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PERFORMANCE, EMISSIONS, AND PHYSICAL CHARACTERISTICS OF A ROTATING COMBUSTION AIRCRAFT ENGINE

by

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16. Abstract

The RC2-75, a liquid-cooled two chamber Rotary Combustion engine (Wankel type), designed for aircraft use, was tested and representative baseline (212 KW, 285 BHP) performance and emissions characteristics established.

The testing included running fuel/air mixture control curves and varied ignition timing to permit selection of desirable and practical settings for running wide open throttle curves, propeller load curves, variable manifold pressure curves covering cruise conditions, and EPA cycle operating points. Performance and emissions data were recorded for all of the points run.

In addition to the test data, information required to characterize the engine and evaluate its performance in aircraft use is provided over a range from one half to twice its present power.

The exhaust emissions results compared to the 1980 EPA requirements in pounds per horsepower cycle were:

	Demonstrated	EPA Standard
HC	0.00264	0.0019
CO	0.03737	0.0420
NO_x	0.00085	0.0015

Standard Day take-off brake specific fuel consumption is 356 g/KW-HR (.585 lb/BHP-HR) for the configuration tested.

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SUMMARY

The primary objective of the program was characterization of the RC2-75 Rotating Combustion Engine as an aircraft engine. Included is the determination of complete engine performance, exhaust emission measurements and the provision of other applicable characterizing information sufficient to permit evaluation of the engine in aircraft applications.

The RC2-75 tested in this program was as originally designed, except for a rotor rework.

It was tested for 106.5 hours and performed without any engine problems, showing good static pressure checks after run-in and at the end of the test.

The testing included running fuel-air mixture control curves and varied ignition timing to permit selection of desirable and practical settings. The following selections resulted:

SELECTED ENGINE SETTINGS		
Operating Conditions	Fuel/Air Ratio	Spark Advance (Degrees BTC)
Full throttle, 3500 to 6000 RPM, Take-Off, Taxi, Climb-Out, Approach	.073	35
Idle	Smooth	35
Cruise, 3500 to 5500 RPM, Best Power	.073	55
Cruise, 3500 to 5500 RPM, Best Economy	.065	55
Propeller Load, 45 to 85% Power	.065	55

These were used to run wide open throttle curves, propeller load curves, variable manifold pressure curves covering cruise conditions, and EPA cycle operating points. Performance and emissions data were recorded for all of the points run.

Three methods of calculating air/fuel ratio from emissions measurements were employed; two carbon balance procedures, one being the Spindt method, and one oxygen balance procedure. Data points were not considered satisfactory unless all three methods agreed within 5% of the measured air/fuel ratio.

A comprehensive program of calibration of all data gathering instruments and equipment was carried out before, during and after the engine test program.

Curves of the performance, emissions, oil and coolant flows, and heat rejection data are presented. Vibratory mount forces are discussed.

The exhaust emissions results compared to the 1980 EPA requirements in pounds/ rated bhp-cycle were:

	Demonstrated	EPA Standard
HC	0.00264	0.0019
CO	0.03737	0.0420
NO_x	0.00085	0.0015

Variable mixture curves for the propeller load cruise range exhaust emissions are shown. These form distinct families related to the powers and speeds run.

In addition to the test data, information required to characterize the engine and evaluate its performance in aircraft use is provided over a range from one half to twice its present power, (212.5 kW, 285 bhp). Sizing curves are shown of displacement vs speed and power, weight vs power, overall size vs displacement, and heat rejection vs power.

Installation drawings were provided for the RC2-75 engine, and outline drawings for RC1-75, RC4-75, RC2-27, and RC2-215 engines.

The specific fuel economy demonstrated for the RC2-75 was 356 g/kW-hr (.585 lb/bhp-hr) at take-off and 326 g/kW-hr (.536 lb/bhp-hr) at 77% power.

INTRODUCTION

CURTISS-WRIGHT has been actively engaged in research and development of rotating combustion engines for 18 years.

Starting in mid-1958, Curtiss-Wright designed and built more than 10 different experimental Wankel engine models (C-W designates their own design series as RC x - y, where x is the number of rotating combustion (RC) engine rotors and y is the displacement, in cubic inches, per rotor), ranging from the small RC1-4.3 to the RC1-1920 (Figure 54). Over 47,000 test hours have been accumulated on our dynamometers and in a broad variety of RC2-60 field test vehicles including various sizes of wheeled and tracked cars and trucks, boats, aircraft, and stationary powerplants.

Direct rotating combustion engine production by Curtiss-Wright remains a consideration primarily in those areas associated with historical orientation: aircraft power and advanced military engines.

A description of the Rotary Engine Development activity at Curtiss-Wright from 1958 to 1971 may be found in Reference 1. It includes information on design features, apex seal development, testing, and application of the Rotary Engine to automotive, aircraft, and small air-cooled engines. Reports giving more details of the aircraft-related testing are listed in the Bibliography.

Curtiss-Wright's flight experience with the RC2-60 automotive prototype led to the development of a liquid-cooled, gasoline fueled rotary engine, in the 300 horsepower class, the RC2-75, for application to military and commercial light aircraft.

The RC2-75 is a liquid-cooled two chamber Rotary Combustion Engine (Wankel type), with an integral propeller shaft gear reduction, (Figure 1). While earlier Curtiss-Wright Rotary Combustion engines were designed for the purpose of research and development activities, and therefore configured for manufacturing methods practical for very small quantities, the RC2-75 Rotary Engine was designed to be a production general aviation engine using manufacturing methods consistent with the size of the general aviation market. The designs used reflect the results of extensive coordination with suppliers regarding processing, cost vs function and durability, and producibility.

The RC2-75 power section is essentially the RC-60 configuration, which has accumulated over 40,000 hours of operation, extended axially from 3 to 3-3/4 in. for increased output. While the engine is fundamentally an expanded RC2-60 with aircraft accessories and integral propeller drive, it does incorporate all applicable low-cost production features developed during an intensive value engineering study conducted with seven teams of design/manufacturing/purchasing/metallurgy specialists on the RC2-60. This engine, using peripheral (radial) intake ports, is intended to have an initial rating of 285 hp at 6000 rpm with increases on the order of 15% planned shortly after introduction, and further growth increases with continued development. The estimated weight of 280 lb dry (358 lb wet, ready to fly including coolers and coolant) is lighter, and the overall dimensions of 21.5 x 23.7 x 31.4 in. are smaller than all existing commercial aviation piston powerplants. A direct-drive version, intended for helicopter or shrouded propeller applications, is still lighter by virtue of the reduction gear savings. The propeller drive engine configuration and approach were continuously reviewed during the process of definition with Piper, Cessna, and Beech, the intended users, as well as the FAA and accessory suppliers.

In addition to the directly applicable RC2-60 development testing cited above, 75 cubic inch power section engines have accumulated over 1100 hours on RC1-75 engines and 345 hours on RC2-75 engines (including 106.5 on engine 7521-8 for this program). Durability experience to date has been good. A 100 hour full throttle, 6000 rpm endurance test was completed on the RC2-75 with no significant problems. Good durability was also demonstrated in an RC1-75 test with enlarged ports which produced 170 bhp at 7000 rpm.

Other RC1-75 tests evaluated surface gap spark plugs located closer to the trochoid surface (Figure 2). Results are shown in Figure 37. Previous RC2-75 tests included an engine installed on a flight stand (Figure 3).

A projection has been made of the overall FAA "Type Certification" activities that would be required by the FAA and Curtiss-Wright to consider the RC2-75 ready for commercial utilization. A program of approximately 24 months duration is required which includes a variety of RC1-75 and RC2-75 testing as outlined in Appendix A. The bulk of the activity is in connection with the many details requring coordination to provide a flyable engine to the end user, even after the basic power unit is satisfactory. This can be taken as an index of the "Maturity" of the RC2-75 compared to the various candidates for alternate general aviation powerplants. It is important to note when comparing the RC2-75 to possible Diesel or Stirling aircraft engines, the various RC2-60 flight tests described above and the production status of the RC2-75. Its nearness to commercial status places the RC2-75 closer to the reciprocating and gas turbine engines in terms of "maturity" as a candidate for General Aviation applications.

The purposes of this effort are:

1. To determine the sea level performance and emissions data of the RC2-75 rotary combustion aircraft engine, and

2. To establish characteristic data to permit evaluation of the engine in a range of sizes from one half to twice its rated power (212.5 kW, 285 bhp).

I. PERFORMANCE AND EMISSIONS ENGINE TESTING

A. Test Engine Description (RC2-75)

Excerpts from the RC2-75 Engine Specification are in Appendix E.

Some of the specific design features of engine 7521-8 are as follows:

An integral gear reduction is provided with a ratio of engine shaft to propeller shaft rpm of 2.741/1. A single spur gear mesh is used, with an estimated mechanical efficiency of 99%.

The RC2-75 is a liquid cooled engine, with a sealed coolant system using reliable lines, connections, and water pump seal. For application to an aircraft engine, the sealed system was the first choice primarily because of its no-coolant-loss feature assuring greater system reliability. Internal engine flow will be maintained under all operating conditions by means of a built-in by-pass thermostat. The locations of the cooling system components, in particular the coolant expansion tank, are affected by the requirement to avoid pump cavitation problems. Liquid cooling permits using heated coolant instead of gases containing carbon monoxide to supply a heat exchanger which provides hot air for cabin heating and de-icing. Greater flexibility in locating the coolant to cooling air heat exchangers exists compared to baffling the cooling air over engine air cooling fins (for example, coolers may be placed in the wings). The net aircraft cooling drag for the RC2-75 is estimated to be one half that resulting from comparable finned air-cooled engines.

The trochoid major axis is inclined 15° from the vertical in a direction to improve spark plug drainage. Since the wing dihedral can be 5°, the twin engine installations will have final angles of 10 and 20° if installation of the engine package parallel to the wing is desired.

In the water system, both the coolant drainage and the steam vapor venting have been set to accommodate major axis inclination from over 20° to 0° to the vertical. This was planned to cover the aircraft and other installations.

The rotor housing intake port drains into the engine and the exhaust port drains out of the engine. Being ported, and having no valves and cams contributes to quieter final noise levels than comparable reciprocating engines.

The rotors used were reworked to have a "short quench" in an effort to reduce crevice volume in the combustion chamber.

The engine tested (7521-8), had a compression ratio of 7.5:1. This selection was made to accommodate the use of 80/87 octane aviation gasoline. This gasoline is no longer available while 100/130 octane is widely available today, permitting the use of higher compression ratios.

The housing configurations have been tailored to satisfy the needs of the permanent molding process. The "production sand" method can cast anything prepared for the permanent mold foundry.

There are four pads for engine mounting brackets on the anti-prop end housing and two on the prop-end housing. This permits accommodation of air frames with either fire wall dynafocal mount systems or bed-mounted systems.

The required engine accessories, i.e., magneto, waterpump, oil pump and oil metering valve are driven through a separate train directly from the propeller reduction gear driven gear. Provisions are also included in this train to add an SAE cable type tachometer drive as optional equipment. It should also be noted that the magneto selected for the engine has an output connector which can be used to indicate engine speed with an electronic tachometer.

Provisions to drive optional airframe accessories such as propeller governor, hydraulic pump, vacuum pump and either a plunger or a rotary type fuel pump are included in a separate gear train on the right hand side of the accessory gearbox. As with the engine accessories this train is also driven from the propeller reduction output gear.

All accessory drive bearings are sintered material with all but the most lightly loaded ones pressure oil fed. Shaft oil seals are provided on all optional drives except the propeller governor pad.

The optional accessory drive gears, which are lightly loaded, have been sized and designed for powdered metal construction to lower manufacturing costs.

The engine accessory drive gears make maximum use of powdered metal components although the water pump drive and the main idler are made from nodular iron castings.

The engine operates in a dry sump configuration; with the scavenge pump directing hot engine oil to the oil tank. For this program, a test stand pump provided engine oil pressure.

Special spark plugs of standard aircraft installation envelope were used throughout the test program. These would be made commercially available with engine production.

The accessories selected for this engine were all in production and have already been certified for light aircraft use.

The Marvel Schebler, Model HA-6, Carburetor used on the engine is a side draft, float type with manual mixture control and with idle cut-off. The carburetor is the same as that previously certified for other light aircraft engine use except for manual mixture needle and jet sizing required to meet the RC engine fuel flow requirements.

The airflow capacity of the carburetor was selected to meet the engine requirements. Air box data has shown the carburetor will flow 1900 PPH of standard air with a carburetor loss of 3 inches mercury.

Provisions are made on the engine to drive a double diaphragm, AC Spark Plug Company type JT fuel pump or a rotary vane, positive displacement, fuel pump with integral relief and bypass valves, as made by Lear-Romec. (Type No. RG or RD.)

B. Test Equipment Description

1. Test Cell Equipment and Configuration

The RC2-75 engine was installed on Test Cell No. WX-24 for conducting the NASA program.

Test Cell No. WX-24 is a complete induction dynamometer test facility with absorbing capacity of 800 hp, complete services, instrumentation and control.

Figure 4 presents a schematic for the engine and dynamometer drive line system. Connection of the engine to the dynamometer was accomplished by appropriate coupling at the prop shaft. Starting was provided by the Westinghouse 225 hp capacity starting motor through a sprague clutch. Absorption was achieved by the General Electric induction type dynamometer.

Figure 5 presents an overall photographic view of the engine and dynamometer drive line consistent with the schematic presented in the previous figure.

Figure 6 presents a close-up view of the engine with the view at the intake and exhaust side. The induction air system including the air bottle plenum, carburetor intake pipes, prop shaft and nose and test stand to engine coupling are notable.

Figure 7 presents a close-up view at the engine anti-prop end showing two of the four rigid bed mount connections and one of the bellows type exhaust pipes connecting into the test stand exhaust manifold system. At the right hand side the engine blow by is Tee'd into the engine air supply just before the air filter.

Figure 8 presents a photograph of the Tester's control station within the control room. As evidenced here, the tester has clear visibility into the engine and dynamometer room while having within reach all primary test controls, instrumentation, gages, etc. Included are engine controls at the desk top (ignition switch, throttle, fuel/air mixture), dynamometer and motoring dynamometer controls at the lower right, airflow (calibrated bellmouth and inclinometer), fuel flow (rotometers), load (cell), rpm (digital counter), with overspeed protection and dynamometer warnings conveniently located immediately surrounding the testers' primary work zone.

Test Cell WX-24 includes provisions for measuring the engine coolant flow and cooling it. There is an oil supply system with cooling and weigh (for flow and consumption) provisions. Flow pressures and temperatures are controlled and monitored in the coolant and lube systems. Since the coolant system is a completely closed system, (no vents to ambient pressure), an accumulator tank and means of pressurizing it were provided to permit control of the cooling system absolute pressure. By this means, a pressure was set which avoided cavitation at the coolant pump inlet at maximum rpm and power. The closed system was then allowed to function without changes at other operating points.

2. <u>Test Cell Instrumentation</u>

a. Description

Basic instrumentation provisions consisting of selected usage and calibration of a portion of that instrumentation normally available at WX-24.

In addition to the airflow, fuel flow and power measurement systems previously discussed, various other pressure gages, mercury and water manometers, flowmeters, thermocouples, I/C and C/A temperature indicators etc. were utilized to record for each test point the basic variables outlined in the Test Plan. Figure 9 is an excerpt from the Test Plan, marked to further define the instrumentation used.

Figures 8 and 10 present additional and more detailed control room/instrument bank photographs reflecting the basic arrangement and equipment used.

b. Calibration

Instrumentation (and Test Equipment) was calibrated and maintained to Curtiss-Wright Quality Control Order No. 03-2 Revision B dated 5/29/73 (Instruments), Quality Control Order No. 03-6 Revision C dated 7/2/74 (Standards). The frequency of calibration was adjusted to suit the short overall test schedule with pre-test, mid-test and post-test calibration conducted as coordinated. Exhaust emission Scott Model 108-H Exhaust Gas Analysis System, was calibrated by Curtiss-Wright Engineering personnel with occasional servicing assistance from Scott Environmental Systems and Beckman Instruments, Inc.

3. Emissions Measurement Equipment

a. Equipment Description

The exhaust gas analysis system used for this test, Scott Model 108-H (Figure 11), was manufactured by Scott Environmental Systems Division of Environmental Tectonics Corporation, Southhampton, Pennsylvania, in conformance with the system specified by the Federal Register of July 17, 1973 and currently incorporated in the Code of Federal Regulations (40CFR87) for aircraft piston engine emissions testing. The system included an oxygen analyzer as required by the contract with NASA. Figure 12 schematically defines the system used.

A heated prefilter was located upstream of a heated bellows pump in the test cell module, mounted close to the sample probe in the engine exhaust duct. This pump drove the exhaust sample through a heated 40-foot sample line (3/8 in. diameter teflon core) to the analyzer console outside the test cell. Three additional filters protected the various legs of the analysis system in the console. For the carbon monoxide, carbon dioxide and oxygen leg, sample gas was dried by passing through refrigerator coils before entering the analyzers. The legs carrying sample gas to the hydrocarbon and nitric oxide were heated up to the analyzer. The heated lines were maintained at a skin temperature of 150°C.

The Scott analyzer console incorporated the filters, plumbing and valving required to supply the sample gas as well as the zero and span gases to the individual analyzers:

CO_2: A Beckman Model 864 Nondispersive Infrared analyzer (NDIR) was used to measure carbon dioxide in ranges of 0 - 15% and 0 - 5%.

CO: A Beckman Model 865 NDIR analyzer was used for carbon monoxide in the ranges of 0 - 12% and 0 - 3%. (This dual cell analyzer was available for measurements in the 0 - 1000 ppm range, which was not used in the course of this carbureted engine test.)

NO_x: A Scott Model 125 Chemiluminescence analyzer was operated in the ranges 0 - 50, 0 - 100, 0 - 500, 0 - 1000 and 0 - 5000 ppm. The thermal converter used to convert nitrogen dioxide to nitric oxide for analysis as total oxides of nitrogen was a Scott Molybdenum converter heated to 390°C.

O_2: A Scott Model 250 Paramagnetic Oxygen analyzer was operated in the ranges of 0 - 1, 0 - 5, 0 - 10 and 0 - 25% oxygen.

THC: Total hydrocarbons were measured with a Scott Model 415 Heated Flame Ionization Detector (FID) in the ranges of 0 - 10, 0 - 50, 0 - 100, 0 - 500, 0 - 1000, 0 - 5000 and 0 - 10,000 ppm as propane.

Three dual-channel recorders provided strip-chart records of the readings of the analyzers. A timing indicator at the right end of each chart was interlocked with the purge/sample control to show periods during which sample readings were taken.

A purge circuit was included in the system to supply filtered air to the test cell module. Valves at that point directed this air supply both to clear the sample probe and to clear the entire sample train during periods between test points. The purge/sample switch controlling the air supply was interlocked to provide a timing indication on each of the recorders.

Federal Register requirements include provisions for introducing span gases for the principal instruments at the sample inlet to the full emissions systems as a means of detecting leaks into the system, contamination resulting in "hydro-carbon hang-up" and establishing residence time for each of the instruments. The equipment provided by Scott included only the timing device as a part of the recorders, to permit residence time readings.

The sample-in gas modifications to the Scott system to meet these requirements included:

(1) Rework of the test cell module to admit the additional gases at the sample inlet.

(2) Addition of a sample-in-manifold box to accommodate six console controlled solenoid valves manifolded to admit any of five gases: HC, CO, CO_2 and NO span gas and HC zero gas, (Figure 5).

(3) Addition of five gas cylinders in the test cell, connected to the sample-in box by Teflon tubing, (Figure 5).

(4) Rework to the Scott console to add the switches and relays necessary to control admission of one of the five gases and interlock with the purge/sample control to define the zero point for residence time indication on the recorder charts.

b. Calibration

Before the test of the RC2-75 engine under this program, a full calibration of all analyzers was performed. The NDIR analyzers were calibrated with ±2% reference gases over their ranges of operation. The THC unit was optimized for minimum oxygen effect. The NO_x converter efficiency was checked with a Scott Model 140 converter efficiency tester and found to have a 94.5% efficiency as defined by the Federal Register procedure. (90% minimum is required.)

Linearity of THC, NO_x and O_2 analyzers was evaluated over all ranges used in this test. Calibration curves, linearity checks, and post test recalibration show agreement with the original manufacturer's calibration. As a typical example, Figure 13 shows the three calibrations carried out on the high CO range 2 curve for converting meter readings to % CO.

c. Operation

The exhaust emission analysis system was located just outside the test cell containing the RC2-75 engine and dynamometer. A 5-point probe was located across the exhaust duct, downstream of the junction of the two exhaust outlets of this two-rotor engine.

After the engine was stabilized on a test point, the emissions equipment was switched from purge to sample mode, and recorder charts were marked with proper test point number and scales used on each of the analyzers, (typical strip charts are shown in Figures 14 and 15).

Instruments were zeroed and spanned at beginning and end of each series of test points (normally four to six) as well as periodically during a series. Span gases used were ±2% reference standards in nitrogen in high pressure cylinders. The hydrocarbon analyzer was spanned with a propane in air standard.

Emissions test data obtained were recorded on strip charts. The raw readings were visually integrated and recorded on engine test log sheets. The data were converted to concentration units by using calibration curves and scale factors.

To verify the validity of a test point from an emissions standpoint, one oxygen balance and two different carbon balance calculations were performed to determine that the calculated air/fuel ratio by these methods agreed with the measured air/fuel ratio within 5 percent. Figure 31 shows the correlation results for the Spindt method.

d. Problem Areas

Residence time was checked as required by the Federal Register. Residence time for the hydrocarbon analyzer was found to be 3.4 seconds. All other analyzers recorded longer residence times, as controlled by analyzer response. All were less than the 10 - 15 seconds permitted by Curtiss-Wright - NASA agreement.

At extreme conditions, the analyzer range available on THC was not adequate to cover the emissions readings found at idle conditions. By respanning to the limit of the gain available in the analyzer, it was found to be possible to extend the upper limit of the instrument to 14,300 ppm propane, as against a normal capability of 10,000 ppm. This adjustment permitted valid readings of THC in the idle mode.

Numerous minor leakage problems in the emission equipment and exhaust duct were located and corrected. Some leaks were detected primarily through the use of the carbon balance calculation.

Recurrent problems were found in the NO_x line heat circuit. Bonding jumpers were replaced on a number of occasions that had resulted in lack of heat. The NO_x line temperature control was overhauled once, then after a subsequent failure, replaced with a control of greater capacity.

As a likely result of these problems, operation of the equipment in the Wet NO_x mode as required by the Federal Register resulted in frequent clogging of the NO_x flowmeters. After repeated purging and cleaning of flowmeters, we were able to obtain consistent Wet NO_x readings only by using the refrigerated condenser to give a stable reading of Dry NO_x before switching to Wet NO_x long enough to stabilize, then returning to Dry NO_x.

All points used to calculate the EPA emissions cycle were based on Wet NO_x readings. Some earlier test points used for RC2-75 characterization were only recorded as Dry NO_x which is felt to give conservative results.

Problems with the CO instrument included:

(1) Lack of flow in one of two parallel sample cells. Traced to interference between internal fan and teflon tubing to short cell, cutting a hole in the tubing and breaking fan blades: fan and teflon tubing replaced, grill added to fan.

(2) Fall-off in readings during steady operation, with no similar indication from other instruments. Traced to

inoperative vent fan in main vent duct of Scott console which permitted exhaust from all analyzers to recirculate into the CO instrument cabinet via a wiring access hole facing the open end of the vent duct. This recirculated exhaust sample affected the optical path of the analyzer and distorted the differential between sample and reference beam of the NDIR.

C. Test Procedures

The test procedure was generally in accordance with the test plan as submitted by Curtiss-Wright and approved by NASA. The basic procedures consisted of the following discrete phases:

1. Engine Break-In

A break-in period of thirty minutes per point for each of twenty points over a wide load and speed range. Static air leak checks indicated good sealing after the engine run-in and after test running was completed.

2. Basic Calibration

Complete calibration of the exhaust emissions measuring equipment, the test cell instrumentation, basic test equipment devices and operation of the engine to support these individual and combined calibration procedures or to define selected engine parameters.

This period was considered to be very critical in terms of "overall" system setup, prior to conducting the specific emissions measurement conditions per the EPA cycle, to insure reliable, repeatable data acquisition.

3. Emissions Measurement

This phase specifically relates to the EPA cycle emissions characteristics determination. However, a wide overlap with Item 2 was anticipated in obtaining emissions data at a variety of engine operational conditions at full throttle and part load, sea level conditions.

In the actual test program, extensive efforts were applied to maintain quality data acquisition through repeated calibration and servicing of various equipment. The majority of this effort was applied to the Scott Exhaust Gas Analysis System, Model 108-H. The servicing necessary for reliable data and continual usage of the Scott system exceeded manhour estimates by a substantial amount. Nevertheless, the basic groundrule of obtaining quality, repeatable data continued to be observed even at the cost of increased equipment servicing, maintenance, calibration, and rerunning some test points.

To this end a desk top computer program was established for the examination of air/fuel ratio from emissions data by three (3) discrete methods. The program was used to examine and verify or reject each test point for agreement within 5% to measured air/fuel ratios, throughout the testing. The computer was located in the control room and the emissions data examined at each test point prior to resetting of the engine to the next point. This procedure, discussed in more detail in Section I, D. of this report served not only to verify reliable emissions measurement and Scott Exhaust Gas Analysis System operation, but was effective in indicating other overall system problems or deficiencies throughout the test (i.e., exhaust system leakage, induction air system leakages, measurement errors and others).

4. Performance

Prior to obtaining test data each day the engine was started and warmed up and the instrumentation checked to confirm proper oil pressure and other parameters. The engine and dynamometer controls were then actuated to set the engine to the desired test plan power, speed, fuel/air ratio and spark timing requirement. The operating point was held constant a sufficient time for all the parameters to stabilize after any required control adjustments had been made. Oil in temperature was stabilized at 168 - 178°F (75.6 - 81.1°C) and coolant-in temperature at 180 - 185°F (82.2 - 85.0°C). Performance data were then recorded on the engine log sheets and test parameters were plotted on curves for comparison with previous data to determine consistency. If a lack of correlation existed analysis of the data would indicate whether the data point should be rerun or corrective action on the engine or instrumentation was required.

5. EPA Cycle

An emissions test was conducted in basic conformance with EPA procedures defined in the Federal Register (Reference 2), with one exception. The idle mode emission data, used in the EPA cycle test results (Figure 36) was obtained prior to the day the other modes were run, and therefore, was out of sequence. The test was conducted to determine the emissions signatures of the RC2-75 as compared to the EPA proposed 1980 standards. Of the five modes specified, take-off at 100% power and approach at 40% were as recommended with climb at 80%, falling within the 75 to 100% recommended range. Idle at 1% power and taxi at 10% power were selected by the contractor as defined in paragraph 87.92 (a)(2) of the reference. Specified procedures were followed throughout the testing and data reduction, (See also Section I, B, 3, c, Emissions Measurement Equipment Operation).

All operating mode data were obtained at 35° BTC ignition timing with .073 fuel/air ratio maintained at all conditions except idle where idle mixture was set for best idle at the selected power and speed condition.

A sample of the fuel being used (Aviation Gasoline, Grade 100) was tested and found to meet the Specifications in ASTM D910-75. The results are in Appendix B.

D. Test Results and Discussion

Complete log sheets, emissions strip charts, calibrations, and data reduction for the test are on file and available for inspection, if required, for the 106:30 hours of running and 312 data points accumulated during the testing of Engine No. 7521-8. Sample data log sheets are shown in Figures 16 and 17.

1. Full Throttle Performance and Emissions

Based on previously accumulated RC2-75 experience and full throttle mixture control curves (Figures 18 and 19), obtained on the test engine at selected ignition timings, it was determined that 35° BTC ignition timing and .073 fuel/air ratio offerred the best compromise for best power and emissions at full throttle and other rich operation conditions. The 35° BTC ignition timing, in addition, was maintained for ground operation, climb and approach related to the EPA emission cycle. It is important to note that since the RC2-75 is a liquid cooled engine, it can be operated at the .073 fuel/air ratio and leaner at all power levels without durability limitations.

Figure 20 presents the observed full throttle data at the ambient conditions noted. Fuel/air ratio was a nominal .075 maintained within a ±1% band. The departure from the desired .073 f/A was inadvertent and adjustment to the desired mixtures would result only in a minor increase in exhaust gas temperature, no change in power and approximately 2.7% decrease in specific fuel consumption, and minor variations in emissions. Shown on the curve in addition to the performance parameters is the induction system pressure drop, amounting to approximately 21 in. H_2O at 6000 rpm of which approximately 50% is attributed to the air cleaner and the remainder to the duct work and airflow measuring system. Figure 21 presents the data of Figure 20 corrected to standard atmospheric conditions of 59°F and 29.92 in. Hg dry air per standard practice, with formulae utilized shown in Appendix C. The standard day take-off power shown is 224 kW (300.4 bhp) at 6000 rpm, which exceeds the engine rating of 212.5 kW (285 bhp). The full throttle airflow varies from a volumetric efficiency of 91% at 3500 rpm to 99.3% at take-off speed with a peak of 104% at 5500 rpm which is approximately 75% power cruise rpm indicating a good cruise critical altitude can be predicted. The BSFC has been adjusted for the corrected power and airflow in addition to modification to .073 f/A. This change is made in the best power range where BSFC is directly proportional to mixture strength because the power change with f/A here is insignificant. The resulting take-off BSFC is 356 g/kW-hr (.585 lb/bhp-hr). Figure 22 is a plot of the estimated full throttle power vs altitude and fuel consumption.

Full throttle exhaust emissions characteristics at the observed conditions are presented in Figure 23 on a pounds per hour basis. The data exhibit anticipated characteristics with the NO_x predictably lower than conventional reciprocating engines at the leaner best power mixture strengths. The observed and the Spindt carbon balance calculated air/fuel ratios are compared on the curve. All formulae utilized in the emissions data reduction are presented in Appendix D. Three methods of calculating air/fuel ratio from emissions measurements were employed; two carbon balance procedures, one being the Spindt method, and one oxygen balance. Data points were not considered satisfactory unless all methods agreed within 5% of the measured air/fuel ratio. Mass emissions rates were calculated by two methods, one being the exhaust volume method prescribed in the EPA standards. Both methods are documented in Appendix D. In addition to the 5% agreement tolerance on air/fuel ratios, the data was not acceptable unless the two mass emissions calculations produced results within 5% of each other.

2. Propeller Load Cruise Performance

Previous experience and survey mixture curves at selected propeller load powers and ignition timings indicate near optimum specific fuel consumption occurs at an ignition timing of 55° BTC with the engine as configured. Although spark timing was manually set to the selected values on the test engine, advice from the magneto manufacturer is that automatic schedules for retarded operation at full throttle and advance for cruise can be accommodated. On this basis, propeller load constant power mixture control curves were obtained at 10% increments of power from 45% through 85% power. Observed exhaust gas temperatures, manifold vacuum, airflow and brake specific fuel consumption vs fuel/air ratio are presented in Figures 24 through 28. Figure 29 is a summary curve showing particularly the best power (.073 fuel/air ratio) and best economy (.065 fuel/air ratio as determined from the individual mixture curves) specific fuel consumption at percents of the rated 212.5 kW (285 bhp) power. The manifold pressures shown on the several curves are individual intake pipe pressures for each rotor and reflect the characteristic of the peripheral (radial) intake port configuration of the RC2-75 resulting in a high port overlap situation. This contributes to pressure waves in the intake pipes affecting the manifold vacuums obtained unless the pressure taps are located precisely. A production engine would incorporate a pressure pick-up location common to both intake pipes.

Figure 30 summarizes the emissions data, converted to mass flow rates, obtained while running the several mixture curves. The curves define distinct families related to the powers and speeds under consideration. It is notable that the minimum HC and CO emissions are obtained at stochiometric and leaner mixtures for all powers with the HC and CO at richer mixtures increasing with increased power and speed at constant fuel air ratios. NO_x emissions, predictably, increase with decreasing mixture ratios and likewise increase with increasing load. Correlation of the Spindt method carbon balance calculated air/fuel ratio with observed air/fuel ratio for the subject propeller load mixture curves are shown in Figure 31. The calculated air/fuel ratio was in all cases richer than the observed, but consistent from rich to lean mixtures, with the deviations averaging approximately 3%.

3. Part Throttle Fuel Consumption and Emissions

In order to provide fuel consumption data applicable for use in aircraft with constant speed propellers, constant speed variable power curves were run at best power (.073 fuel/air ratio) mixtures at 6000 rpm with 35° BTC ignition advance and 5500 through 3500 rpm with 55° BTC ignition advance. Additionally, curves at best economy (.065 fuel/air ratio) were obtained at 55° BTC ignition for cruise speed range operation from 5500 through 3500 rpm. Correlation with the mixture curves run on propeller load was excellent. These data are shown for best power and best economy in Figures 32 and 33, respectively. Figures 34 and 35, respectively, define the mass HC, CO and NO_x emissions rates versus power for the best power and best economy conditions under consideration as a function of power. With the exception of the HC emissions at 3500 rpm consistent results were obtained at the best power, .073 f/A, mixture ratio. This could indicate a trend at light loads and low speed, as shown, for increasing HC emissions or erroneous HC measurements. Carbon balance air/fuel ratio calculations do not readily detect errors in HC and NO_x measurements due to the small magnitudes of these exhaust constituents compared to CO, CO_2 and O_2. Best economy emissions characteristics, Figure 35, indicate a consistent NO_x family of higher levels than best power mixtures, similar but lower HC emissions as compared to the best power mixture data, and inconsistencies in the CO data. These variations are attributed to minor variations in mixture strength during the test in the range of fuel/air ratios near stochiometric where a strong transition occurs in both HC and CO emissions, as noted on the mixture curves of Figure 30.

4. EPA Exhaust Emissions Test Results

All operating mode data were obtained at 35° BTC ignition timing with .073 fuel/air ratio maintained at all conditions except idle where idle mixture was set for best idle at the selected power and speed condition.

