) | 50 | 76 | 50 | 62 |
| At 275° F (Max.) | 90 | 97 | 90 | 96 |
| Distillation End Point | 338° F Max. | | 338° F Max. | |
| Final Boiling Point °F | | 319 | | 322 |
| Tel Content, ML/U.S.Gal. | 4.0 Max. | 3.9 | 4.6 Max. | 4.5 |
| Color | Green | Green | Purple | Purple |

4. NAFEC used 100/130 (octane rated) aviation gasoline for the piston engine emission tests. The following analysis of a typical fuel sample (table A-2) made at the U.S. Naval Air Propulsion Test Center (NAPTC), Trenton, N.J. (reference 8).

TABLE A-2. ANALYSIS OF NAFEC FUEL SAMPLE, 100/130 FUEL

| Item | NAFEC Sample 100/130 | Grade 100/130 (MIL-G-5572E) Spec Limits | |
|-------------------------------|----------------------------|--|--------|
| | | Min. | Max. |
| Freezing Point, °F | Below -76° F | | -76 |
| Reid Vapor Press., PSI | 6.12 | 5.5 | 7.0 |
| Sulfur % By Weight | 0.024 | | 0.05 |
| Lower Heating Value BTU/lb | | 18,700 | |
| Heat of Comb. (NET) BTU/lb | 18,900 | | |
| Distillation, %Evaporated | | <u>Distillation %Evaporation</u> | |
| At 158° F | 10 | | |
| At 167° F (Min) | | 167° F | 10 |
| At 167° F (Max.) | | | 40 |
| At 210° F | 40 | | 167° F |
| At 220° F | 50 | | |
| At 221° F | | 221° F | 50 |
| At 242° F | 90 | | |
| At 275° F | | 275° F | 90 |
| Distillation End Point | 313° F | | 338° F |
| Specific Gravity @60° F | 0.7071 | Report | Report |
| API Gravity @60° F | 68.6 | No Limit | |
| Tel Content, ML/U.S. Gal. | 1.84 | | 4.60 |

Computation for the fuel hydrogen-carbon ratio is based on the fuel net heating value, hf equal to 18,900 BTU/lb and figure A-1.

$$\begin{aligned}
 C/H &= 5.6 \\
 C &= 12.011 \\
 C_8 &= 8 \times 12.011 = 96.088 \\
 H_v &= (96.088) \div 5.6 = 17.159 \\
 H &= 1.008 \\
 Y &= (17.159) \div 1.008 = 17.022 \quad \text{Use } Y = 17
 \end{aligned}$$

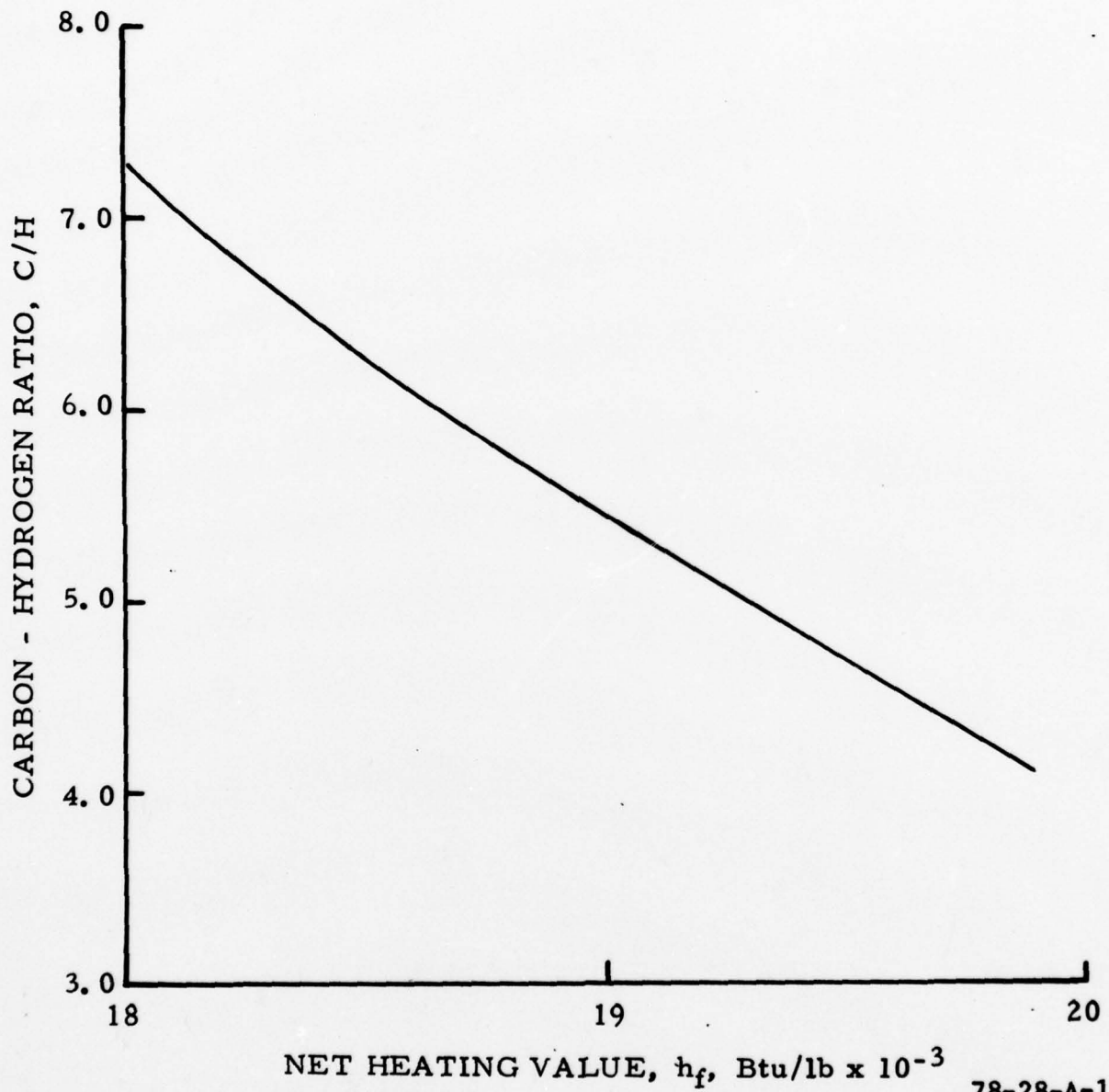


FIGURE A-1. NET HEATING VALUE FOR AVIATION GASOLINE AND CARBON-HYDROGEN RATIO CORRELATION

APPENDIX B

COMPOSITION OF AIR (GENERAL PROPERTIES)

1. Dry air is a mixture of gases that has a representative volumetric analysis in percentages as follows:

- Oxygen (O₂)--20.99%
- Nitrogen (N₂)--78.03%
- Argon (A)--0.94% (Also includes traces of the rare gases neon, helium, and krypton)
- Carbon Dioxide (CO₂)--0.03%
- Hydrogen (H₂)--0.01%

2. For most calculations it is sufficiently accurate to consider dry air as consisting of:

- O₂ = 21.0%
- N₂ = 79.0% (including all other inert gases)

3. The moisture or humidity in atmospheric air varies over wide limits, depending on meteorological conditions, its presence in most cases simply implies an additional amount of essentially inert material.

Note: Information given in items 1, 2, and 3 is recommended for computation purposes (reference 3, 4, 9, and 10).

TABLE B-1. MASS ANALYSIS OF PURE DRY AIR

| <u>Gas</u> | <u>Volumetric Analysis %</u> | <u>Mole Fraction</u> | <u>Molecular Weight</u> | <u>Relative Weight</u> |
|-----------------|------------------------------|----------------------|-------------------------|------------------------|
| O ₂ | 20.99 | 0.2099 | 32.00 | 6.717 |
| N ₂ | 78.03 | 0.7803 | 28.016 | 21.861 |
| A | 0.94 | 0.0094 | 39.944 | 0.376 |
| CO ₂ | 0.03 | 0.0003 | 44.003 | 0.013 |
| Inert Gases | 0.01 | 0.0001 | 48.0 | 0.002 |
| | 100.00 | 1.000 | | 28.969 = M for air |

4. The molecular weight of the apparent nitrogen can be similarly determined by dividing the total mass of the inert gases by the total number of moles of these components:

$$M_{\text{Apparent Nitrogen}} = \frac{2225}{79.01} = 28.161$$

5. This appendix advocates the term nitrogen as referring to the entire group of inert gases in the atmosphere and therefore the molecular weight of 28.161 will be the correct value (rather than the value 28.016 for pure nitrogen).

6. In combustion processes the active constituent is oxygen (O₂), and the apparent nitrogen can be considered to be inert. Then for every mole of oxygen supplied, 3.764 moles of apparent nitrogen accompany or dilute the oxygen in the reaction:

$$\frac{79.01}{20.99} = 3.764 \frac{\text{Moles Apparent Nitrogen}}{\text{Mole Oxygen}}$$

7. The information given in items 4, 5, and 6 is recommended for computational purposes in reference 4. Therefore, one mole of air (dry), which is composed of one mole of oxygen (O₂) and 3.764 moles of nitrogen (N₂), has a total weight of 137.998 pounds.

$$(O_2 + 3.764 N_2) = 137.998$$

This gives the molecular weight of air = 28.97.

APPENDIX C

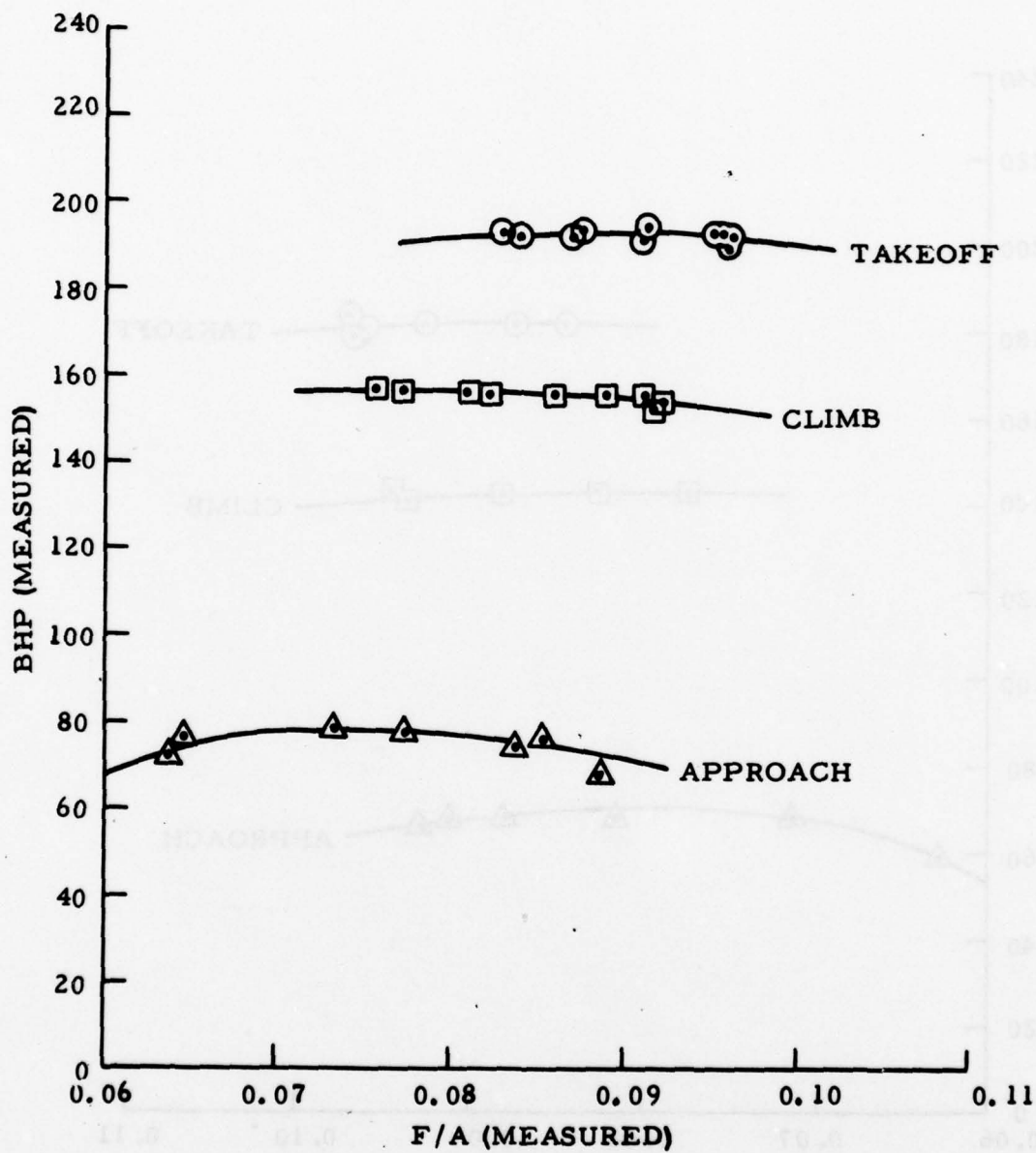
NAFEC TEST DATA AND WORKING PLOTS FOR ANALYSIS AND EVALUATION
OF AVCO LYCOMING IO-360-A1B6D ENGINE

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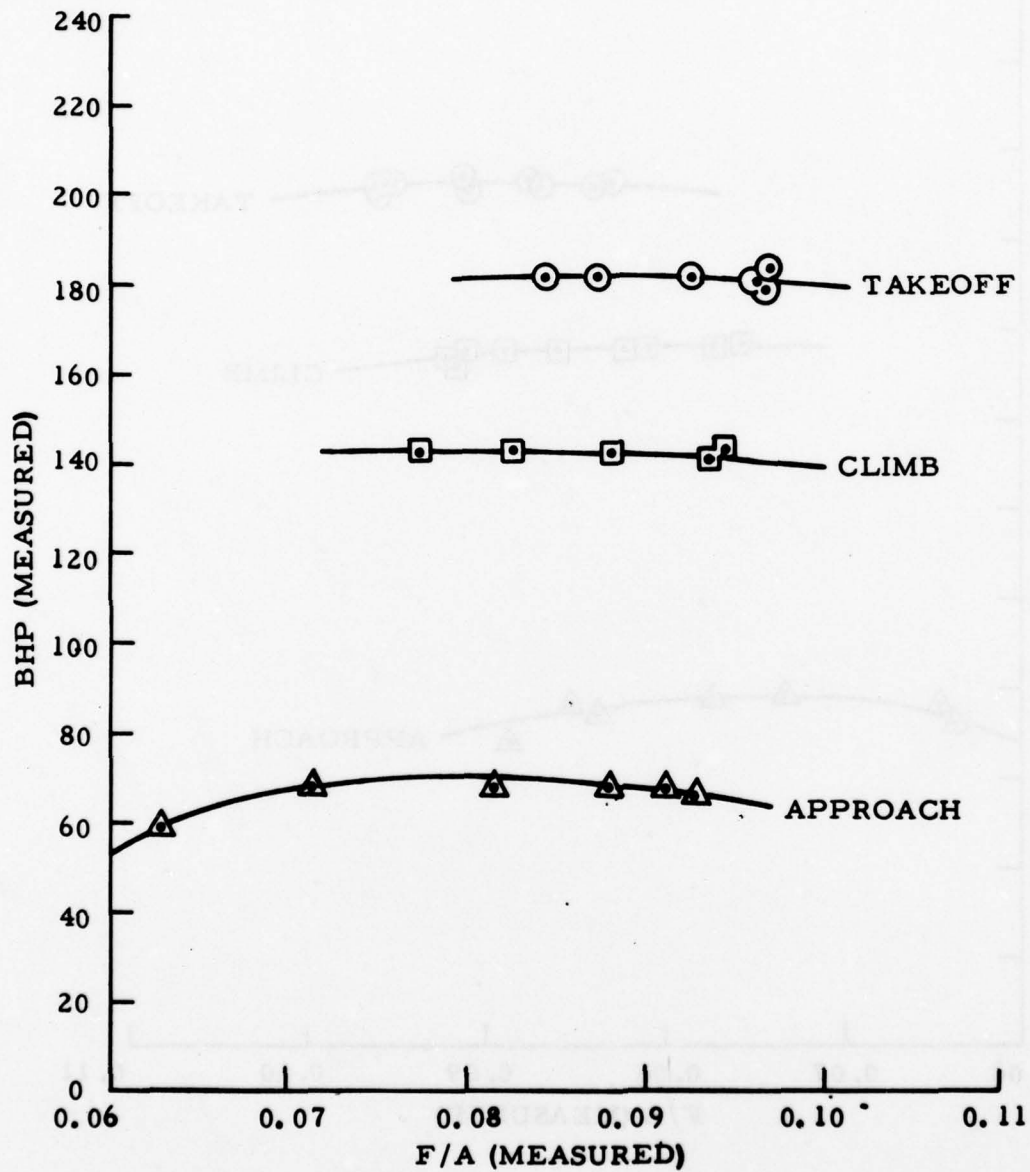
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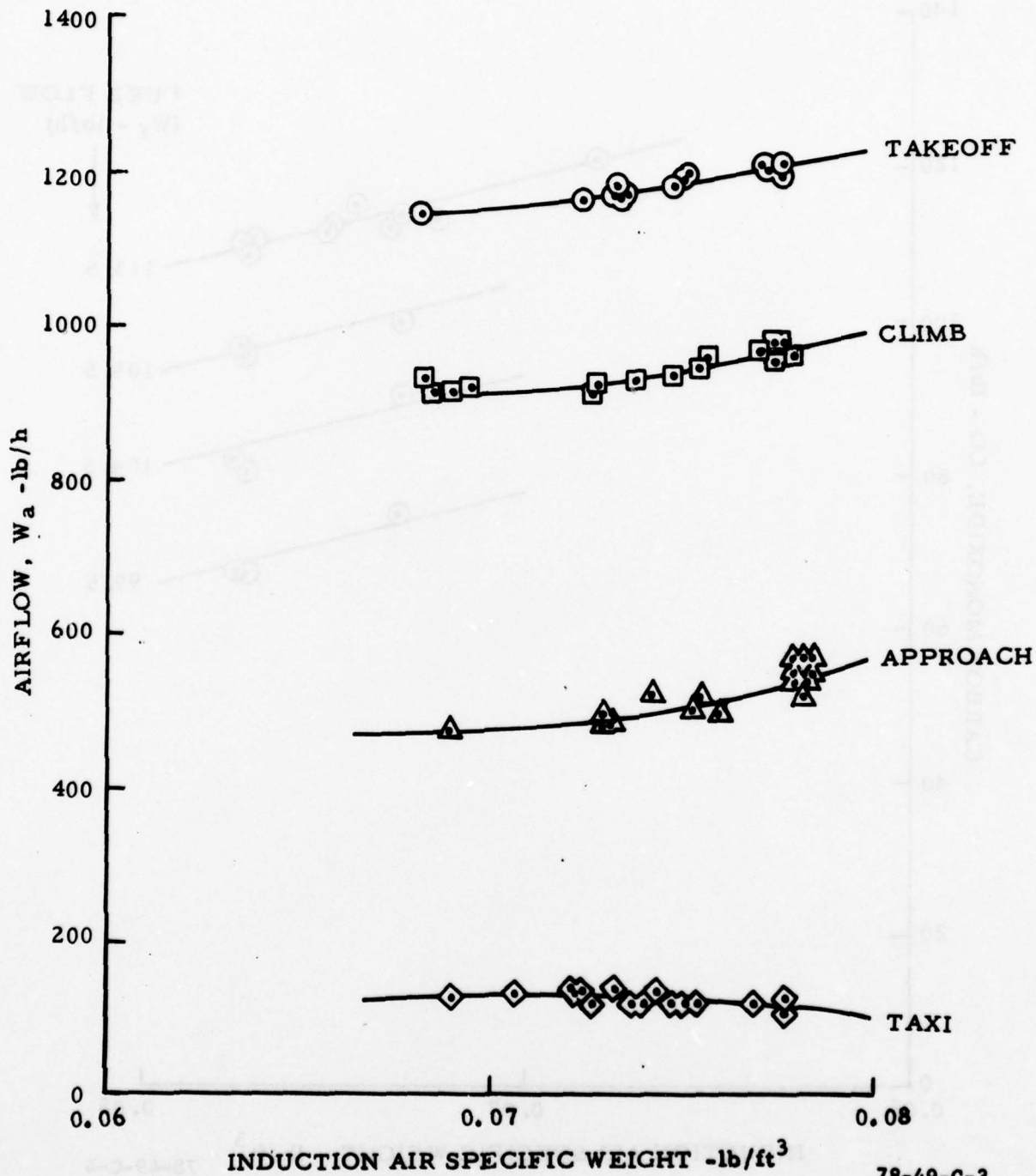
78-49-C-1