Figure 36 is a tabulation of data relating to the emission cycle test with the engine parameters of power, airflow, and fuel flow, raw emissions concentrations, observed and calculated air/fuel ratios, dry to wet emissions correction factor and calculated exhaust density, emission rates, cycle emissions and cycle emissions per rated horsepower. Cycle emission per rated horsepower are compared with the EPA 1980 standards.

Results of the test show that the RC2-75 NO_x emissions are approximately 43% below the limit with CO emissions at 11% below while the HC emissions must be reduced by 28% to meet the standard. Inspection of the data shows that the idle and taxi modes contribute 84.5% of the total HC emissions.

The probability of achieving the required improvement is very good with modifications to the power section of the RC2-75. The engine tested (Engine No. 7521-8), was configured per the original designs made for this engine, except for a "short quench" rotor rework to reduce the crevice volume. As part of the aircraft engine development effort at Curtiss-Wright, but not as a part of this contract, a number of one rotor engines of the same basic power unit design (RC1-75) have been tested to evaluate modifications on a performance basis. Figure 37 illustrates on RC1-75 engines the effect, on specific fuel consumption at 77% power, of these modifications. The configuration changes were originally intended for improved fuel consumption. However, by the nature of the combustion improvements, they can be expected to reduce HC and CO emissions with some penalty in NO_x due to improved operating efficiencies.

Inspection of the curve shows the excellent BSFC correlation between the RC2-75 and RC1-75 with the same rotor (7.5:1 compression ratio) and .63 inch retraction from the trochoid surface to the spark plug. Increasing the compression ratio improved the fuel consumption predictably with the same spark plug arrangement. Additional benefits were: improved scavenging of the retracted spark plug, reduced cycle to cycle combustion variations due to higher quality ignition, and resulting improved flame propagation, and more complete combustion. Additional improvements were achieved by moving the spark plug electrodes closer to the trochoid surface, illustrated in Figure 2, which enhances the ability of the plug to see a fresh charge each cycle. Improvement in HC emissions can also be predicted for the configuration change where the clearance between the rotor housing and rotor surface at and near minimum volume is increased by modifying the trailing portion of the rotor face. The nature of this change reduces wall quenching effects which directly reduce hydrocarbon emissions. This change had previously been incorporated in the RC2-60-U5 automotive engine and produced up to a 10% reduction in HC emissions.

Other modifications or configurations with potential for HC reduction are: ceramic coatings on the rotor surface for higher temperatures, reduced port overlap and higher operating temperatures. Related to porting, a combination port arrangement where the peripheral intake ports would be maintained for high power operation and side ports utilized for basically the taxi and idle modes are feasible and adaptable to the RC2-75 engine. The low overlap resulting from the side intake ports reduces the exhaust dilution of the fresh charge at the high manifold vacuums at the light loads thus improving firing regularity and completeness of combustion leading to reduced emissions of unburned fuel.

The taxi condition contributes approximately 70% of the total EPA HC value. During the testing at different ignition timing settings it was noted that tests at taxi conditions with spark angle advance of 45 to 50° BTC resulted in lower HC values than the selected 35° BTC setting. Since it may not be practical to provide for a 45 or 50° BTC setting for taxi in an automatic schedule for varying spark angle timing, the demonstrated results have been presented using the higher HC values obtained with the 35° BTC spark angle. For the record, and possible future use, the comparative overall EPA cycle results using the HC results at 45 and 50° BTC were:

	35° BTC	45° and 50° BTC	EPA 1980 Standard
HC $\left(\frac{\text{lb}}{\text{BHP-cycle}}\right)$	.00264	.00241	.0019

It should be noted that the EPA operating points are discrete single conditions, all run at 35° BTC ignition timing and rich fuel/air ratio (.073). The cruise and propeller load performance and emissions curves have been run at 55° BTC ignition timing with both best economy (.065) and best power (.073) fuel/air ratios. It is therefore not possible to make direct correlations. The EPA take-off condition is a point on the WOT variable rpm curve, however the WOT curve was run at .075 fuel/air ratio, and the EPA take-off point was run at .073 fuel-air ratio. In addition, they were run on different days, which generally results in some data scatter.

5. Oil and Coolant Flows and Heat Rejection, Oil Consumption, Vibratory Forces, and Operational Limits

Oil and Coolant Flows and Heat Rejection

Figures 38, 39, 41, and 42 present the oil and coolant flows and heat rejection obtained during the testing. In each case the data is presented as a function of engine power, with a family of curves showing the variation with rpm. The results are consistent with the data from earlier rotary combustion liquid-cooled engine testing. The coolant and oil temperatures experienced during running are listed on the curves. The coolant temperature into the engine averaged 83.6°C (182°F) and the coolant temperature out of the engine averaged 91.9°C (197°F). The oil temperature into the engine was 78.3 ± 3°C (173 ± 5°F).

The RC2-75 testing to date has been with conventional oil and coolant temperatures. However, based on analytic studies of structural, combustion, and durability factors, it has been projected that engine operation with a maximum coolant out temperature of 250°F and a maximum oil in temperature of 260/265°F will prove feasible. It is intended that these maximum temperatures would occur only at "hot day" conditions during the climb-out phase of flight. For such a system, the cruise temperatures would be well below the maximum temperatures reached, with the use of cowl flaps a possibility to raise the cruise temperatures somewhat. Surveys of major oil companies indicated that sump temperature peaks of 300°F would be permissible. From trends of similar engines, the higher oil and coolant temperatures should lead to improvements in fuel economy and HC emissions.

The coolers shown on the LS33449 Installation Drawing (Figure 48) have been sized for 277 lb/min cooling airflow at 3.8 inches of water pressure drop, and the maximum temperatures mentioned above occurring at hot day 100% power.

The proposed temperatures will reduce the heat rejection to the oil and coolant and increase the driving temperature differential at the oil and coolant coolers, thereby permitting the use of coolers that are smaller, lighter, and less costly. A specific example of the benefits resulting from higher coolant temperatures is shown by the following tabulation, in which the relative cooler size is shown for systems having maximum coolant out temperatures of 230°F and 250°F.

Relative Cooler Size		
Maximum Coolant Out Temperature °F	For Same Cooling Drag	For Same Cooling Air Pressure Drop
230	1.22	1.17
250	1.0	1.0

Compact aluminum construction was indicated over steel and brazed copper designs on the basis of size and weight considerations.

Curtiss-Wright studies have indicated that liquid-cooled rotary combustion engines are more desirable than air-cooled rotary combustion engines for future aircraft engine applications. The essential difference, from the size and weight standpoint, lies in the greater heat transfer capacity of liquid cooling under conditions of nucleate boiling as opposed to the air-cooling system using forced convection. Future designs can be expected to find air-cooled engine becoming cooling limited at a level of maximum heat flux below that of liquid-cooled engines. Beyond that point, liquid-cooled engines can be smaller and lighter. Liquid-cooled engines are generally less costly to produce and are shown to be quieter.

The hardware item differences are the blower and cooling air ducting on one hand, and the water pump and coolant cooler on the other. The housing configurations are basically different in ways which affect cost, structural stiffness and acoustical behavior.

Oil Consumption

Oil consumption observations during the 106.5 hour test period indicated generally typical consumption levels for the particular RC2-75 experimental configuration used. 0.9 lbs/hr was consumed in the basic oil system (oil seal leakage and some minor external leaks encountered in the overall engine/test stand system). Oil introduced with the fuel for apex seal lubrication at a level of 1% is additional consumption. The resultant overall rate is then dependent upon the particular testing and the fuel usage rate. In general, the overall rate of oil consumption should not exceed approximately 0.4 lbs/hr to be competitive. The particular engine configuration used in this test did not incorporate the latest development features in terms of minimizing oil consumption. These later features, consisting of increased oil seal drain back openings, were evaluated on the RC1-75 single rotor rig during 1975 (Figure 40). The RC2-75 results have been added for comparison. These data show substantial improvements for the revised oil seal drain configurations.

The scope and nature of this test program called for maintaining operating conditions at a point only long enough to obtain performance and emissions data. Instantaneous oil consumption data requires running at a point for a longer time. Since the test program consisted of running for short times at a great variety of conditions, it was felt that the average obtained by the total oil consumed in the basic oil system divided by the total time was appropriate for this test program.

The increase in oil consumption for Engine 7501 Build 8 after 62 hours was due to a failure not connected with the oil control system. It should be noted that these RC1-75 development configurations are considered to be directly transferable to the RC2-75 with appropriate but minimal development efforts.

Curtiss-Wright rotary engines have typically permitted longer times between required oil changes than reciprocating engines. This can compensate for higher rotary engine oil consumption rates if the metered oil for apex seal lubrication does in fact result in higher oil consumption rates for the developed rotary engine compared to its competition.

Since the incorporation in the RC2-75 of the modifications shown to improve oil consumption for Engine 7501-8 (Figure 40) may result in lowered HC exhaust emissions, this effect will be monitored during future programs.

<u>Vibratory Forces</u>

The engine tested was bed mounted with four rigid attachment points (Figure 7). In aircraft installations a conventional engine mounting system would be employed providing vibratory force isolation. In such a system, which Curtiss-Wright has installed on it's RC2-75 flight test stand (Figure 3), it is desired that the six natural frequencies in the six degrees of freedom are equal to approximately 1000 cycles/minute or less. This reduces the vibratory forces into the airframe to less than five percent of the values resulting from rigid connections. Based on the above and the maximum excursions recorded on the vibration pickups (Figure 6) during the test program, an estimate has been made of the vibratory loads which would be imposed on a typical airframe structure. Using the assumption of even load distribution among the four bed mount attaching points, each mount point would impose a side shear load of $\pm$ 10.4 kg (23 lb) and a vertical load of $\pm$ 11.3 kg (25 lb) on the airframe structure.

<u>Operational Limits</u>

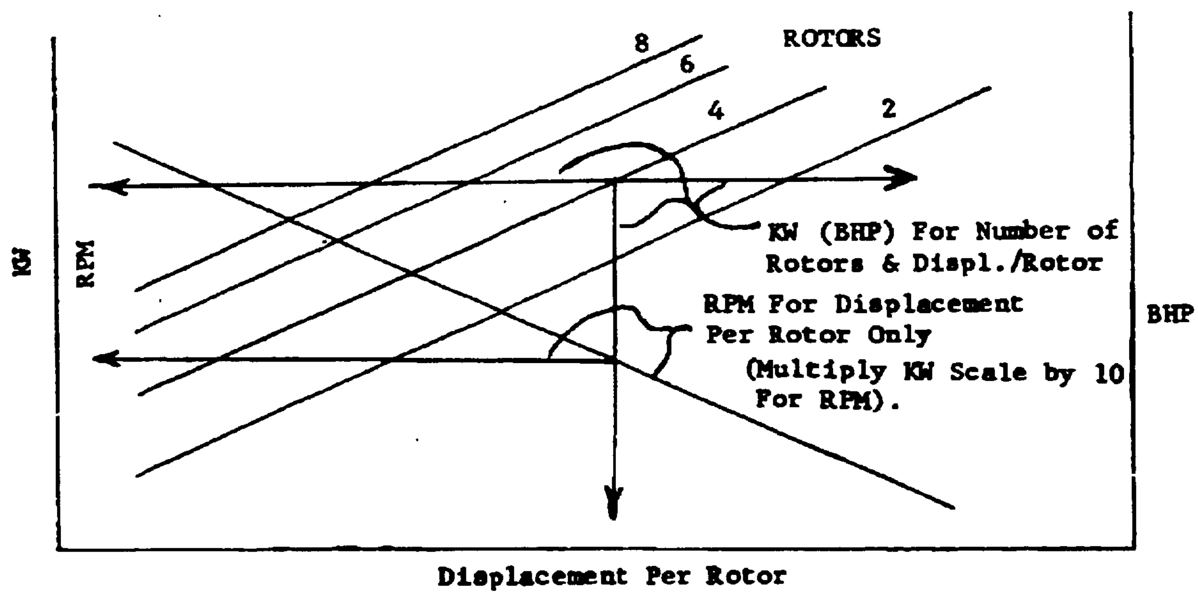
Regarding generalized operational limitations, - such as detonation, ambient conditions, instability, - none has surfaced up to this point that are more restrictive than those of the current reciprocating engines available for general aviation use. In fact it is felt that rotary combustion engines will probably have slightly better margin for detonation free operation, and when detonation occurs, it will probably be less damaging. In addition, since these are water-cooled engines, they do not require the cooling effect of rich fuel/air mixtures utilizing by today's air-cooled reciprocating aviation engines. Exhaust valve burning at lean mixtures is another reciprocating aircraft engine concern affecting operational limits, - which is absent in the rotary engine. This eases the limiting factors when selecting engine settings to meet fuel economy, power and emissions requirements.

II. ENGINE CHARACTERIZATION

A. Generalized Engine Displacement, Size, Power, Weight and Speed Variation

Sizing curves have been completed for aircraft Rotary Combustion engines to define projected weight, displacement and overall dimensions for a given power requirement.

The use of Figure 43 (Power and Speed vs Displacement Per Rotor) is as shown:



Weight vs power of the projected engines are shown in Figure 44. The relation of weight to brake horsepower and number of rotors is self-explanatory. The parameters for a given engine on both curves are related by use of the same value for power. Engine overall dimensions given in Figure 45 are based on displacement per rotor.

The ratio of trochoid size to rotor width has been kept constant for all curves, rotor width/shaft eccentricity = 5. A constant ratio of generating radius/shaft eccentricity is assumed, resulting in geometrically similar combustion chambers for all engine sizes. The speeds have been selected to give the same apex seal sliding velocity at maximum shaft speed for all the engine sizes. This results in the shaft speed being controlled by displacement per rotor only. The foregoing, together with the normal relationship of power, rpm, displacement, and mean effective pressure, are the basis for the curves.

Each of the curves lists the conditions or items included as the basis for the data. When using the curves for the RC2-75, the actual displacement per rotor, 76.2 cubic inches, should be read.

These curves were used to size two rotor engines rated at approximately one half and twice the power of the RC2-75. These power ratings can also be obtained by using one rotor (RC1-75) and four rotor (RC4-75) arrangements which use the same rotor and rotor housing parts as the RC2-75 engine. The resulting data has been tabulated:

Engine	Rated Power kW (bhp)	Rated rpm	Figure No.	Weights kg (lb)
RC 2-27	104 (140)	8,400	49	54.5 (120)
RC 1-75	104 (140)	6,000	51	93 (205)
RC 2-75	209 (280)	6,000	46	127 (280)
RC 4-75	418 (560)	6,000	52	228 (502)
RC 2-215	418 (560)	4,250	50	267 (587)

Note that the shaft rated rpm varies with the engine displacement per rotor in order to keep the same apex seal sliding velocity at rated shaft speed for all engines. The rpm's shown vary inversely to the cube roots of the displacements per rotor.

B. Installation Drawings, Various Sized Engines

A series of installation drawings have been provided to give further definition to the RC2-75 engine, and to aid in characterizing the engine as the power varies.

LS33450, 2 Sheets, Preliminary Installation Drawing, RC2-75 (Figures 46 and 47). This is a fully developed installation drawing of the RC2-75, the engine tested in this program. The various accessories shown are defined, and coolant and oil cooler sizes are listed. The bases for these coolers are noted on LS33449, described below. In order to fit all the accessories at one end, the accessory gear cover housing has "wings" extending larger than the hot section outline. This permits mounting accessories on both sides of the "wings."

LS33449, Preliminary Installation Drawing, RC2-75 (Figure 48). This drawing shows a possible close coupled arrangement, for the RC2-75, which includes a coolant cooler, oil cooler, oil tank, and coolant expansion tank. These components can be mounted on the air frame, therefore final location will depend on the requirements of each individual application. The conditions regarding system temperatures and cooling air requirements used to size the coolers are noted on the drawing and are discussed in Section I.D.5.

SK12600, Preliminary Installation Drawing, RC2-27 (Figure 49). This is an outline drawing showing the size and arrangement of a two rotor engine rated at approximately one half the power of the RC2-75. The power is 104 kW (140 bhp) at 8,400 rpm. The resulting envelope permits single mesh spur gear reductions for propeller speeds down to 2500 rpm. The engine center of gravity location shown for this and the following drawings are approximate, based on inspection and comparison to known engine data.

Since accessories generally do not vary in size as the engines do with different power ratings, for the small frontal area of this engine, it was necessary to arrange the accessories at both ends. This approach to achieving 104 kW (140 bhp) tends toward a cigar shaped engine. It is recognized that only certain applications call for this (such as wing mounted, or ducted fan installations).

SK12601, Preliminary Installation Drawing, RC2-215 (Figure 50). This is an outline drawing showing the size and arrangement of a two rotor engine rated at approximately twice the power of the RC2-75. The power is 425 kW (570 bhp) at 4250 rpm. It was possible to arrange all the accessories at one end of the engine without the "wings" on the RC2-75 arrangement. This results in a relatively compact arrangement.

SK12580, Preliminary Installation Drawing, RC1-75 (Figure 51). This outline drawing shows the size and arrangement of a one rotor engine rated at approximately one half the power of the RC2-75. The power is 104 kW (140 bhp) at 6000 rpm. This arrangement tends toward a shortened, larger frontal area package, which might be desired in a single engine airplane where the pilot determines the frontal area, and the engine is firewall mounted in front of the pilot.

SK12579, Preliminary Installation Drawing, RC4-75 (Figure 52). This outline drawing shows the size and arrangement of a four rotor engine rated at approximately twice the power of the RC2-75. The power is 425 kW (570 bhp) at 6000 rpm.

C. Oil and Coolant Flows and Heat Rejection

In order to further facilitate the evaluation of different sizes of rotary engines in aircraft applications, sizing curves of engine oil and coolant flow and heat rejection are shown in Figure 53. The variables are plotted against shaft power. The oil and coolant system temperatures should approximate those shown in Figure 42, (coolant average, 87.8°C (189.5°F) and oil in 78.3°C (173°F)). If the higher oil and coolant maximum temperatures discussed in Section I,D.5. are incorporated the curves in Figure 53 will require modification.

D. Scaling Considerations and Significant Variables

Rotary Combustion Engines can be made in the range of sizes discussed previously (27 to 215 cubic inches of displacement per rotor) without being limited by size factors affecting performance, durability, manufacturing, or cost aspects. Figure 54 shows the rotors of the variety of working engine sizes Curtiss-Wright has designed, (ranging from 4.3 to 2,500 cubic inches in displacement per rotor). Some new engine candidate sizes are also shown in white.

For parts that are essentially scaled up in all respects, the stress levels remain constant. Figure 55 illustrates this for the shaft torsional shear stress of three different sized engines. The variations in displacement, shaft diameter, power, rpm, and average torque are shown while the average torsional shear stress is constant at 600 psi for the three different shafts.

When designing a new different sized engine geometrically similar to an existing engine, the linear dimensional ratio is called the scale factor, L. While many dimensions are scaled directly, some are not, - such as the thickness of heat transfer walls, - or tolerances. For parts that are directly scaled, the weight will vary in proportion to L^3. Where heat transfer walls are present, an attempt is made to keep the thickness constant regardless of engine size. This is often modified by structural and manufacturing aspects. For a heat transfer wall of exactly the same thickness the weight would vary in proportion to L^2. Parts from different sized engines have been weighed and the weight scaling factors determined for estimating purposes. The values of the exponents fall between 2 and 3 depending on the function of the part. Figure 56 shows the 75 to 2500 cubic inch rotors to scale. Using the scale factor and actual weights, an exponent of 2.785 was found to relate the rotor weights.

III. CONCLUSIONS

The RC2-75 Rotary Aircraft engine was tested and a representative baseline established of its performance and emissions characteristics. In addition, characteristic information required to evaluate the engine's performance in aircraft use over a range from one half to twice its rated power was provided.

A. It was determined that 35° BTC ignition timing and .073 fuel/air ratio offer the best compromise for best power and emissions at full throttle and other rich operation conditions. The 35° BTC ignition timing, in addition, was maintained for ground operation, climb, and approach as related to the EPA emissions cycle. The engine emissions, compared to the EPA 1980 proposed requirements, were 43% below for the NO_x emissions, 11% below for the CO emissions, and 39% above for the HC emissions. The taxi and idle conditions accounted for 85% of the demonstrated HC value. Takeoff BSFC is 356 g/kW-hr (.585 lb/bhp-hr).

B. For cruise conditions optimum specific fuel consumption occurs at an ignition timing of 55° BTC. For best power a .073 fuel/air ratio was used, and for best economy a .065 fuel/air ratio. The brake specific fuel economy demonstrated for the RC2-75 was 326 g/kW-hr (.536 lb) bhp-hr at 77% power and is considered representative for the configuration tested.

C. The engine is rated at 285 brake horsepower at 6000 rpm.

IV. RECOMMENDATIONS

Having established a valid baseline at the current stage of the RC2-75 development program, and with the engine functioning well and indicating good durability, the way is cleared to evaluate a number of modifications aimed at improving the specific fuel consumption and emissions levels.

Single rotor engine testing (RC1-75) has established that certain modifications improve specific fuel economy. For example, prior tests of the RC1-75 showed that modifications can improve the specific fuel consumption to 279 g/kW-hr (.459 lb/bhp-hr) at 77% power. These types of changes are recommended below in addition to modifications based on experience with Curtiss-Wright's RC2-60 engines. It is likely that with these modifications, the RC2-75 fuel consumption and emissions can be improved sufficiently to meet the EPA 1980 emissions requirements without add-on devices or any sacrifice in performance or durability.

A. Close-In Spark Plug Testing

Evaluated by successively deeper machined spark plug seats, directly in aluminum housing.

B. Autotronics C-D Ignition

May be needed to consistently ignite with surface gap plugs at low power conditions such as taxi and idle.

C. Fuel Injection

Evaluate whether taxi condition HC emissions are improved. If they are, complete evaluation for full range of engine operation.

D. Rokide Rotor

This may help improve combustion regularity and reduce wall quenching by increasing the rotor surface temperature.

E. Combination Ports

Using both peripheral and side ports permits avoiding the high port overlap at low loads that is present with the peripheral port in the current test engine. At low loads the side intake only would be open, and at high loads, both would be open.

F. Higher Compression Ratio Rotors

RC1-75 testing with 8.5:1 rotors has demonstrated SFC benefits. Original 7.5 to 1 compression ratio was based on use of 80/87 octane fuel - no longer available. Current aviation fuel is 100/130. 8.5:1 and 9.5:1 rotors should be evaluated.

V. FIGURES

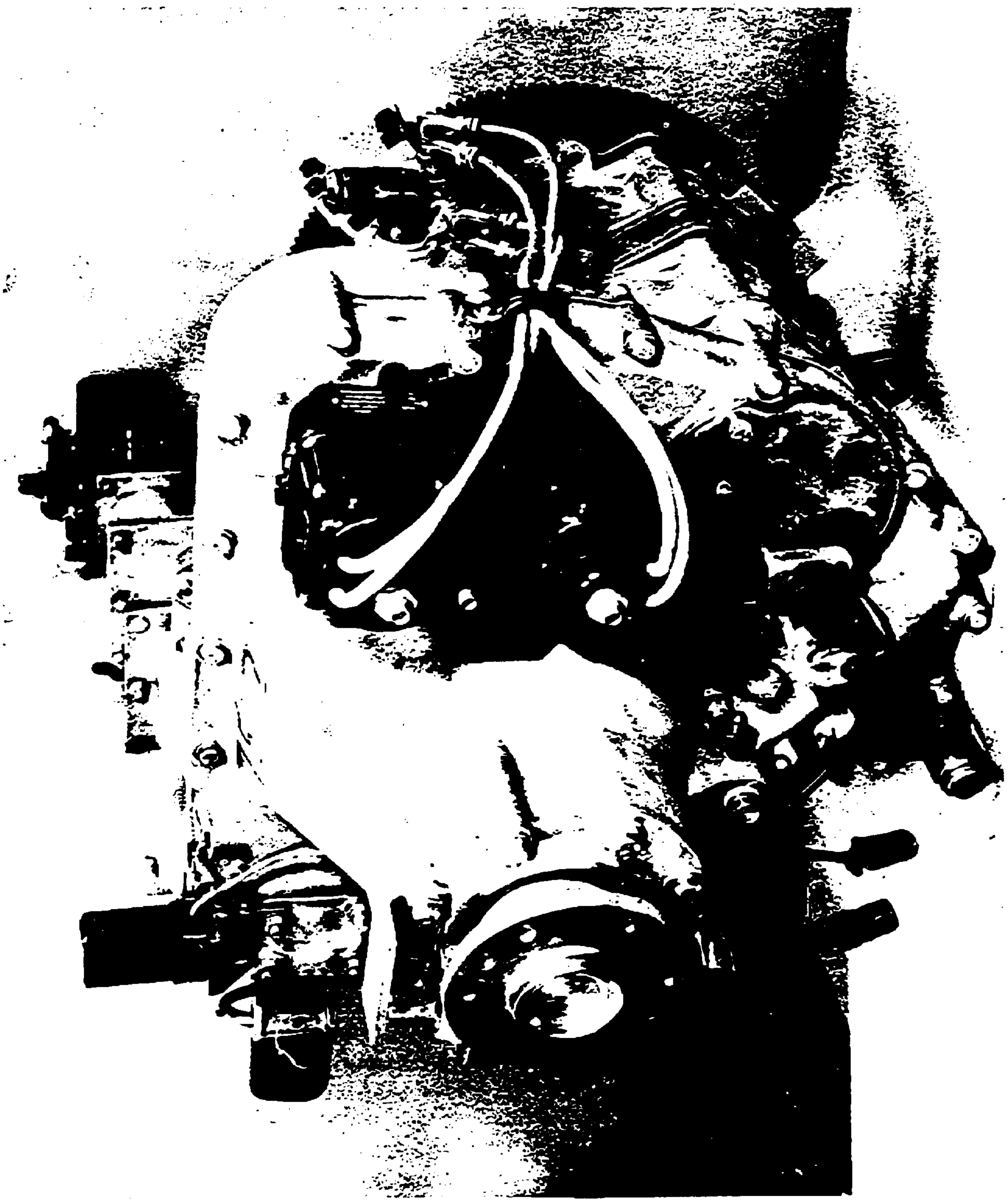


Figure 1. The RC2-75 Rotary Engine.

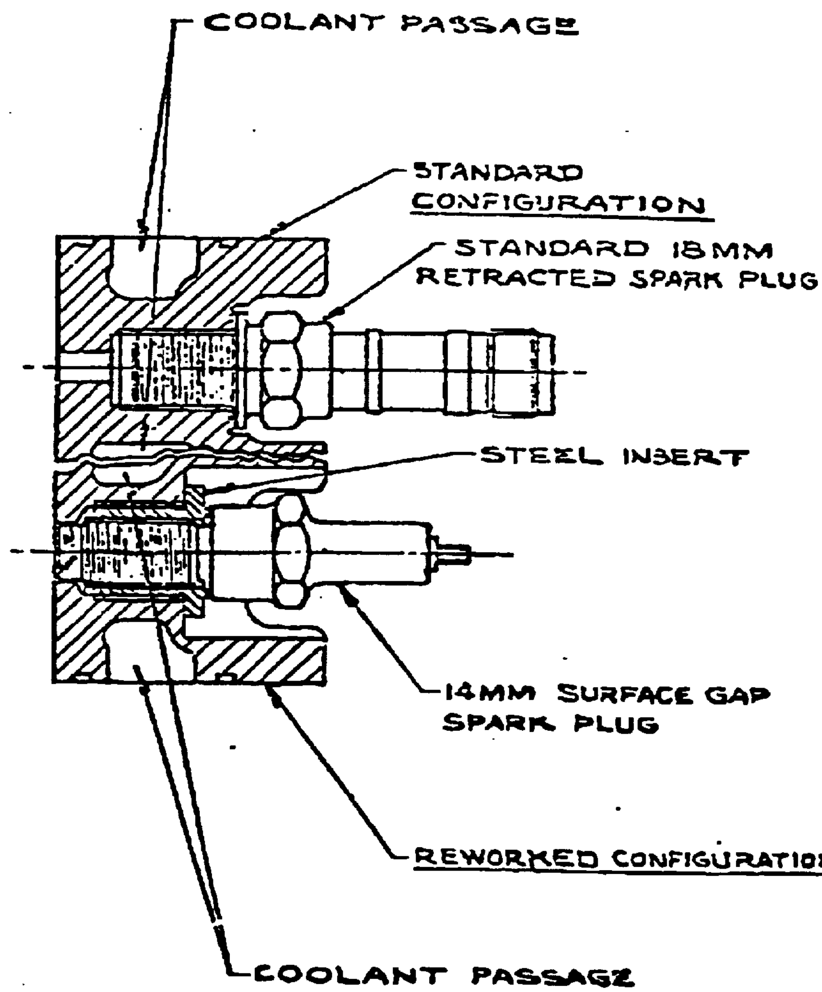
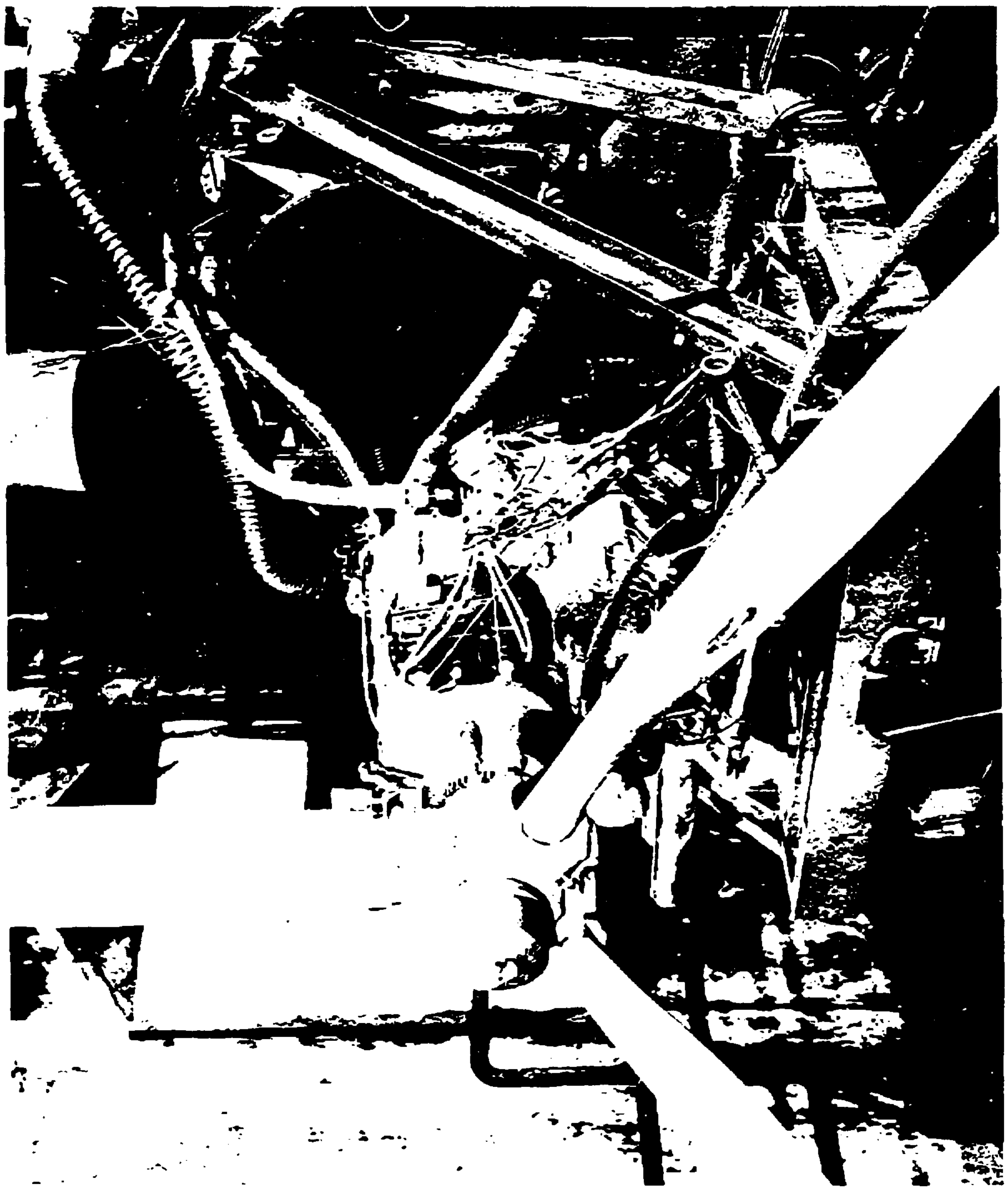


Figure 2. Comparison of Configurations, Close in surface Gap Spark Plug and Standard Retracted Spark Plugs Tested in an RC1-75 Engine.



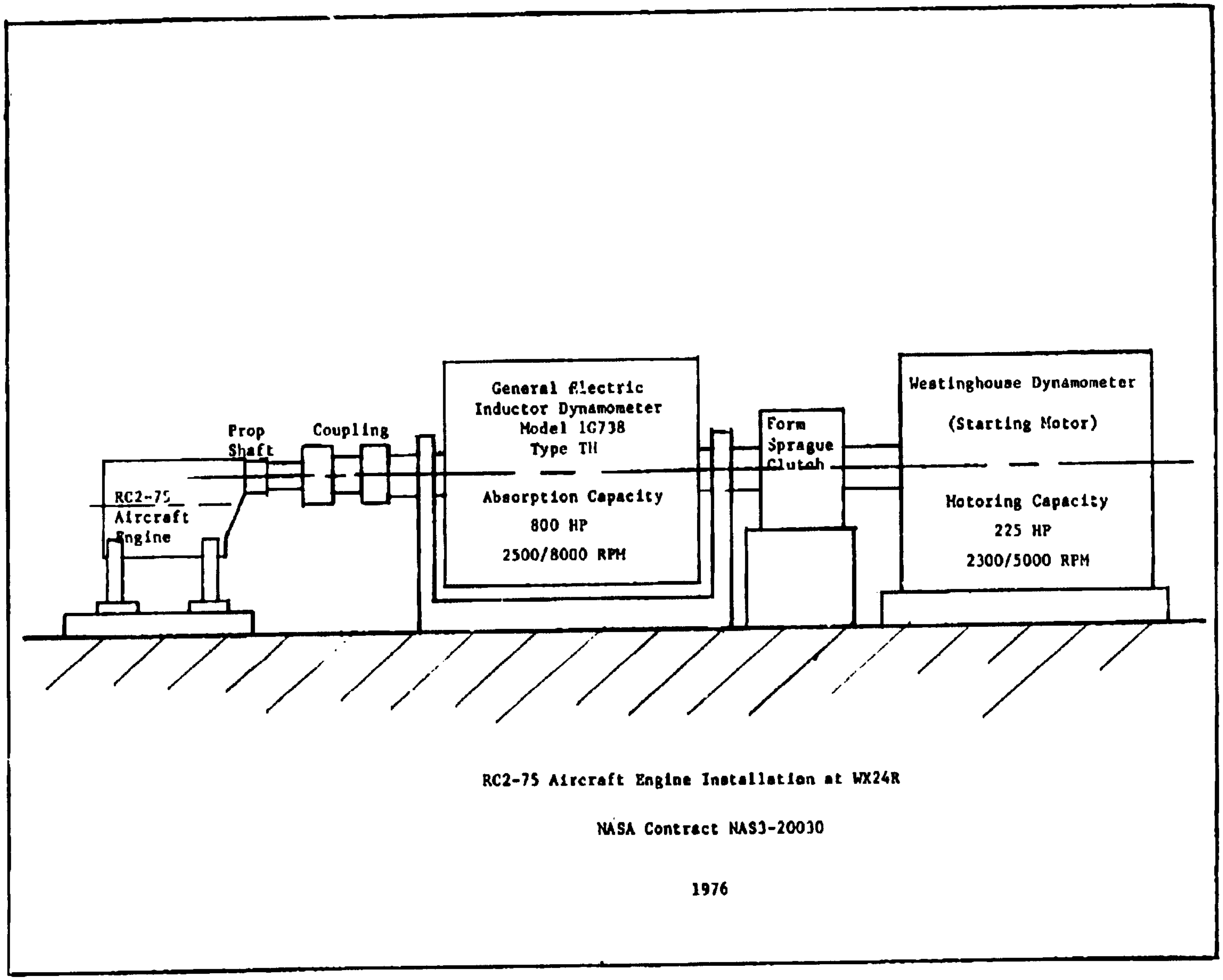
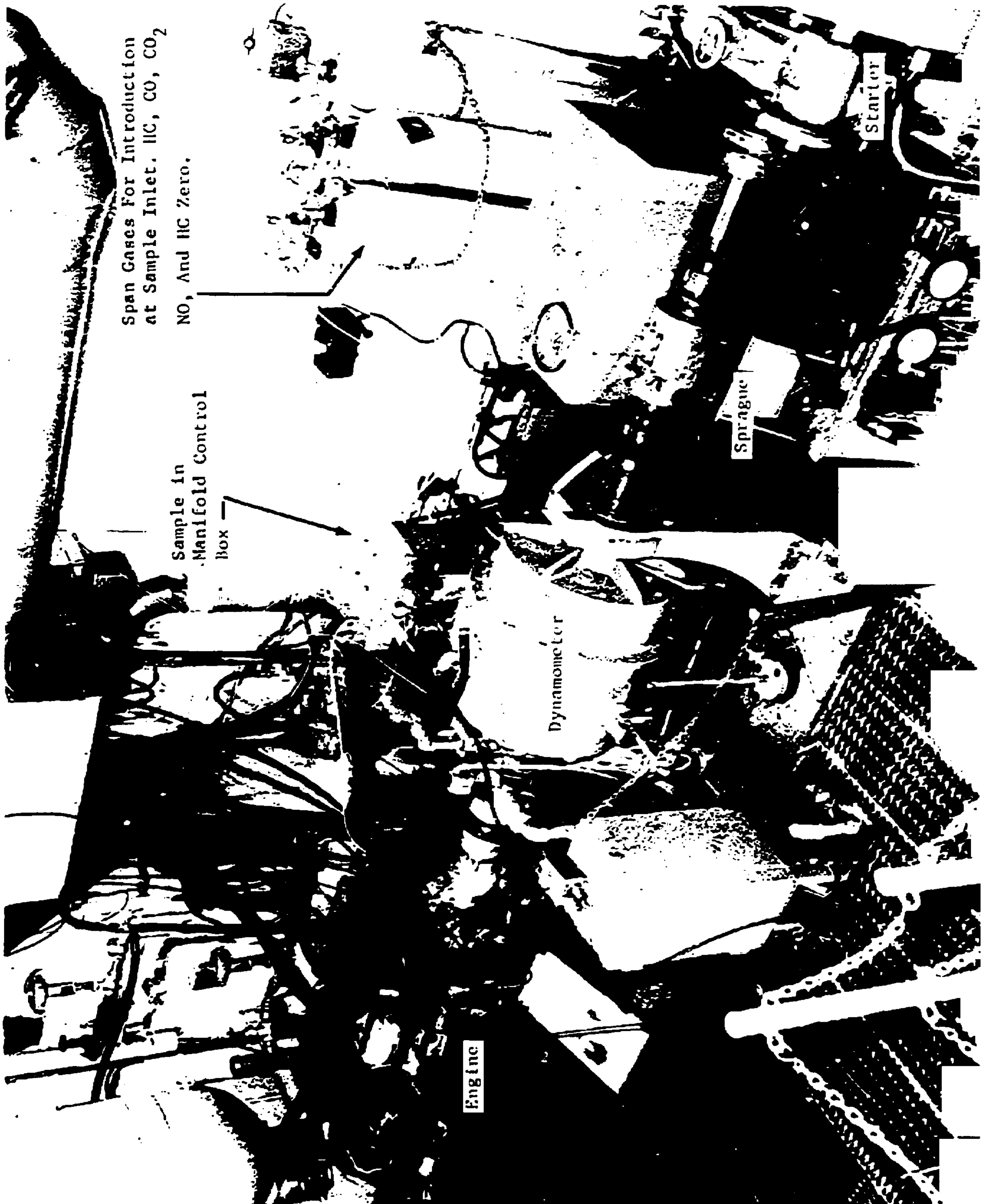


Figure 4. Schematic of the RC2-75 Engine and the Dynamometer Drive Line System.



Span Gases For Introduction
at Sample Inlet. HC, CO, CO_2
NO, And HC Zero.
Starter
Sprague
Sample in
Manifold Control
Box
Dynamometer
Engine

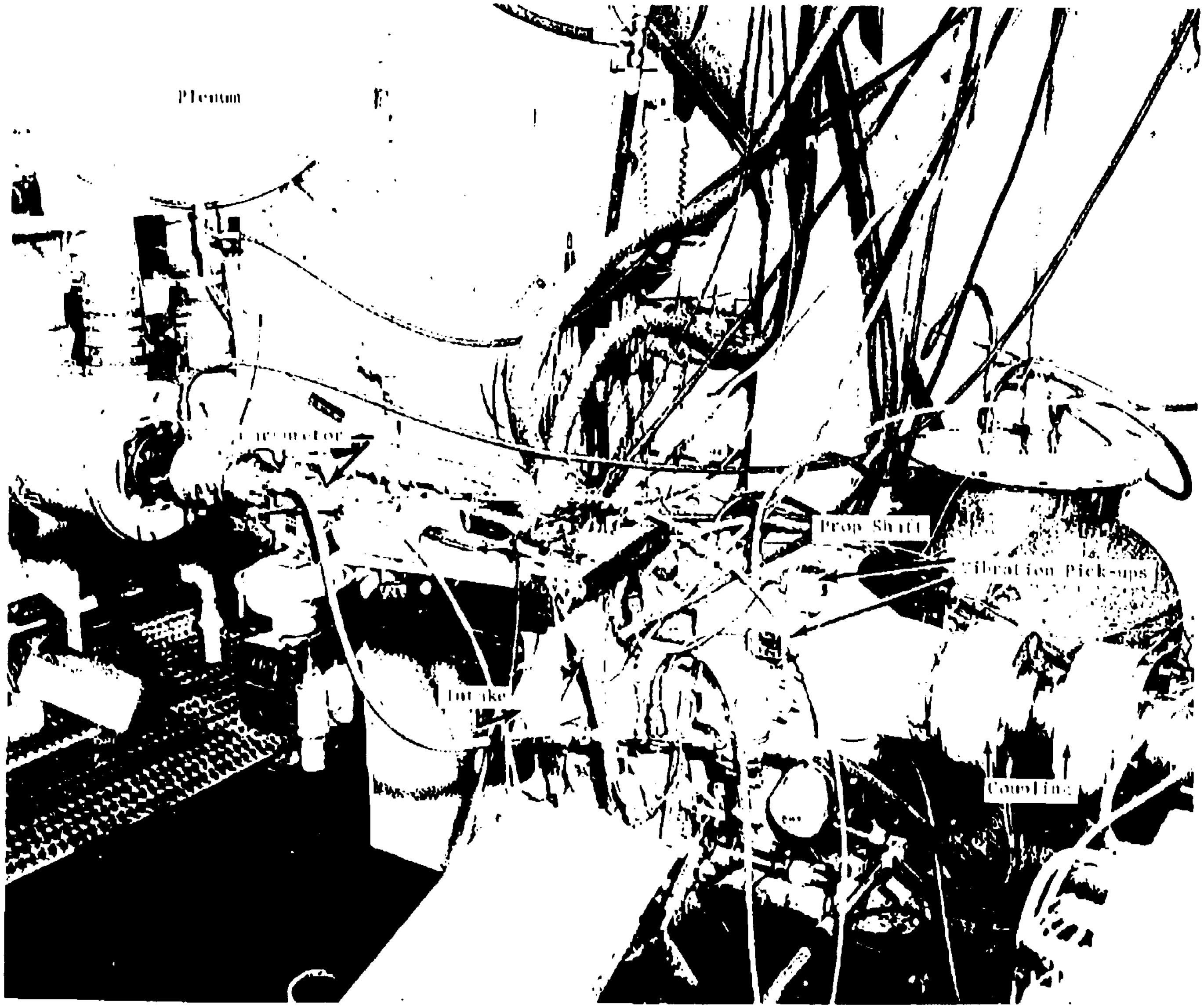


Figure 6 . Close-Up From the Propeller End and Intake and Exhaust Side of the RC2-75 in the Test Cell.

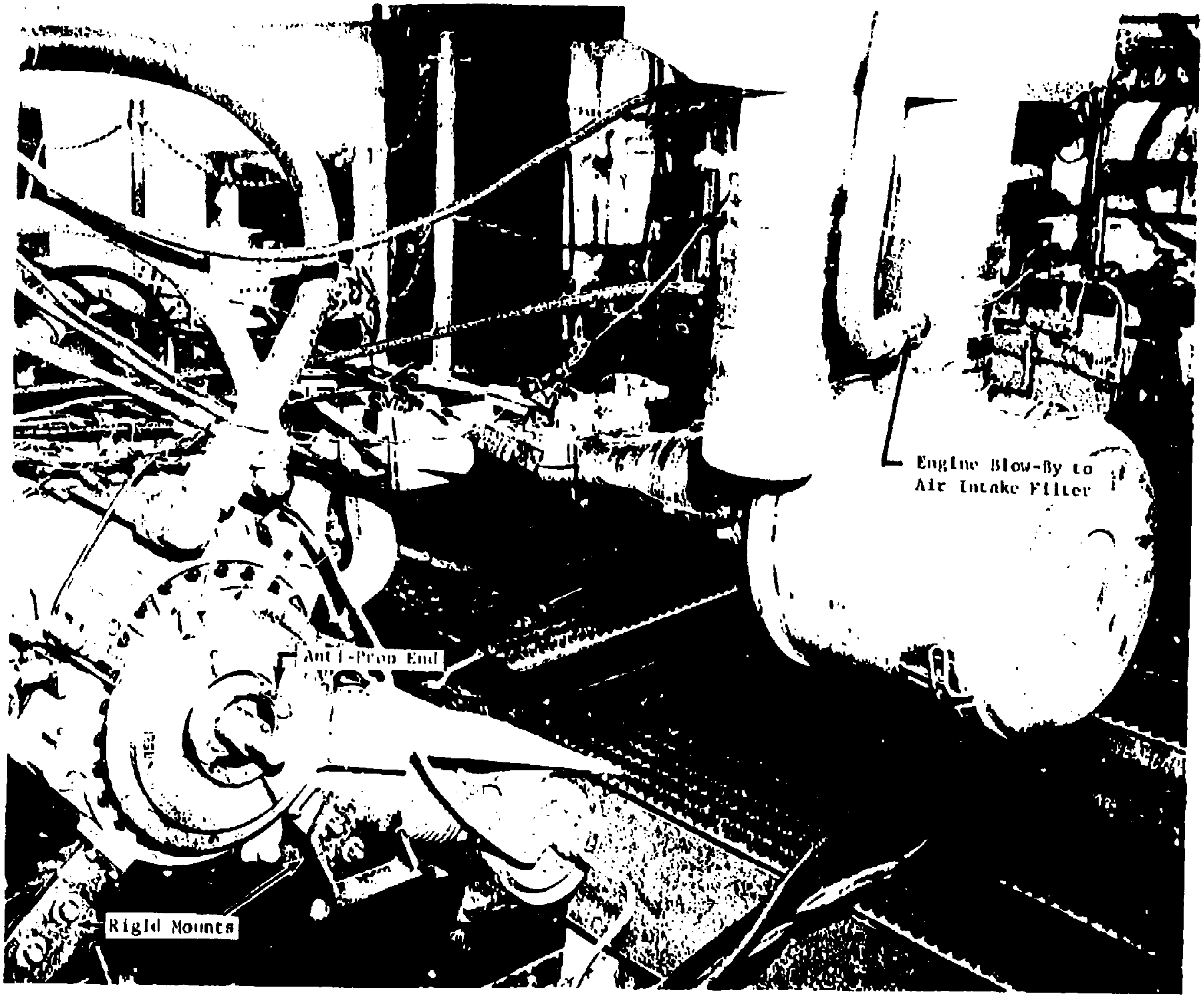


Figure 7. Close-UP From the Anti-Propeller End of the RC2-75 in the Test Cell.

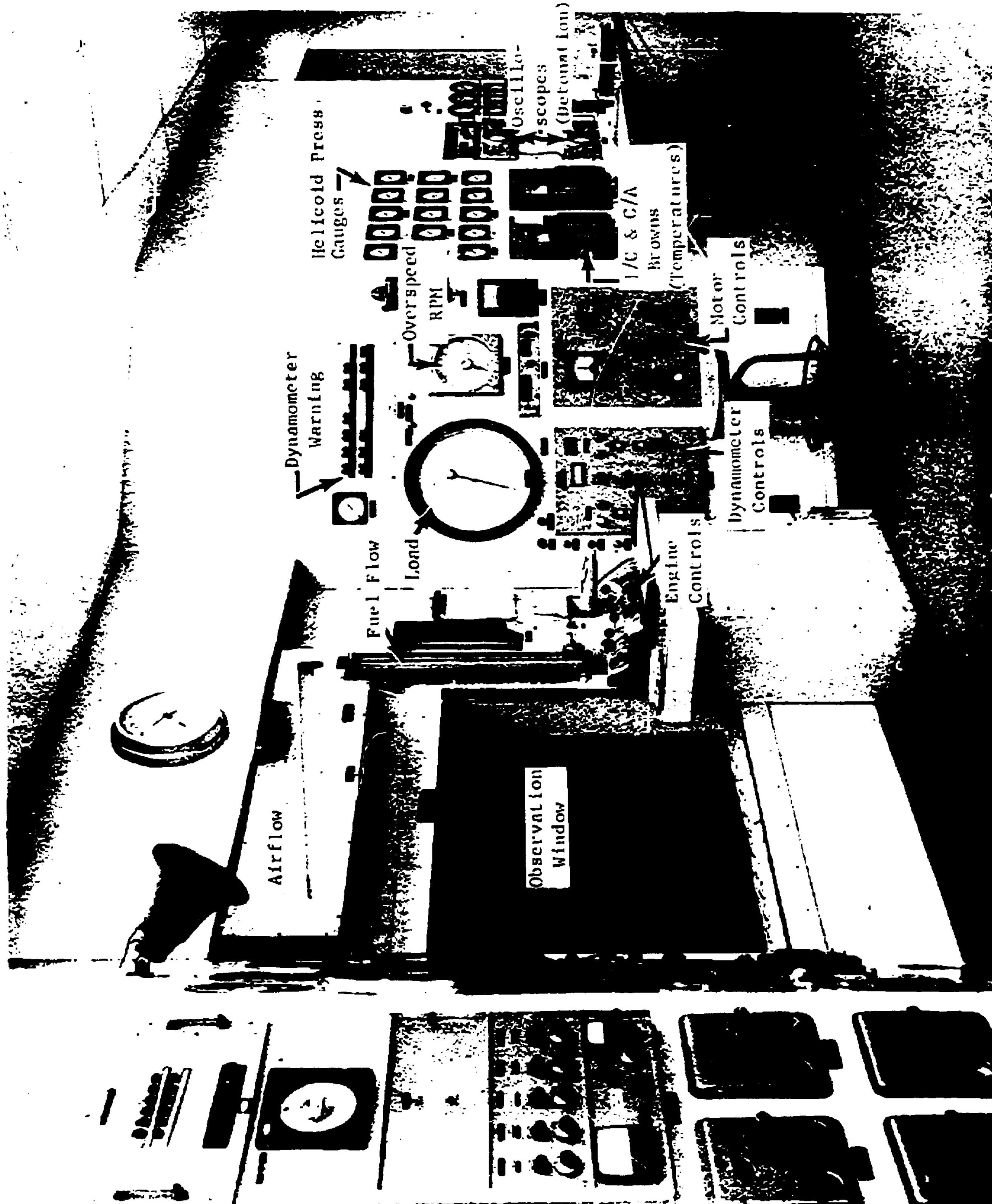


Figure 8. Tester's Control Station and Control Room.

EXCERPT FROM TEST PLAN

MEASUREMENTS AND PRECISION

Test data recorded will be in accordance with the listing below.

1. **Basic Engine Variables**

			Data Accuracy
Time of Day	0-2400 Hours		
Start	Time of		
Stop	Time of		
Motoring Time	Hours		
Total Engine Time	Hours		
RPM	Mainshaft Revolutions per Minute Hewlett Packard, Digital, Pre-Set Counter		± 1 Count
Ignition Timing	Degrees, BTC		
Dynamometer Load	LBS (Emery Cell)	± .1% of Load Range = .6 Load Readability	
BHP	-	± .25%	
Air Flow	Lbs./Hr.		± .15%
Fuel Flow	Lbs./Hr.	Rotometer ± .5% with ± $\frac{1}{3}$ % Readabili	
S.F.C.	Lbs./BHP-Hr.		
S.A.C.	Lbs./BHP-Hr.		
C.A.T.	°F	I/C Thermos	
M.P. (Prop & Anti-Prop Ends)	"Hg.		± .05 in.Hg
Oil Pressure	psig	Helicoid Gauge	
Oil In Temperature	°F	I/C Thermo	
Oil Out Temperature	°F	I/C Thermo	Brown Indicator
Coolant Pressure	psig	Helicoid Gauge	
Coolant In Temperature	°F	I/C Thermo	
Coolant Out Temperature	°F	I/C Thermo	
Coolant Flow	Lbs./Hr.	(Potter Flow Meter (Brown Indicator)	
E.G.T. (Prop & Anti-Prop Ends)	°F	C/A Thermo	± 5°
E.B.P. (Prop & Anti-Prop Ends)	"Hg		
Barometer	"Hg	(Sling Psy.) (Dry Bulb) (Wet Bulb) (Vapor Press) (Psy. Chart)	

2. **Exhaust Emissions**

THC	PPM Propane	Scott Model 108-	± 5 %
CO, Dry,	o/o	"	± 5 %
CO_2, Dry,	o/o	"	± 5 %
O_2 Dry	o/o	"	± 5 %
NO, Wet	PPM	"	± 5 %
NO_x Wet,	PPM	"	± 5 %

Figure 9. Table of Test Data Recorded and Instruments Used.

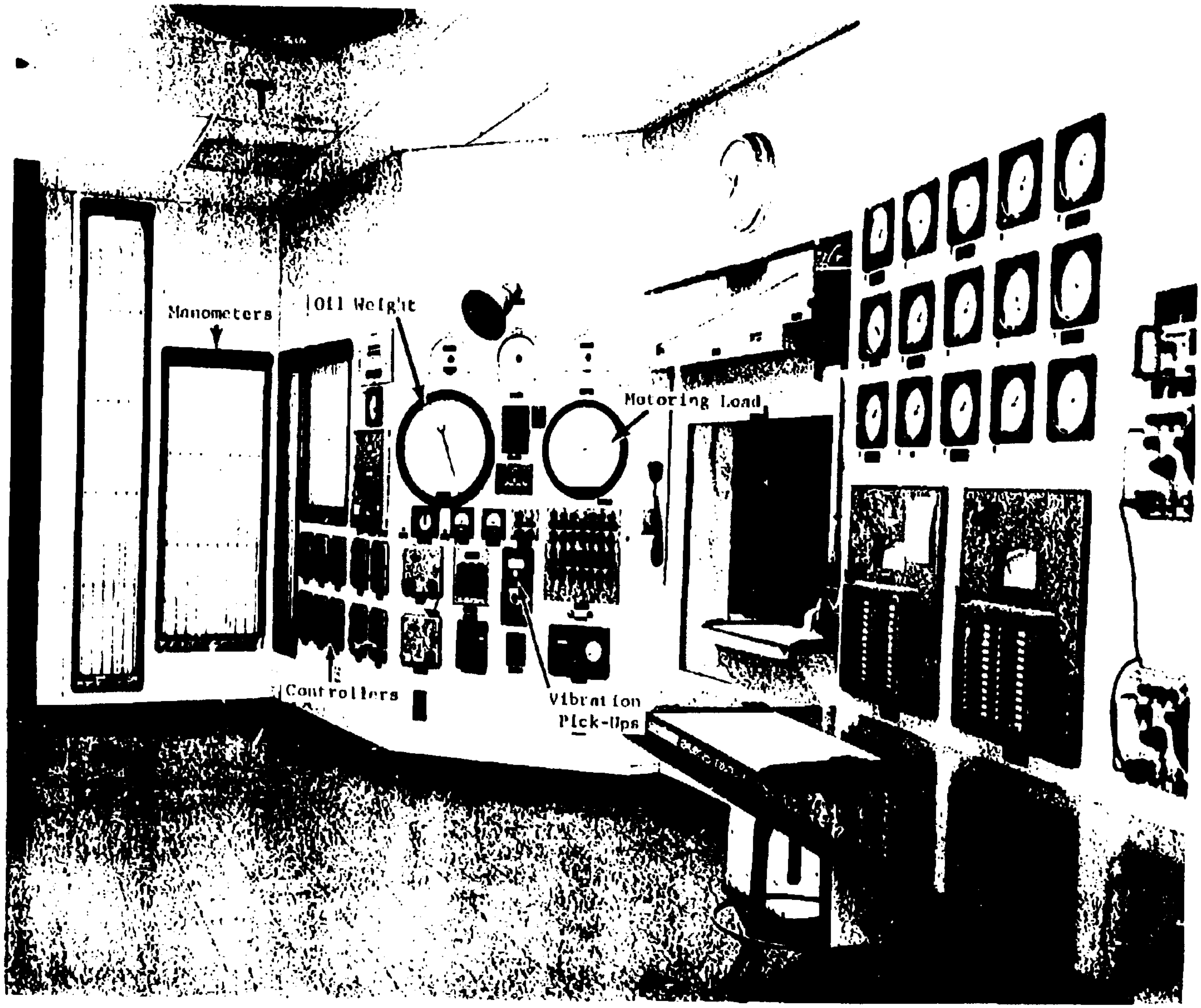


Figure 10. Left Side of Control Room and Instruments.

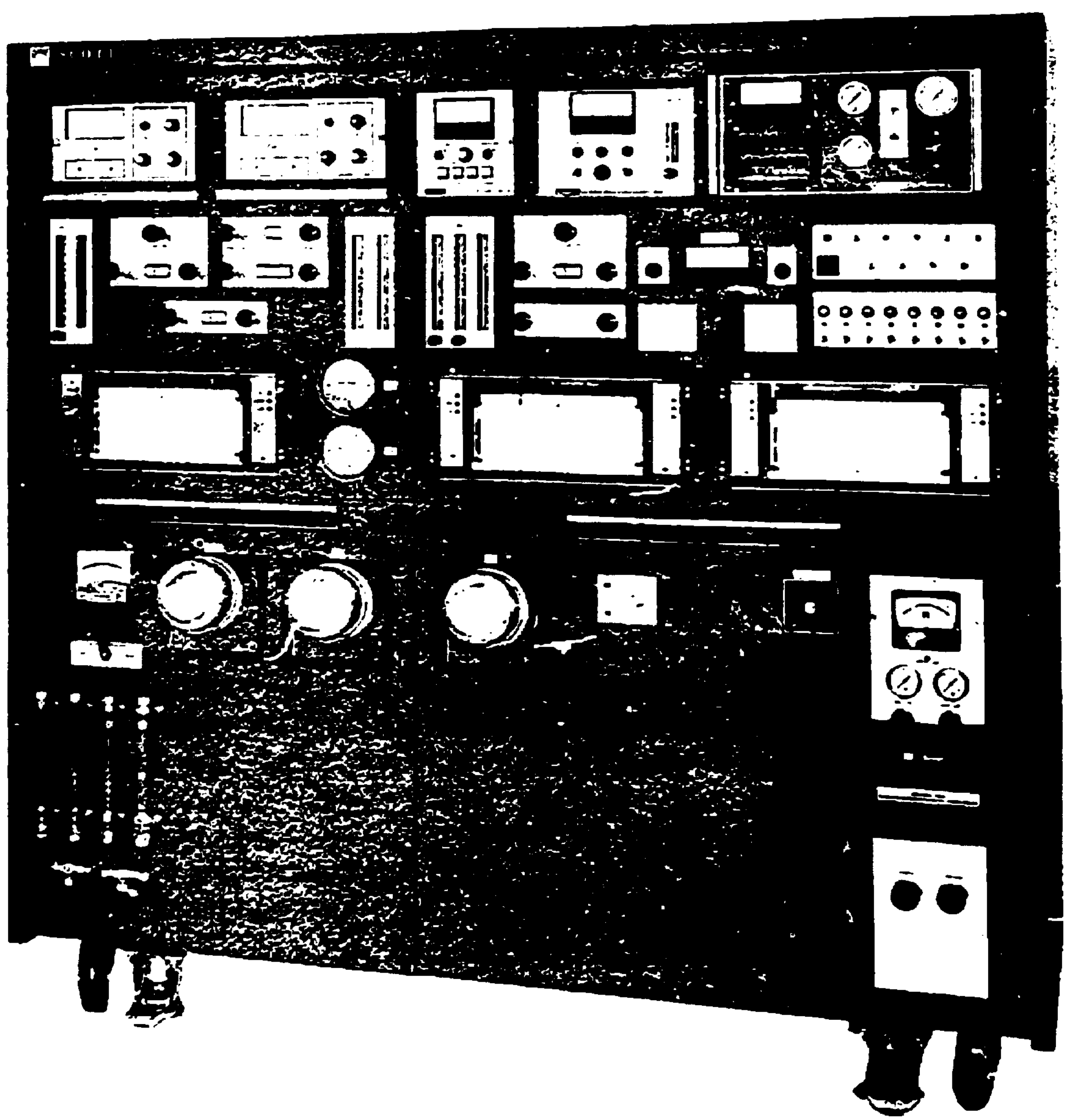


Figure 11. Scott Model 108-H Exhaust Gas Analysis System Console.

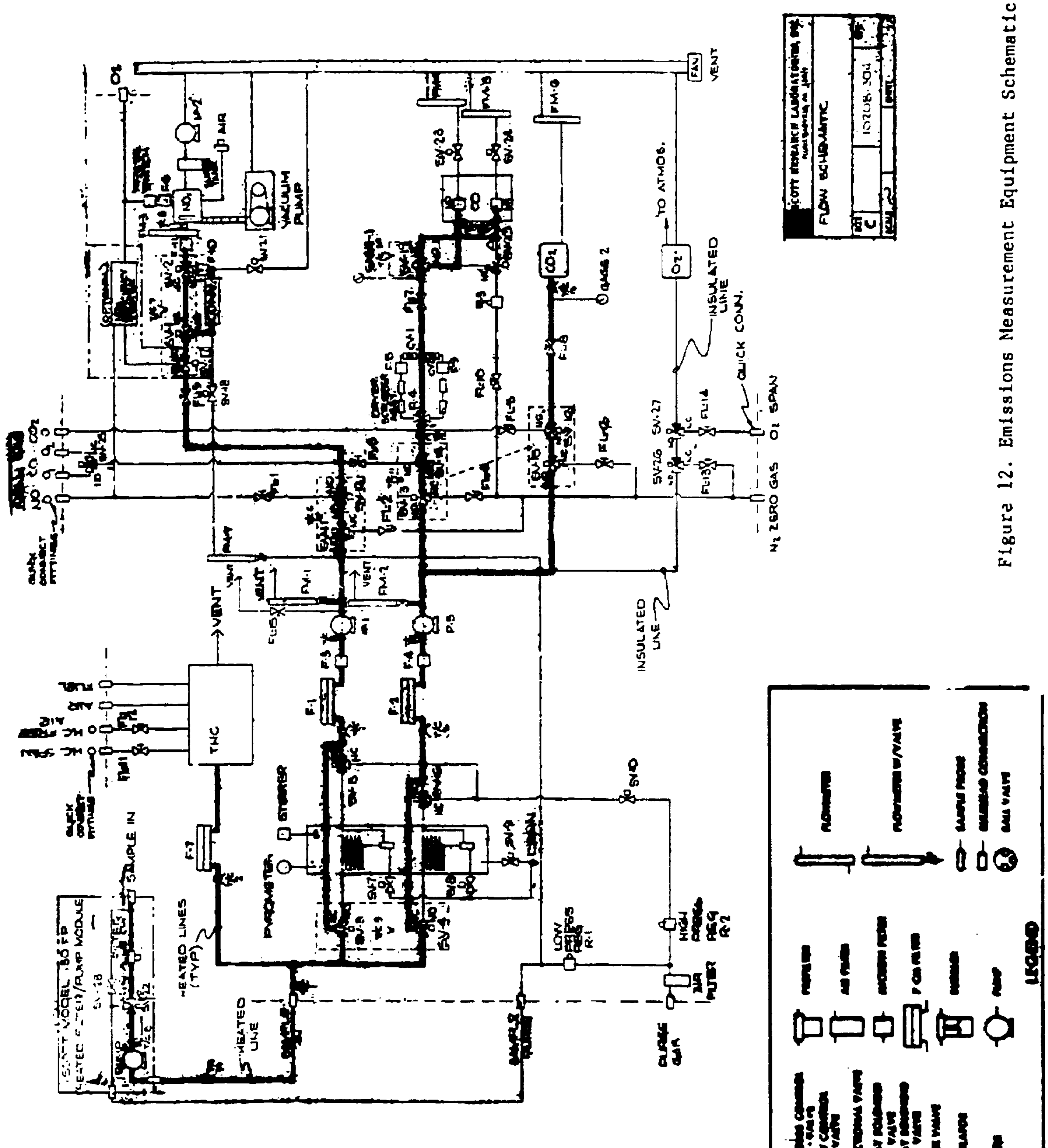


Figure 12. Emissions Measurement Equipment Schematic

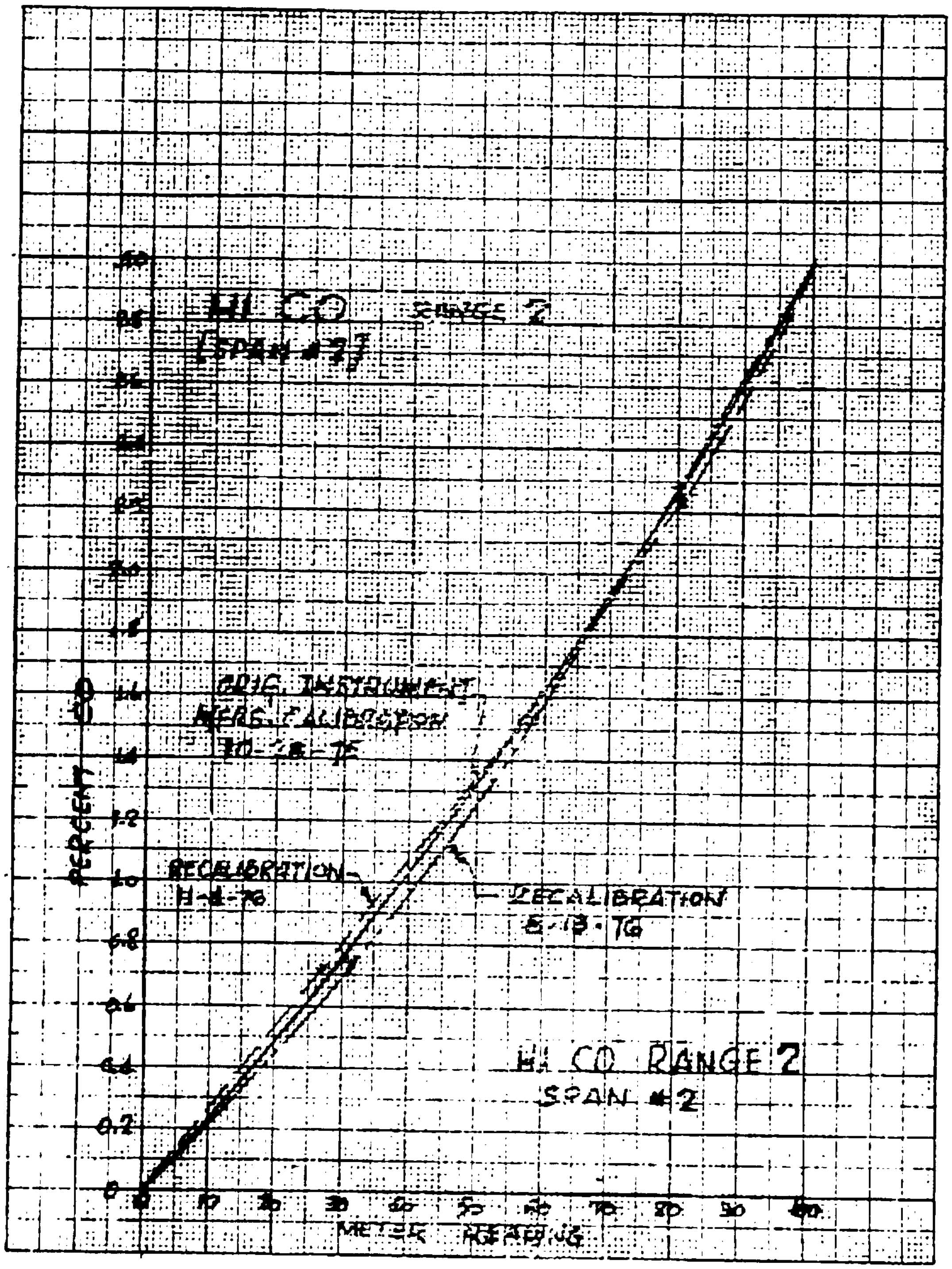


Figure 13. High CO Range 2 Conversion Curve, Meter Reading to % CO, With Recalibrations.