FIGURE C-1. MEASURED PERFORMANCE--AVCO LYCOMING IO-360-A1B6D ENGINE--TAKEOFF, CLIMB, AND APPROACH MODES--NOMINAL SEA LEVEL AIR DENSITY 0.0771 lb/ft³



78-49-C-2

FIGURE C-2. MEASURED PERFORMANCE--AVCO LYCOMING IO-360-11B6D ENGINE--
TAKEOFF, CLIMB, AND APPROACH MODES--NOMINAL SEA LEVEL AIR
DENSITY 0.0730 lb/ft³



78-49-C-3

FIGURE C-3. AIRFLOW AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE—NOMINAL SEA LEVEL TEST DATA

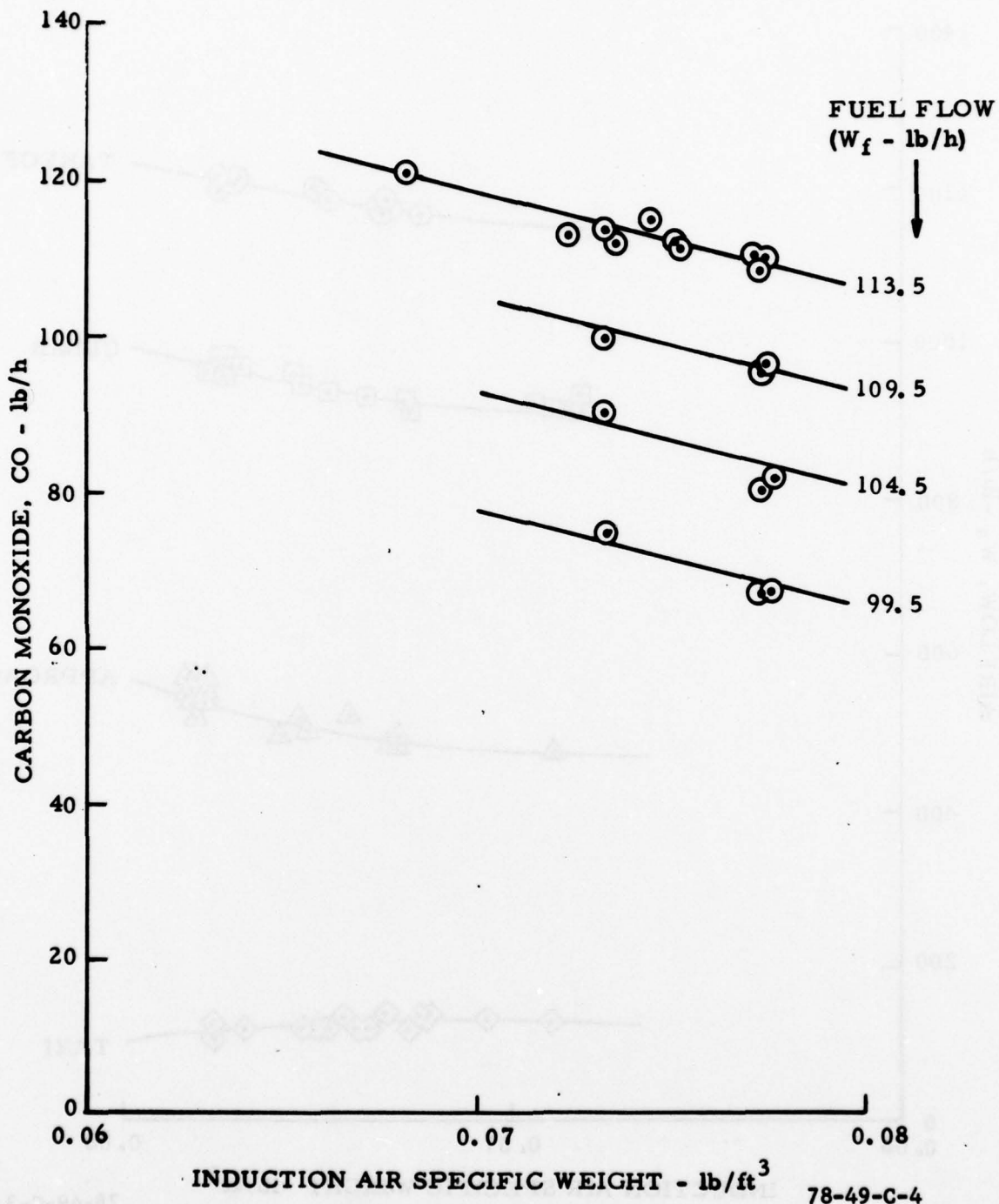


FIGURE C-4. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-A1B6D ENGINE

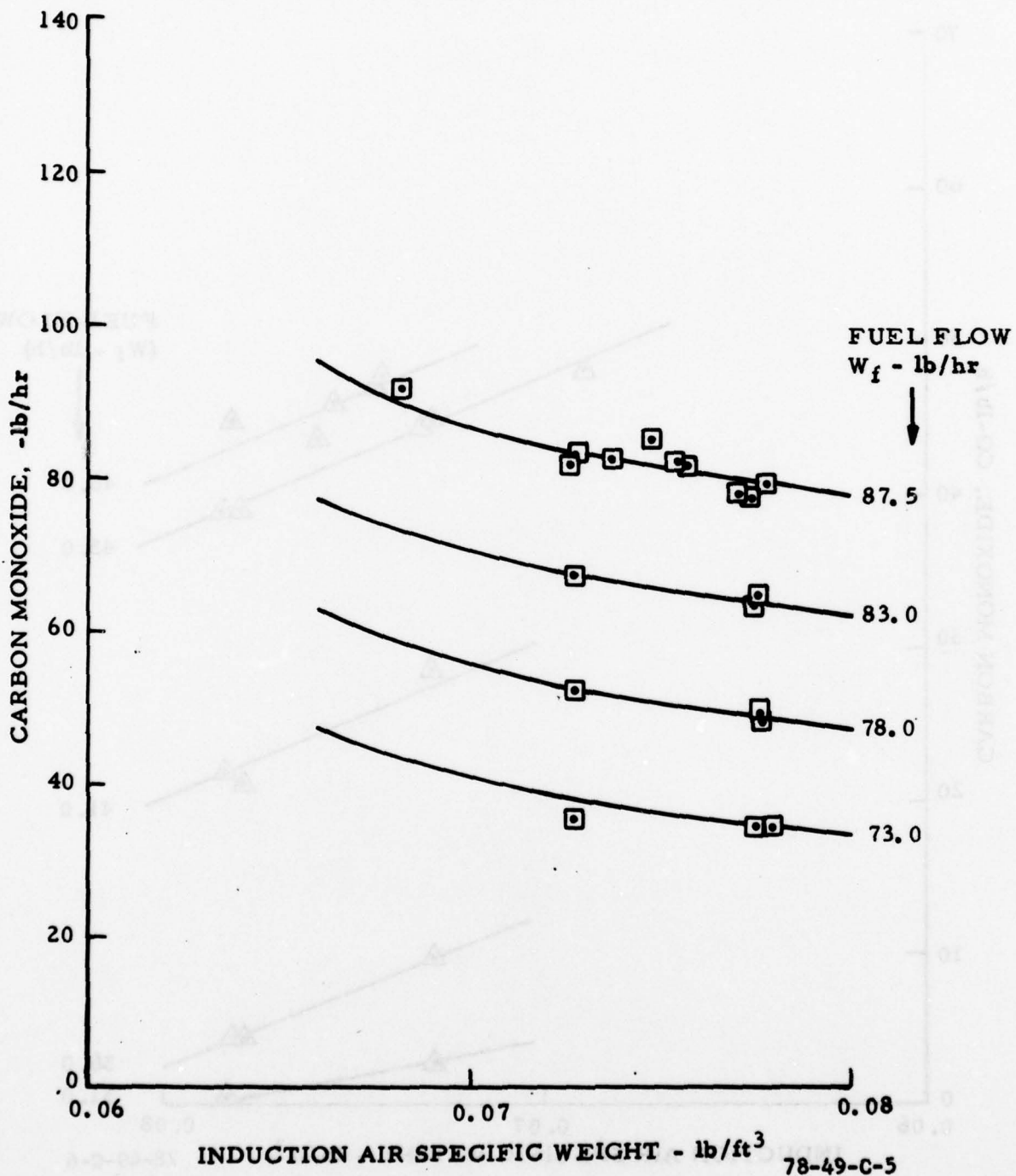


FIGURE C-5. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-A1B6D ENGINE

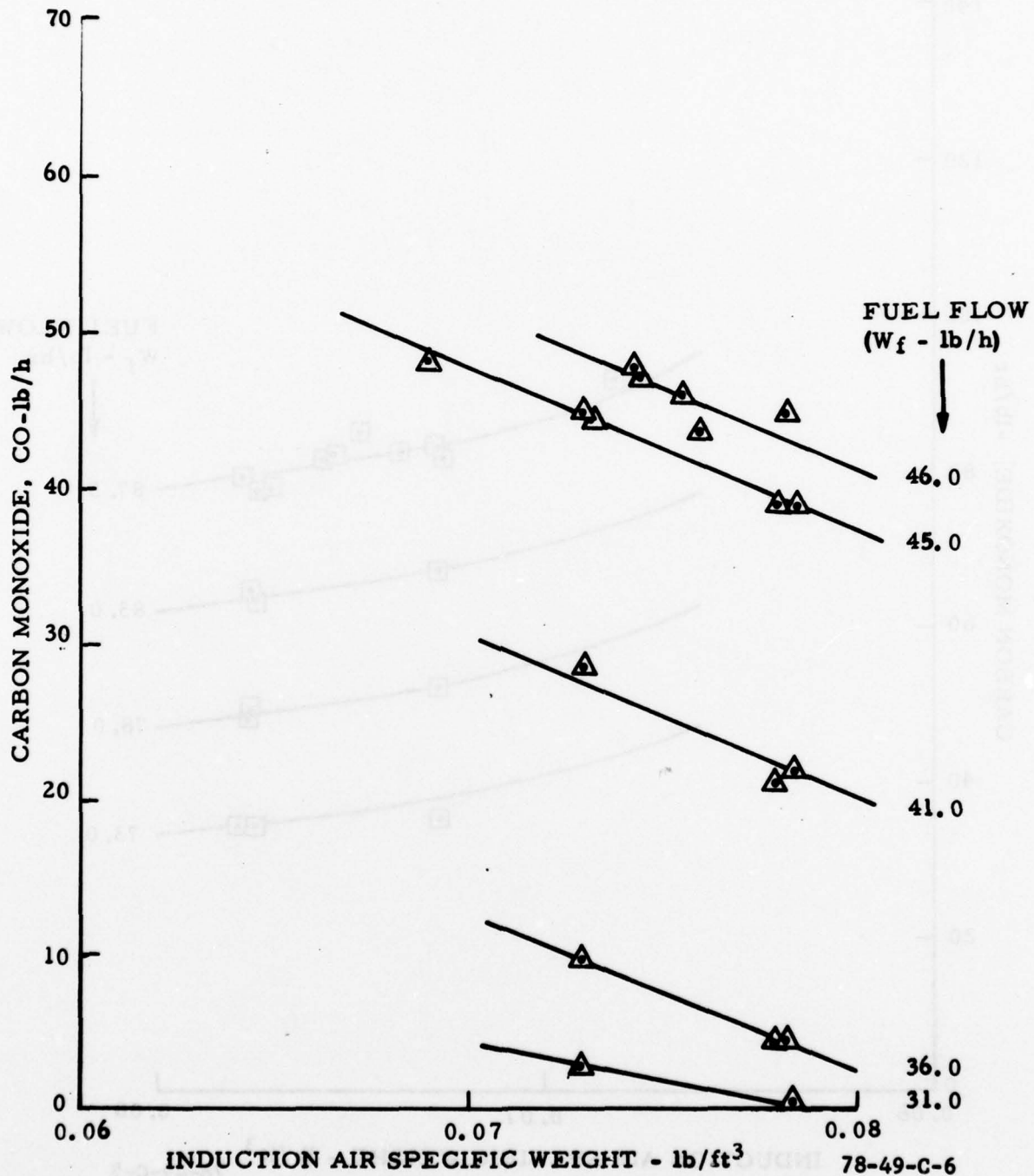
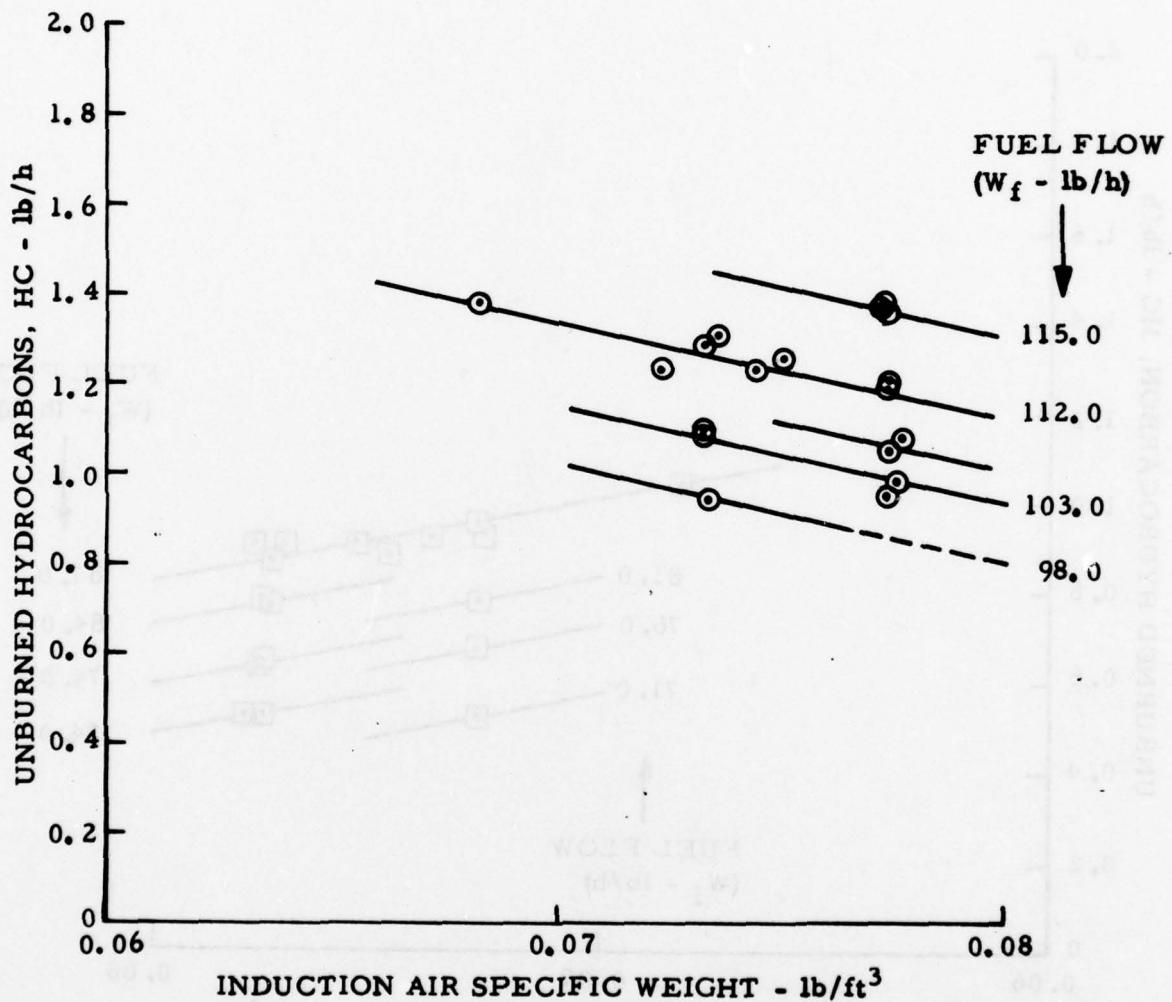