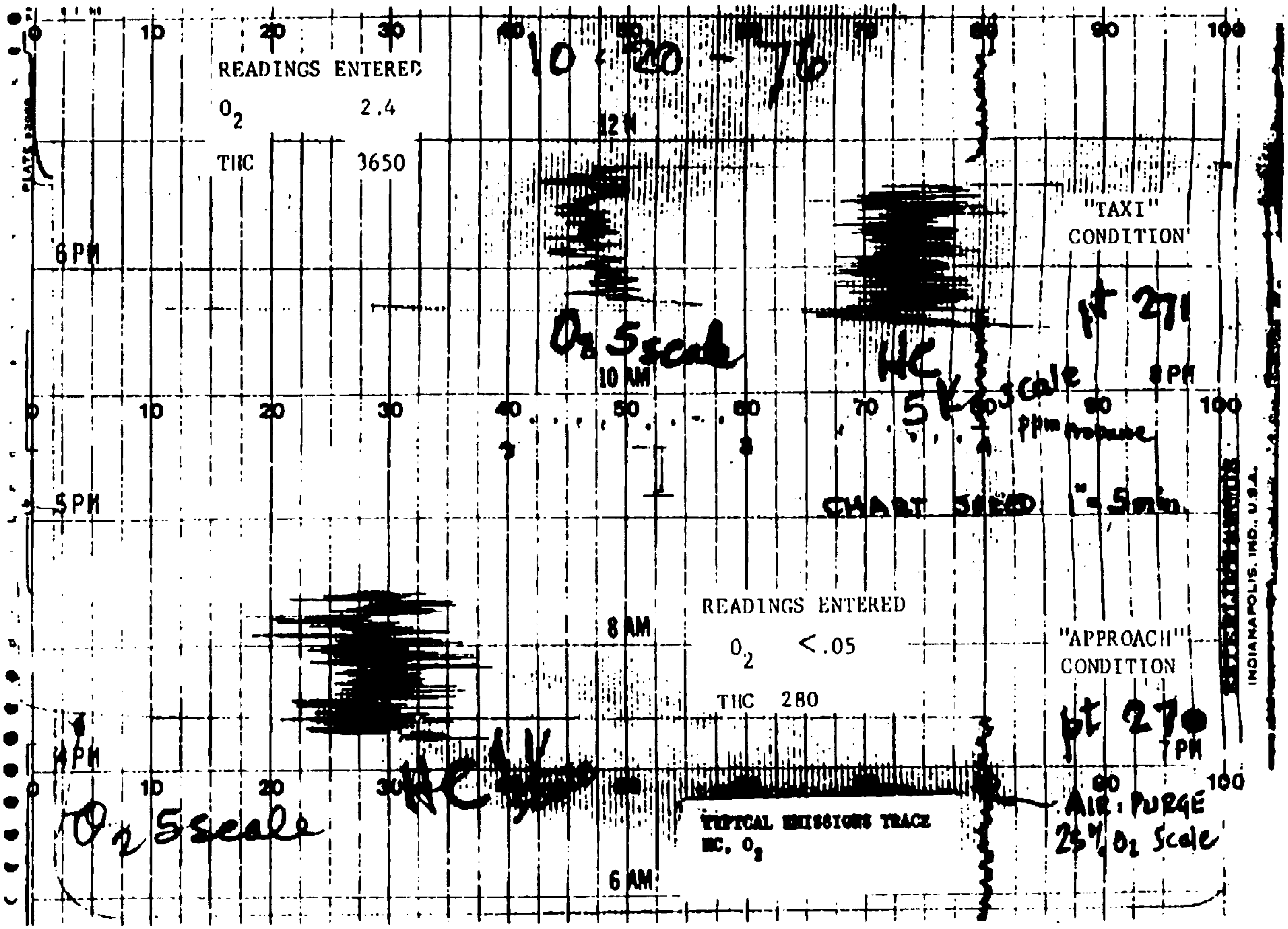


Figure 14. Typical Emissions Strip Chart for HC and O_2 (Approach and Taxi Conditions Shown).

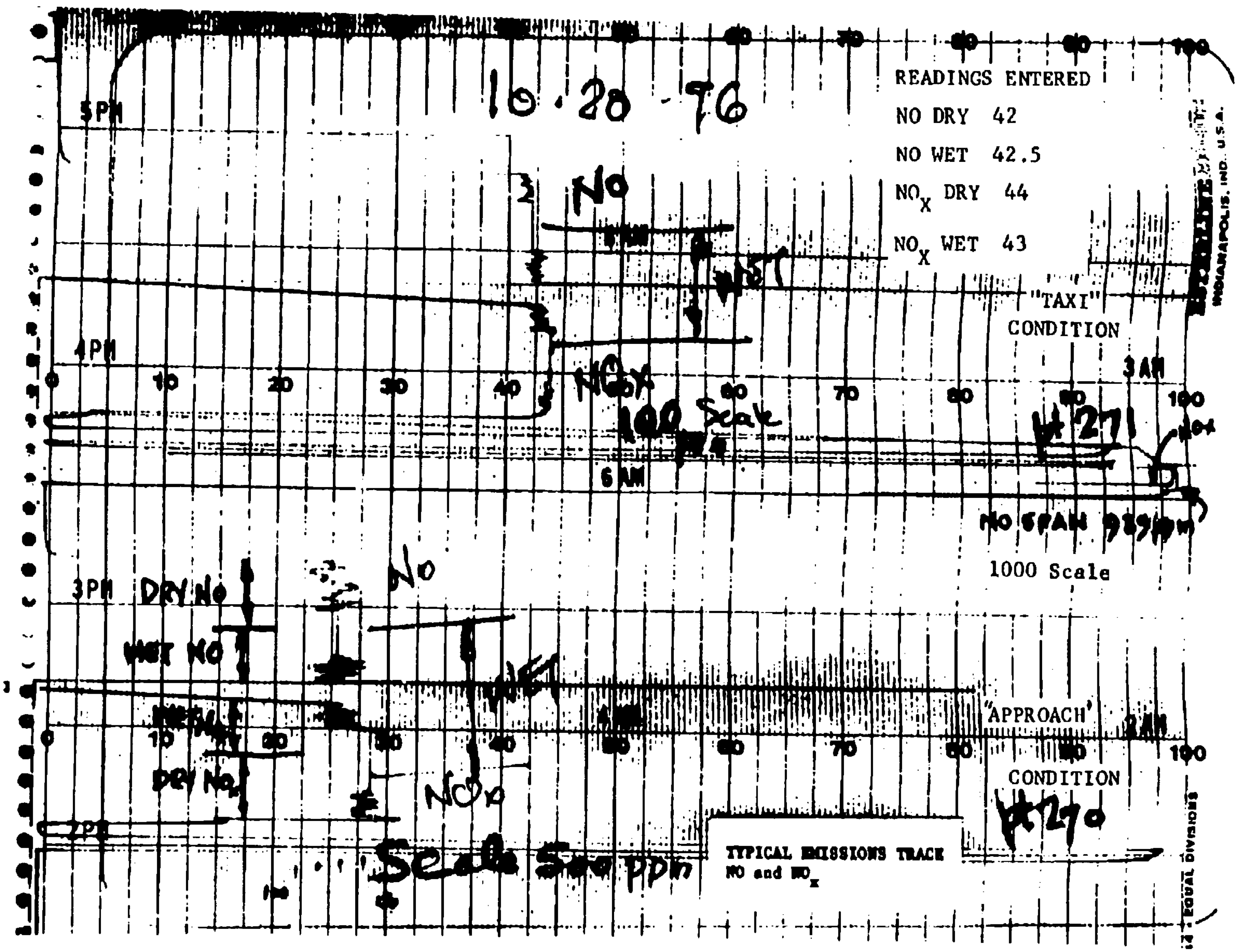


Figure 15. Typical Emissions Strip Chart for NO and NO_X (Approach and Taxi Conditions Shown).

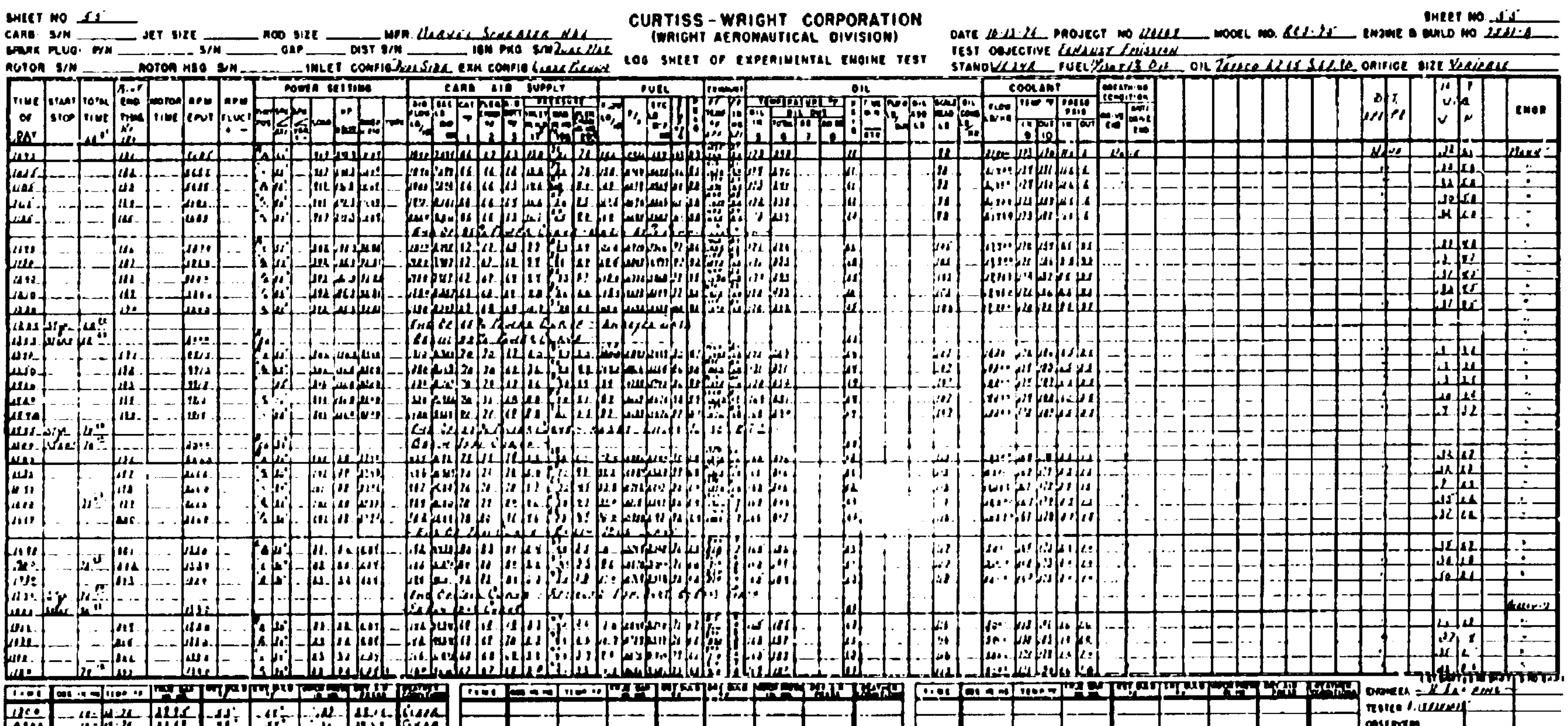


Figure 16. Sample Data Log Sheet - Performance

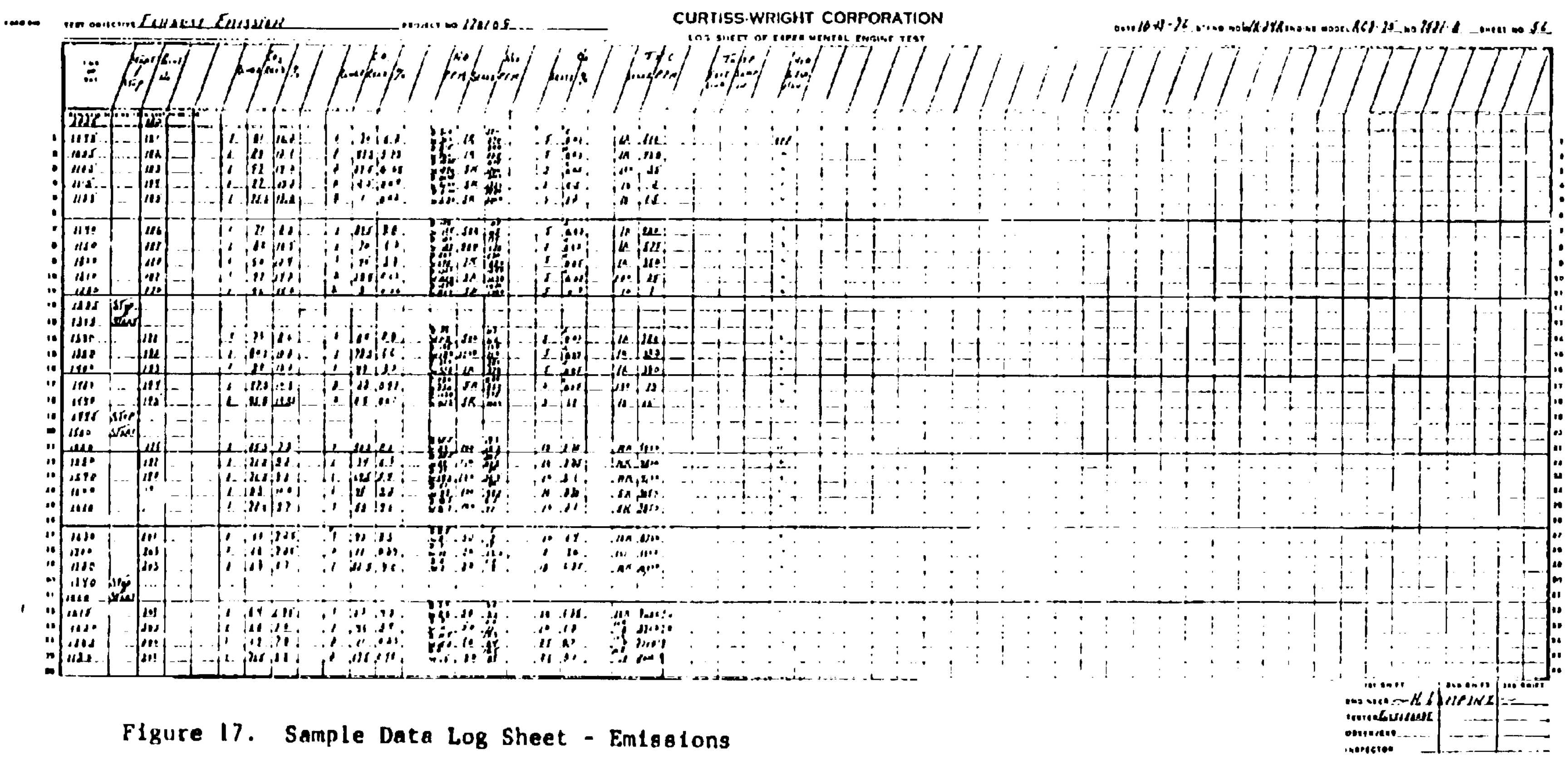
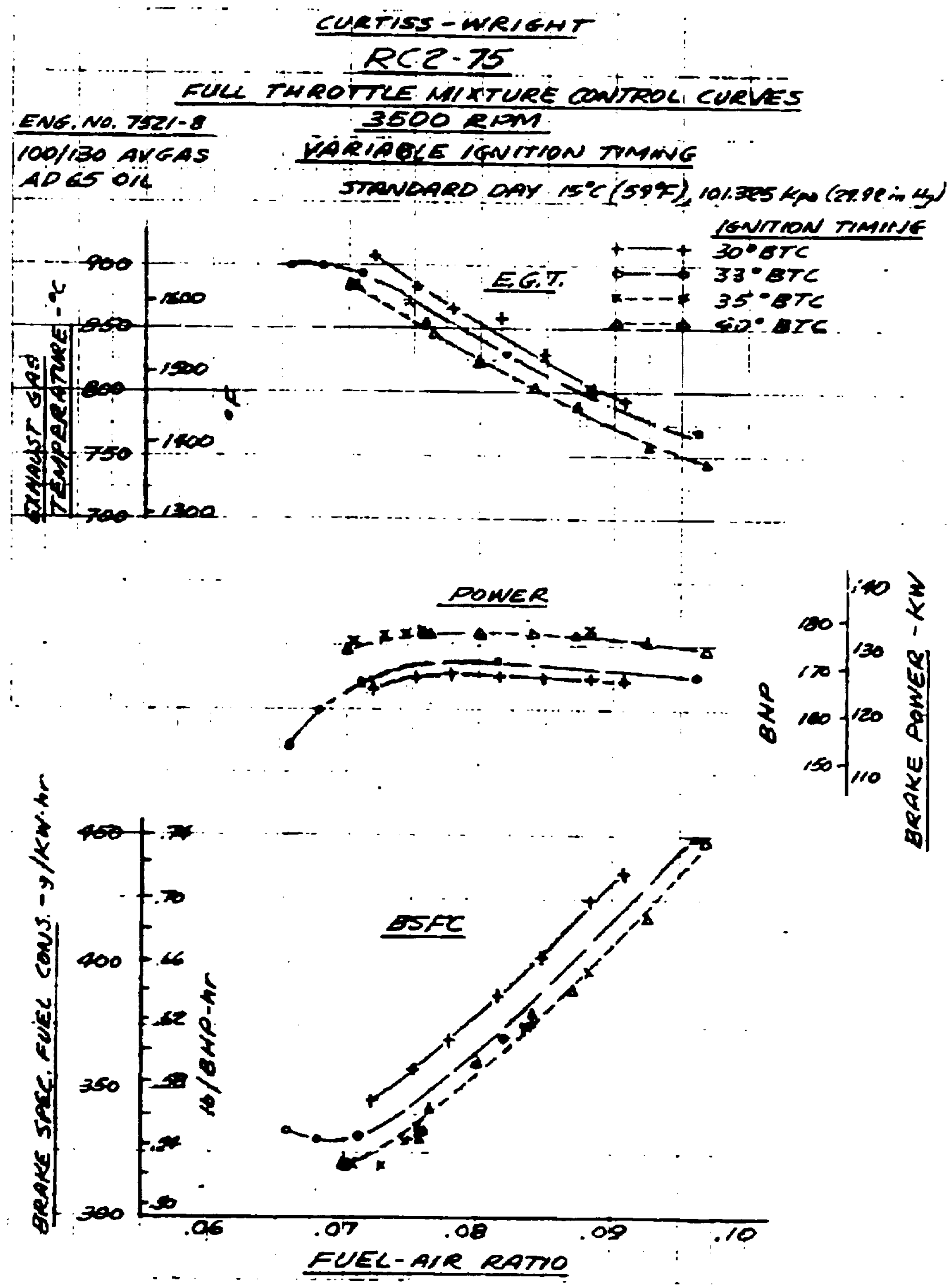


Figure 17. Sample Data Log Sheet - Emissions



CURTISS-WRIGHT
RC2-75
FULL THROTTLE MIXTURE CONTROL CURVES
3500 RPM
VARIABLE IGNITION TIMING
ENG. NO. 7521-8
100/130 AVGAS
AD 65 OIL
STANDARD DAY 15°C (59°F), 101.325 kPa (29.92 in Hg)
IGNITION TIMING
30° BTC
33° BTC
35° BTC
40° BTC
E.G.T.
EXHAUST GAS TEMPERATURE - °C
°F
POWER
BHP
BRAKE POWER - KW
BSFC
BRAKE SPEC. FUEL CONS. - g/KW·hr
lb/BHP-hr
FUEL-AIR RATIO

Figure 18

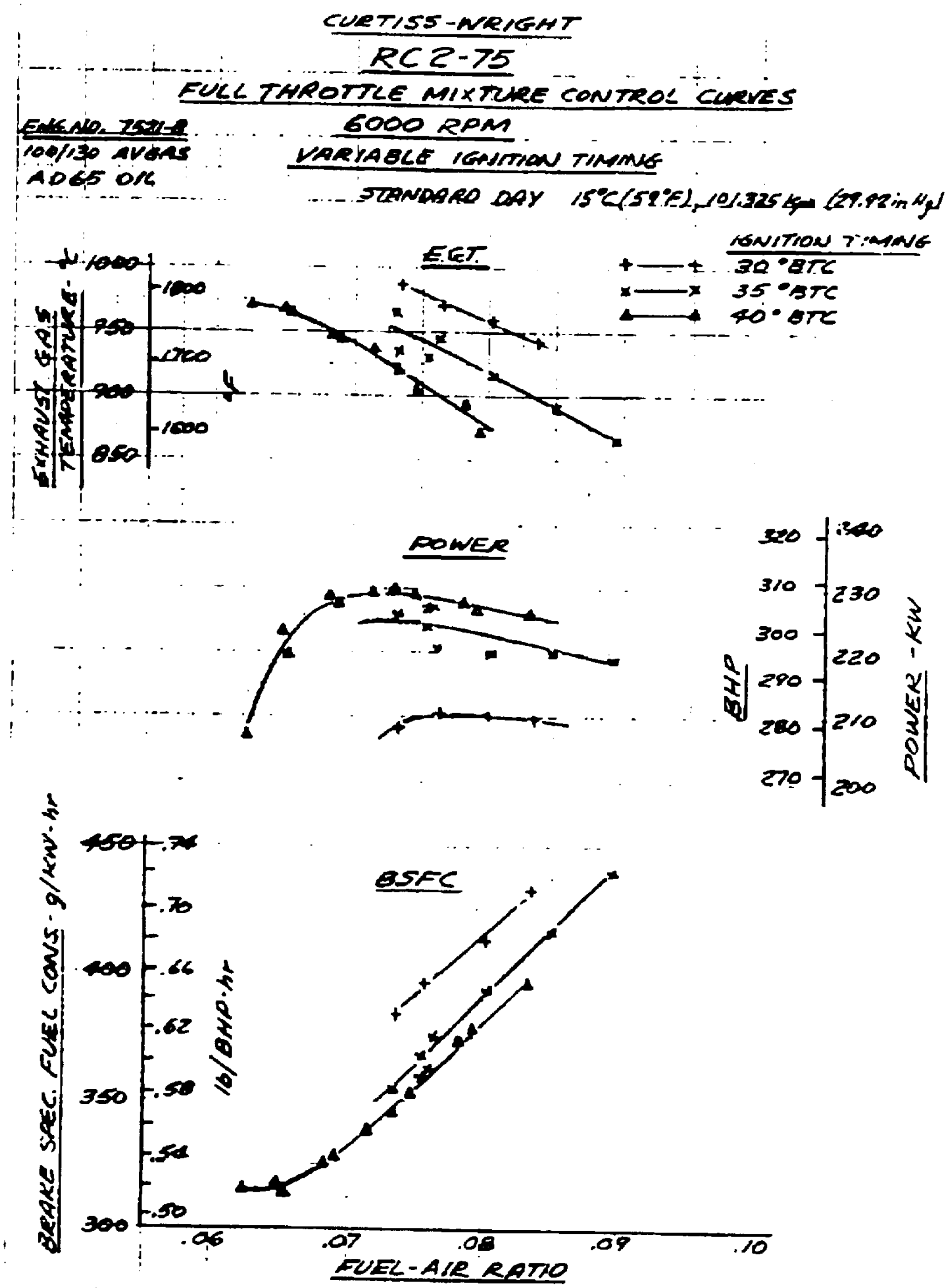

CURTISS-WRIGHT
RC2-75
FULL THROTTLE MIXTURE CONTROL CURVES
ENG. NO. 7521-B
100/130 AVGAS
AD65 OIL
6000 RPM
VARIABLE IGNITION TIMING
STANDARD DAY 15°C (59°F), 101.325 kPa (29.92 in Hg)
IGNITION TIMING
30° BTC
35° BTC
40° BTC
EGT
EXHAUST GAS TEMPERATURE
1000
950
900
850
1800
1700
1600
POWER
BHP
POWER - KW
320
310
300
290
280
270
240
230
220
210
200
BSFC
BRAKE SPEC. FUEL CONS. - g/KW·hr
lb/BHP·hr
450
400
350
300
.74
.70
.66
.62
.58
.54
.50
.06
.07
.08
.09
.10
FUEL-AIR RATIO

Figure 19

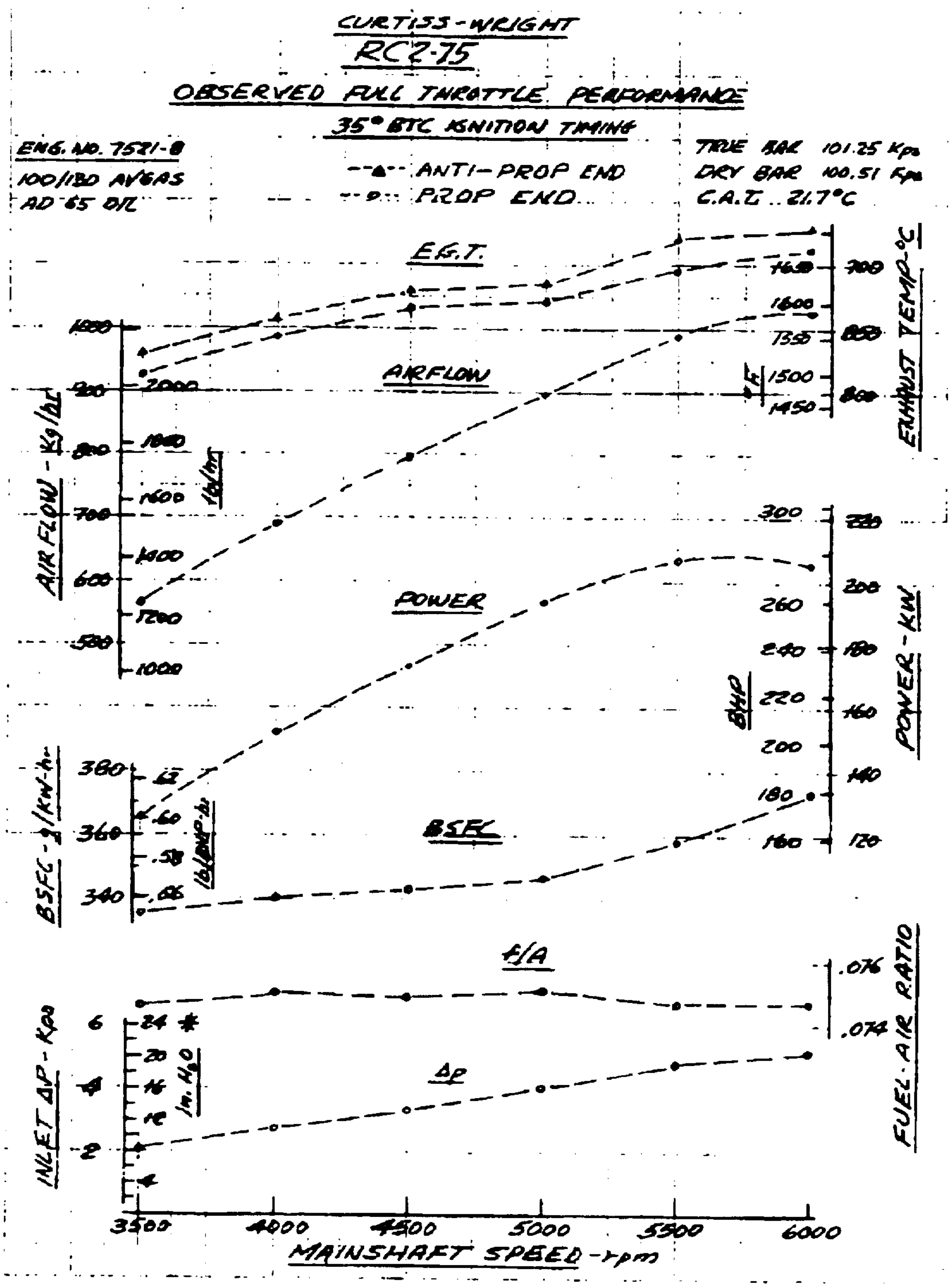


Figure 20. Observed Full Throttle Performance.

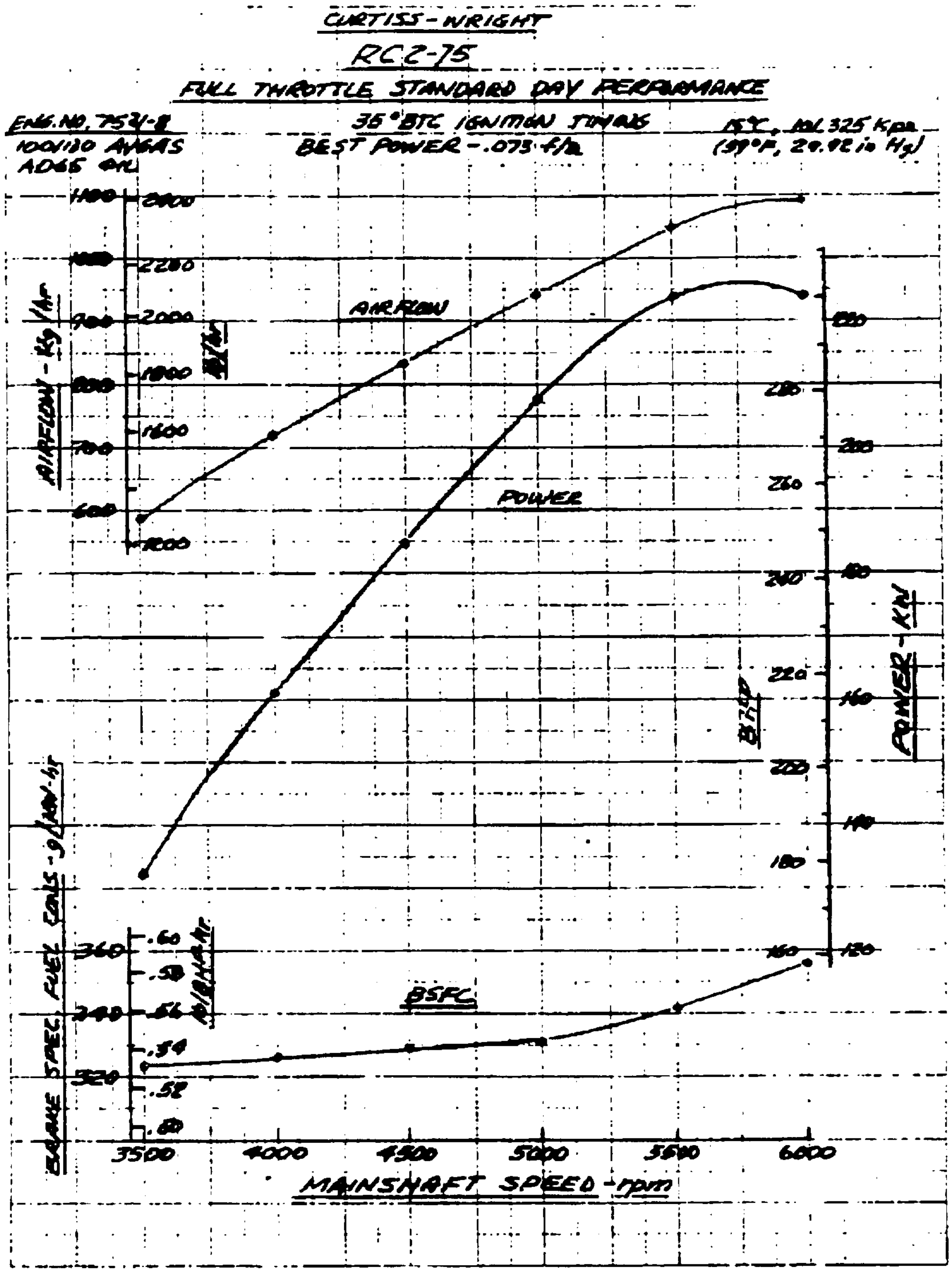


Figure 21. Full Throttle Standard Day Performance.