FIGURE C-6. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-A1B6D ENGINE



78-49-C-7

FIGURE C-7. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL FLOW SCHEDULES—AVCO LYCOMING IO-360-A1B6D ENGINE

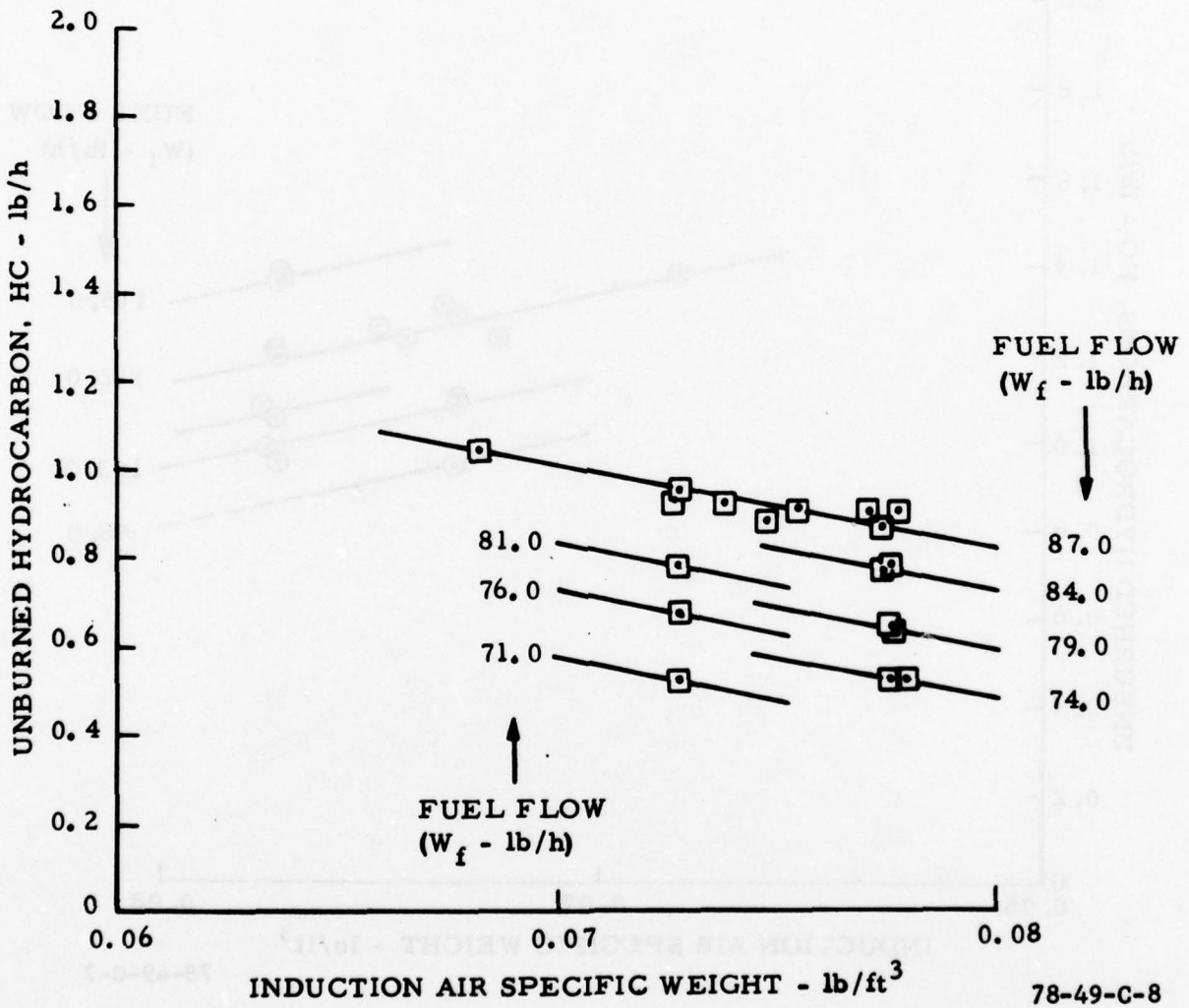
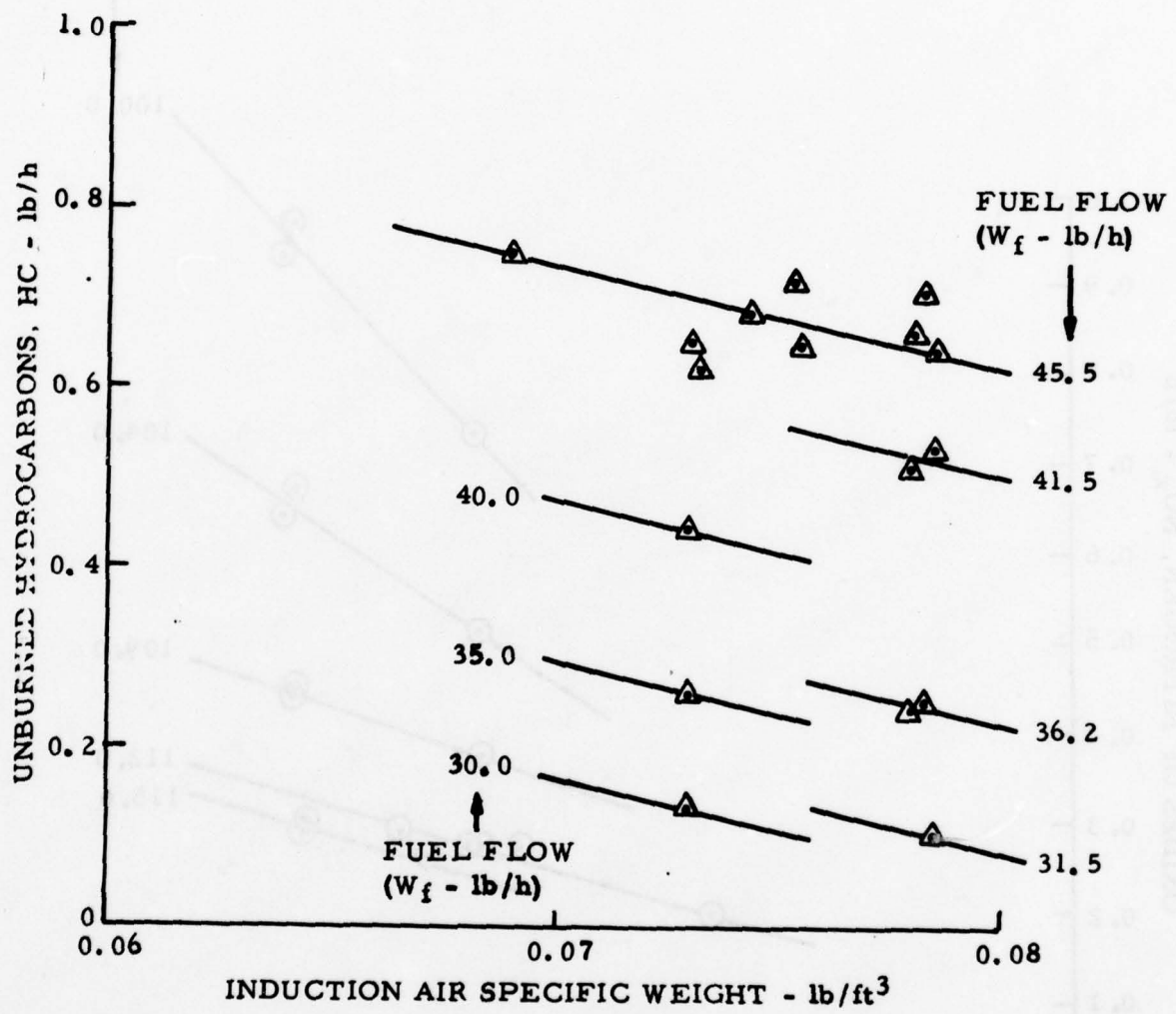
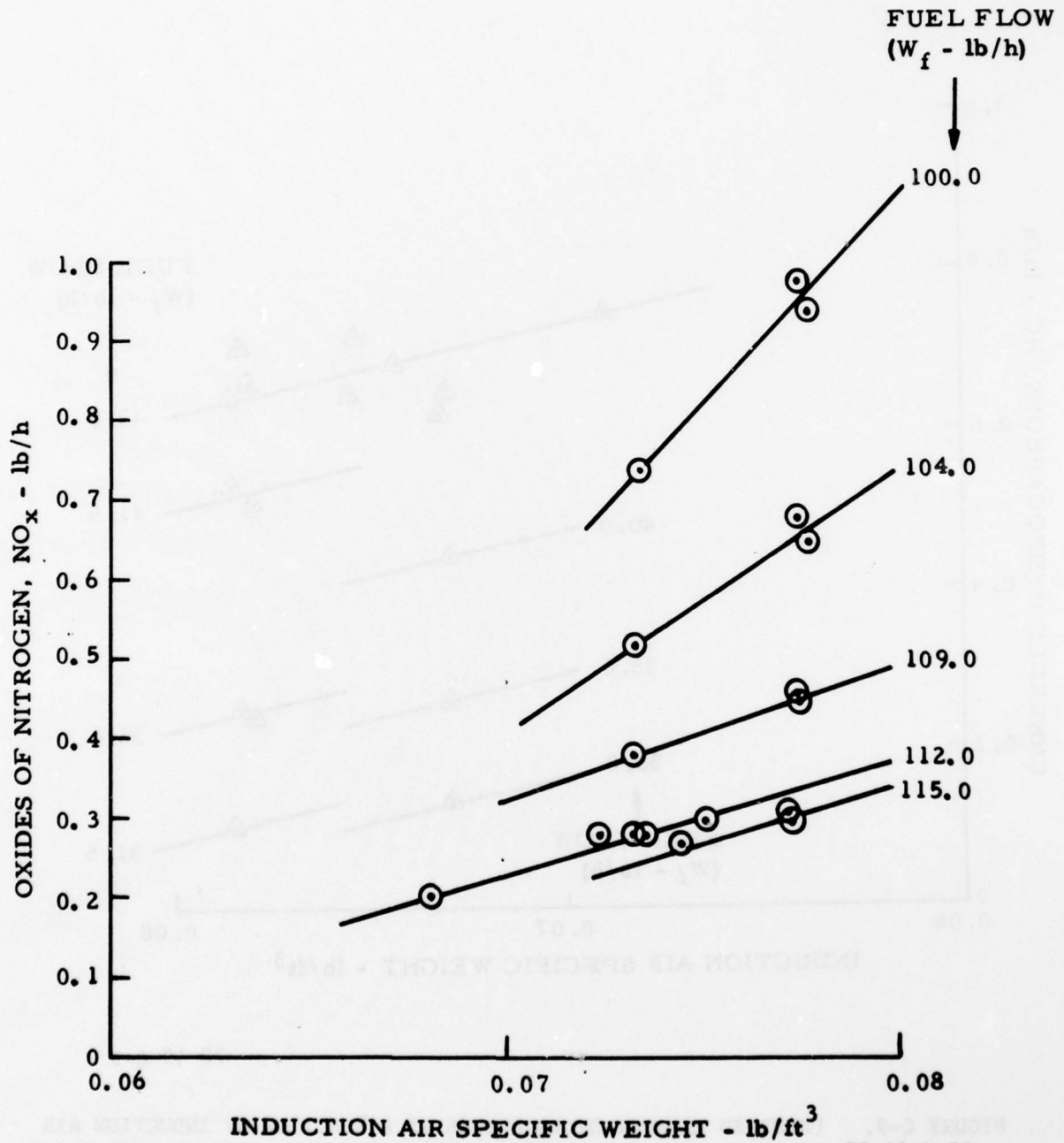


FIGURE C-8. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-A1B6D ENGINE



78-49-C-9

FIGURE C-9. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-1B6D ENGINE



78-49-C-10

FIGURE C-10. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-A1B6D ENGINE

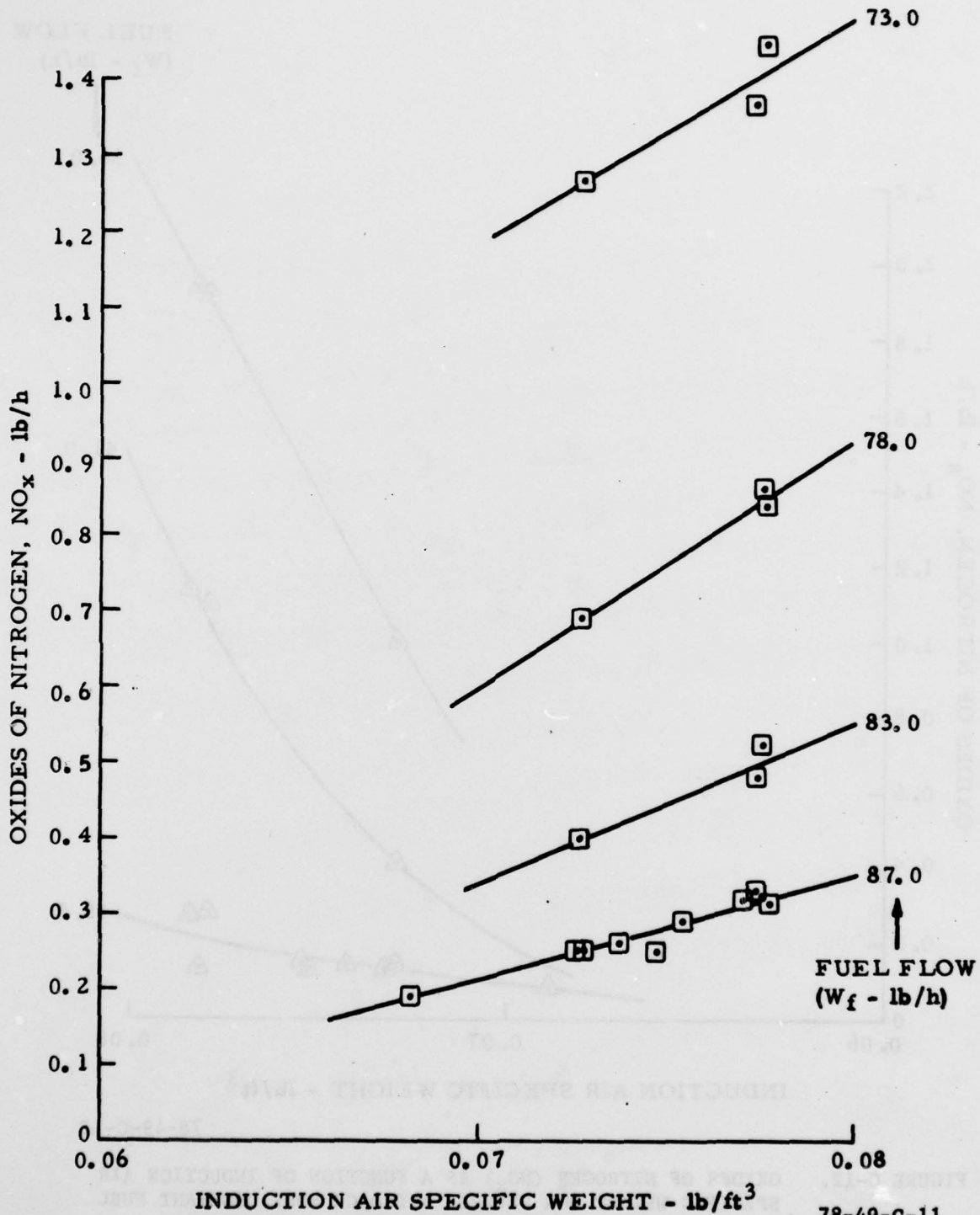
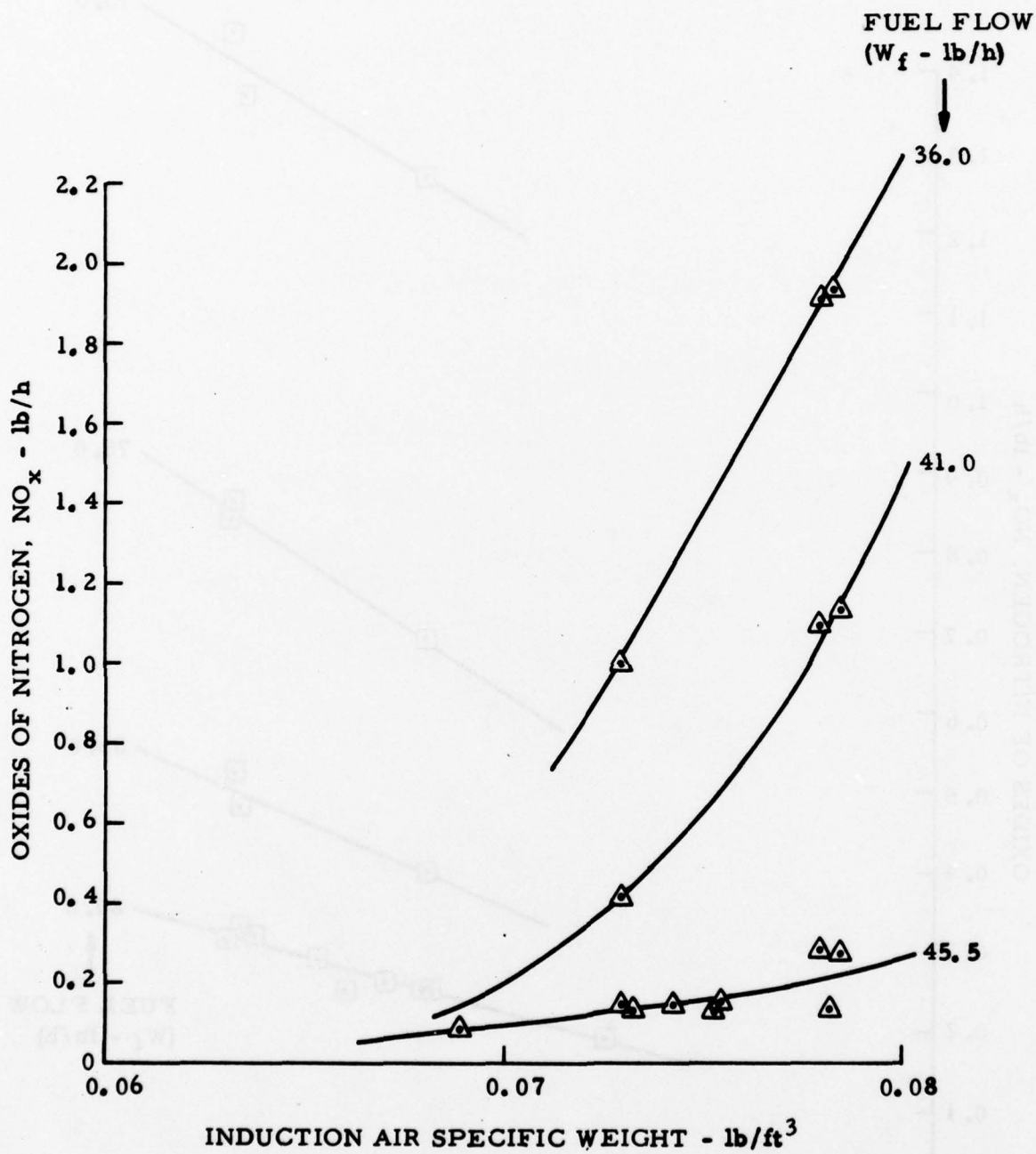
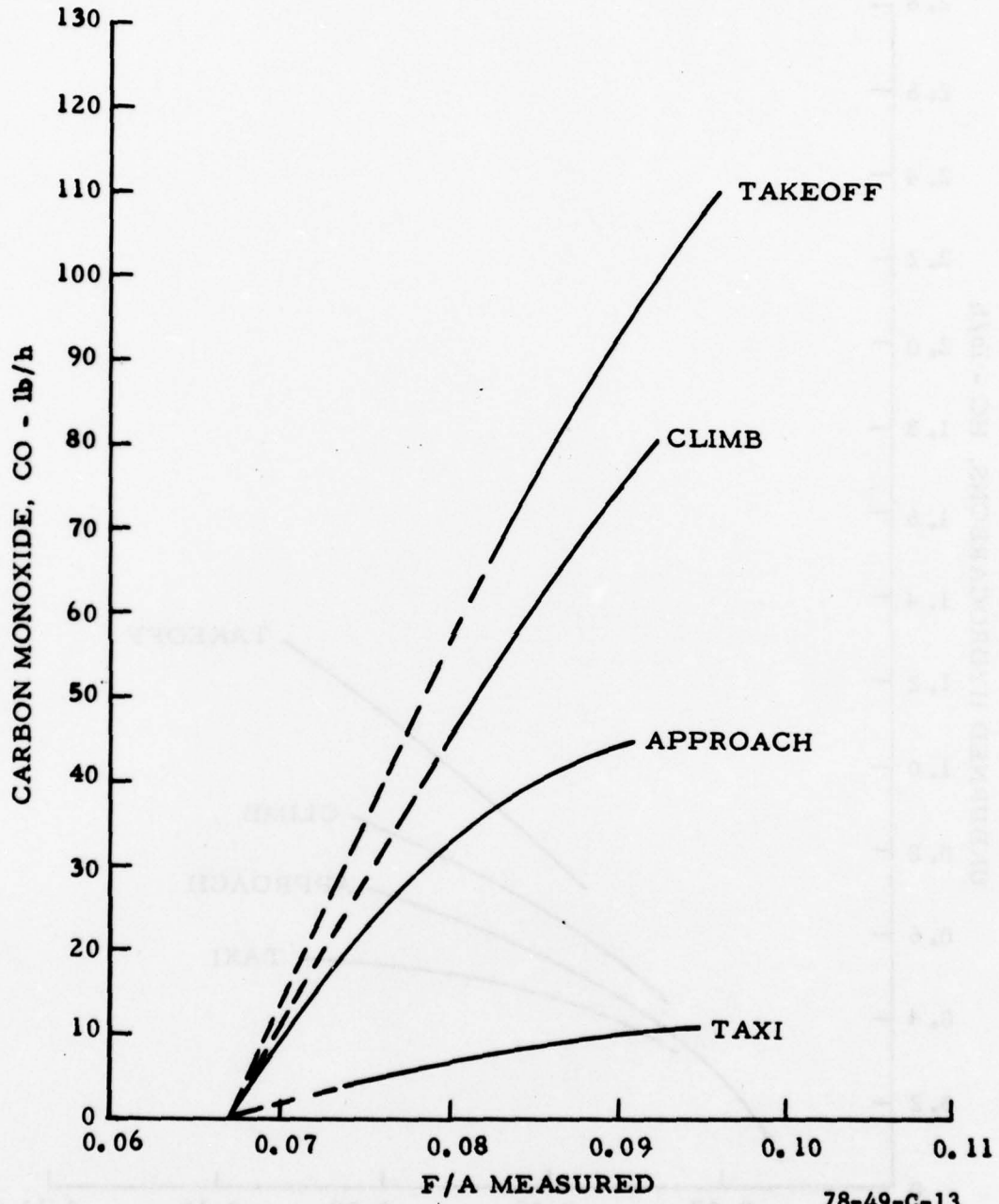