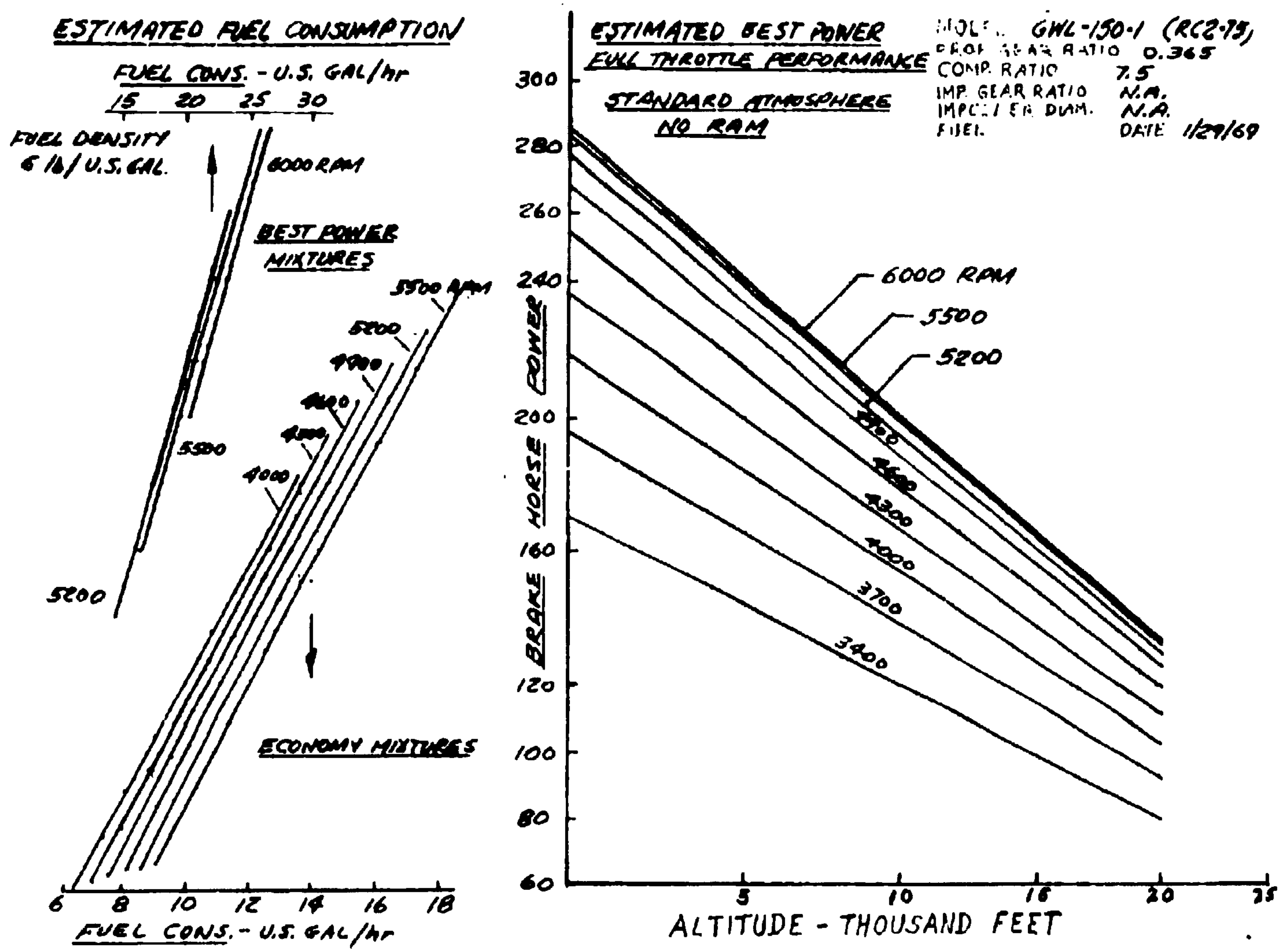


Figure 22. Full Throttle Power vs. Altitude and Fuel Consumption.

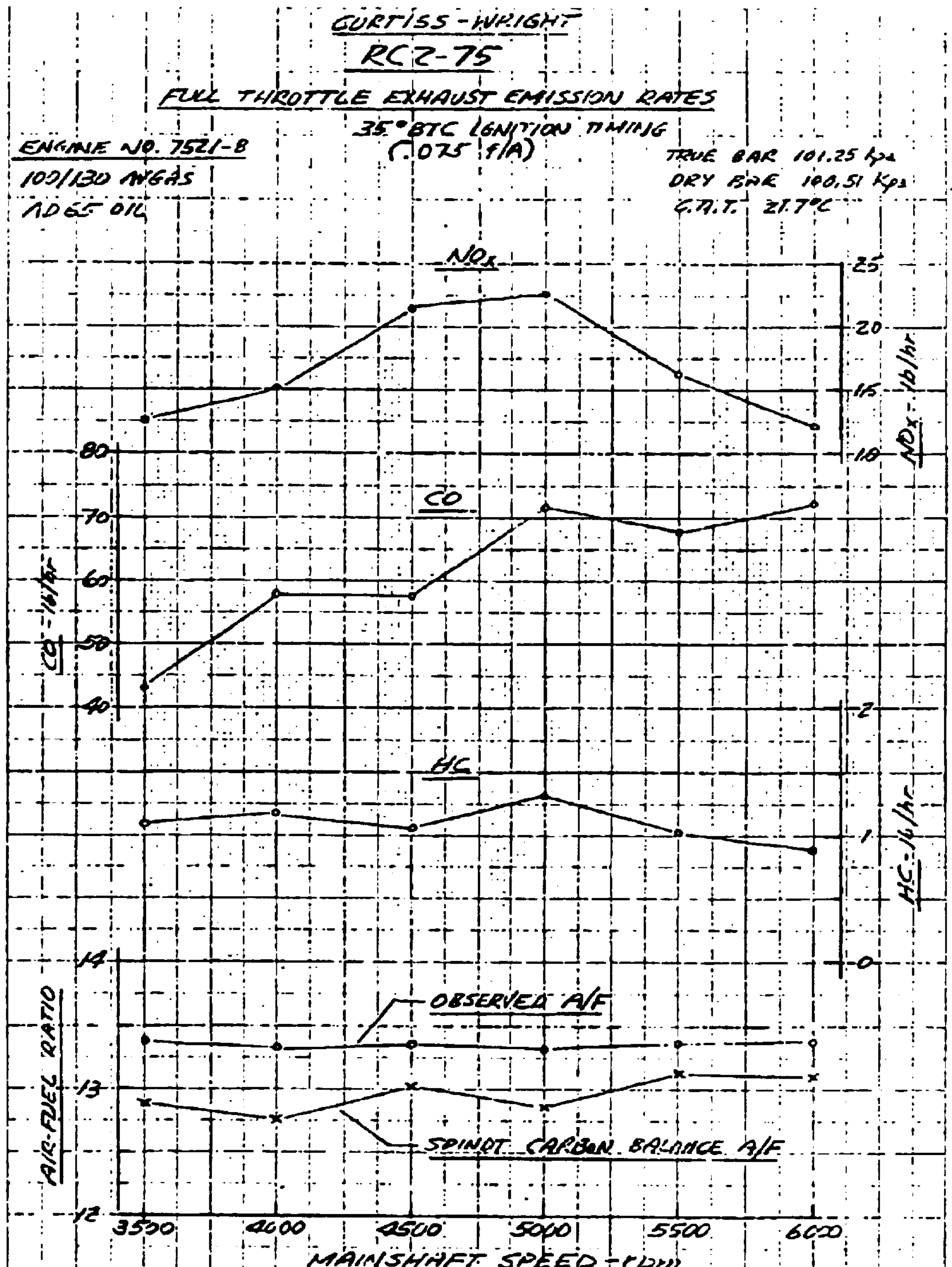


Figure 23. Full Throttle Exhaust Emission Rates.

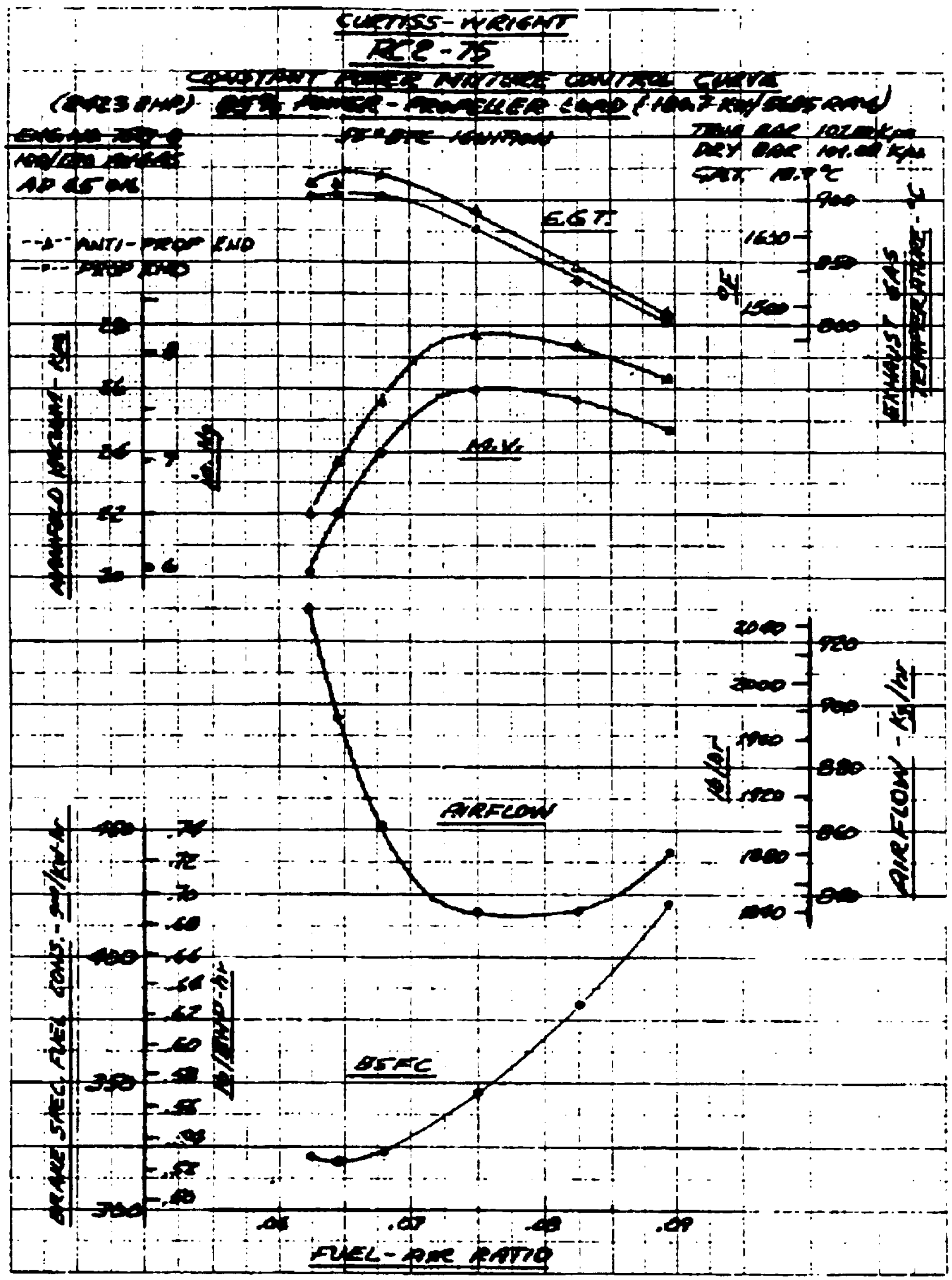


Figure 24. Constant Power Mixture Control Curve, 85% Power - Propeller Load.

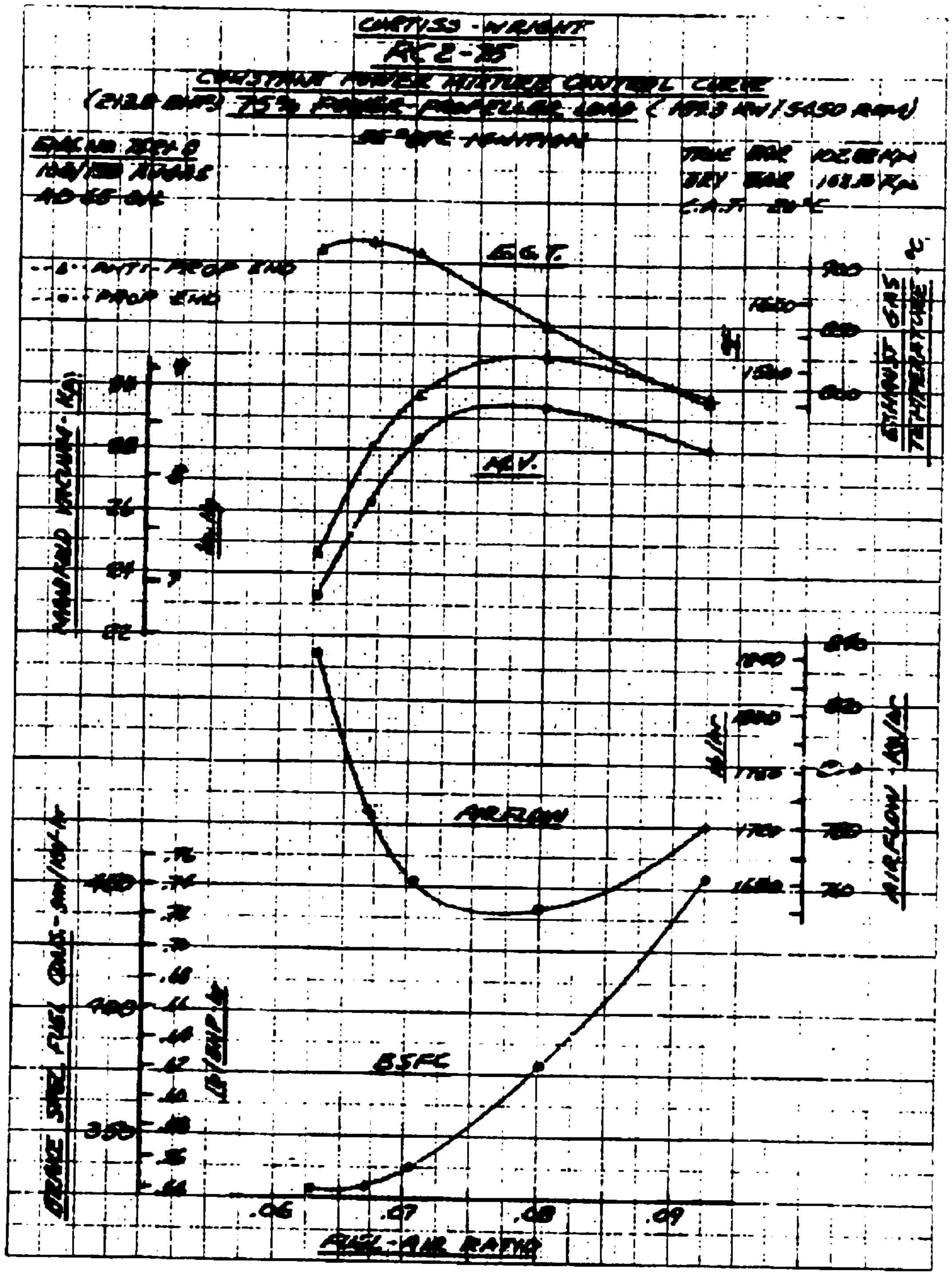


Figure 25. Constant Power Mixture Control Curve, 75% Power - Propeller Load.

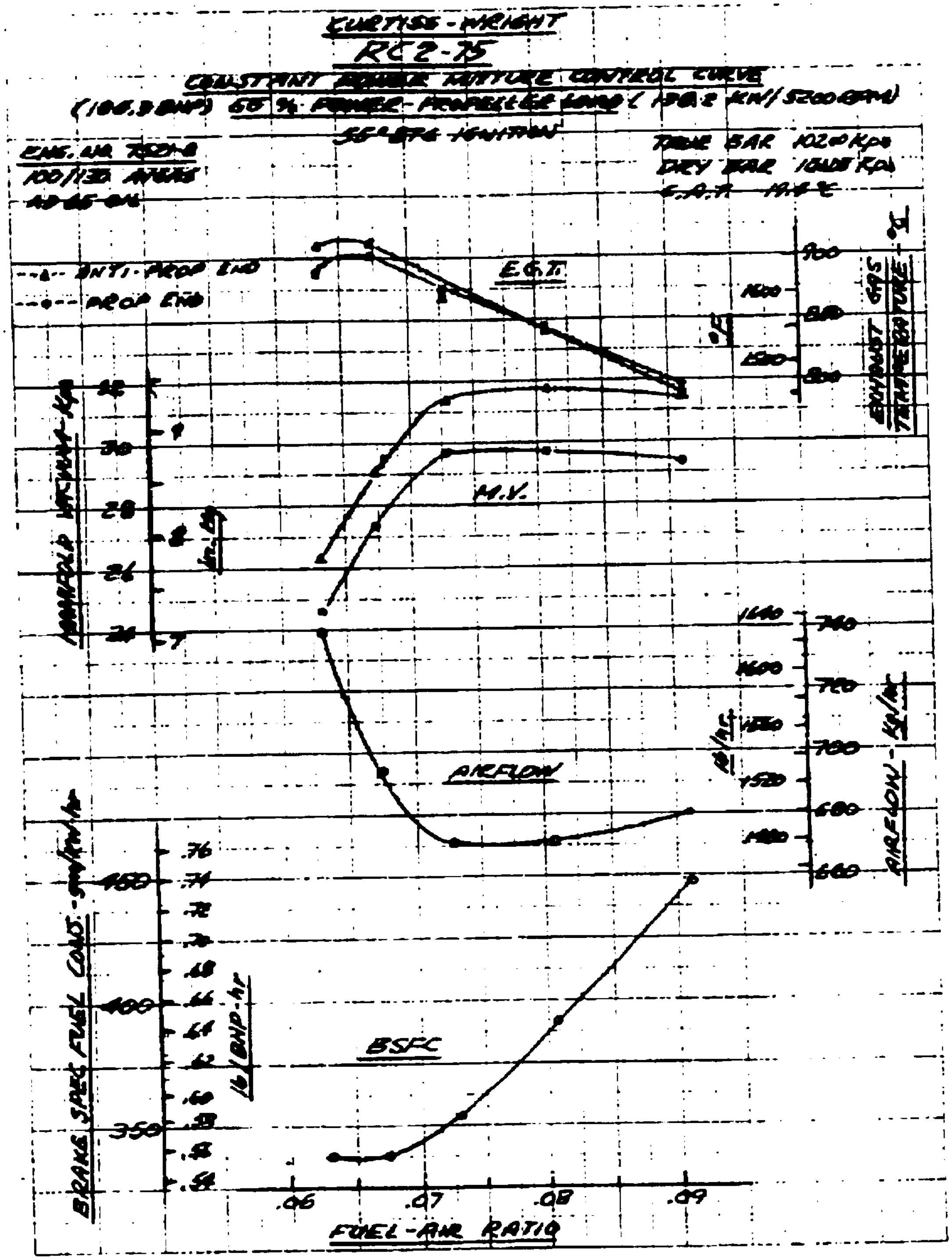


Figure 26. Constant Power Mixture Control Curve, 65% Power-- Propeller Load.

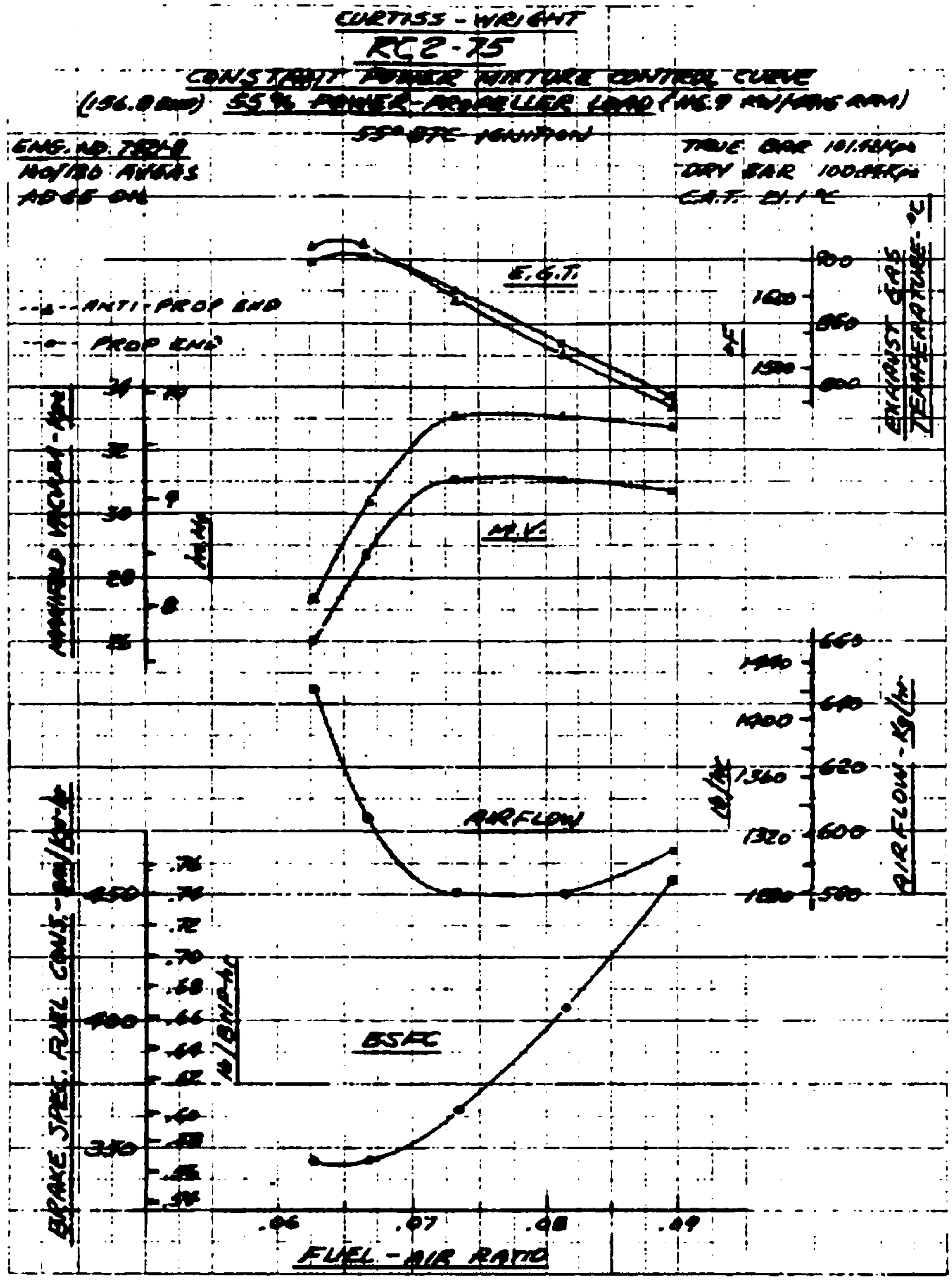


Figure 27. Constant Power Mixture Control Curve, 55% Power - Propeller Load.

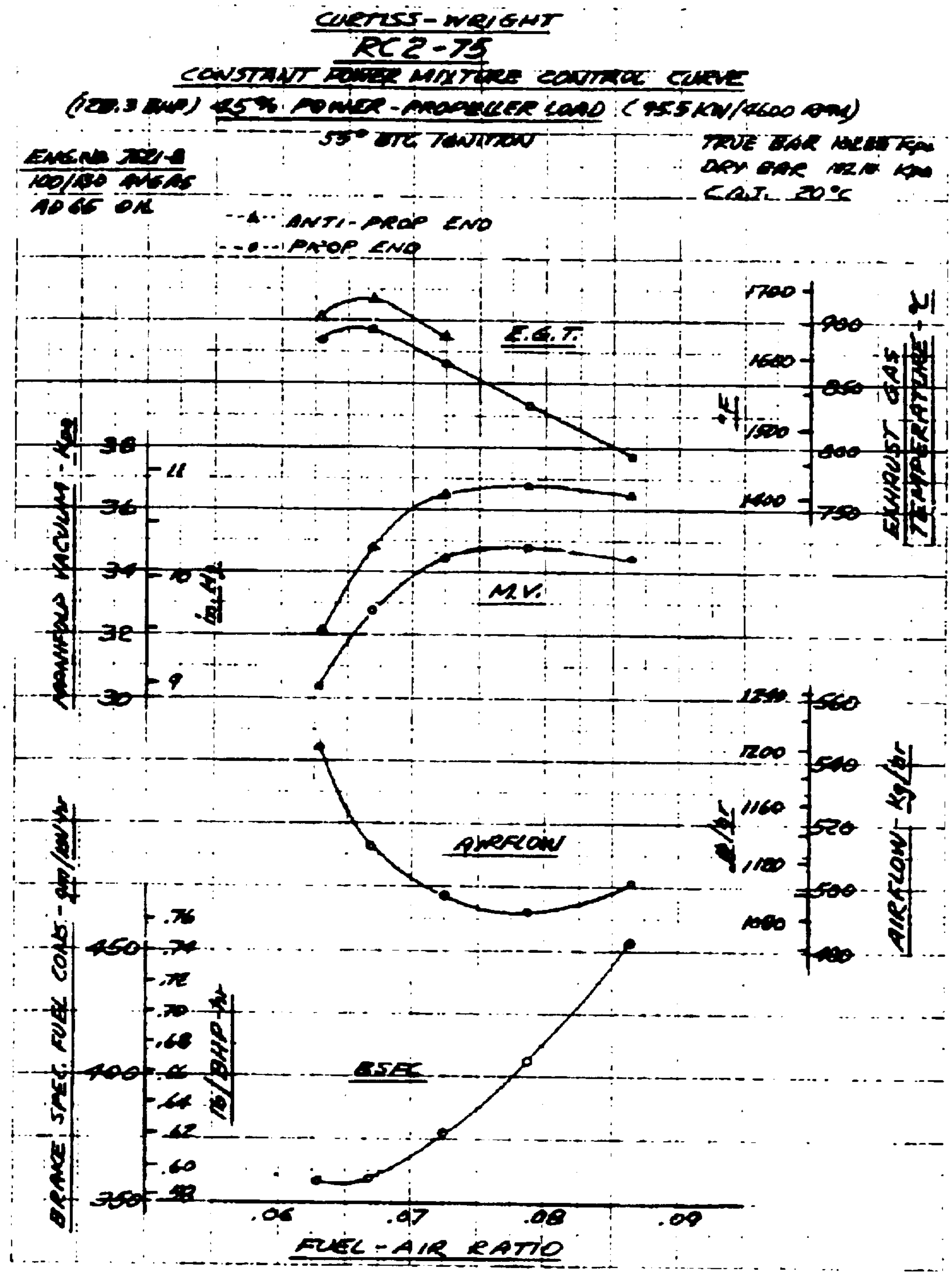


Figure 28. Constant Power Mixture Control Curve, 45% Power - Propeller Load.

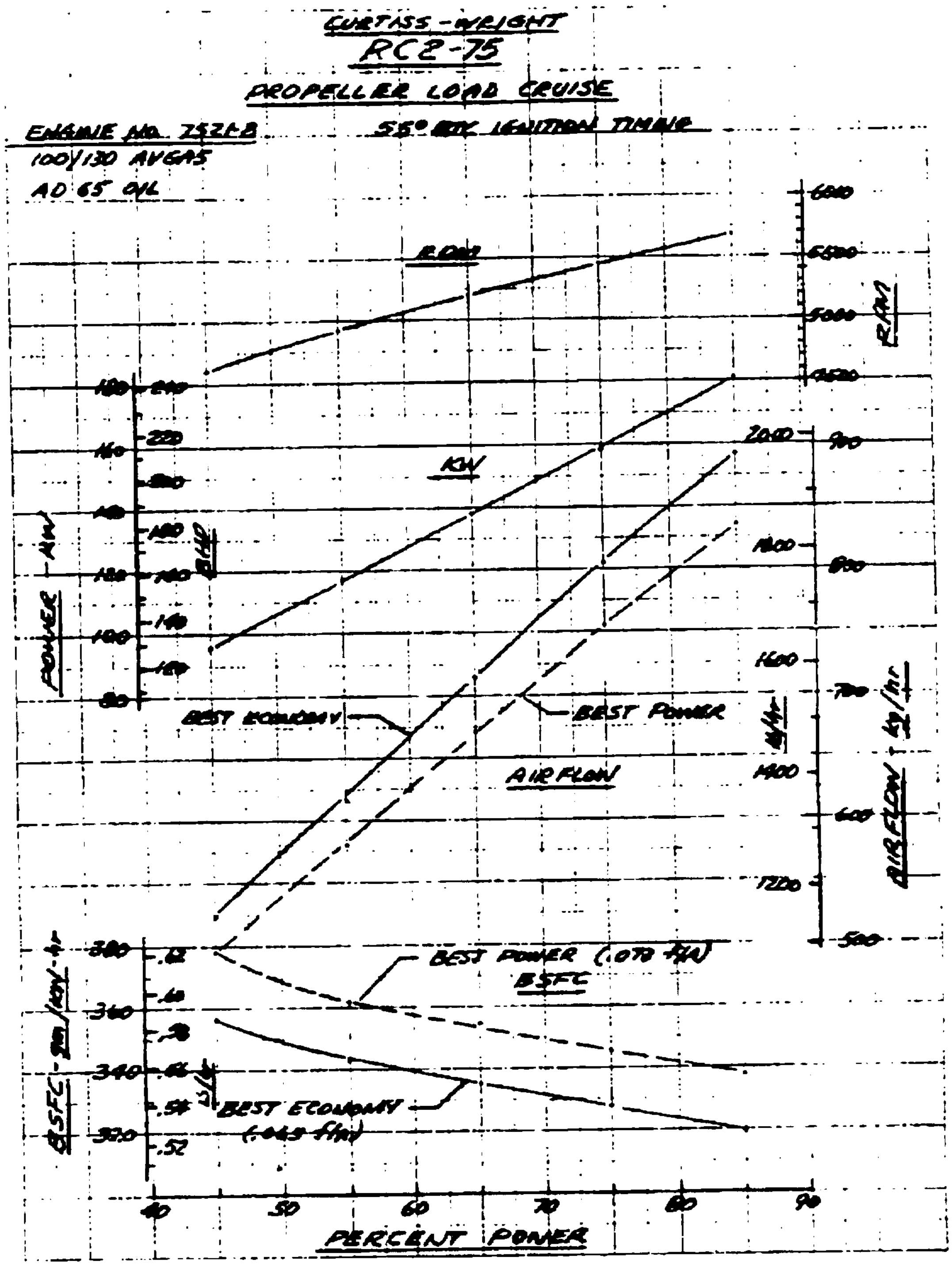


Figure 29. Propeller Load Cruise, Best Power And Best Economy.

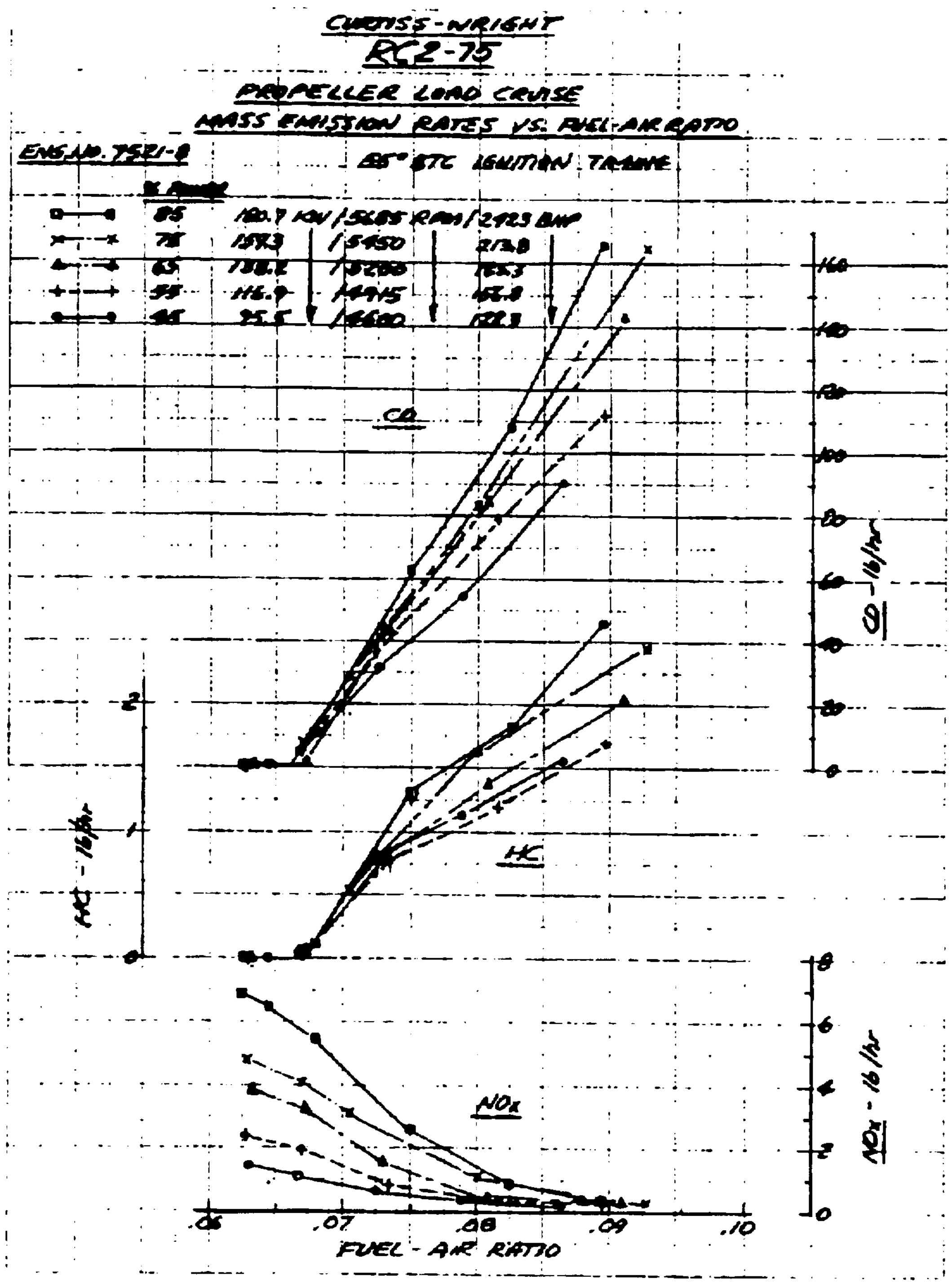


Figure 30. Propeller Load Cruise, Mass Emission Rates vs Fuel-Air Ratio.