FIGURE C-11. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL FLOW SCHEDULES—AVCO LYCOMING IO-360-A1B6D ENGINE



78-49-C-12

FIGURE C-12. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL FLOW SCHEDULES--AVCO LYCOMING IO-360-A1B6D ENGINE



78-49-C-13

FIGURE C-13. SEA LEVEL STANDARD-DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-1B6D ENGINE--CARBON MONOXIDE

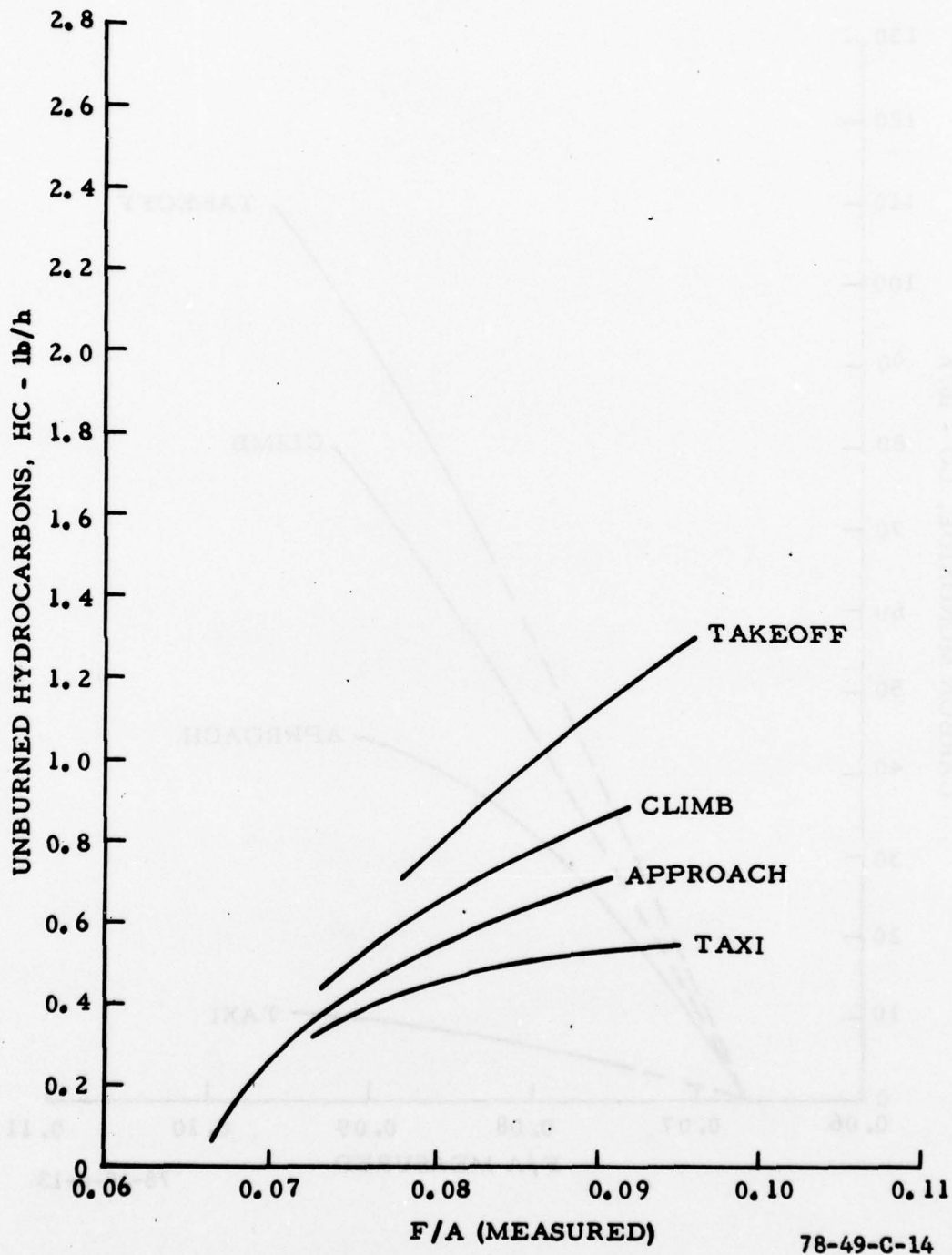


FIGURE C-14. SEA LEVEL STANDARD-DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE--UNBURNED HYDROCARBONS (CH₄)

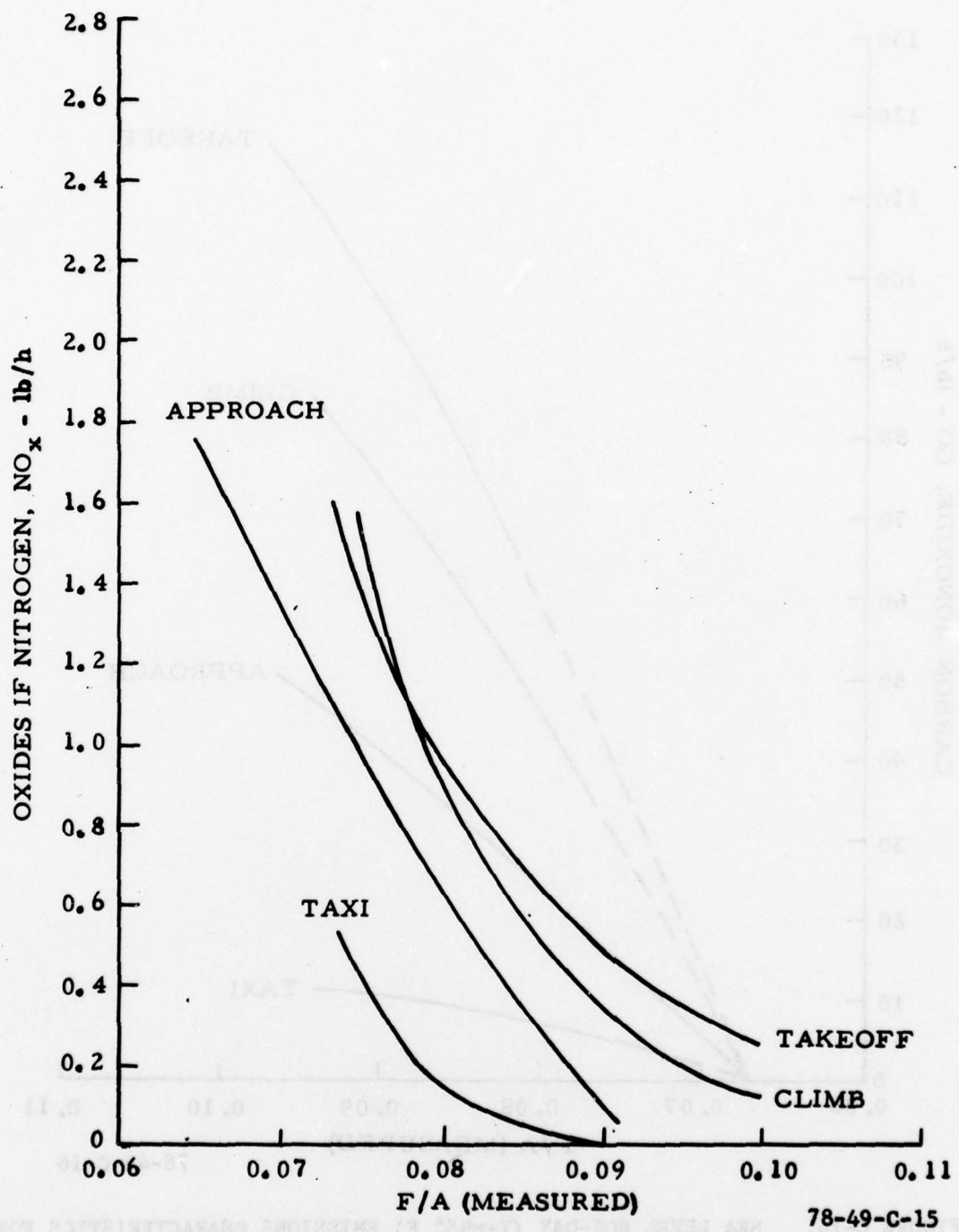
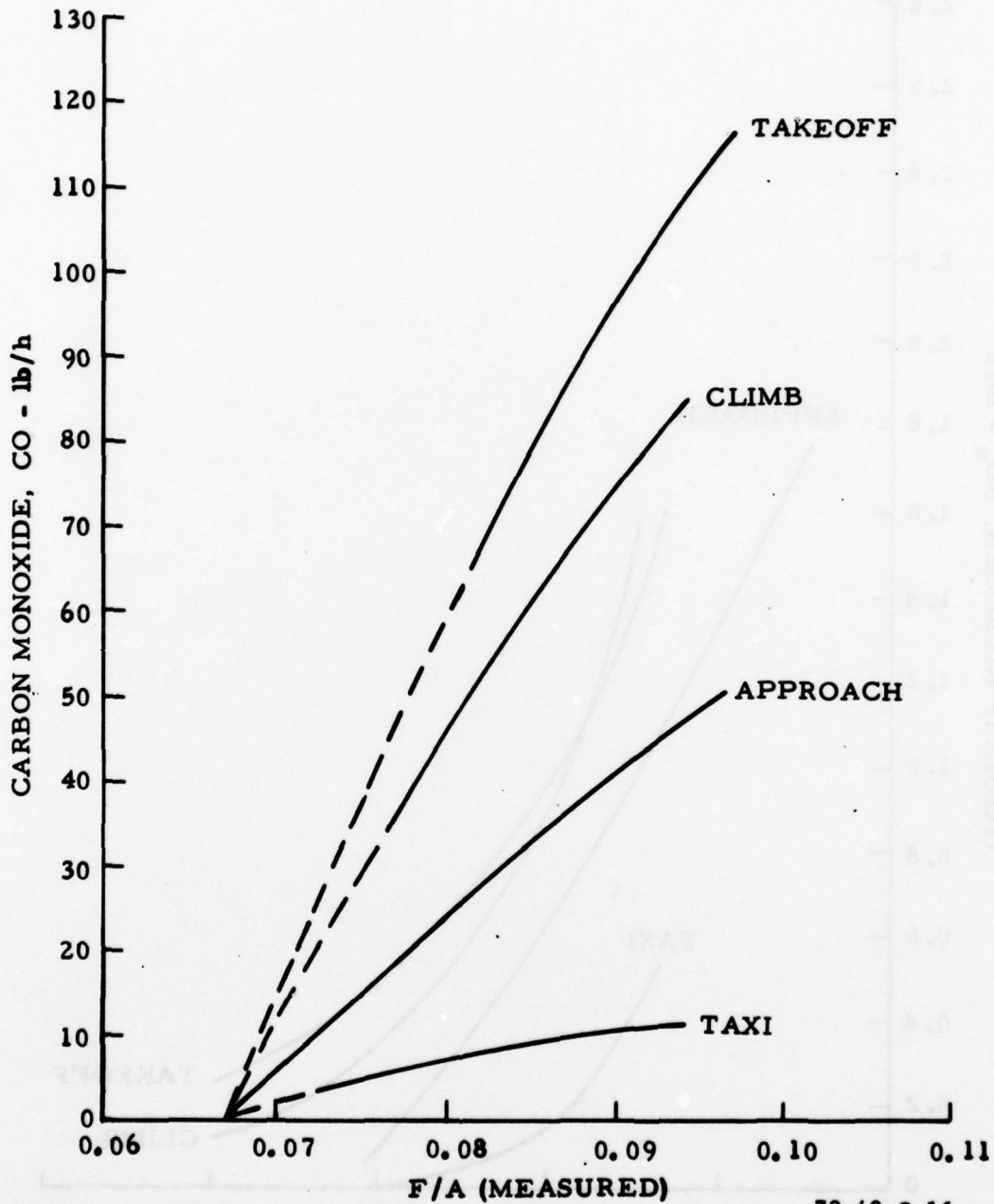


FIGURE C-15. SEA LEVEL STANDARD-DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE--OXIDES OF NITROGEN (NO)



78-49-C-16

FIGURE C-16. SEA LEVEL HOT-DAY ($T_1=95^\circ$ F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE—CARBON MONOXIDE

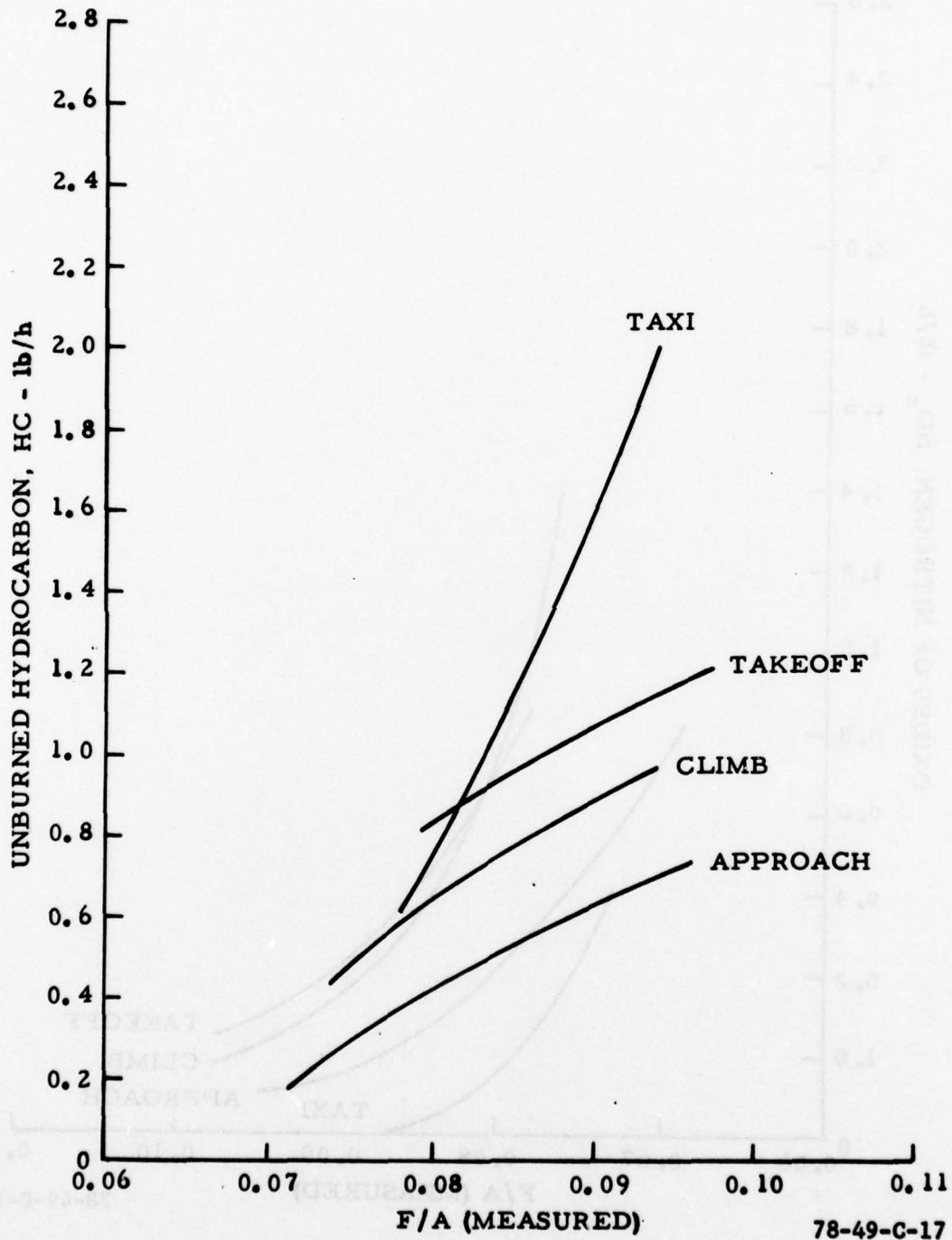


FIGURE C-17. SEA LEVEL HOT-DAY ($T_1=95^\circ F$) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE--UNBURNED HYDROCARBONS

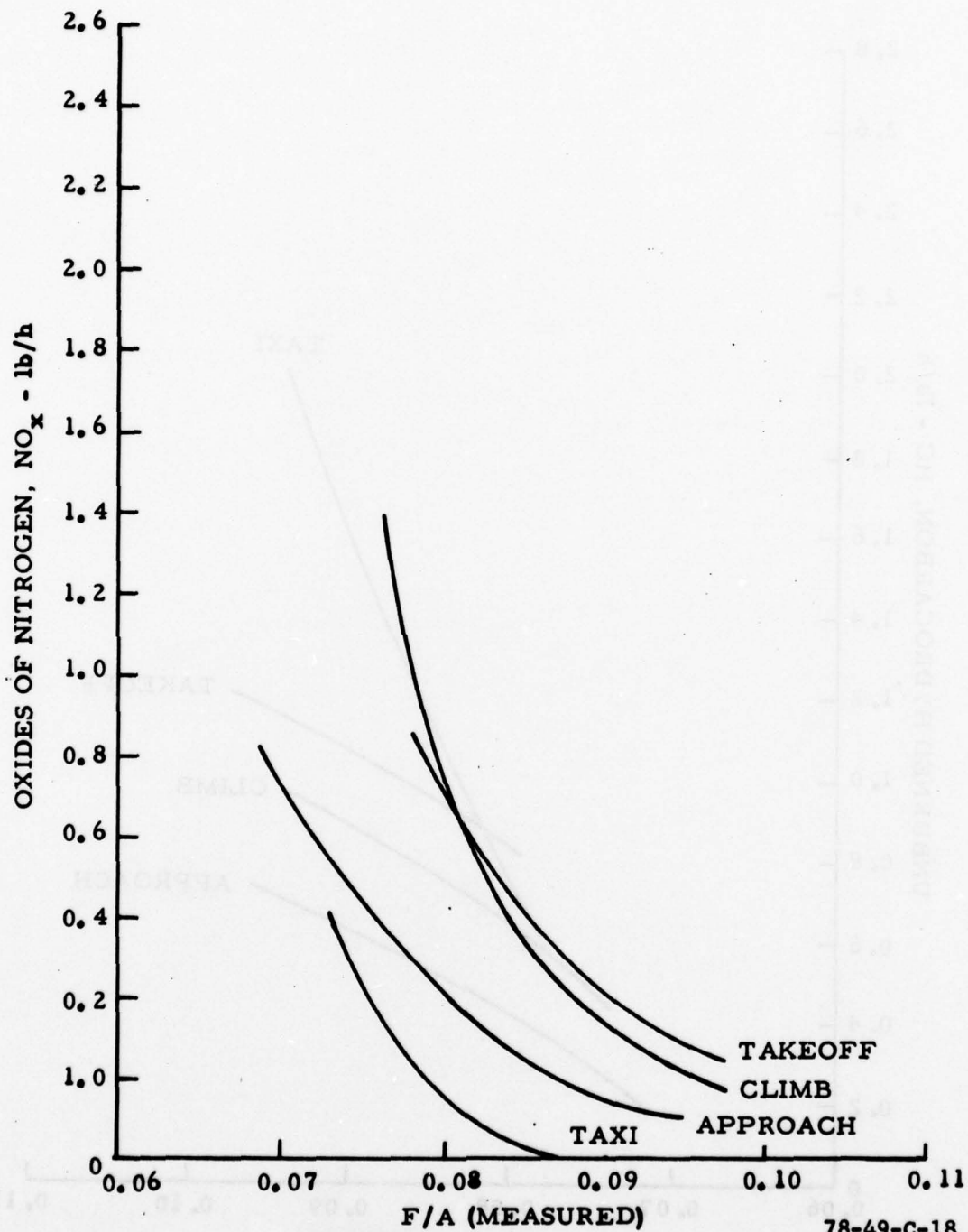


FIGURE C-18. SEA LEVEL HOT-DAY ($T_1=95^\circ$ F) EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE--OXIDES OF NITROGEN (NO)

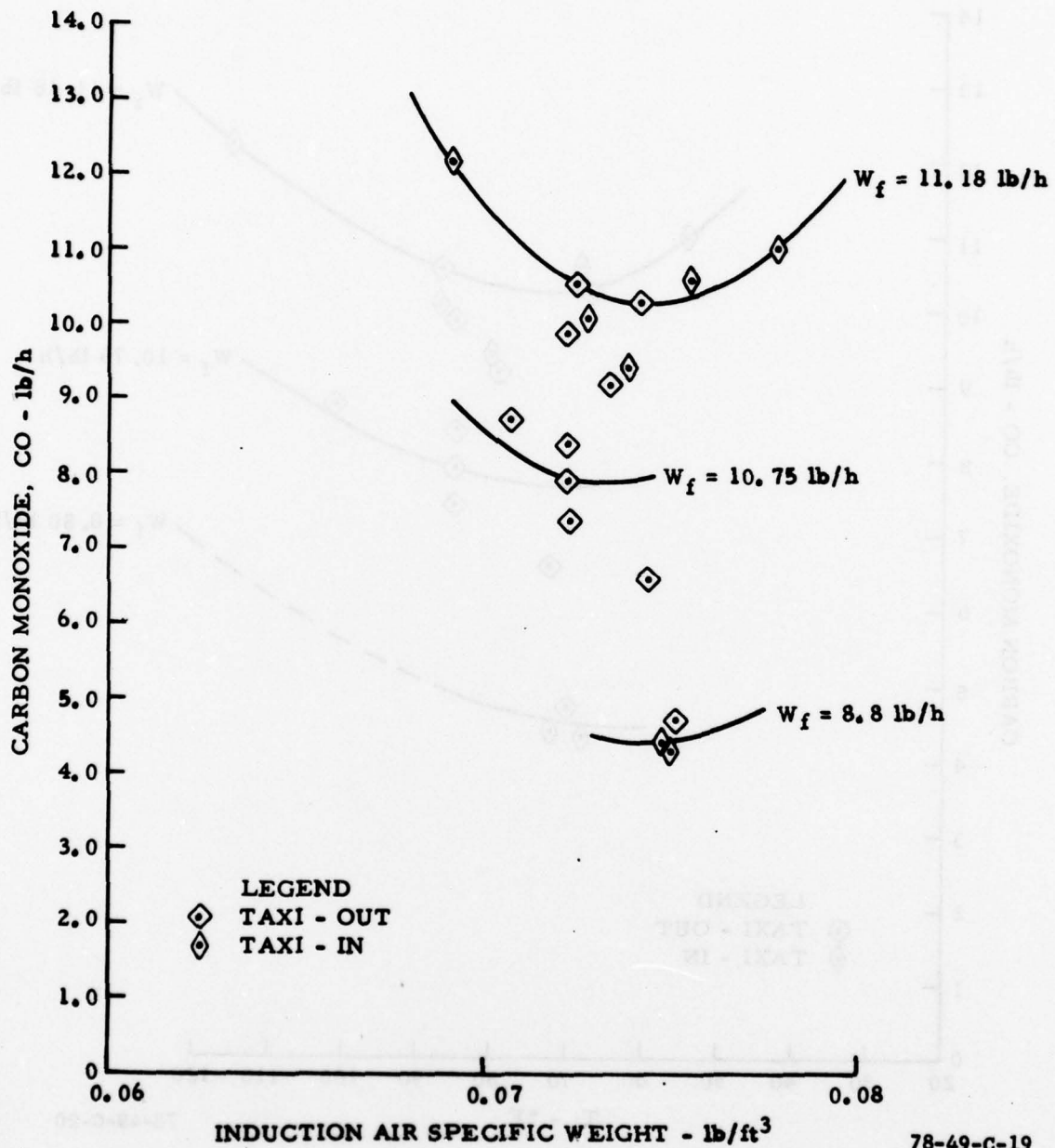


FIGURE C-19. TAXI MODE EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT

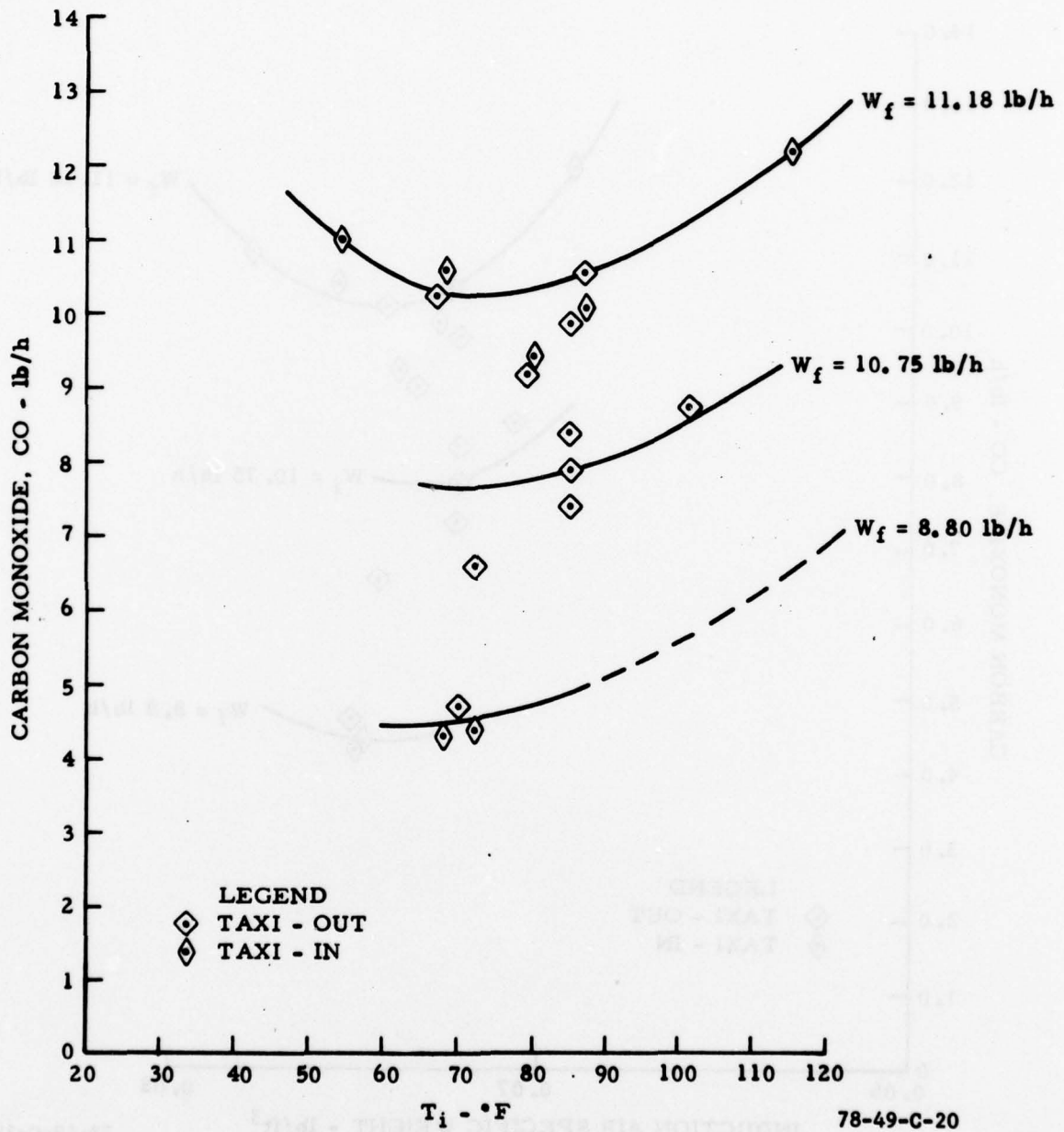
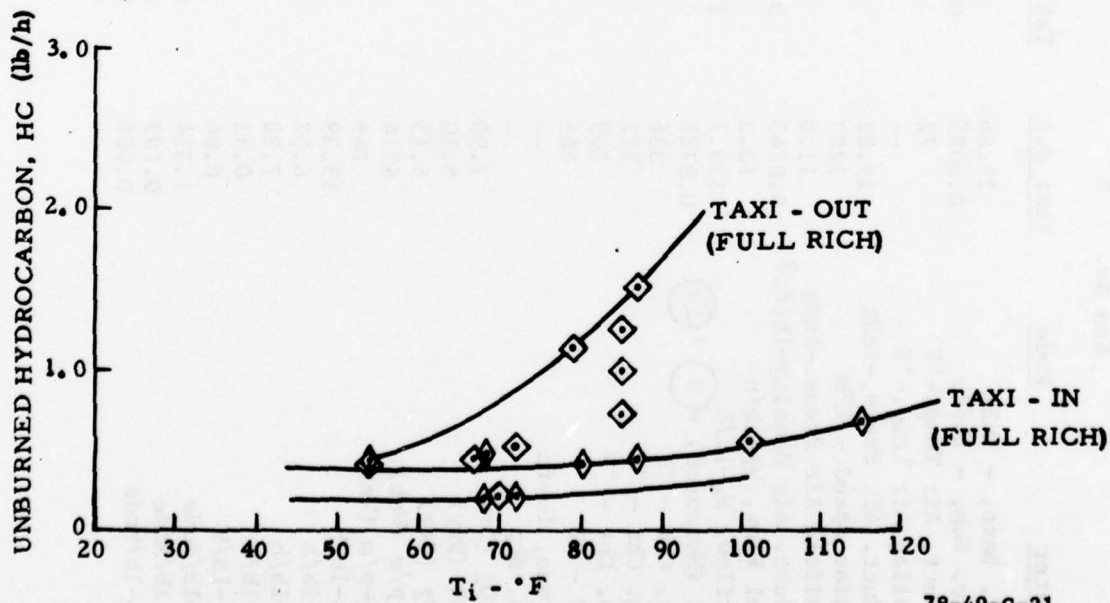
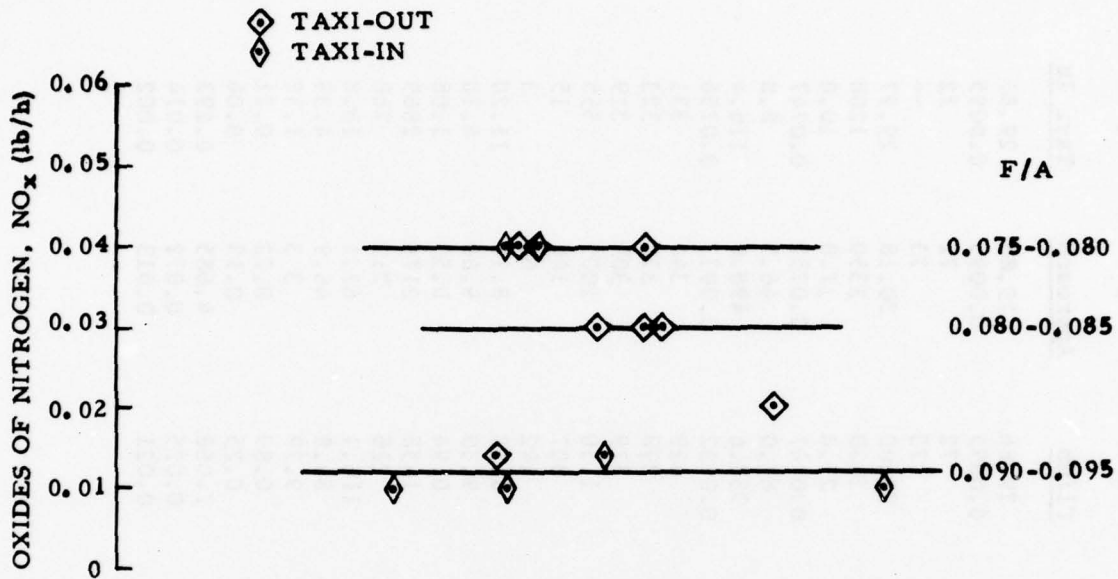


FIGURE C-20. TAXI MODE EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE WITH VARYING AMBIENT (OR INDUCTION) AIR TEMPERATURES (CO)



78-49-C-21

FIGURE C-21. TAXI MODE EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-360-A1B6D ENGINE WITH VARYING AMBIENT (OR INDUCTION) AIR TEMPERATURES (HC AND NO_x)