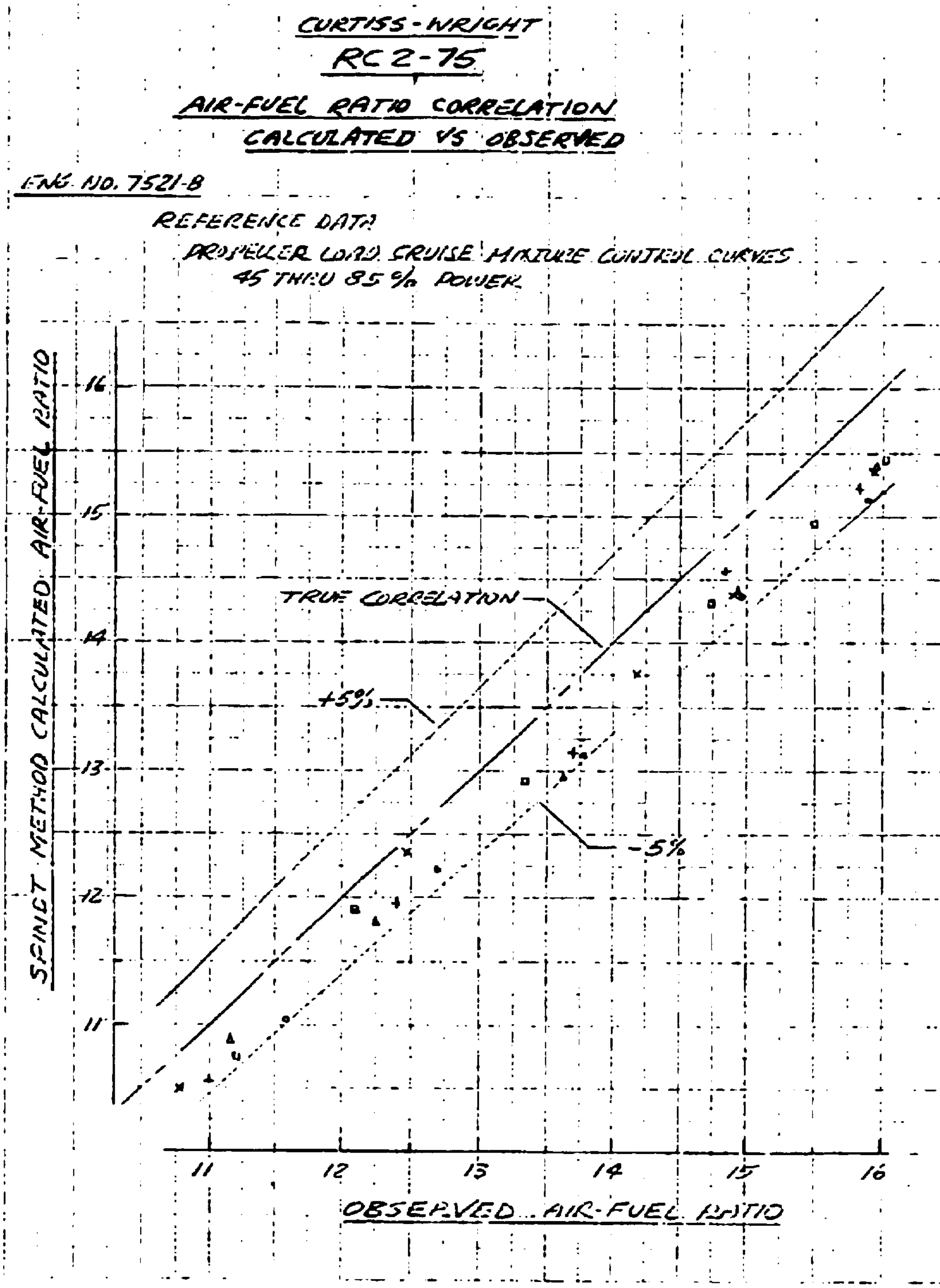


Figure 31. Air-Fuel Ratio Correlation, Calculated vs Observed.

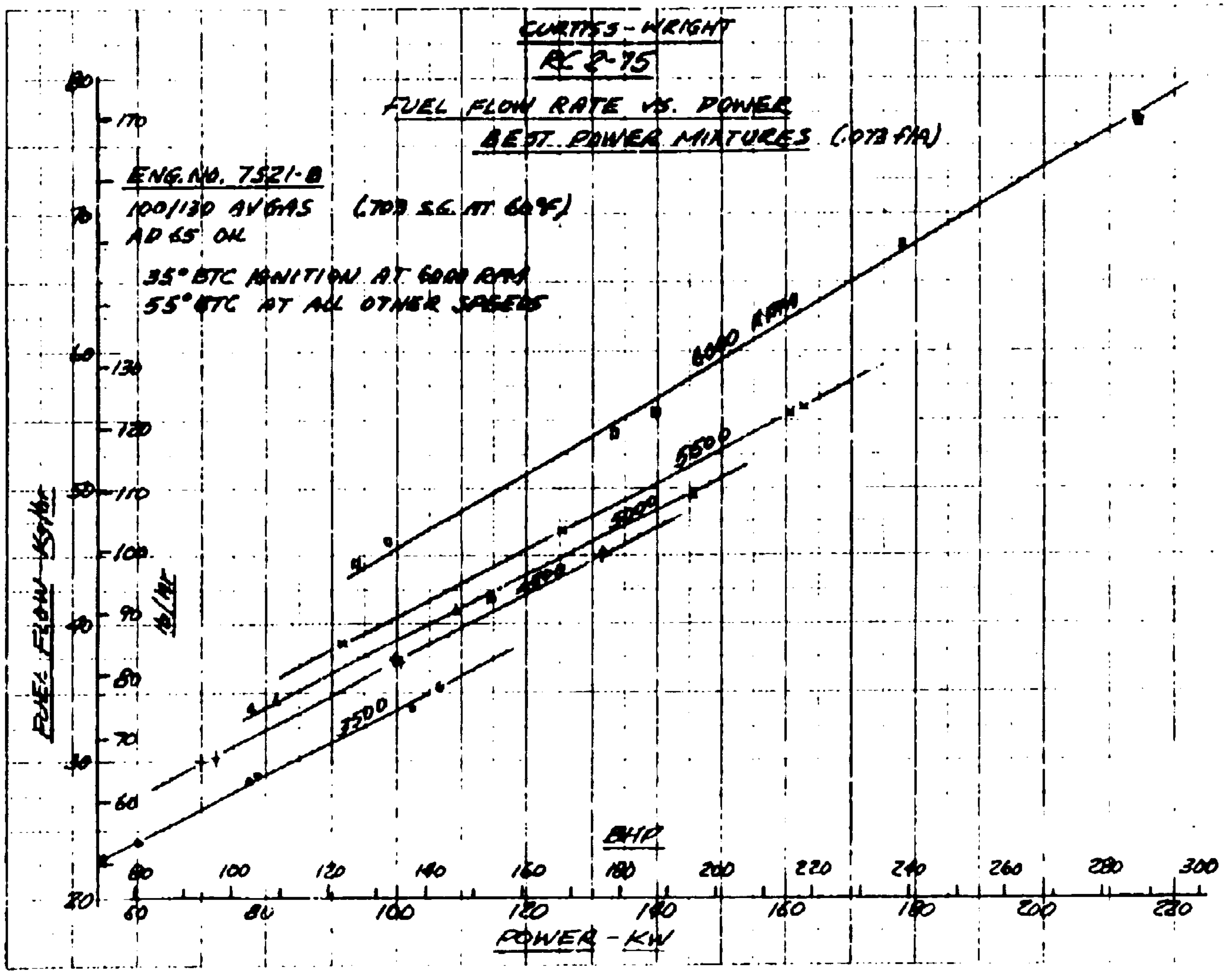


Figure 32. Fuel Flow Rate vs Power, Best Power Mixture.

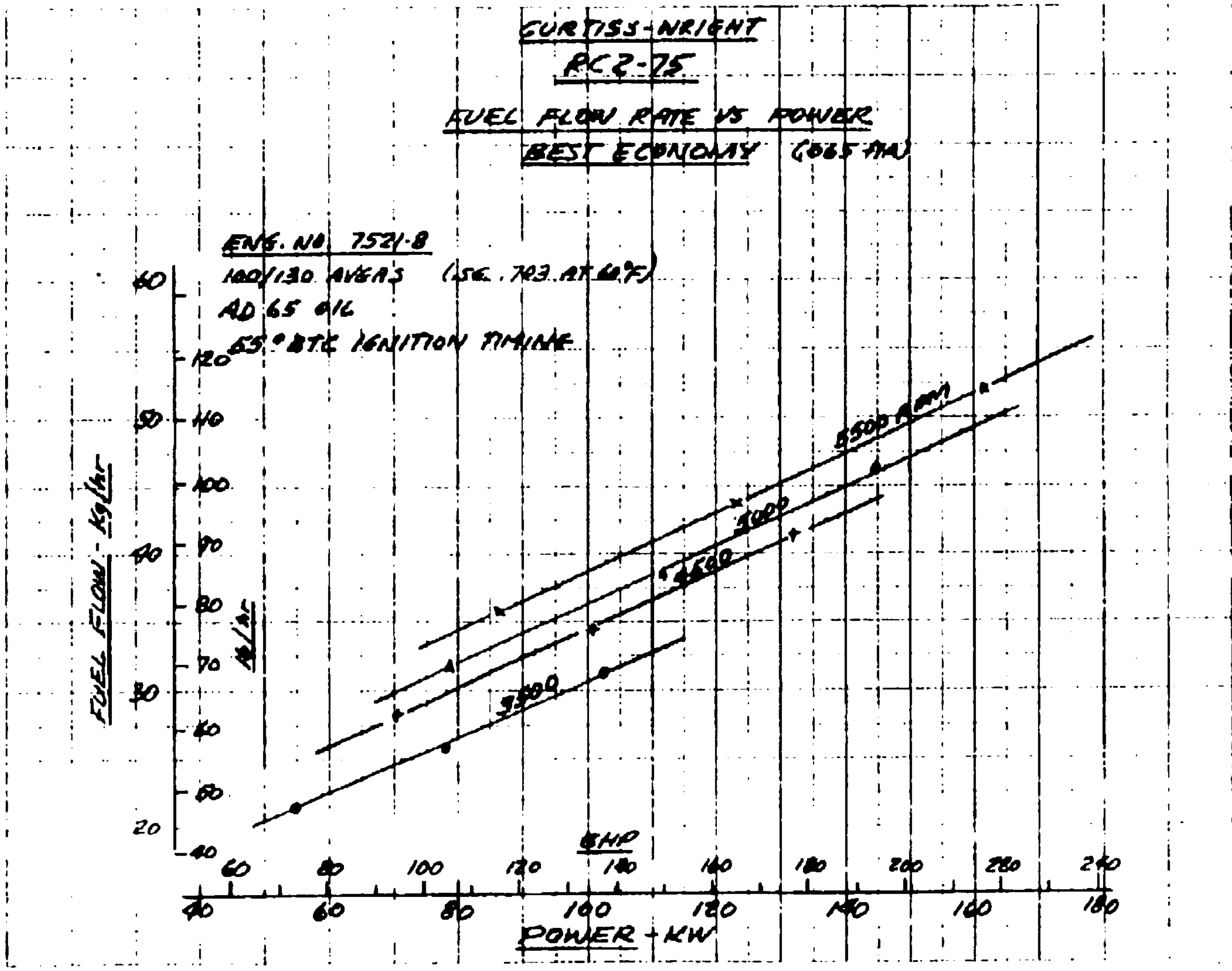


Figure 33. Fuel Flow Rate vs Power, Best Econmony.

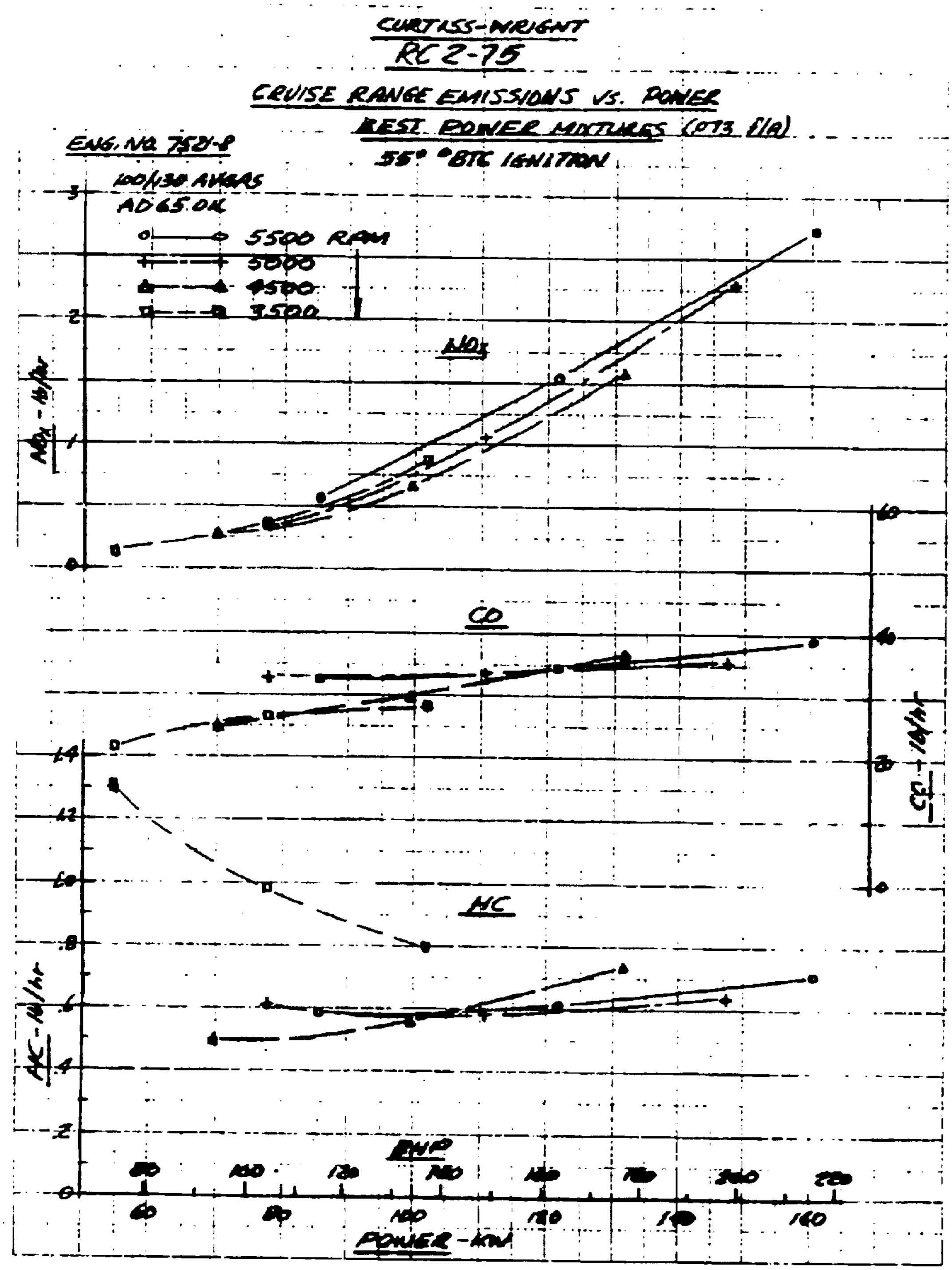


Figure 34. Cruise Range Emissions vs Power, Best Power Mixtures.

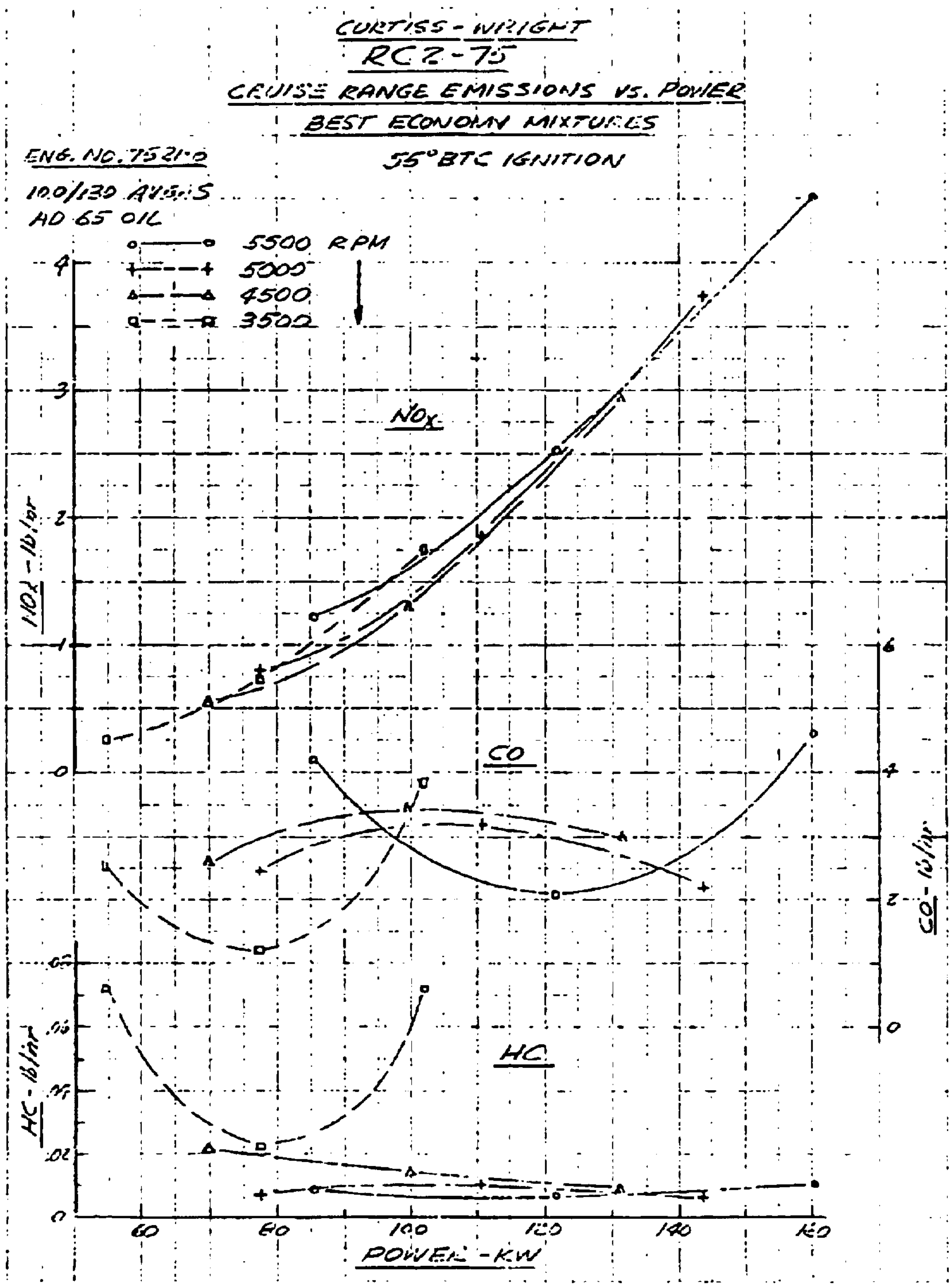


Figure 35. Cruise Range Emissions vs Power Best Economy Mixtures.

EPA EXHAUST EMISSIONS TEST RESULTS

285 BHP CURTISS-WRIGHT RC2-75 ENGINE NO. 7521-8
(Ignition Timing, 35° BTC)

	Idle	Taxi	Take-Off	Climb	Approach
KW	2.4	21	215	170	85
BHP	3.2	28	288	228	114
RPM	1330	2660	6000	5400	5200
Air Flow - lb/hr	142.000	406.000	2,320.000	1,840.000	1,160.000
Fuel Flow - lb/hr	10.800	29.600	169.000	134.000	85.000
Air-Fuel Ratio	13.148	13.716	13.728	13.731	13.647
CO_2, % dry	6.200	10.700	12.750	12.750	12.400
CO, % dry	4.400	3.000	2.900	2.900	3.300
THC, PPMC wet	38,571.000	10,950.000	600.000	780.000	840.000
O_2, % dry	6.750	2.400	0.000	0.000	0.000
NO_x, PPM wet	6.300	43.000	550.000	760.000	127.000
H_2O Correction	0.92037	0.89099	0.86517	0.86486	0.86301
A/F-Spindt Carbon Bal.	12.95457	13.68732	13.34775	13.33008	13.15666
A/F-Stivender Oxygen Bal.	12.80934	13.30191	13.21285	13.21261	13.10602
Exhaust Density, lb/ft^3	0.07374	0.07437	0.07439	0.07439	0.07430
HC, lb/hr	2.88589	2.31574	0.72492	0.74737	0.50824
CO, lb/hr	6.09172	11.36507	60.94562	48.31582	34.64385
NO_x, lb/hr	0.00155	0.02997	2.18987	2.39977	0.25323
HC, lb/Cycle	0.09620	0.54034	0.00362	0.06228	0.05082
CO, lb/Cycle	0.20306	2.65185	0.30473	4.02632	3.46439
NO_x, lb/Cycle	0.00005	0.00699	0.01095	0.19998	0.02532

	Demonstrated	EPA Standard
HC Emissions, lb/Cycle/Rated HP	0.00264	0.0019
CO Emissions, lb/Cycle/Rated HP	0.03737	0.0420
NO_x Emissions, lb/Cycle/Rated HP	0.00085	0.0015

NOTE: Idle mode not run in sequence with other modes. See Section IC.5.on Page 14.

Figure 36. Table of EPA Exhaust Emissions Test Results.

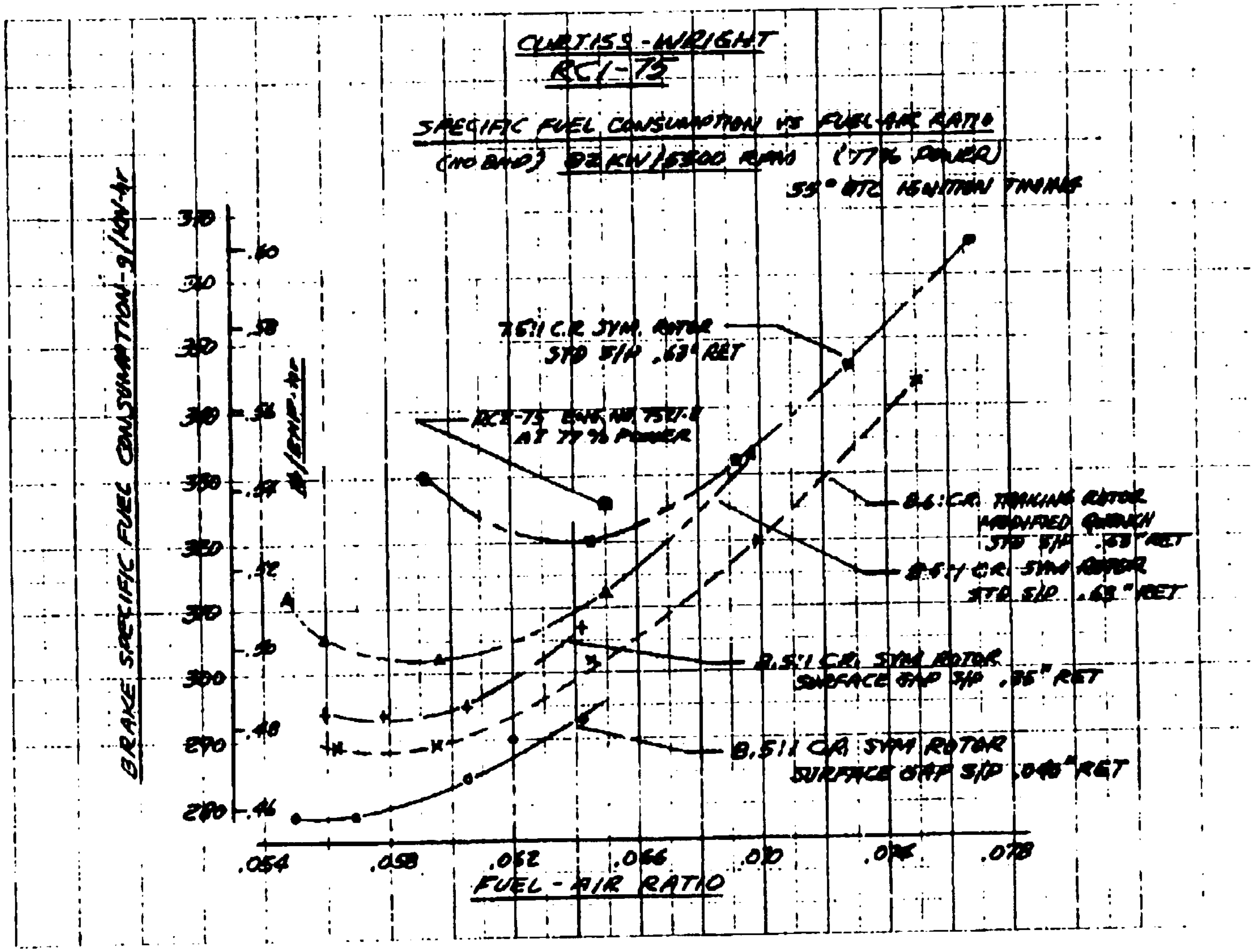


Figure 37. RC1-75, Specific Fuel Consumption vs Fuel-Air Ratio, Various Modifications.

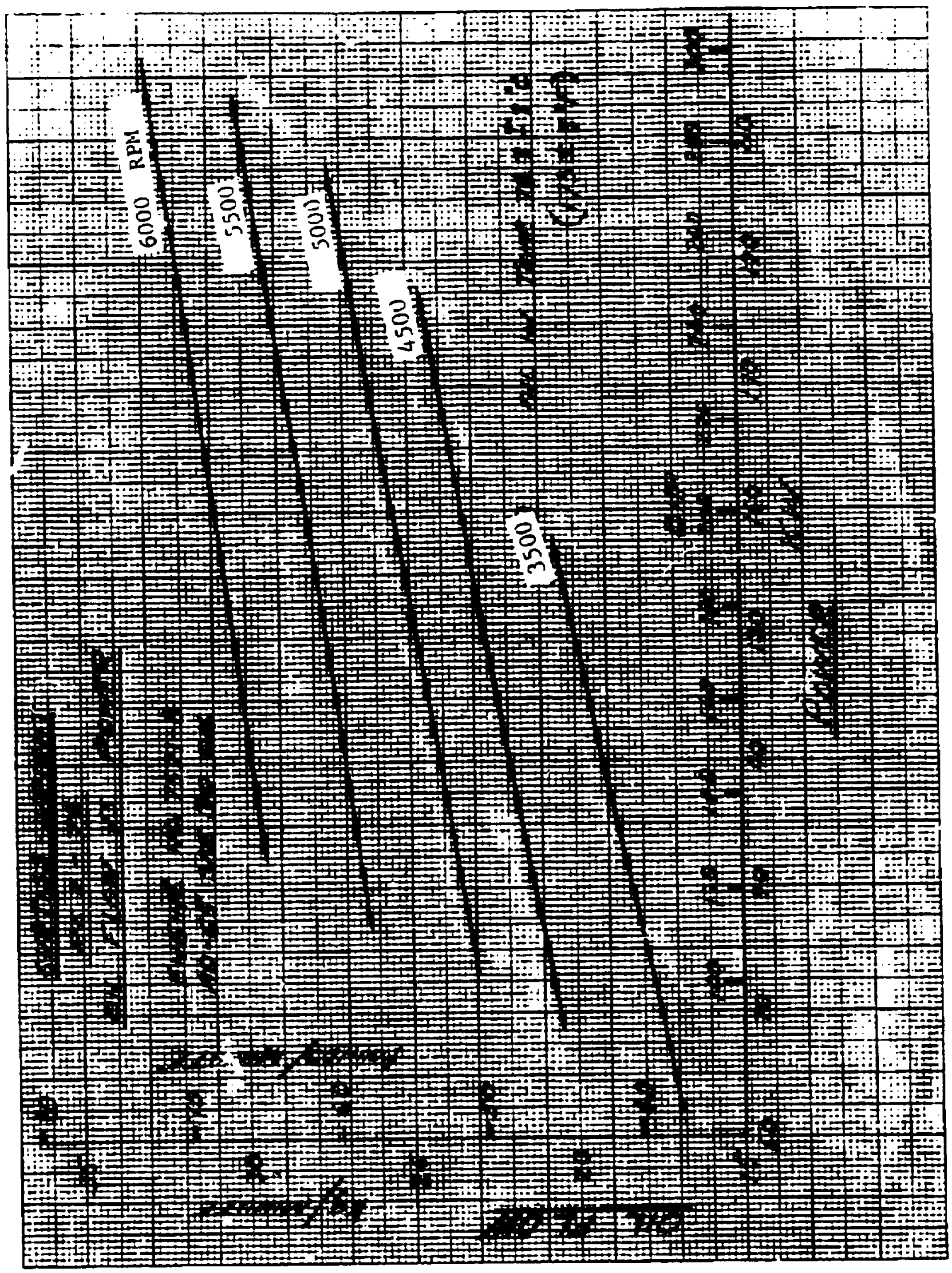


Figure 38. Oil Flow vs Power for Constant Speed.

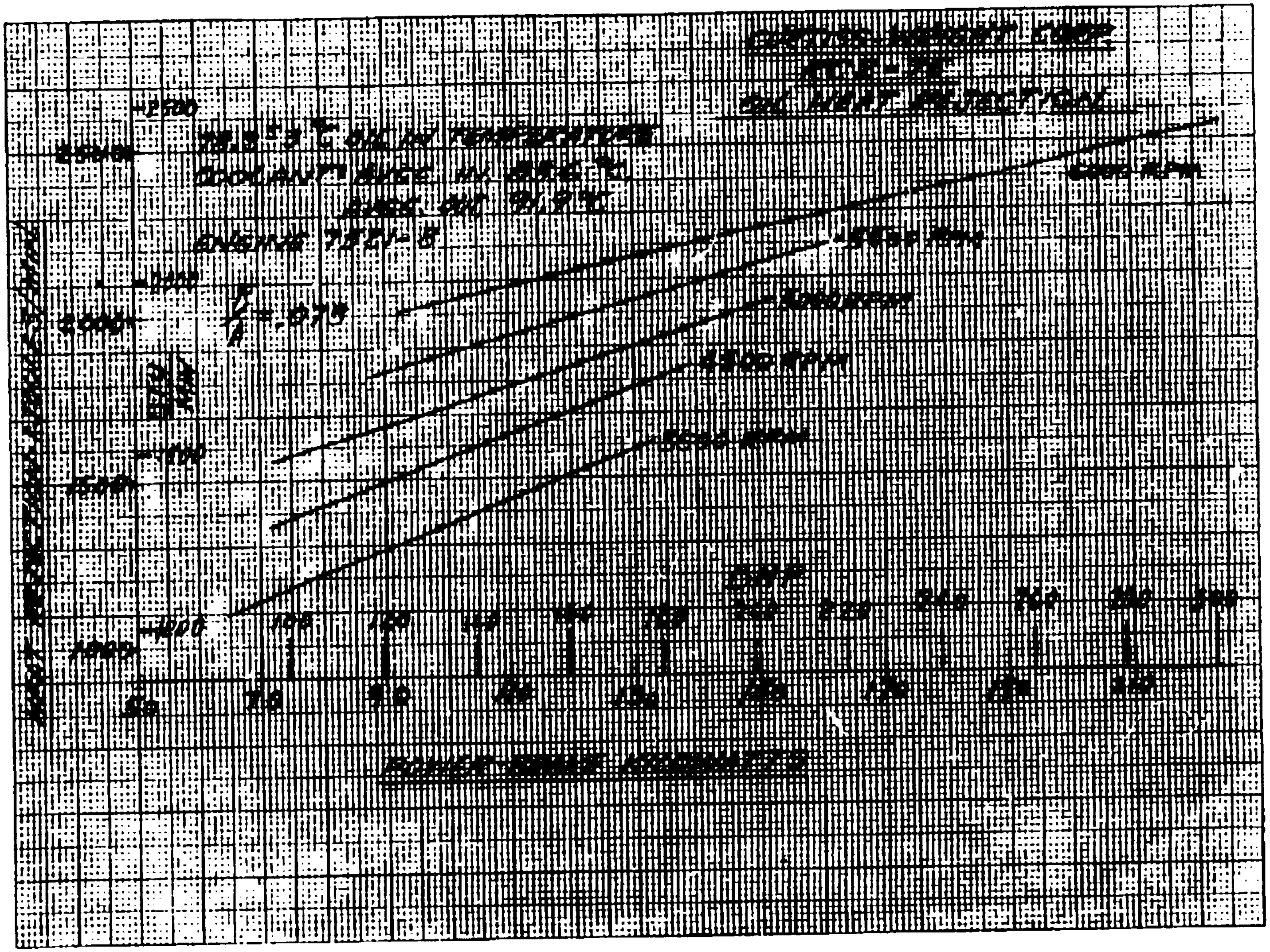


Figure 39. Oil Heat Rejection vs Power for Constant Speeds.