TABLE C-1. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--BASELINE 1
(NO IDLE, FIVE-MODE) SPARK SETTING 25° BTC

| Parameter | Mode | Run No. | | | | | |
|---|------|----------|---------|--------|----------|---------|--|
| | | 2 | 3 | 4 | 5 | 6 | |
| | | Taxi Out | Takeoff | Climb | Approach | Taxi In | |
| 1. Act. Baro. - inHg | | 29.86 | 29.86 | 29.86 | 29.86 | 29.86 | |
| 2. Spec. Hum. - lb/lb | | 0.0095 | 0.0095 | 0.0095 | 0.0095 | 0.0095 | |
| 3. Induct. Air Temp. - °F | | 72 | 72 | 72 | 72 | 72 | |
| 4. Cooling Air Temp. - °F | | -- | 74 | 73 | 73 | -- | |
| 5. Induct. Air Press. - inHg | | 29.82 | 29.86 | 30.00 | 30.18 | 29.97 | |
| 6. Engine Speed - RPM | | 1200 | 2700 | 2430 | 2350 | 1200 | |
| 7. Manifold Air Press. - inHg | | 11.0 | 29.1 | 27.0 | 17.0 | 10.0 | |
| 8. Induct. Air Density - lb/ft ³ | | 0.0743 | 0.0744 | 0.0747 | 0.0752 | 0.0747 | |
| 9. Fuel Flow, W _f - lb/h | | 10.2 | 113.0 | 87.0 | 46.5 | 8.8 | |
| 10. Airflow, W _a - lb/h | | 130.7 | 1178.6 | 933.6 | 498.6 | 116.4 | |
| 11. F/A (Measured) = 9 / 10 | | 0.0780 | 0.0959 | 0.0932 | 0.0933 | 0.0756 | |
| 12. Max. Cht - °F | | 336 | 441 | 429 | 346 | 331 | |
| 13. Avg. Cht - °F | | 327 | 422 | 398 | 322 | 323 | |
| 14. Min. Cht - °F | | 309 | 411 | 379 | 309 | 319 | |
| 15. EGT - °F | | 465 | 1240 | 1150 | 1005 | 555 | |
| 16. Torque, lb-ft | | -- | 340 | 307 | 140 | 15 | |
| 17. Obs. Bhp | | -- | 175 | 142 | 63 | 3 | |
| 18. % CO ₂ (Dry) | | 7.90 | 8.10 | 8.10 | 8.10 | 11.20 | |
| 19. % CO (Dry) | | 5.30 | 9.90 | 9.30 | 9.60 | 4.10 | |
| 20. % O ₂ (Dry) | | 5.15 | 0.39 | 0.94 | 0.59 | 1.08 | |
| 21. HC-p/m (Wet) | | 6314 | 1570 | 1458 | 2179 | 2869 | |
| 22. NO _x -p/m (Wet) | | 246 | 187 | 216 | 211 | 268 | |
| 23. CO ₂ -lb/h | | 15.39 | 147.4 | 116.1 | 62.1 | 18.8 | |
| 24. CO-lb/h | | 6.57 | 114.7 | 84.8 | 46.9 | 4.39 | |
| 25. O ₂ -lb/h | | 7.30 | 5.16 | 9.79 | 3.3 | 1.32 | |
| 26. HC-lb/h | | 0.51 | 1.23 | 0.89 | 0.72 | 0.21 | |
| 27. NO _x -lb/h | | 0.04 | 0.27 | 0.25 | 0.13 | 0.04 | |
| 28. CO-lb/Mode | | 1.314 | 0.573 | 7.068 | 4.685 | 0.293 | |
| 29. HC-lb/Mode | | 0.103 | 0.006 | 0.075 | 0.072 | 0.014 | |
| 30. NO _x -lb/Mode | | 0.008 | 0.001 | 0.021 | 0.013 | 0.002 | |

TABLE C-2. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--BASELINE 2--
 RUN NOS. 29 THROUGH 33

| Parameter | Mode | Run No. | 29 | 30 | 31 | 32 | 33 |
|---|------|---------|--------|--------|--------|--------|--------|
| 1. Act. Baro. - inHg | | | 29.86 | 29.86 | 29.86 | 29.86 | 29.86 |
| 2. Spec. Hum. - lb/lb | | | 0.0080 | 0.0080 | 0.0080 | 0.0080 | 0.0080 |
| 3. Induct. Air Temp. - °F | | | 87 | 87 | 87 | 87 | 87 |
| 4. Cooling Air Temp. - °F | | | -- | 91 | 90 | 91 | -- |
| 5. Induct. Air Press. - inHg | | | 29.85 | 29.84 | 30.00 | 30.17 | 29.95 |
| 6. Engine Speed - RPM | | | 1200 | 2700 | 2430 | 2350 | 1200 |
| 7. Manifold Air Press. - inHg | | | 11.5 | 29.1 | 27.0 | 17.0 | 10.0 |
| 8. Induct. Air Density - lb/ft ³ | | | 0.0723 | 0.0723 | 0.0726 | 0.0731 | 0.0726 |
| 9. Fuel Flow, Wf - lb/h | | | 12.6 | 112.0 | 85.0 | 44.5 | 10.6 |
| 10. Airflow, Wa - lb/h | | | 133.8 | 1160.6 | 909.6 | 479.9 | 115.4 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | | 0.0942 | 0.0965 | 0.0934 | 0.0927 | 0.0919 |
| 12. Max. Cht - °F | | | 333 | 447 | 437 | 368 | 323 |
| 13. Avg. Cht - °F | | | 330 | 428 | 410 | 340 | 315 |
| 14. Min. Cht - °F | | | 327 | 417 | 394 | 325 | 311 |
| 15. EGT - °F | | | 545 | 1258 | 1150 | 1010 | 554 |
| 16. Torque, lb-ft | | | 21 | 349 | 304 | 148 | 18 |
| 17. Obs. Bhp | | | 5 | 179 | 141 | 66 | 4 |
| 18. % CO ₂ (Dry) | | | 6.96 | 8.23 | 8.23 | 8.29 | 8.33 |
| 19. % CO (Dry) | | | 7.94 | 9.83 | 9.14 | 9.39 | 8.98 |
| 20. % O ₂ (Dry) | | | 5.30 | 0.62 | 1.15 | 0.87 | 0.61 |
| 21. HC-p/m (Wet) | | | 17117 | 1597 | 1559 | 1979 | 6025 |
| 22. NO _x -p/m (Wet) | | | 202 | 191 | 222 | 224 | 80 |
| 23. CO ₂ -lb/h | | | 14.50 | 148.2 | 115.2 | 61.4 | 14.66 |
| 24. CO-lb/h | | | 10.52 | 112.6 | 81.4 | 44.2 | 10.06 |
| 25. O ₂ -lb/h | | | 8.03 | 8.12 | 11.7 | 4.68 | 0.78 |
| 26. HC-lb/h | | | 1.51 | 1.23 | 0.93 | 0.62 | 0.45 |
| 27. NO _x -lb/h | | | 0.03 | 0.28 | 0.25 | 0.13 | 0.01 |
| 28. CO-lb/Mode | | | 2.105 | 0.563 | 6.785 | 4.424 | 0.671 |
| 29. HC-lb/Mode | | | 0.302 | 0.006 | 0.078 | 0.062 | 0.030 |
| 30. NO _x -lb/Mode | | | 0.007 | 0.001 | 0.021 | 0.013 | 0.001 |

TABLE C-3. AVCO LYCOMING IO-360-A1B6D ENGINE NAPEC TEST DATA--BASELINE 3---
 RUN NOS. 137 THROUGH 141 (DRY BOTTLED AIR)

| Parameter | Mode | Run No. | 140 | 141 | 142 | 143 | 144 |
|---|------|---------|----------|---------|--------|----------|---------|
| | | | Taxi Out | Takeoff | Climb | Approach | Taxi In |
| 1. Act. Baro. - inHg | | | 30.07 | 30.07 | 30.07 | 30.07 | 30.07 |
| 2. Spec. Hum. - lb/lb | | | -- | -- | -- | -- | -- |
| 3. Induct. Air Temp. - °F | | | 54 | 54 | 53 | 54 | 54 |
| 4. Cooling Air Temp. - °F | | | -- | 53 | 53 | 53 | -- |
| 5. Induct. Air Press. - inHg | | | 30.12 | 29.94 | 30.08 | 30.30 | 30.13 |
| 6. Engine Speed - RPM | | | 1200 | 2700 | 2430 | 2300 | 1200 |
| 7. Manifold Air Press. - inHg | | | 10.0 | 29.0 | 27.0 | 17.0 | 9.8 |
| 8. Induct. Air Density - lb/ft ³ | | | 0.0777 | 0.0772 | 0.0777 | 0.0781 | 0.0777 |
| 9. Fuel Flow, W _f - lb/h | | | 11.6 | 115.0 | 89.0 | 45.5 | 10.6 |
| 10. Airflow, W _a - lb/h | | | 122.0 | 1200.6 | 972.6 | 514.1 | 120.5 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | | 0.0951 | 0.0958 | 0.0915 | 0.0885 | 0.0880 |
| 12. Max. Cht - °F | | | 335 | 445 | 429 | 332 | 306 |
| 13. Avg. Cht - °F | | | 331 | 421 | 402 | 307 | 298 |
| 14. Min. Cht - °F | | | 327 | 407 | 385 | 293 | 292 |
| 15. EGT - °F | | | 509 | 1256 | 1157 | 950 | 518 |
| 16. Torque, lb-ft | | | 30 | 369 | 330 | 156 | 33 |
| 17. Obs. Bhp | | | 7 | 190 | 153 | 68 | 8 |
| 18. % CO ₂ (Dry) | | | 7.73 | 8.23 | 8.39 | 7.92 | 7.55 |
| 19. % CO (Dry) | | | 9.26 | 9.24 | 8.45 | 9.01 | 9.41 |
| 20. % O ₂ (Dry) | | | 9.15 | 0.08 | 0.14 | 0.14 | 0.15 |
| 21. HC-p/m (Wet) | | | 4983 | 1750 | 1433 | 2132 | 5642 |
| 22. NO _x -p/m (Wet) | | | 82 | 204 | 259 | 216 | 68 |
| 23. CO ₂ -lb/h | | | 14.40 | 152.6 | 123.3 | 61.9 | 13.90 |
| 24. CO-lb/h | | | 10.98 | 108.3 | 79.0 | 44.8 | 11.02 |
| 25. O ₂ -lb/h | | | 0.20 | 1.07 | 1.50 | 0.80 | 0.20 |
| 26. HC-lb/h | | | 0.40 | 1.38 | 0.91 | 0.71 | 0.44 |
| 27. NO _x -lb/h | | | 0.01 | 0.30 | 0.31 | 0.13 | 0.01 |
| 28. CO-lb/Mode | | | 2.196 | 0.541 | 6.541 | 4.483 | 0.735 |
| 29. HC-lb/Mode | | | 0.081 | 0.007 | 0.076 | 0.071 | 0.029 |
| 30. NO _x -lb/Mode | | | 0.002 | 0.002 | 0.026 | 0.013 | 0.001 |

TABLE C-4. AVCO LYCOMING IO-360-A1B6D ENGINE NAPEC TEST DATA--BASELINE 4--
 RUN NOS. 909 THROUGH 913

| Parameter | Mode | Run No. | 909 | 910 | 911 | 912 | 913 |
|---|------|---------|--------|--------|--------|--------|--------|
| 1. Act. Baro. - inHg | | | 29.90 | 29.90 | 29.90 | 29.90 | 29.90 |
| 2. Spec. Hum. - lb/lb | | | 0.0075 | 0.0075 | 0.0075 | 0.0075 | 0.0075 |
| 3. Induct. Air Temp. - °F | | | 70 | 68 | 68 | 68 | 68 |
| 4. Cooling Air Temp. - °F | | | -- | 69 | 70 | 69 | -- |
| 5. Induct. Air Press. - inHg | | | 30.01 | 29.90 | 30.04 | 30.03 | 29.85 |
| 6. Engine Speed - RPM | | | 1200 | 2700 | 2430 | 2350 | 1200 |
| 7. Manifold Air Press. - inHg | | | 10.1 | 29.1 | 27.0 | 17.0 | 10.0 |
| 8. Induct. Air Density - lb/ft ³ | | | 0.0750 | 0.0750 | 0.0754 | 0.0754 | 0.0749 |
| 9. Fuel Flow, Wf - lb/h | | | 8.7 | 113.0 | 88.0 | 46.5 | 8.8 |
| 10. Airflow, Wa - lb/h | | | 114.9 | 1189.5 | 945.8 | 513.8 | 114.5 |
| 11. F/A (Measured) = 9 / 10 | | | 0.0757 | 0.0950 | 0.0930 | 0.0905 | 0.0769 |
| 12. Max. Cht - °F | | | 361 | 436 | 432 | 347 | 363 |
| 13. Avg. Cht - °F | | | 351 | 416 | 399 | 318 | 353 |
| 14. Min. Cht - °F | | | 338 | 406 | 380 | 304 | 347 |
| 15. EGT - °F | | | 554 | 1256 | 1157 | 1004 | 554 |
| 16. Torque, lb-ft | | | 26 | 375 | -- | -- | -- |
| 17. Obs. Bhp | | | 6 | 193 | -- | -- | -- |
| 18. % CO ₂ (Dry) | | | 11.30 | 8.30 | 8.40 | 8.40 | 11.40 |
| 19. % CO (Dry) | | | 4.40 | 9.60 | 8.90 | 9.20 | 4.10 |
| 20. % O ₂ (Dry) | | | 1.03 | 0.42 | 0.79 | 0.63 | 0.99 |
| 21. HC-p/m (Wet) | | | 2739 | 1579 | 1461 | 1940 | 2566 |
| 22. NO _x -p/m (Wet) | | | 296 | 206 | 245 | 240 | 316 |
| 23. CO ₂ -lb/h | | | 18.9 | 152.2 | 121.3 | 65.8 | 18.9 |
| 24. CO-lb/h | | | 4.7 | 112.0 | 81.8 | 45.9 | 4.3 |
| 25. O ₂ -lb/h | | | 1.3 | 5.60 | 8.30 | 3.6 | 1.2 |
| 26. HC-lb/h | | | 0.2 | 1.25 | 0.91 | 0.65 | 0.2 |
| 27. NO _x -lb/h | | | 0.04 | 0.30 | 0.29 | 0.15 | 0.04 |
| 28. CO-lb/Mode | | | 0.937 | 0.560 | 6.818 | 4.590 | 0.288 |
| 29. HC-lb/Mode | | | 0.039 | 0.006 | 0.076 | 0.065 | 0.012 |
| 30. NO _x -lb/Mode | | | 0.008 | 0.002 | 0.024 | 0.015 | 0.003 |

TABLE C-5. AVCO LYCOMING IO-360-A1B6D ENGINE NAFC TEST DATA--BASELINE 5--
 RUN NOS. 104 THROUGH 108 (HOT AIR)

| Parameter | Mode | Run No. | 104 | 105 | 106 | 107 | 108 |
|---|------|---------|--------|--------|--------|--------|--------|
| 1. Act. Baro. - inHg | | | 29.73 | 29.73 | 29.73 | 29.73 | 29.73 |
| 2. Spec. Hum. - lb/lb | | | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 |
| 3. Induct. Air Temp. - °F | | | 101 | 119 | 121 | 120 | 115 |
| 4. Cooling Air Temp. - °F | | | 122 | 122 | 122 | 123 | 123 |
| 5. Induct. Air Press. - inHg | | | 29.89 | 29.75 | 29.92 | 30.148 | 29.92 |
| 6. Engine Speed - RPM | | | 1200 | 2700 | 2430 | 2275 | 1200 |
| 7. Manifold Air Press. - inHg | | | 10.5 | 29.2 | 27.0 | 17.0 | 10.5 |
| 8. Induct. Air Density - lb/ft ³ | | | 0.0706 | 0.0681 | 0.0682 | 0.0689 | 0.0690 |
| 9. Fuel Flow, Wf - lb/h | | | 11.0 | 112.0 | 86.0 | 43.0 | 11.6 |
| 10. Airflow, Wa - lb/h | | | 129.9 | 1146.2 | 929.9 | 471.6 | 123.5 |
| 11. F/A (Measured) = 9 / 10 | | | 0.0847 | 0.0977 | 0.0925 | 0.0912 | 0.0939 |
| 12. Max. Cht - °F | | | 259 | 433 | 423 | 352 | 277 |
| 13. Avg. Cht - °F | | | 247 | 419 | 402 | 330 | 265 |
| 14. Min. Cht - °F | | | 241 | 413 | 388 | 318 | 260 |
| 15. EGT - °F | | | 536 | 1220 | 1112 | 932 | 572 |
| 16. Torque, lb-ft | | | -- | 340 | 300 | 140 | -- |
| 17. Obs. Bhp | | | -- | 175 | 139 | 61 | -- |
| 18. % CO ₂ (Dry) | | | 8.66 | 7.65 | 7.73 | 7.43 | 7.52 |
| 19. % CO (Dry) | | | 6.97 | 10.56 | 9.94 | 10.27 | 9.93 |
| 20. % O ₂ (Dry) | | | 2.95 | 0.76 | 1.19 | 1.28 | 1.58 |
| 21. HC-p/m (Wet) | | | 6530 | 1799 | 1714 | 2431 | 8249 |
| 22. NO _x -p/m (Wet) | | | 122 | 143 | 170 | 141 | 77 |
| 23. CO ₂ -lb/h | | | 16.99 | 137.4 | 54.7 | 54.7 | 14.46 |
| 24. CO-lb/h | | | 8.71 | 120.7 | 91.4 | 48.1 | 12.16 |
| 25. O ₂ -lb/h | | | 4.21 | 9.93 | 6.74 | 6.85 | 2.21 |
| 26. HC-lb/h | | | 0.54 | 1.38 | 1.05 | 0.75 | 0.67 |
| 27. NO _x -lb/h | | | 0.02 | 0.20 | 0.19 | 0.08 | 0.01 |
| 28. CO-lb/Mode | | | 1.741 | 0.604 | 7.617 | 4.609 | 0.810 |
| 29. HC-lb/Mode | | | 0.108 | 0.007 | 0.087 | 0.075 | 0.045 |
| 30. NO _x -lb/Mode | | | 0.004 | 0.001 | 0.016 | 0.008 | 0.001 |

TABLE C-6. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--BASELINE 6--
 RUN NOS. 923 THROUGH 927

| Parameter | Mode | Run No. | 923 | 924 | 925 | 926 | 927 |
|---|------|---------|--------|--------|--------|--------|--------|
| 1. Act. Baro. - inHg | | | 29.91 | 29.91 | 29.91 | 29.91 | 29.91 |
| 2. Spec. Hum. - lb/lb | | | 0.0075 | 0.0075 | 0.0075 | 0.0075 | 0.0075 |
| 3. Induct. Air Temp. - °F | | | 79 | 79 | 80 | 80 | 80 |
| 4. Cooling Air Temp. - °F | | | 119 | 79 | 80 | 81 | 108 |
| 5. Induct. Air Press. - inHg | | | 29.79 | 29.90 | 30.05 | 30.22 | 30.01 |
| 6. Engine Speed - RPM | | | 1200 | 2700 | 2430 | 2350 | 1200 |
| 7. Manifold Air Press. - inHg | | | 11.4 | 29.0 | 27.0 | 17.0 | 10.1 |
| 8. Induct. Air Density - lb/ft ³ | | | 0.0732 | 0.0735 | 0.0737 | 0.0742 | 0.0737 |
| 9. Fuel Flow, W _f - lb/h | | | 11.95 | 113.0 | 87.0 | 45.5 | 10.60 |
| 10. Airflow, W _a - lb/h | | | 134.2 | 1169.0 | 927.4 | 518.1 | 114.8 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | | 0.0890 | 0.0967 | 0.0938 | 0.0878 | 0.0923 |
| 12. Max. Cht - °F | | | 357 | 414 | 428 | 365 | 333 |
| 13. Avg. Cht - °F | | | 343 | 399 | 400 | 336 | 322 |
| 14. Min. Cht - °F | | | 327 | 392 | 380 | 322 | 313 |
| 15. EGT - °F | | | 536 | 1238 | 1148 | 1004 | 545 |
| 16. Torque, lb-ft | | | 20 | 357 | 312 | 151 | 28 |
| 17. Obs. Bhp | | | 5 | 184 | 144 | 68 | 6 |
| 18. % CO ₂ (Dry) | | | 7.34 | 8.24 | 8.29 | 8.26 | 8.71 |
| 19. % CO (Dry) | | | 7.11 | 9.71 | 9.07 | 9.38 | 8.44 |
| 20. % O ₂ (Dry) | | | 3.89 | 0.61 | 1.09 | 0.85 | 1.11 |
| 21. HC-p/m (Wet) | | | 12,735 | 1679 | 1517 | 2040 | 5264 |
| 22. NO _x -p/m (Wet) | | | 186 | 193 | 229 | 228 | 101 |
| 23. CO ₂ -lb/h | | | 14.88 | 149.1 | 118.2 | 66.0 | 15.26 |
| 24. CO-lb/h | | | 9.17 | 111.9 | 82.3 | 47.7 | 9.41 |
| 25. O ₂ -lb/h | | | 5.73 | 8.03 | 11.3 | 4.94 | 1.41 |
| 26. HC-lb/h | | | 1.13 | 1.31 | 0.93 | 0.68 | 0.40 |
| 27. NO _x -lb/h | | | 0.03 | 0.28 | 0.26 | 0.14 | 0.014 |
| 28. CO-lb/Mode | | | 1.835 | 0.559 | 6.858 | 4.769 | 0.627 |
| 29. HC-lb/Mode | | | 0.226 | 0.007 | 0.077 | 0.068 | 0.0265 |
| 30. NO _x -lb/Mode | | | 0.006 | 0.001 | 0.022 | 0.014 | 0.001 |

TABLE C-7. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--TAKEOFF--
T.O. MODE--RUN NOS. 16 THROUGH 19

| Parameter | Mode | Run No. | | | |
|---|------|---------|---------|---------|---------|
| | | 16 | 17 | 18 | 19 |
| | | Takeoff | Takeoff | Takeoff | Takeoff |
| 1. Act. Baro. - inHg | | 29.91 | 29.91 | 29.91 | 29.91 |
| 2. Spec. Hum. - lb/lb | | 0.0080 | 0.0080 | 0.0080 | 0.0080 |
| 3. Induct. Air Temp. - °F | | 81 | 81 | 81 | 81 |
| 4. Cooling Air Temp. - °F | | 81 | 81 | 82 | 82 |
| 5. Induct. Air Press. - inHg | | 29.90 | 29.90 | 29.90 | 29.91 |
| 6. Engine Speed - RPM | | 2700 | 2700 | 2700 | 2700 |
| 7. Manifold Air Press. - inHg | | 29.1 | 29.1 | 29.1 | 29.1 |
| 8. Induct. Air Density - lb/ft ³ | | 0.0732 | 0.0732 | 0.0732 | 0.0733 |
| 9. Fuel Flow, W _f - lb/h | | 113.0 | 108.0 | 103.0 | 98.0 |
| 10. Airflow, W _a - lb/h | | 1175.1 | 1169.1 | 1181.2 | 1163.7 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | 0.0962 | 0.0924 | 0.0872 | 0.0842 |
| 12. Max. Cht - °F | | 441 | 452 | 462 | 471 |
| 13. Avg. Cht - °F | | 423 | 432 | 442 | 451 |
| 14. Min. Cht - °F | | 413 | 423 | 431 | 442 |
| 15. EGT - °F | | 1256 | 1285 | 1310 | 1335 |
| 16. Torque, lb-ft | | 352 | 354 | 353 | 354 |
| 17. Obs. Bhp | | 181 | 182 | 181.5 | 182 |
| 18. % CO ₂ (Dry) | | 8.20 | 8.81 | 9.44 | 10.12 |
| 19. % CO (Dry) | | 9.80 | 8.74 | 7.93 | 6.76 |
| 20. % O ₂ (Dry) | | 0.65 | 0.68 | 0.53 | 0.59 |
| 21. HC-p/m (Wet) | | 1646 | 1406 | 1436 | 1288 |
| 22. NO _x -p/m (Wet) | | 191 | 267 | 365 | 534 |
| 23. CO ₂ -lb/h | | 149.4 | 157.3 | 168.5 | 175.4 |
| 24. CO-lb/h | | 113.6 | 99.3 | 90.1 | 74.6 |
| 25. O ₂ -lb/h | | 8.61 | 8.83 | 6.88 | 7.44 |
| 26. HC-lb/h | | 1.29 | 1.08 | 1.09 | 0.95 |
| 27. NO _x -lb/h | | 0.28 | 0.38 | 0.52 | 0.74 |
| 28. CO-lb/Mode | | 0.568 | 0.497 | 0.450 | 0.373 |
| 29. HC-lb/Mode | | 0.006 | 0.005 | 0.005 | 0.005 |
| 30. NO _x -lb/Mode | | 0.001 | 0.002 | 0.003 | 0.004 |

TABLE C-8. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--T.O. MODE--RUN NOS. 167 THROUGH 174
(AMBIENT AND DRY BOTTLED AIR)

| Parameter | Mode | Run No. | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 |
|---|------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| | | | Takeoff | Takeoff | Takeoff | Takeoff | Takeoff | Takeoff | Takeoff | Takeoff |
| 1. Act. Baro. - inHg | | | 30.05 | 30.05 | 30.05 | 30.05 | 30.05 | 30.05 | 30.05 | 30.05 |
| 2. Spec. Hum. - lb/lb | | | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0010 |
| 3. Induct. Air Temp. - °F | | | 56 | 53 | 55 | 52 | 55 | 51 | 55 | 52 |
| 4. Cooling Air Temp. - °F | | | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 |
| 5. Induct. Air Press. - inHg | | | 30.02 | 29.92 | 30.04 | 29.92 | 30.04 | 29.94 | 30.04 | 29.94 |
| 6. Engine Speed - RPM | | | 2700 | 2700 | 2700 | 2700 | 2700 | 2700 | 2700 | 2700 |
| 7. Manifold Air Press. - inHg | | | 19.0 | 19.0 | 29.0 | 29.0 | 29.0 | 29.0 | 29.0 | 29.0 |
| 8. Induct. Air Density - lb/ft ³ | | | 0.0771 | 0.0773 | 0.0773 | 0.0774 | 0.0773 | 0.0776 | 0.0773 | 0.0775 |
| 9. Fuel Flow, W _f - lb/h | | | 115.0 | 115.0 | 110.0 | 110.0 | 105.0 | 105.0 | 100.0 | 100.0 |
| 10. Airflow, W _a - lb/h | | | 1206.0 | 1201.3 | 1207.6 | 1212.1 | 1202.6 | 1209.9 | 1207.6 | 1194.1 |
| 11. F/A (Measured) - (9) / (10) | | | 0.0954 | 0.0957 | 0.0911 | 0.0908 | 0.0873 | 0.0868 | 0.0828 | 0.0837 |
| 12. Max. Cht - °F | | | 440 | 445 | 455 | 456 | 467 | 468 | 475 | 478 |
| 13. Avg. Cht - °F | | | 416 | 420 | 432 | 432 | 441 | 442 | 450 | 453 |
| 14. Min. Cht - °F | | | 401 | 405 | 416 | 416 | 425 | 427 | 438 | 440 |
| 15. EGT - °F | | | 1238 | 1256 | 1274 | 1274 | 1321 | 1321 | 1335 | 1335 |
| 16. Torque, lb-ft | | | 376 | 373 | 377 | 372 | 375 | 374 | 375 | 374 |
| 17. Obs. Bhp | | | 193 | 192 | 194 | 191 | 193 | 192 | 193 | 192 |
| 18. % CO ₂ (Dry) | | | 7.67 | 7.57 | 8.42 | 8.31 | 9.16 | 9.02 | 9.93 | 9.76 |
| 19. % CO (Dry) | | | 9.33 | 9.36 | 8.17 | 8.22 | 6.99 | 7.09 | 5.88 | 5.98 |
| 20. % O ₂ (Dry) | | | 0.83 | 0.82 | 0.90 | 0.81 | 0.91 | 0.80 | 0.80 | 0.74 |
| 21. HC-p/m (Wet) | | | 1719 | 1695 | 1515 | 1523 | 1358 | 1389 | 1240 | 1285 |
| 22. NO _x -p/m (Wet) | | | 209 | 203 | 313 | 303 | 469 | 449 | 688 | 662 |
| 23. CO ₂ -lb/h | | | 142.2 | 139.7 | 154.2 | 152.7 | 164.7 | 163.1 | 176.9 | 172.0 |
| 24. CO-lb/h | | | 110.1 | 110.0 | 95.2 | 96.1 | 80.0 | 81.6 | 66.7 | 67.1 |
| 25. O ₂ -lb/h | | | 11.2 | 11.0 | 12.0 | 10.8 | 11.9 | 10.5 | 10.4 | 9.48 |
| 26. HC-lb/h | | | 1.37 | 1.35 | 1.19 | 1.20 | 1.05 | 1.08 | 0.95 | 0.98 |
| 27. NO _x -lb/h | | | 0.31 | 0.30 | 0.46 | 0.45 | 0.68 | 0.65 | 0.98 | 0.94 |
| 28. CO-lb/Mode | | | 0.551 | 0.550 | 0.476 | 0.481 | 0.400 | 0.408 | 0.333 | 0.335 |
| 29. HC-lb/Mode | | | 0.007 | 0.007 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 |
| 30. NO _x -lb/Mode | | | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.005 | 0.005 |

TABLE C-9. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--CLIMB
MODE--RUN NOS. 20 THROUGH 23

| Parameter | Mode | Run No. | | |
|---|------|---------|--------|--------|
| | | 20 | 20 | 23 |
| 1. Act. Baro. - inHg | | 29.86 | 29.86 | 29.86 |
| 2. Spec. Hum. - lb/lb | | 0.0080 | 0.0080 | 0.0080 |
| 3. Induct. Air Temp.-°F | | 87 | 87 | 87 |
| 4. Cooling Air Temp.-°F | | 89 | 90 | 90 |
| 5. Induct. Air Press.-inHg | | 29.99 | 29.99 | 29.99 |
| 6. Engine Speed - RPM | | 2430 | 2430 | 2430 |
| 7. Manifold Air Press.-inHg | | 27.0 | 27.0 | 27.0 |
| 8. Induct. Air Density-lb/ft ³ | | 0.0727 | 0.0727 | 0.0727 |
| 9. Fuel Flow, W _f -lb/h | | 86.0 | 81.0 | 71.0 |
| 10. Airflow, W _a -lb/h | | 921.1 | 921.1 | 918.0 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | 0.0934 | 0.0879 | 0.0773 |
| 12. Max. Cht - °F | | 411 | 417 | 433 |
| 13. Avg. Cht - °F | | 388 | 392 | 409 |
| 14. Min. Cht - °F | | 374 | 375 | 392 |
| 15. EGT - °F | | 1150 | 1170 | 1240 |
| 16. Torque, lb-ft | | 306 | 309 | 310 |
| 17. Obs. Bhp | | 142 | 143 | 143 |
| 18. % CO ₂ (Dry) | | 8.04 | 9.28 | 11.11 |
| 19. % CO (Dry) | | 9.21 | 7.58 | 4.14 |
| 20. % O ₂ (Dry) | | 1.10 | 1.30 | 1.80 |
| 21. HC-p/m (Wet) | | 1576 | 1324 | 924 |
| 22. NO _x -p/m (Wet) | | 217 | 363 | 1192 |
| 23. CO ₂ -lb/h | | 113.8 | 129.2 | 148.8 |
| 24. CO-lb/h | | 83.0 | 67.2 | 35.3 |
| 25. O ₂ -lb/h | | 11.3 | 13.2 | 17.5 |
| 26. HC-lb/h | | 0.96 | 0.79 | 0.53 |
| 27. NO _x -lb/h | | 0.25 | 0.40 | 1.27 |
| 28. CO-lb/Mode | | 6.913 | 5.599 | 2.941 |
| 29. HC-lb/Mode | | 0.080 | 0.066 | 0.044 |
| 30. NO _x -lb/Mode | | 0.021 | 0.034 | 0.106 |

TABLE C-10. AVCO LYCOMING IO-360-ALB6D ENGINE NAFEC TEST DATA--CLIMB MODE--RUN NOS. 159 THROUGH 166
(AMBIENT AND DRY BOTTLES AIR)

| Parameter | Mode | Run No. | | | | | | | |
|---|------|---------|--------|--------|--------|--------|--------|--------|--------|
| | | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 |
| 1. Act. Baro. - inHg | | 30.04 | 30.04 | 30.04 | 30.04 | 30.04 | 30.04 | 30.04 | 30.05 |
| 2. Spec. Hum. - lb/lb | | 0.0035 | --- | 0.0035 | --- | 0.0035 | --- | 0.0035 | 0.0030 |
| 3. Induct. Air Temp. - °F | | 57 | 58 | 56 | 55 | 56 | 54 | 56 | 52 |
| 4. Cooling Air Temp. - °F | | 53 | 53 | 52 | 53 | 53 | 53 | 53 | 53 |
| 5. Induct. Air Press. - inHg | | 30.16 | 30.08 | 30.16 | 30.08 | 30.16 | 30.08 | 30.16 | 30.09 |
| 6. Engine Speed - RPM | | 2430 | 2430 | 2430 | 2430 | 2430 | 2430 | 2430 | 2430 |
| 7. Manifold Air Press. - inHg | | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 |
| 8. Induct. Air Density - lb/ft ³ | | 0.0773 | 0.0770 | 0.0775 | 0.0774 | 0.0775 | 0.0776 | 0.0775 | 0.0779 |
| 9. Fuel Flow, W _f -lb/h | | 89.0 | 89.0 | 84.0 | 84.0 | 84.0 | 79.0 | 74.0 | 74.0 |
| 10. Airflow, W _a -lb/h | | 977.8 | 966.7 | 979.1 | 950.4 | 979.1 | 961.1 | 979.1 | 958.2 |
| 11. F/A (Measured) - (9) / (10) | | 0.0910 | 0.0921 | 0.0858 | 0.0884 | 0.0807 | 0.0822 | 0.0756 | 0.0772 |
| 12. Max. Cht - °F | | 417 | 414 | 424 | 423 | 432 | 433 | 439 | 440 |
| 13. Avg. Cht - °F | | 393 | 392 | 400 | 400 | 409 | 410 | 416 | 417 |
| 14. Min. Cht - °F | | 374 | 375 | 384 | 384 | 393 | 392 | 400 | 401 |
| 15. EGT - °F | | 1157 | 1157 | 1184 | 1184 | 1211 | 1211 | 1238 | 1238 |
| 16. Torque, lb-ft | | 336 | 334 | 336 | 336 | 338 | 337 | 339 | 338 |
| 17. Obs. Bhp | | 155.5 | 154.5 | 155.5 | 155.5 | 156.4 | 155.9 | 156.8 | 156.4 |
| 18. % CO ₂ (Dry) | | 8.08 | 7.95 | 8.83 | 8.71 | 9.76 | 9.63 | 10.58 | 10.43 |
| 19. % CO (Dry) | | 8.18 | 8.27 | 6.89 | 6.98 | 5.34 | 5.31 | 3.77 | 3.86 |
| 20. % O ₂ (Dry) | | 1.54 | 1.52 | 1.62 | 1.55 | 1.81 | 1.77 | 2.08 | 2.01 |
| 21. HC-p/m (Wet) | | 1359 | 1437 | 1262 | 1264 | 1047 | 1053 | 884 | 894 |
| 22. NO _x -p/m (Wet) | | 279 | 270 | 442 | 421 | 745 | 735 | 1287 | 1233 |
| 23. CO ₂ -lb/h | | 120.0 | 117.1 | 129.3 | 124.2 | 140.7 | 136.4 | 150.5 | 145.0 |
| 24. CO-lb/h | | 77.3 | 77.5 | 64.2 | 63.3 | 49.0 | 47.9 | 34.1 | 34.2 |
| 25. O ₂ -lb/h | | 16.6 | 16.3 | 17.2 | 16.1 | 19.0 | 18.2 | 21.5 | 20.3 |
| 26. HC-lb/h | | 0.87 | 0.91 | 0.79 | 0.78 | 0.65 | 0.64 | 0.53 | 0.53 |
| 27. NO _x -lb/h | | 0.33 | 0.32 | 0.52 | 0.48 | 0.86 | 0.84 | 1.45 | 1.37 |
| 28. CO-lb/Mode | | 6.443 | 6.461 | 5.354 | 5.277 | 4.083 | 3.990 | 2.844 | 2.847 |
| 29. HC-lb/Mode | | 0.072 | 0.076 | 0.066 | 0.065 | 0.054 | 0.053 | 0.044 | 0.044 |
| 30. NO _x -lb/Mode | | 0.028 | 0.027 | 0.043 | 0.040 | 0.072 | 0.070 | 0.121 | 0.114 |