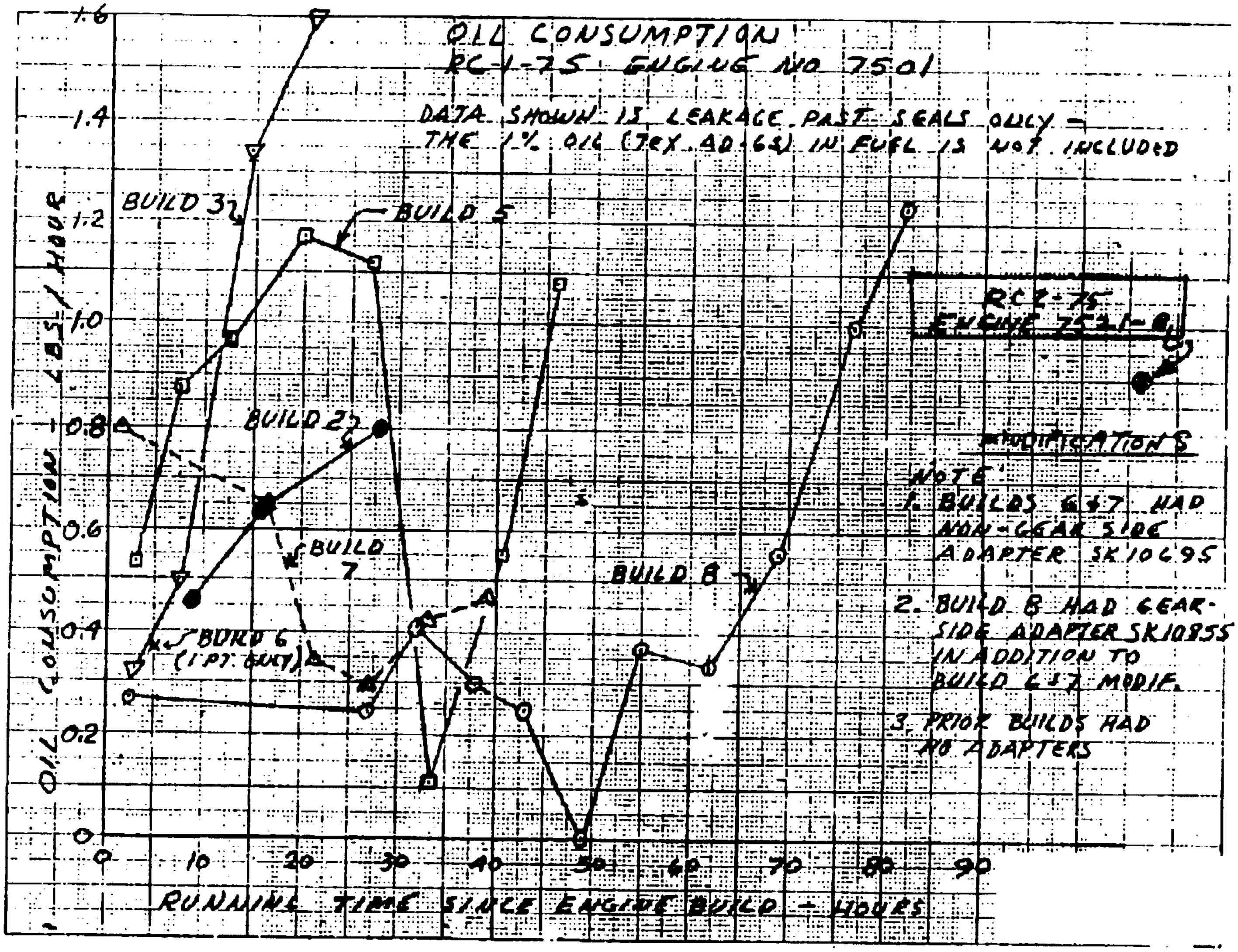


Figure 40. RC1-75 Oil Consumption.

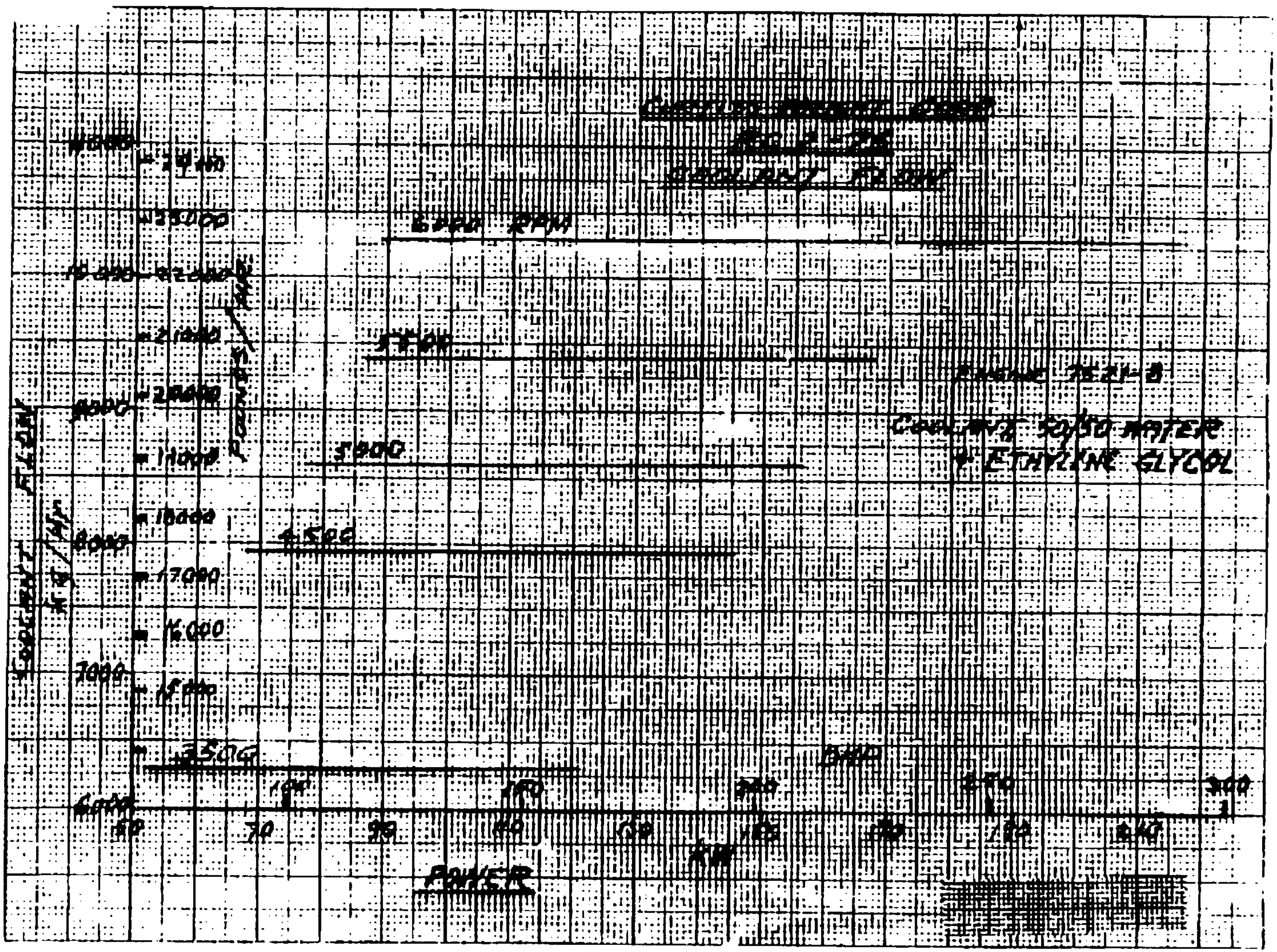


Figure 41. Coolant Flow vs Power for Constant Speed.

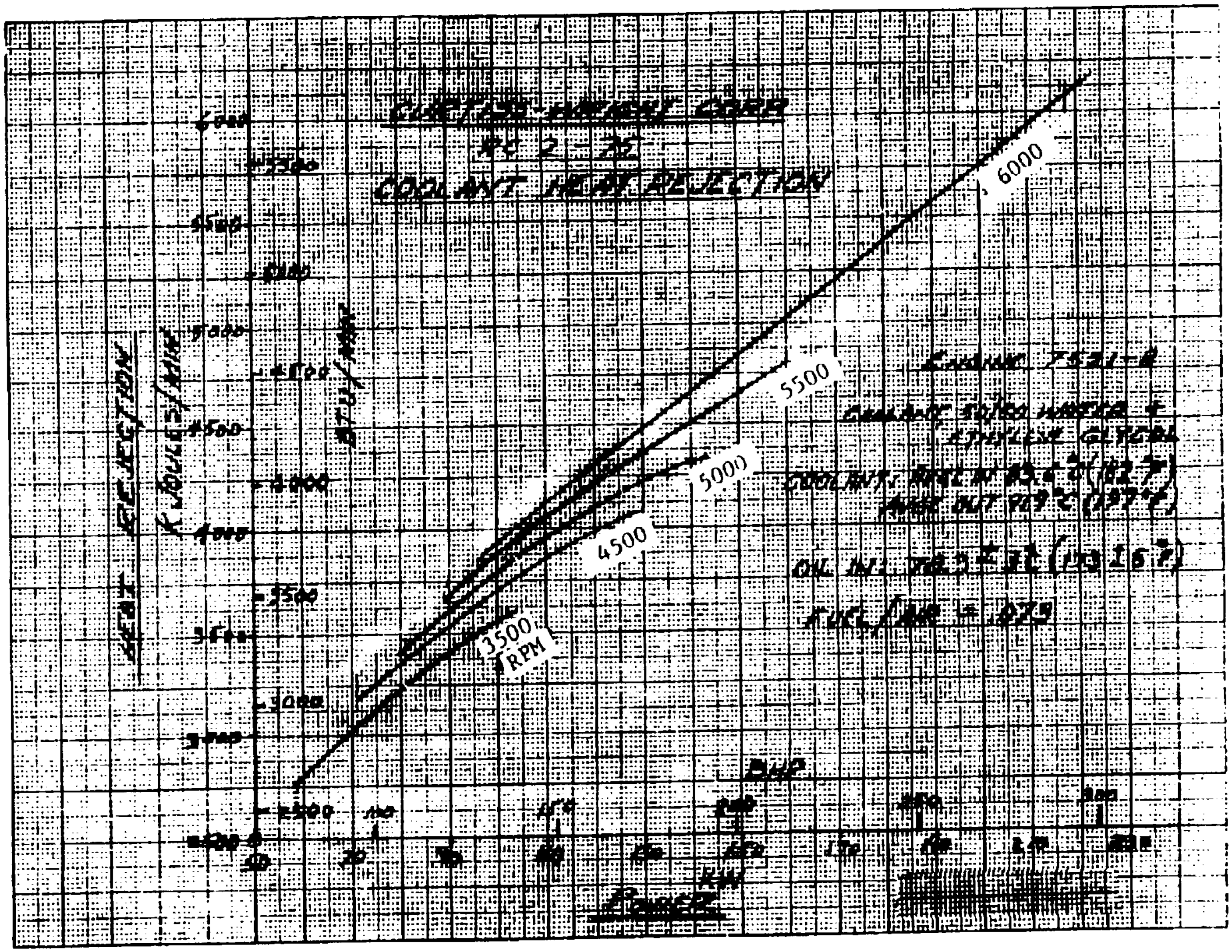


Figure 42. Coolant Heat Rejection vs Power for Constant Speeds.

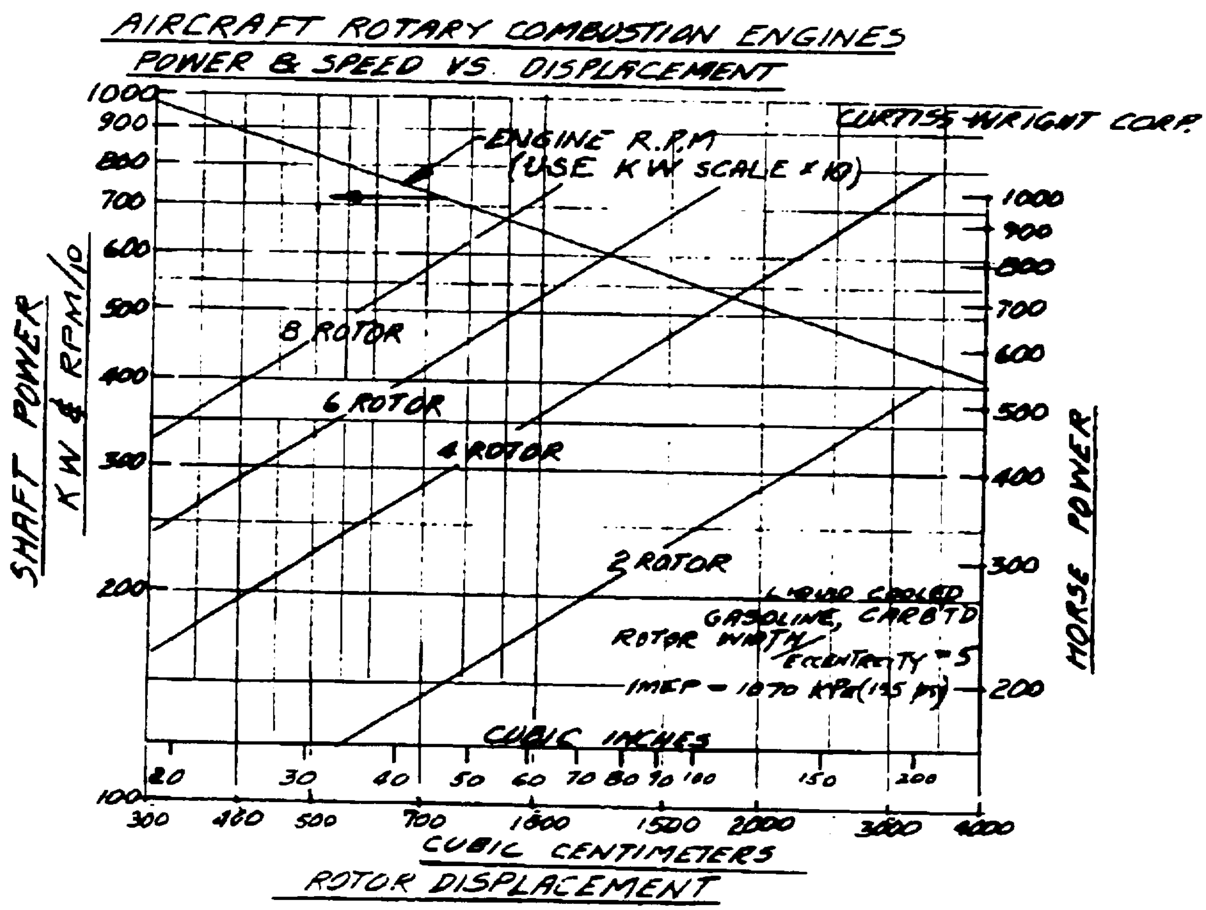


Figure 43. Engine Sizing-Power And Speed vs Displacement.

CURTISS-WRIGHT

AIRCRAFT ROTARY COMBUSTION ENGINES

STANDARD ENGINE WEIGHT VS POWER

Integral Prop Shaft Gear Reduction

Gasoline Carbureted

Rotor width/Eccentricity = 5

Included	Not Included
Carburetor & Manifold	Alternator & Drive
Single Drive Dual Magneto, Plugs, Leads	Cooler and External Coolant
Flywheel & Ring Gear	Starter
Coolant in Engine	Oil Cooler, Tank
	Exhaust Manifold

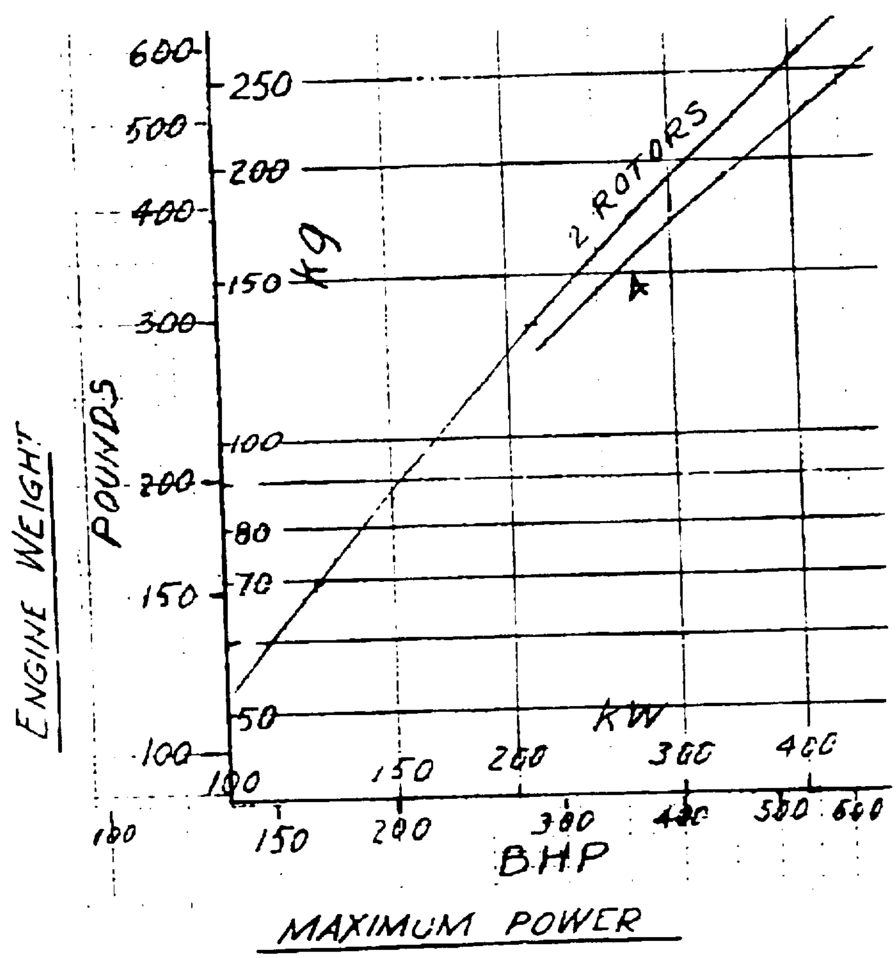


Figure 44. Engine Sizing - Standard Engine Weight vs Horsepower.

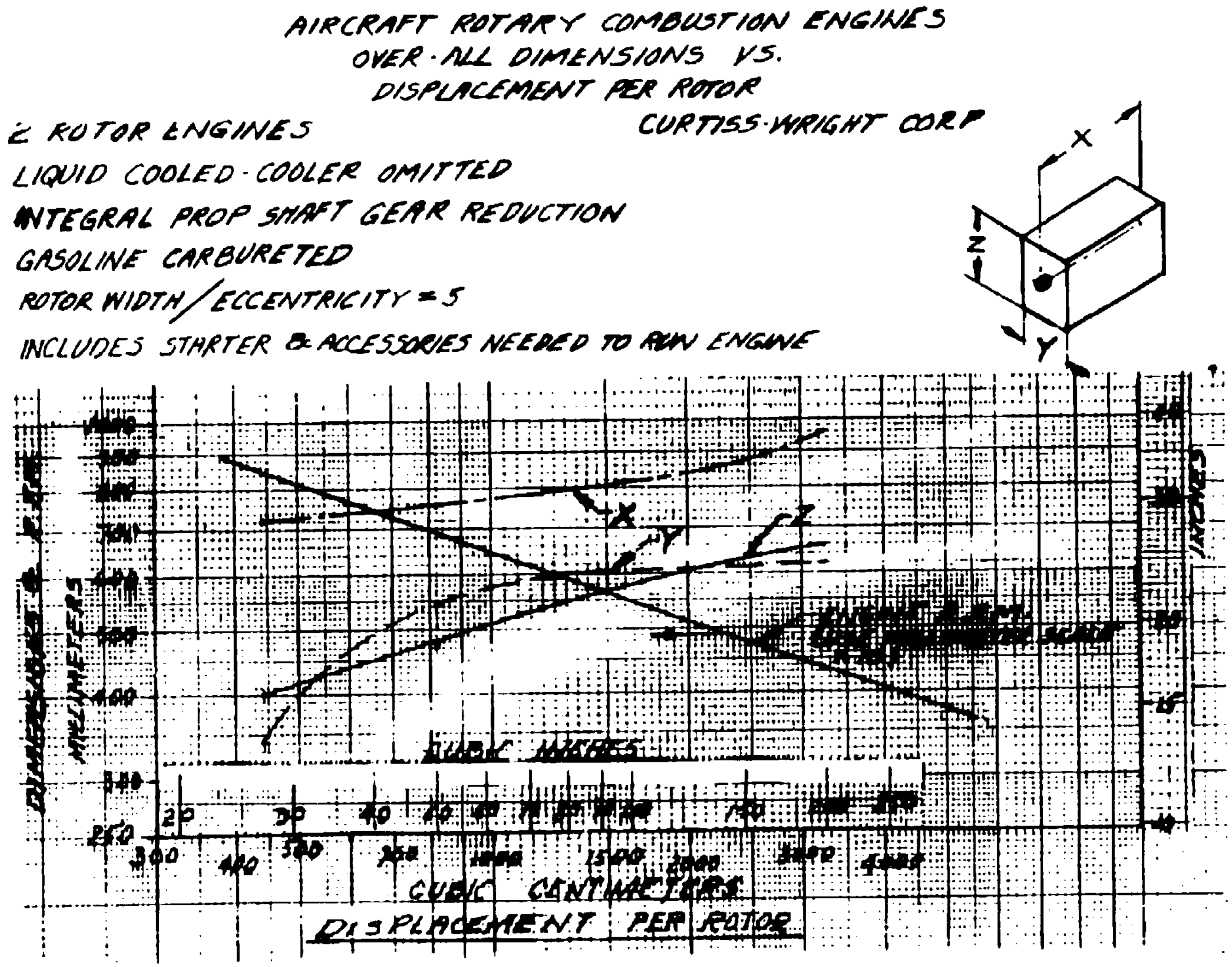


Figure 45. Engine Sizing - Overall Dimensions and Speed vs Displacement Per Rotor, 2 Rotor Engines.

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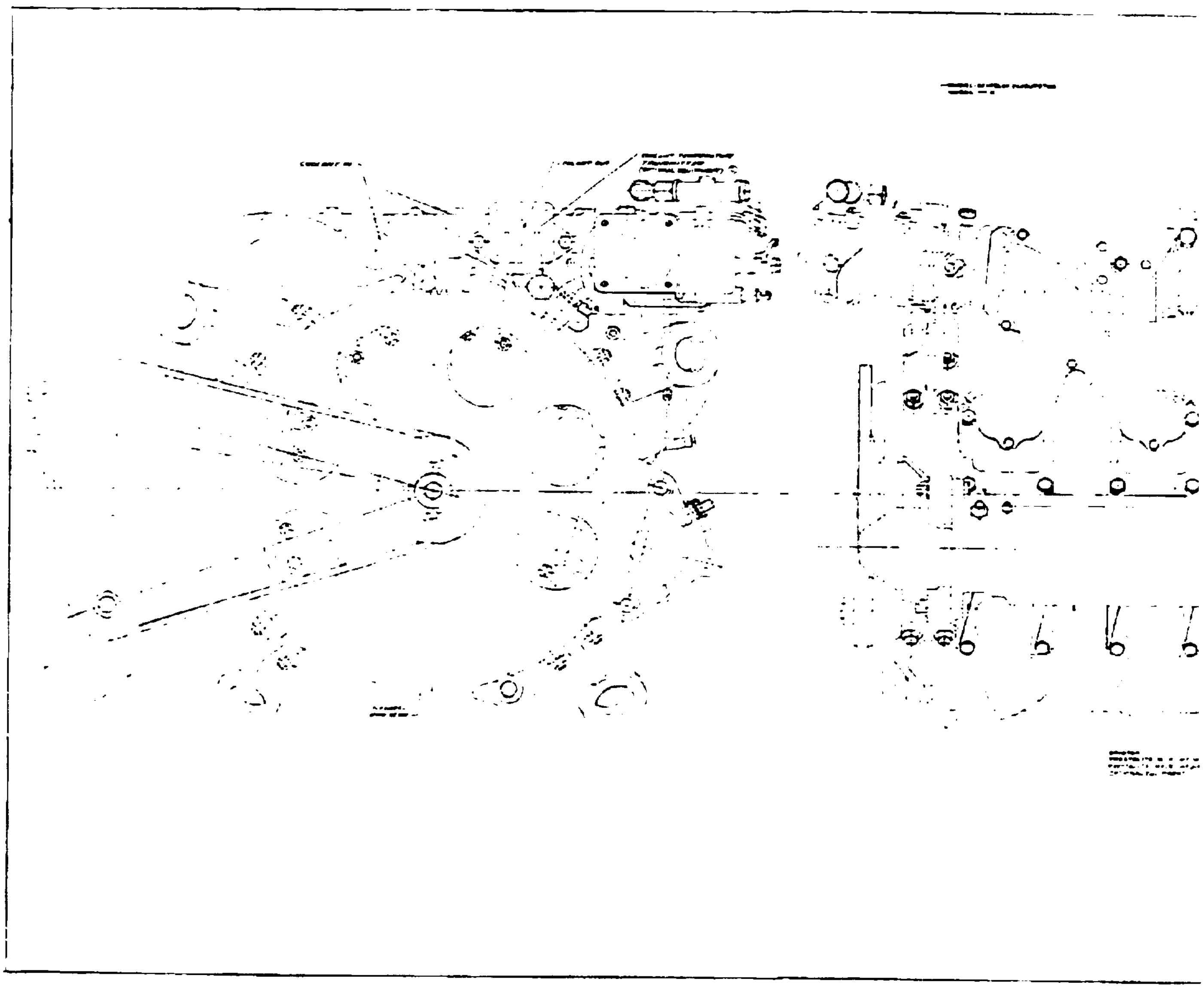
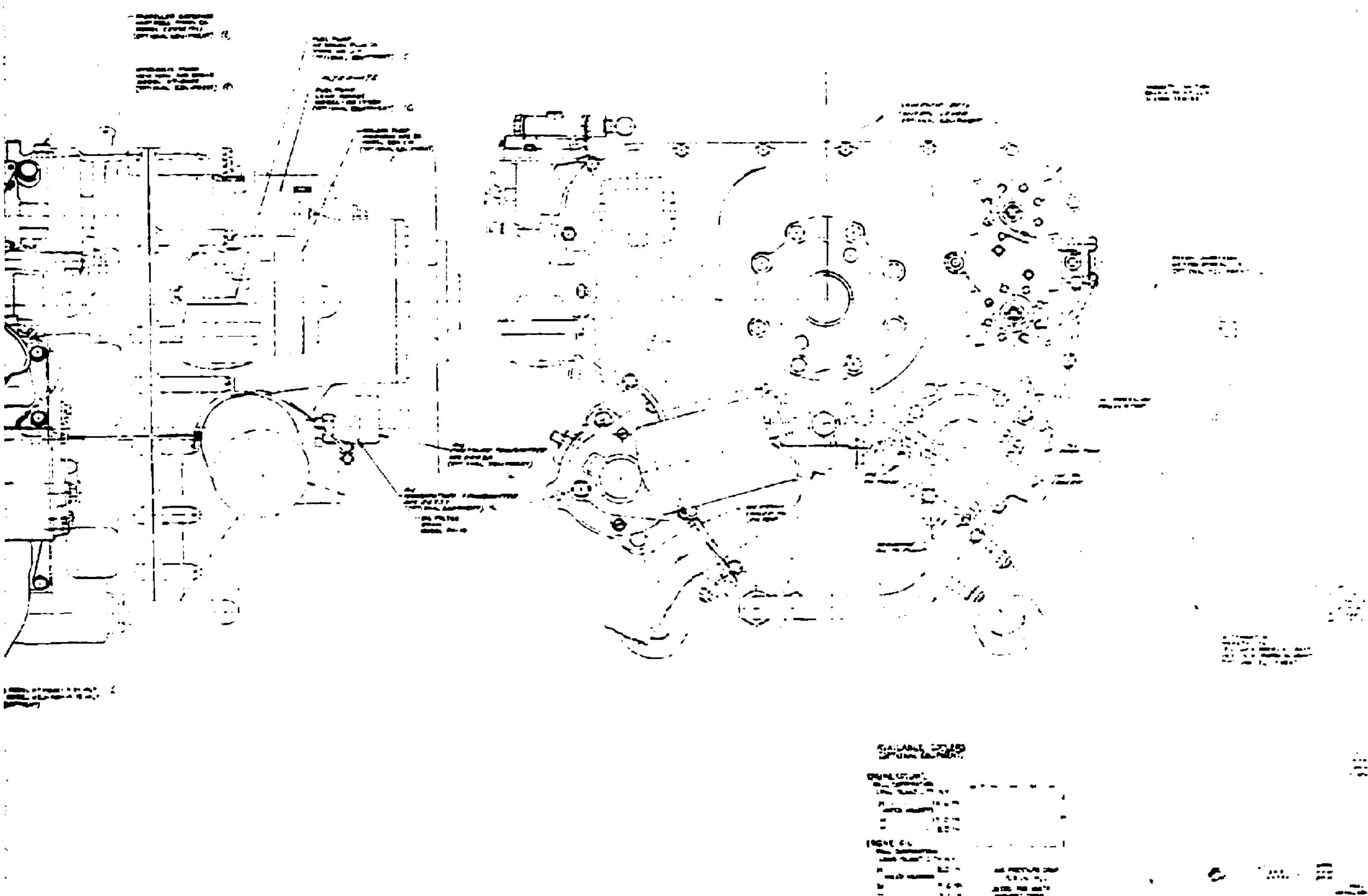


Figure 46. Preliminary Installation Drawing LS 33450 Sheet 1 (RC2-75)



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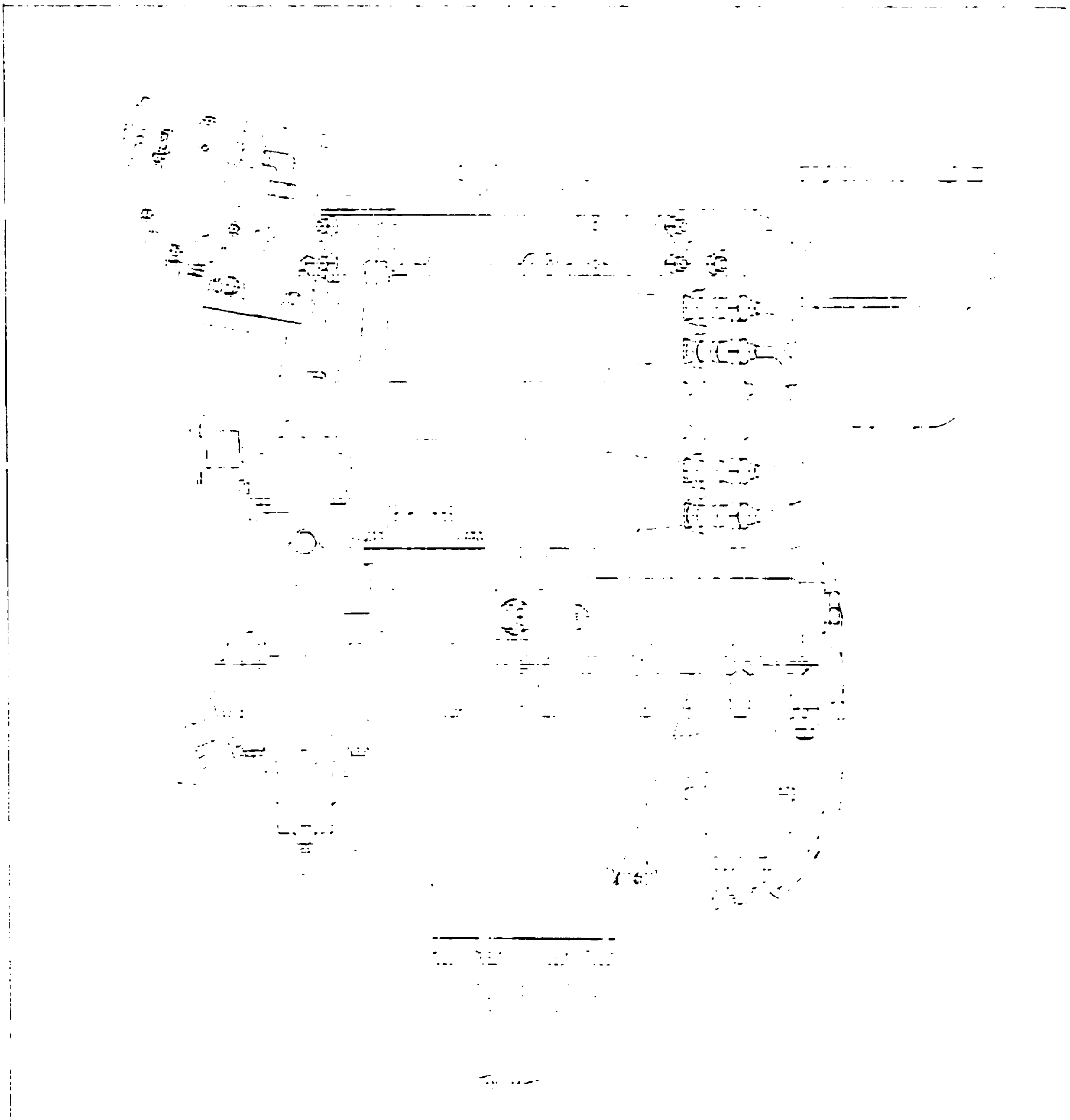

Figure 47 . Preliminary Installation Drawing LS 33450 Sheet 2 (RC2-75) 212.5 KW (285 BHP), 6000 RPM.