TABLE C-11. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--
CLIMB MODE--RUN NOS. 122 THROUGH 125 (SEA LEVEL HOT DAY)

| Parameter | Run No. | | | |
|---|---------|--------|--------|--------|
| | 122 | 123 | 124 | 125 |
| 1. Act. Baro. - inHg | 29.60 | 29.60 | 29.60 | 29.60 |
| 2. Spec. Hum. - lb/lb | 0.0110 | 0.0110 | 0.0110 | 0.0110 |
| 3. Induct. Air Temp. - °F | 109 | 113 | 115 | 117 |
| 4. Cooling Air Temp. - °F | 116 | 116 | 117 | 118 |
| 5. Induct. Air Press. - inHg | 29.80 | 29.81 | 29.82 | 29.81 |
| 6. Engine Speed - RPM | 2430 | 2430 | 2430 | 2430 |
| 7. Manifold Air Press. - inHg | 27.0 | 27.0 | 27.0 | 27.0 |
| 8. Induct. Air Density - lb/ft ³ | 0.0694 | 0.0689 | 0.0687 | 0.0685 |
| 9. Fuel Flow, W _f - lb/h | 87.0 | 82.0 | 77.0 | 72.0 |
| 10. Airflow, W _a - lb/h | 917.7 | 911.5 | 910.2 | 911.8 |
| 11. F/A (Measured) - $\frac{9}{10}$ / $\frac{10}{10}$ | 0.0948 | 0.0900 | 0.0846 | 0.0790 |
| 12. Max. Cht - °F | 410 | 428 | 443 | 453 |
| 13. Avg. Cht - °F | 389 | 406 | 421 | 431 |
| 14. Min. Cht - °F | 374 | 388 | 405 | 415 |
| 15. EGT - °F | 1121 | 1139 | 1166 | 1193 |
| 16. Torque, lb-ft | 300 | 301 | 302 | 302 |
| 17. Obs. Bhp | 138.8 | 139.3 | 139.7 | 139.7 |
| 18. % CO ₂ (Dry) | 7.83 | 8.37 | 9.33 | 10.04 |
| 19. % CO (Dry) | 9.71 | 8.68 | 6.93 | 5.65 |
| 20. % O ₂ (Dry) | 1.28 | 1.33 | 1.54 | 1.61 |
| 21. HC-p/m (Wet) | 1750 | 1576 | 1315 | 1111 |
| 22. NO _x -p/m (Wet) | 167 | 232 | 430 | 671 |

TABLE C-12. AVCO LYCOMING IO-360-A1B60 ENGINE NAFEC TEST DATA--APPROACH
 MODE--RUN NOS. 24 THROUGH 27

| Parameter | Mode | Run No. | | | |
|---|------|----------|----------|----------|----------|
| | | 24 | 25 | 26 | 27 |
| | | Approach | Approach | Approach | Approach |
| 1. Act. Baro. - inHg | | 29.85 | 29.85 | 29.85 | 29.85 |
| 2. Spec. Hum. - lb/lb | | 0.0080 | 0.0080 | 0.0080 | 0.0080 |
| 3. Induct. Air Temp. - °F | | 88 | 88 | 88 | 88 |
| 4. Cooling Air Temp. - °F | | 91 | 91 | 91 | 91 |
| 5. Induct. Air Press. - inHg | | 30.15 | 30.16 | 30.16 | 30.16 |
| 6. Engine Speed - RPM | | 2350 | 2350 | 2350 | 2280 |
| 7. Manifold Air Press. - inHg | | 17.0 | 17.0 | 17.0 | 17.0 |
| 8. Induct. Air Density - lb/ft ³ | | 0.0729 | 0.0729 | 0.0729 | 0.0729 |
| 9. Fuel Flow, W _f - lb/h | | 45.0 | 40.0 | 35.0 | 30.0 |
| 10. Airflow, W _a - lb/h | | 493.8 | 490.9 | 490.9 | 476.3 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | 0.0911 | 0.0815 | 0.0713 | 0.0630 |
| 12. Max. Cht - °F | | 342 | 347 | 353 | 326 |
| 13. Avg. Cht - °F | | 317 | 322 | 331 | 318 |
| 14. Min. Cht - °F | | 305 | 311 | 323 | 300 |
| 15. EGT - °F | | 1005 | 1050 | 1130 | 1060 |
| 16. Torque, lb-ft | | 151 | 152 | 151 | 137 |
| 17. Obs. Bhp | | 68 | 68 | 68 | 59.5 |
| 18. % CO ₂ (Dry) | | 8.38 | 10.32 | 12.64 | 12.39 |
| 19. % CO (Dry) | | 9.26 | 6.13 | 2.15 | 0.65 |
| 20. % O ₂ (Dry) | | 0.86 | 0.92 | 1.24 | 3.03 |
| 21. HC-p/m (Wet) | | 2004 | 1427 | 875 | 468 |
| 22. NO _x -p/m (Wet) | | 236 | 714 | 1784 | 1733 |
| 23. CO ₂ -lb/h | | 63.7 | 75.1 | 88.6 | 83.8 |
| 24. CO-lb/h | | 44.8 | 28.4 | 9.60 | 2.80 |
| 25. O ₂ -lb/h | | 4.75 | 4.87 | 6.32 | 14.91 |
| 26. HC-lb/h | | 0.65 | 0.44 | 0.26 | 0.13 |
| 27. NO _x -lb/h | | 0.14 | 0.41 | 0.995 | 0.92 |
| 28. CO-lb/Mode | | 4.480 | 2.838 | 0.960 | 0.280 |
| 29. HC-lb/Mode | | 0.065 | 0.044 | 0.026 | 0.013 |
| 30. NO _x -lb/Mode | | 0.014 | 0.041 | 0.0995 | 0.092 |

TABLE C-13. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA ---APPROACH MODE---
 RUN NOS. 151 THROUGH 158

| Parameter | Mode | Run No. | | | | | | |
|---|------|---------|--------|------------|------------|--------|--------|--------|
| | | 151 | 152 | 153 | 154 | 155 | 156 | 157 |
| 1. Act. Baro. - inHg | | 30.34 | 30.34 | 30.34 | 30.34 | 30.34 | 30.34 | 30.34 |
| 2. Spec. Hum. - lb/lb | | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 | 0.0040 |
| 3. Induct. Air Temp. - °F | | 57 | 58 | 57 | 58 | 56 | 58 | 57 |
| 4. Cooling Air Temp. - °F | | 57 | 57 | 56 | 56 | 57 | 57 | 57 |
| 5. Induct. Air Press. - inHg | | 30.60 | 30.44 | 30.59 | 30.44 | 30.44 | 30.465 | 30.60 |
| 6. Engine Speed - RPM | | 2350 | 2350 | 2350 | 2350 | 2350 | 2275 | 2275 |
| 7. Manifold Air Press. - inHg | | 17.0 | 16.9 | 17.0 | 17.0 | 17.1 | 17.1 | 17.1 |
| 8. Induct. Air Density - lb/ft ³ | | 0.0784 | 0.0779 | 0.0784 | 0.0779 | 0.0782 | 0.0779 | 0.0784 |
| 9. Fuel Flow, W _f - lb/h | | 45.5 | 46.5 | 41.5 | 41.5 | 36.5 | 36.0 | 31.5 |
| 10. Airflow, W _a - lb/h | | 543.9 | 548.9 | 565.9 | 536.5 | 565.1 | 564.1 | 532.5 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | 0.0837 | 0.0853 | 0.0733 | 0.0774 | 0.0646 | 0.0638 | 0.0592 |
| 12. Max. Cht - °F | | 350 | 347 | 352 | 352 | 345 | 346 | 313 |
| 13. Avg. Cht - °F | | 319 | 315 | 325 | 326 | 326 | 328 | 303 |
| 14. Min. Cht - °F | | 304 | 300 | 312 | 314 | 311 | 311 | 283 |
| 15. EGT - °F | | 1031 | 1031 | 1067 | 1076 | 1112 | 1094 | 1040 |
| 16. Torque, lb-ft | | 166 | 170 | 175 | 174 | 171 | 162 | 151 |
| 17. Obs. Bhp | | 74.3 | 76.1 | 78.3 | 77.9 | 76.5 | 72.5 | 65.4 |
| 18. % CO ₂ (Dry) | | 9.32 | 9.34 | 11.37 | 11.38 | 12.95 | 12.77 | 11.66 |
| 19. % CO (Dry) | | 7.39 | 7.38 | 4.11 | 4.17 | 0.86 | 0.83 | 0.06 |
| 20. % O ₂ (Dry) | | 1.39 | 1.31 | 1.72 | 1.57 | 2.65 | 2.75 | 4.85 |
| 21. HC-p/m (Wet) | | 1862 | 1907 | 1532 | 1521 | 757 | 720 | 316 |
| 22. NO _x -p/m (Wet) | | 413 | 425 | 1740 (EST) | 1740 (EST) | 3074 | 3044 | 2161 |
| 23. CO ₂ -lb/h | | 76.8 | 77.3 | 94.4 | 89.9 | 104.9 | 103.5 | 88.8 |
| 24. CO-lb/h | | 38.8 | 38.9 | 21.0 | 21.0 | 4.43 | 4.28 | 0.29 |
| 25. O ₂ -lb/h | | 8.33 | 7.89 | 10.38 | 9.02 | 15.61 | 16.20 | 26.9 |
| 26. HC-lb/h | | 0.64 | 0.66 | 0.53 | 0.51 | 0.25 | 0.24 | 0.10 |
| 27. NO _x -lb/h | | 0.27 | 0.28 | 1.13 | 1.09 | 1.93 | 1.91 | 1.27 |
| 28. CO-lb/Mode | | 3.875 | 3.889 | 2.172 | 2.096 | 0.443 | 0.428 | 0.029 |
| 29. HC-lb/Mode | | 0.064 | 0.066 | 0.053 | 0.051 | 0.025 | 0.024 | 0.010 |
| 30. NO _x -lb/Mode | | 0.027 | 0.028 | 0.113 | 0.109 | 0.193 | 0.191 | 0.127 |

TABLE C-14. AVCO LYCOMING IO-360-A1B6D ENGINE NAFEC TEST DATA--TAXI
MODE--RUN NOS. 12 THROUGH 15

| Parameter | Mode | Run No. | | |
|---|------|---------|--------|--------|
| | | 12 | 13 | 14 |
| | | Taxi | Taxi | Taxi |
| 1. Act. Baro. - inHg | | 29.86 | 29.86 | 29.86 |
| 2. Spec. Hum. - lb/lb | | 0.0085 | 0.0085 | 0.0085 |
| 3. Induct. Air Temp.-°F | | 85 | 85 | 85 |
| 4. Cooling Air Temp.-°F | | 128 | 125 | 122 |
| 5. Induct. Air Press.-inHg | | 29.68 | 29.66 | 29.65 |
| 6. Engine Speed - RPM | | 1200 | 1200 | 1200 |
| 7. Manifold Air Press.-inHg | | 12.0 | 12.0 | 11.9 |
| 8. Induct. Air Density-lb/ft ³ | | 0.0722 | 0.0721 | 0.0721 |
| 9. Fuel Flow, Wf-lb/h | | 10.6 | 11.2 | 11.6 |
| 10. Airflow, Wa-lb/h | | 132.7 | 132.9 | 134.3 |
| 11. F/A (Measured) = $\frac{9}{10}$ | | 0.0799 | 0.0843 | 0.0864 |
| 12. Max. Cht - °F | | 376 | 370 | 373 |
| 13. Avg. Cht - °F | | 358 | 354 | 356 |
| 14. Min. Cht - °F | | 340 | 337 | 341 |
| 15. EGT - °F | | 500 | 509 | 527 |
| 16. Torque, lb-ft | | 18 | 20 | 21 |
| 17. Obs. Bhp | | 4 | 5 | 5 |
| 18. % CO ₂ (Dry) | | 7.00 | 6.73 | 7.19 |
| 19. % CO (Dry) | | 5.77 | 6.18 | 7.47 |
| 20. % O ₂ (Dry) | | 6.44 | 5.98 | 5.29 |
| 21. HC-p/m (Wet) | | 8713 | 11472 | 11520 |
| 22. NO _x -p/m (Wet) | | 277 | 214 | 212 |
| 23. CO ₂ -lb/h | | 14.05 | 13.51 | 14.91 |
| 24. CO-lb/h | | 7.37 | 7.89 | 9.86 |
| 25. O ₂ -lb/h | | 9.40 | 8.73 | 7.98 |
| 26. HC-lb/h | | 0.72 | 0.97 | 0.99 |
| 27. NO _x -lb/h | | 0.04 | 0.03 | 0.03 |
| 28. CO-lb/Mode | | 1.965 | 2.105 | 2.630 |
| 29. HC-lb/Mode | | 0.193 | 0.259 | 0.265 |
| 30. NO _x -lb/Mode | | 0.012 | 0.009 | 0.009 |

TABLE C-15. TOTAL EMISSIONS CHARACTERISTICS AVCO LYCOMING IO-360-ALB6D ENGINE--SEA LEVEL STANDARD DAY

| Mode | CO lb/hr | CO lb/Mode | HC lb/hr | HC lb/Mode | NO _x lb/hr | NO _x lb/Mode | F/A | Max. CHT-°F |
|-----------------------|-------------|---------------|-------------|---------------|--------------------------|----------------------------|--------|----------------|
| Taxi (16.0 - Min.) | 10.0 | 2.667 | 0.550 | 0.1467 | 0 | 0 | 0.0950 | |
| Takeoff (0.3 - Min.) | 110.0 | 0.550 | 1.300 | 0.0065 | 0.350 | 0.00175 | 0.0950 | 440 |
| Climb (5.0 - Min.) | 80.0 | 6.667 | 0.900 | 0.0750 | 0.300 | 0.02500 | 0.0920 | 425 |
| Approach (6.0 - Min.) | 45.0 | 4.500 | 0.700 | 0.0700 | 0 | 0 | 0.0920 | 345 |
| lb/Cycle | | 14.384 | | 0.2982 | | 0.02675 | | |
| lb/Cycle/RBHP | | 0.0719 | | 0.00149 | | 0.000134 | | |
| Federal Limit | | 0.0420 | | 0.00190 | | 0.00150 | | |
| Diff. = (6) - (7) | | + .0299 | | - .00041 | | - .001366 | | |
| (8) + (7) x 100 | | 71.2 | | -21.6 | | -91.1 | | |
| % of STD. = (9) + 100 | | 171.2 | | 78.4 | | 8.9 | | |

TABLE C-16. TOTAL EMISSIONS CHARACTERISTICS AVCO LYCOMING IO-360-ALB6D ENGINE--SEA LEVEL HOT DAY
(T_i=95° F, INDUCTION AIR DENSITY = 0.0714 lb/ft³)

| Mode | CO lb/hr | CO lb/Mode | HC lb/hr | HC lb/Mode | NO _x lb/hr | NO _x lb/Mode | F/A | Max. CHT-°F |
|-----------------------|-------------|---------------|-------------|---------------|--------------------------|----------------------------|--------|----------------|
| Taxi (16.0 - Min.) | 10.0 | 2.667 | 2.000 | 0.5333 | 0 | 0 | 0.0940 | |
| Takeoff (0.3 - Min.) | 115.0 | 0.575 | 1.200 | 0.0060 | 0.150 | 0.00075 | 0.0970 | 440 |
| Climb (5.0 - Min.) | 85.0 | 7.083 | 0.975 | 0.0812 | 0.130 | 0.01083 | 0.0940 | 420 |
| Approach (6.0 - Min.) | 47.5 | 4.750 | 0.700 | 0.0700 | 0.050 | 0.00500 | 0.0940 | 355 |
| lb/Cycle | | 15.075 | | 0.6905 | | 0.01658 | | |
| lb/Cycle/RBHP | | 0.0754 | | 0.00345 | | 0.000083 | | |
| Federal Limit | | 0.042 | | 0.0019 | | 0.0015 | | |
| Diff. = (6) - (7) | | 0.0334 | | 0.00155 | | - .00142 | | |
| (8) + (7) x 100 | | 79.5 | | 81.6 | | -94.5 | | |
| % of STD. = (9) + 100 | | 179.5 | | 181.6 | | 5.5 | | |

TABLE C-17. ARITHMETIC AVERAGING OF BASELINE DATA AVCO LYCOMING IO-360-A1B6D ENGINE

| Baseline No. | CO | | HC | | NO _x | | Avg. Cycle T ₁ -°F | | Avg. Cycle F | |
|--|---------------|---------------|---------------|---------------|-----------------|---------------|-------------------------------|--------------------------|--------------|---------|
| | lb/Cycle/RBHP | lb/Cycle/RBHP | lb/Cycle/RBHP | lb/Cycle/RBHP | lb.Cycle/RBHP | lb.Cycle/RBHP | Cycle T ₁ -°F | Cycle T ₁ -°F | Cycle F | Cycle F |
| 1 * | 0.0697 | 0.00135 | 0.000225 | 72 | 0.0840 | | | | | |
| 2 ** | 0.0727 | 0.00239 | 0.000215 | 87 | 0.0934 | | | | | |
| 3 | 0.0725 | 0.00132 | 0.000220 | 54 | 0.0920 | | | | | |
| 4 * | 0.0660 | 0.00099 | 0.000260 | 69 | 0.0825 | | | | | |
| 5 * | 0.0769 | 0.00161 | 0.000150 | 111 | 0.0890 | | | | | |
| 6 | 0.0732 | 0.00202 | 0.000220 | 80 | 0.0902 | | | | | |
| Avg. Baseline | 0.0718 | 0.00161 | 0.000215 | 79 | 0.0885 | | | | | |
| Federal Standard | 0.0420 | 0.00190 | 0.00150 | | | | | | | |
| Percent (%) of Standard (Applies to Emiss. Data Only) | 171.0 | 84.7 | 14.3 | 79 | 0.0885 | | | | | |

NOTES:

* Engine cleared prior to testing in the taxi-out mode

** This baseline test was preceded by several takeoff, climb and approach mode lean-out tests