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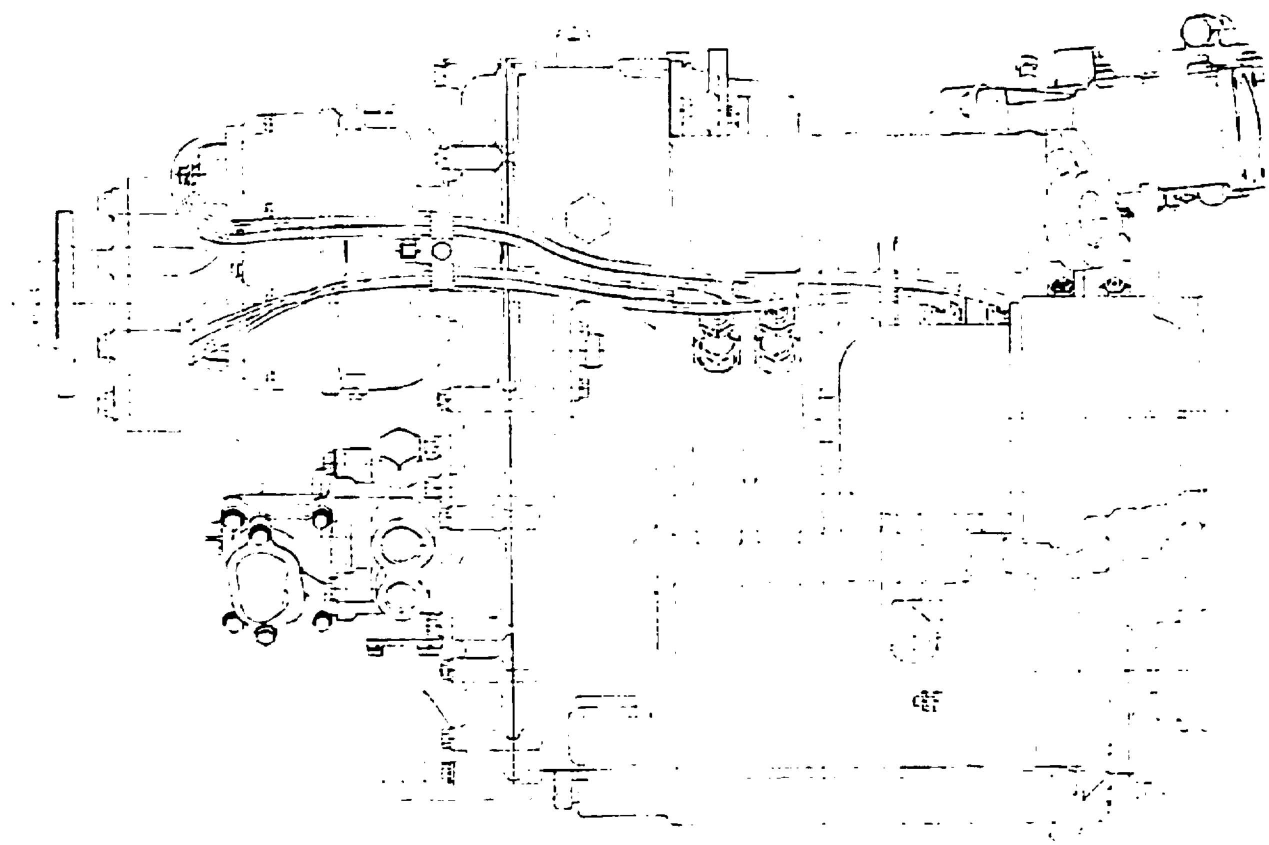

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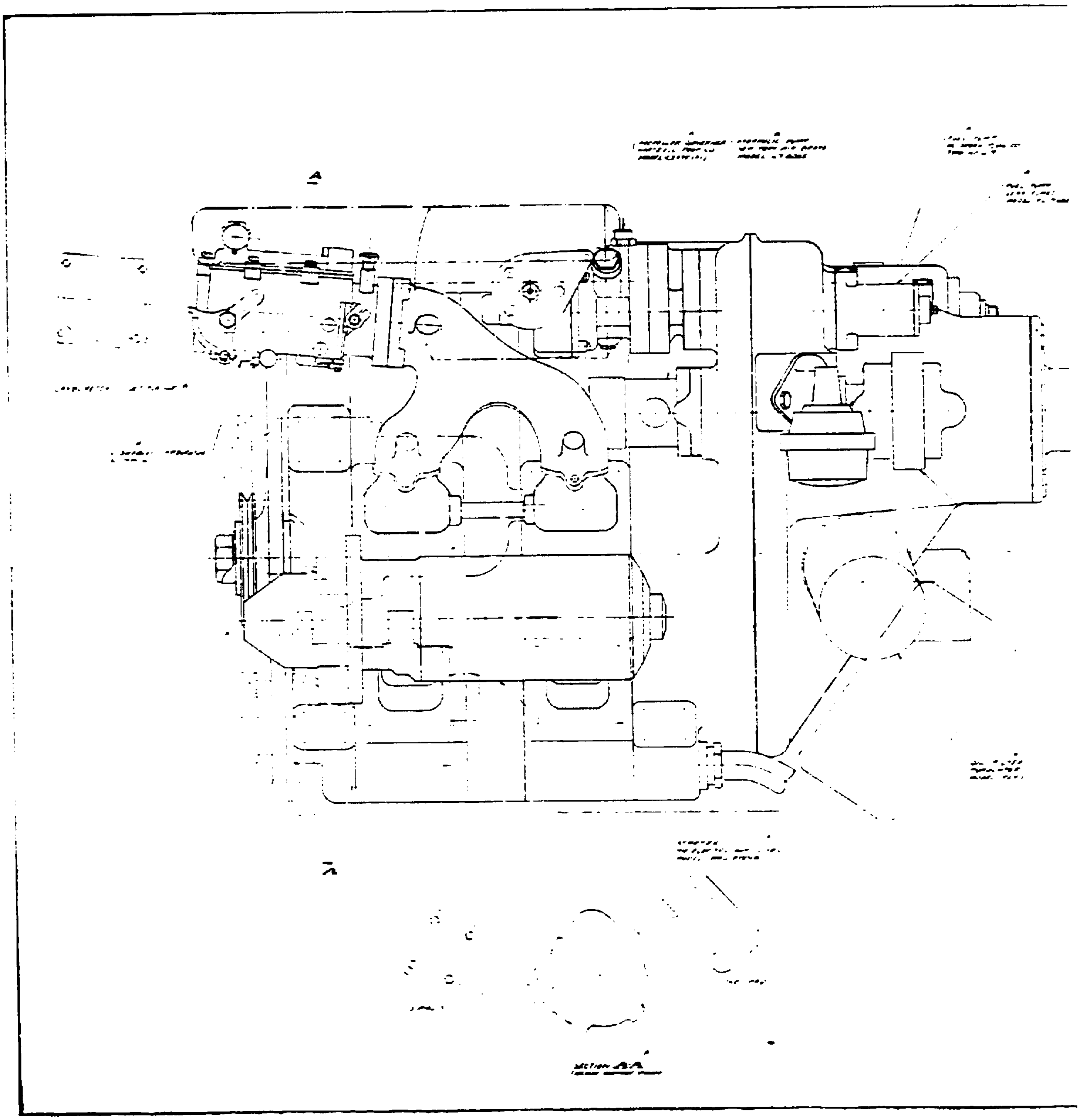

Figure 48. Preliminary Installation Drawing LS 33449 (RC2-75)

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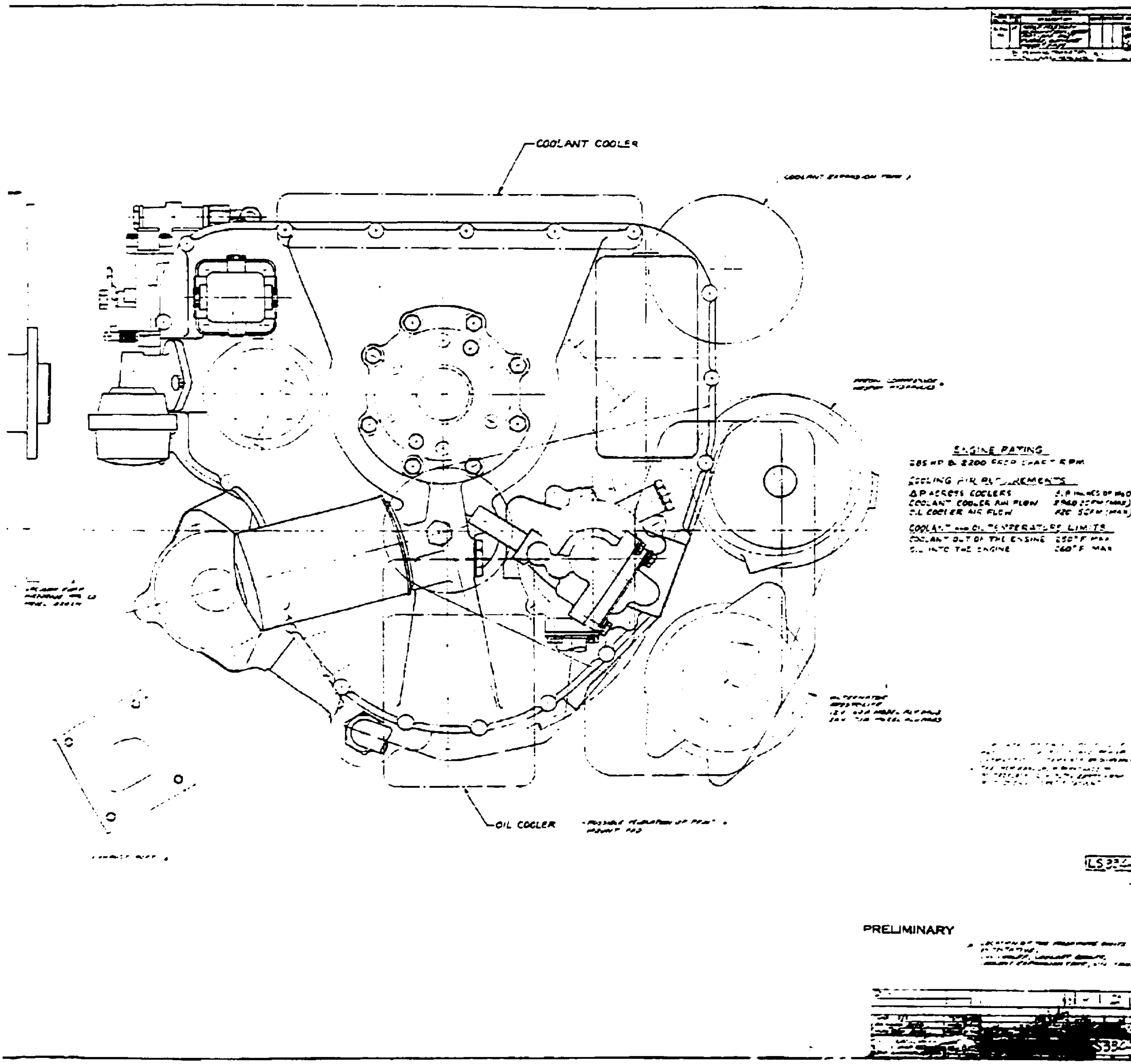

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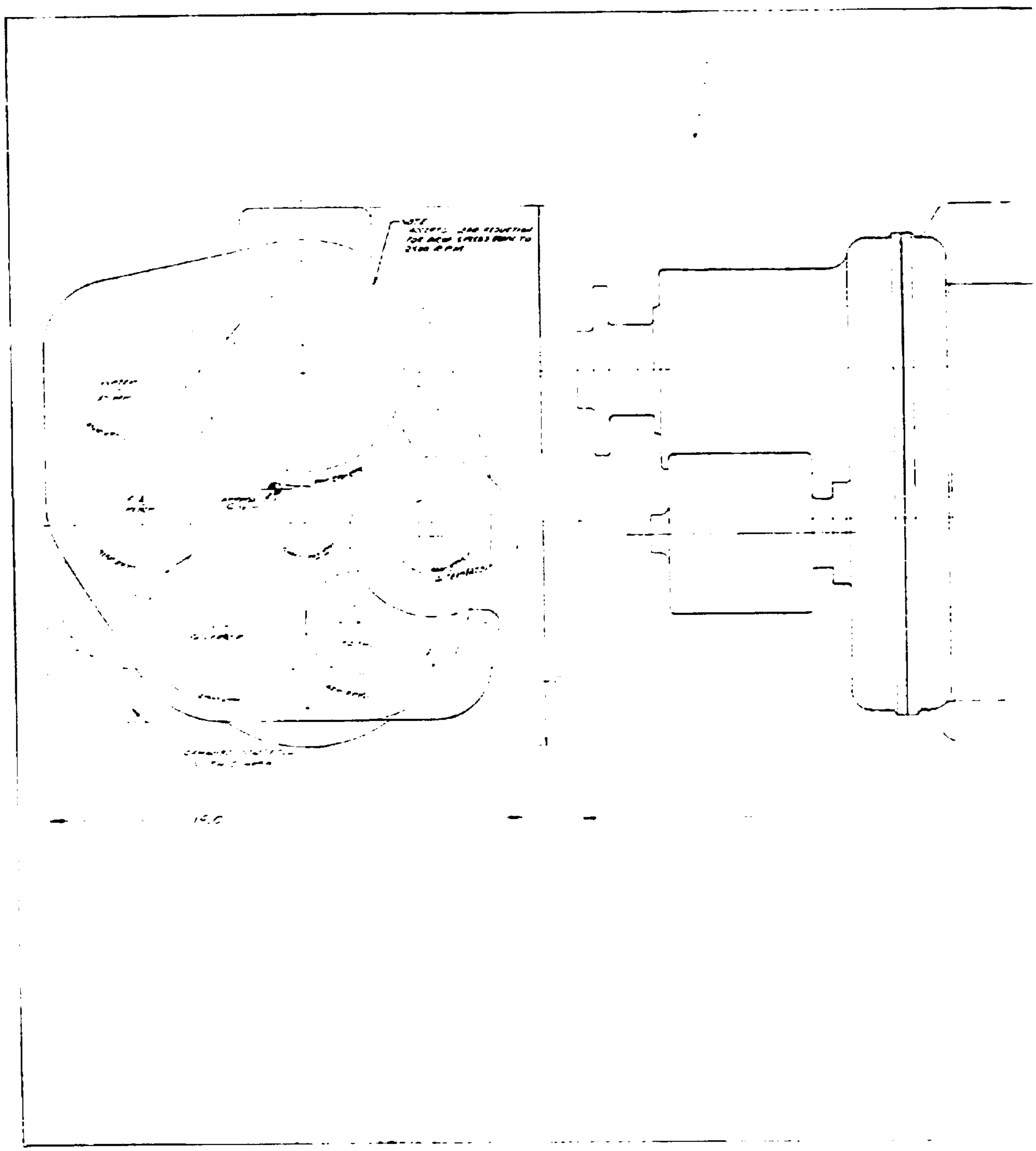

Figure 49. Preliminary Installation Drawing SK 12600 (RC2-27). 104 KW (140 BHP), 8400 RPM.

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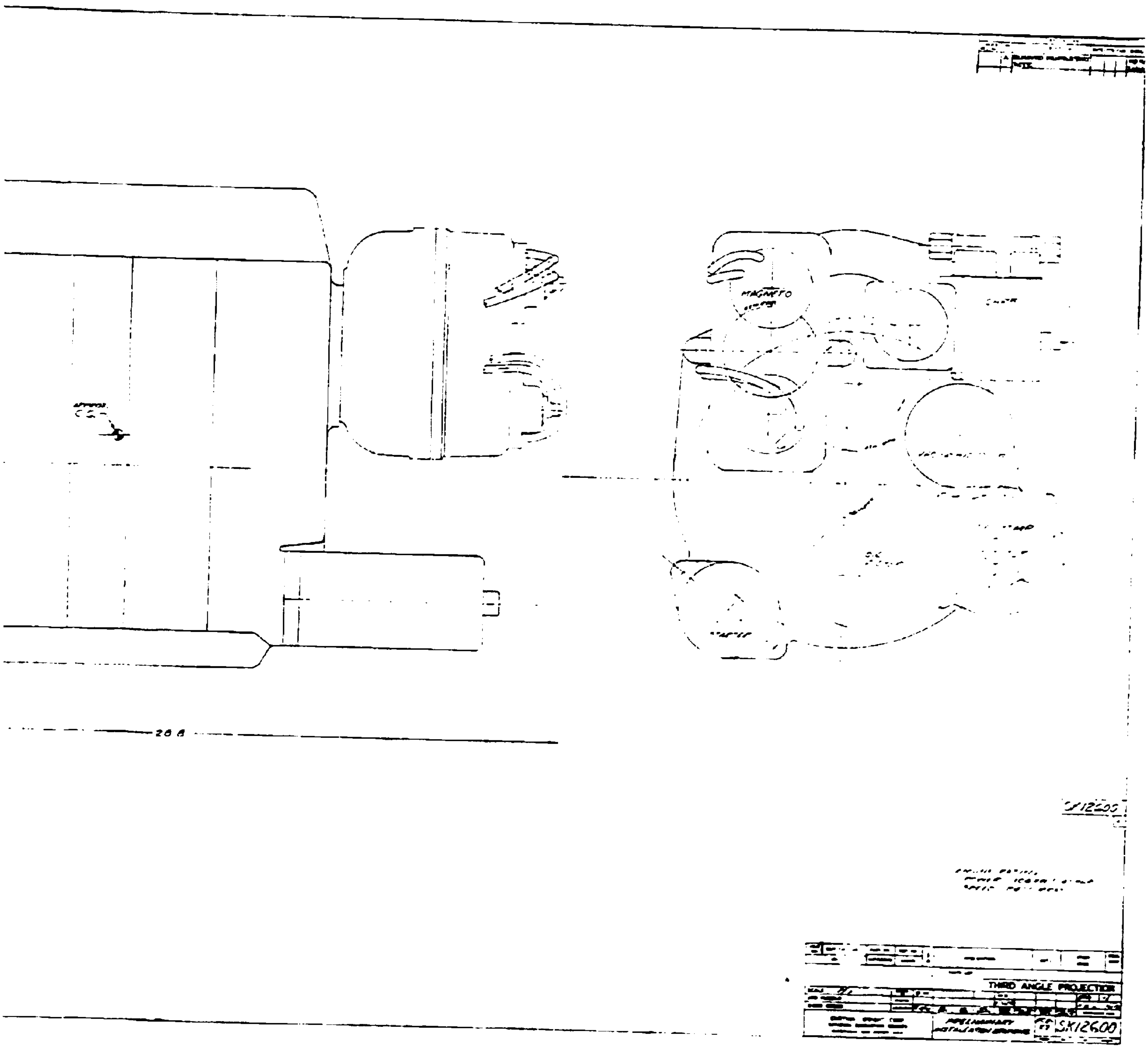

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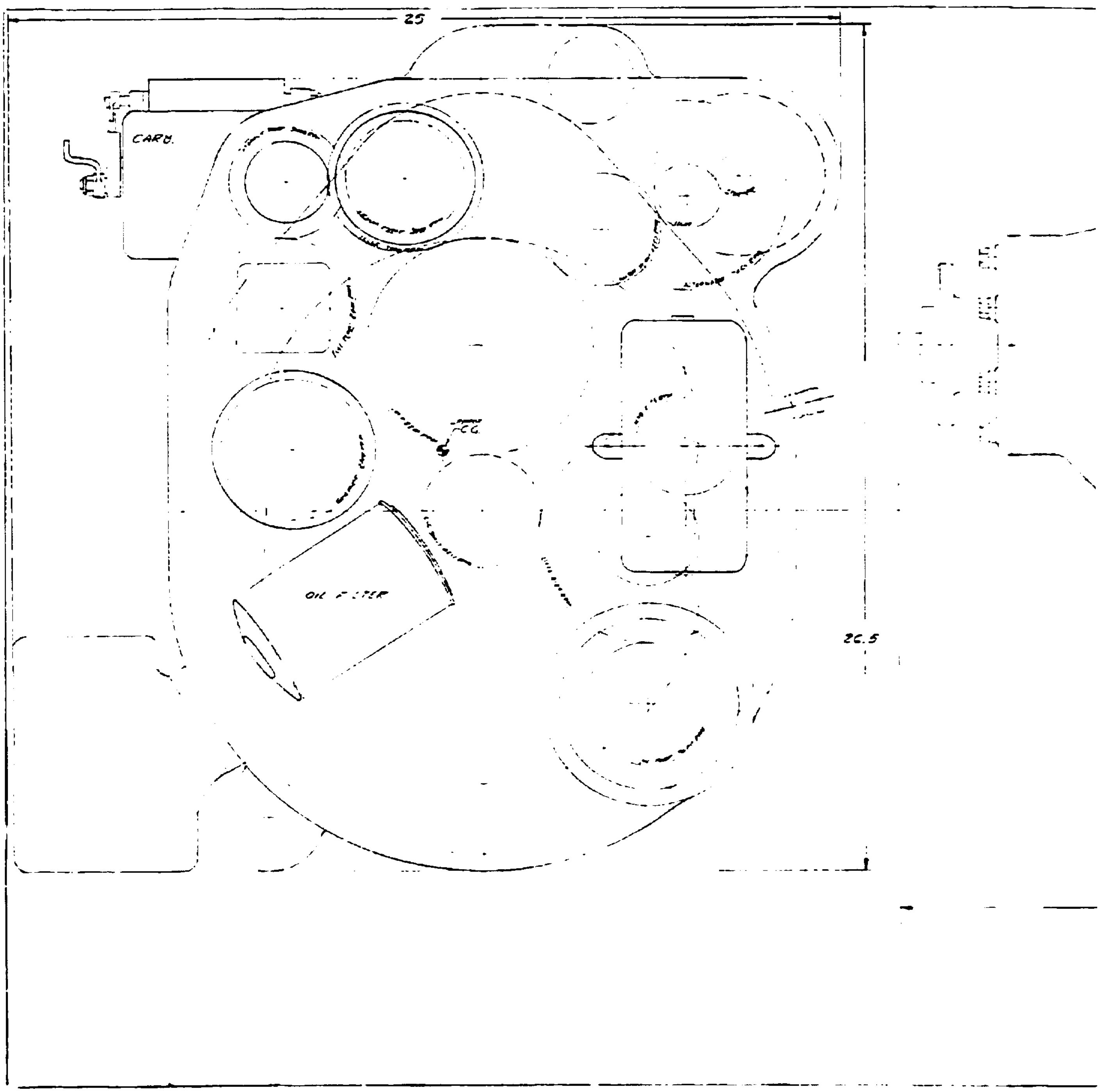

Figure 30 Preliminary Installation Drawing SK 12601 (RC2-215). 425 KW (570 BHP), 4250 RPM.

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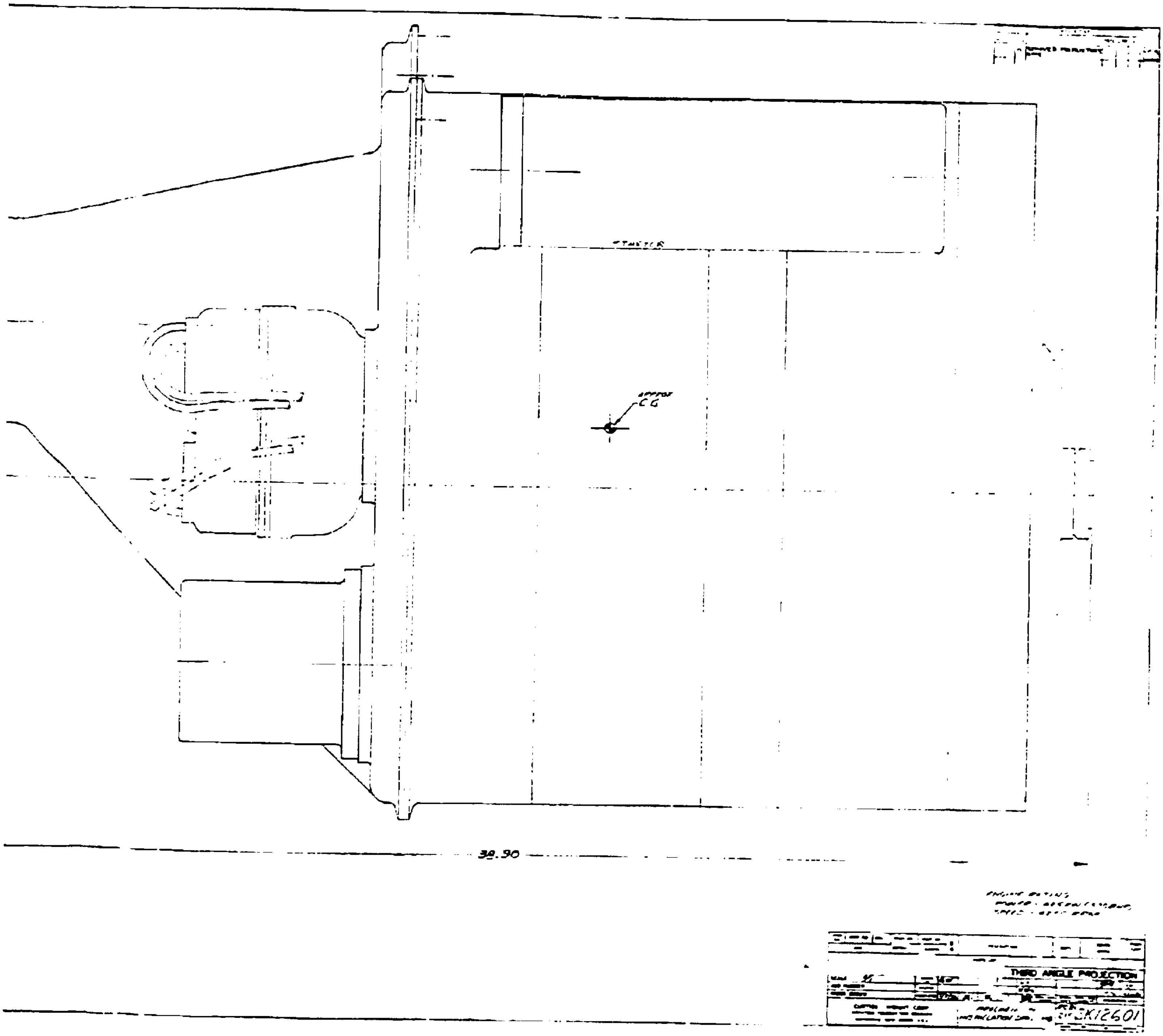

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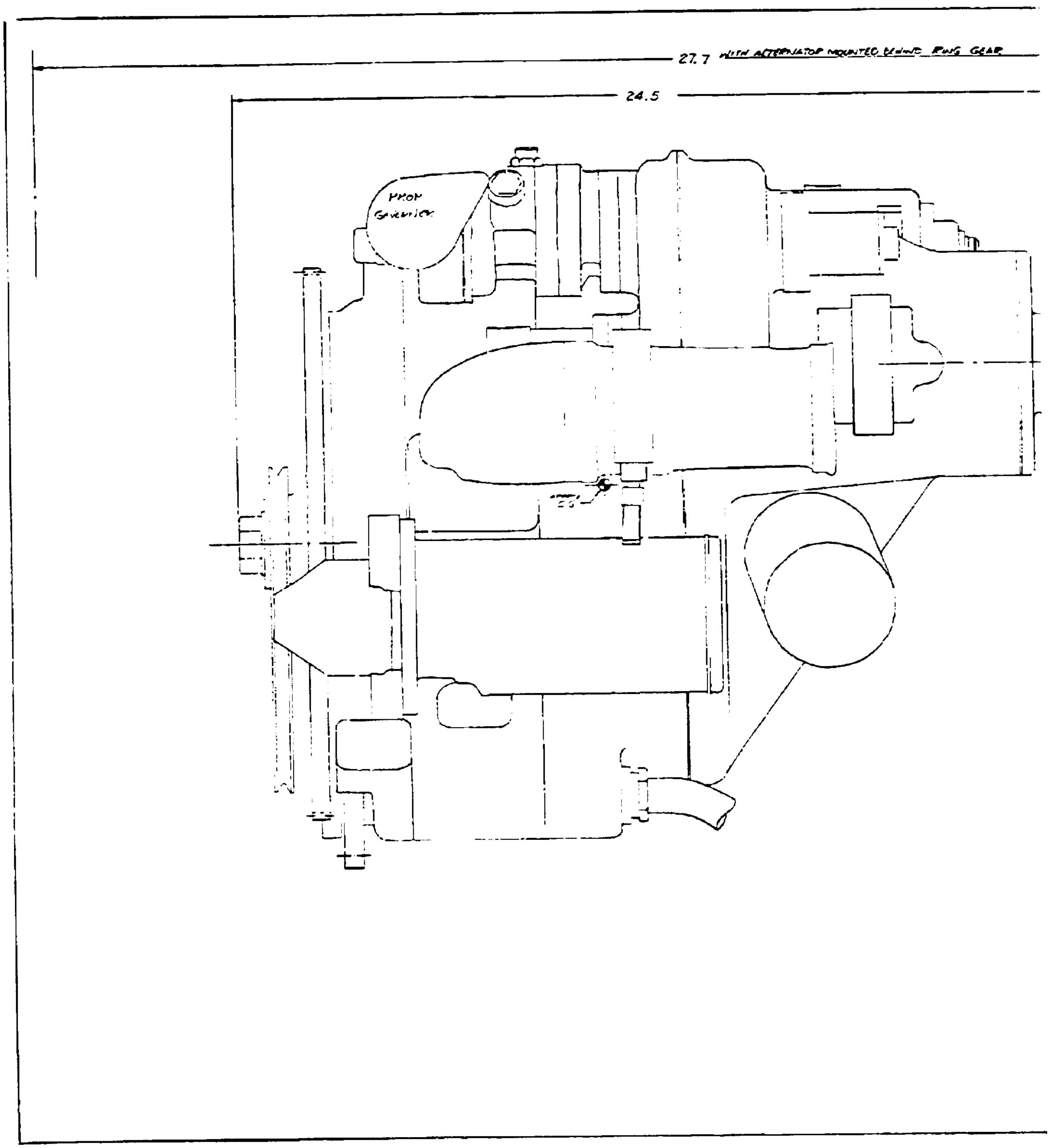

Figure 51. Preliminary Installation Drawing SK 12580 (RC1-75).
104 KW (140 BHP), 6000 RPM.

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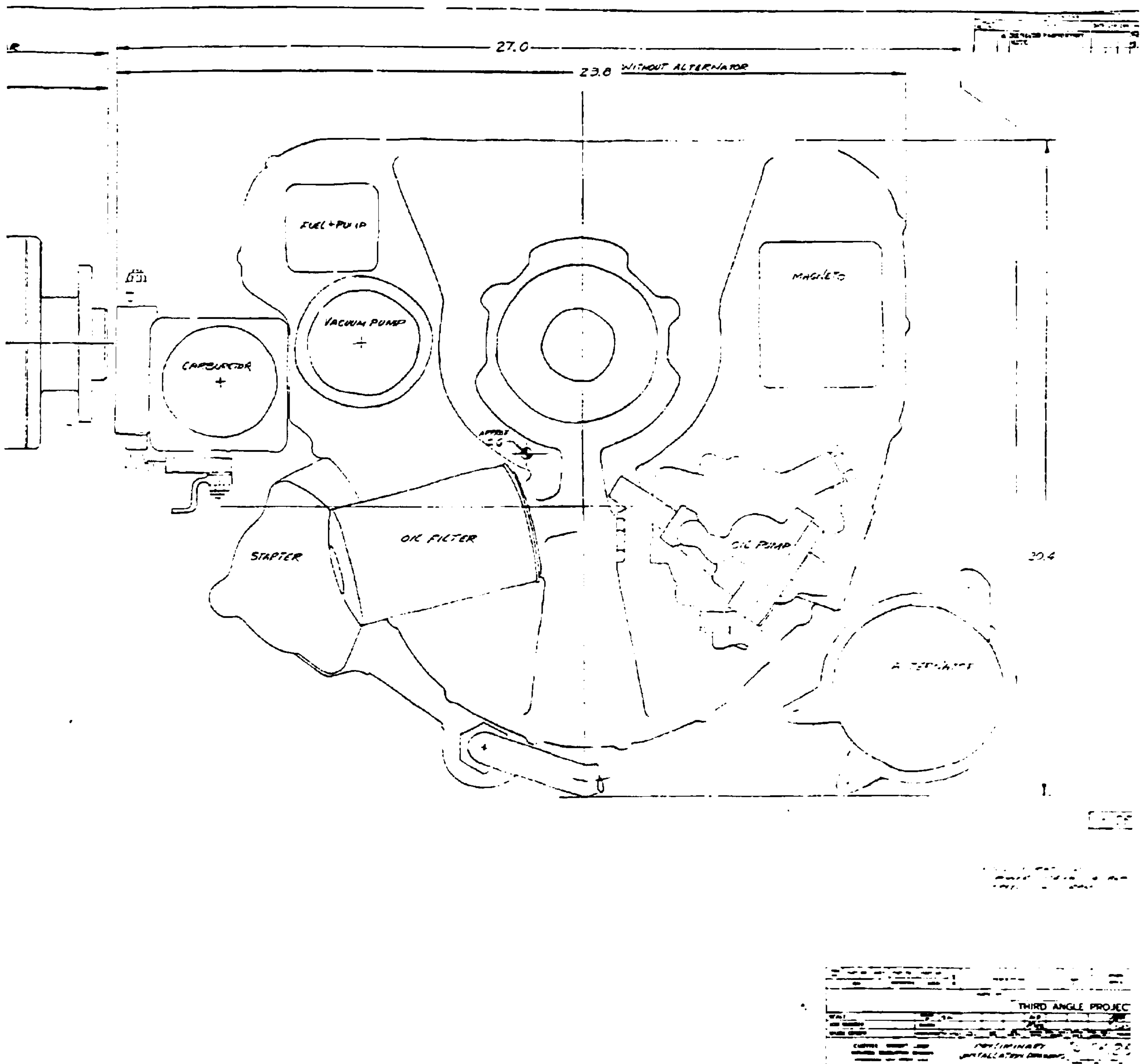

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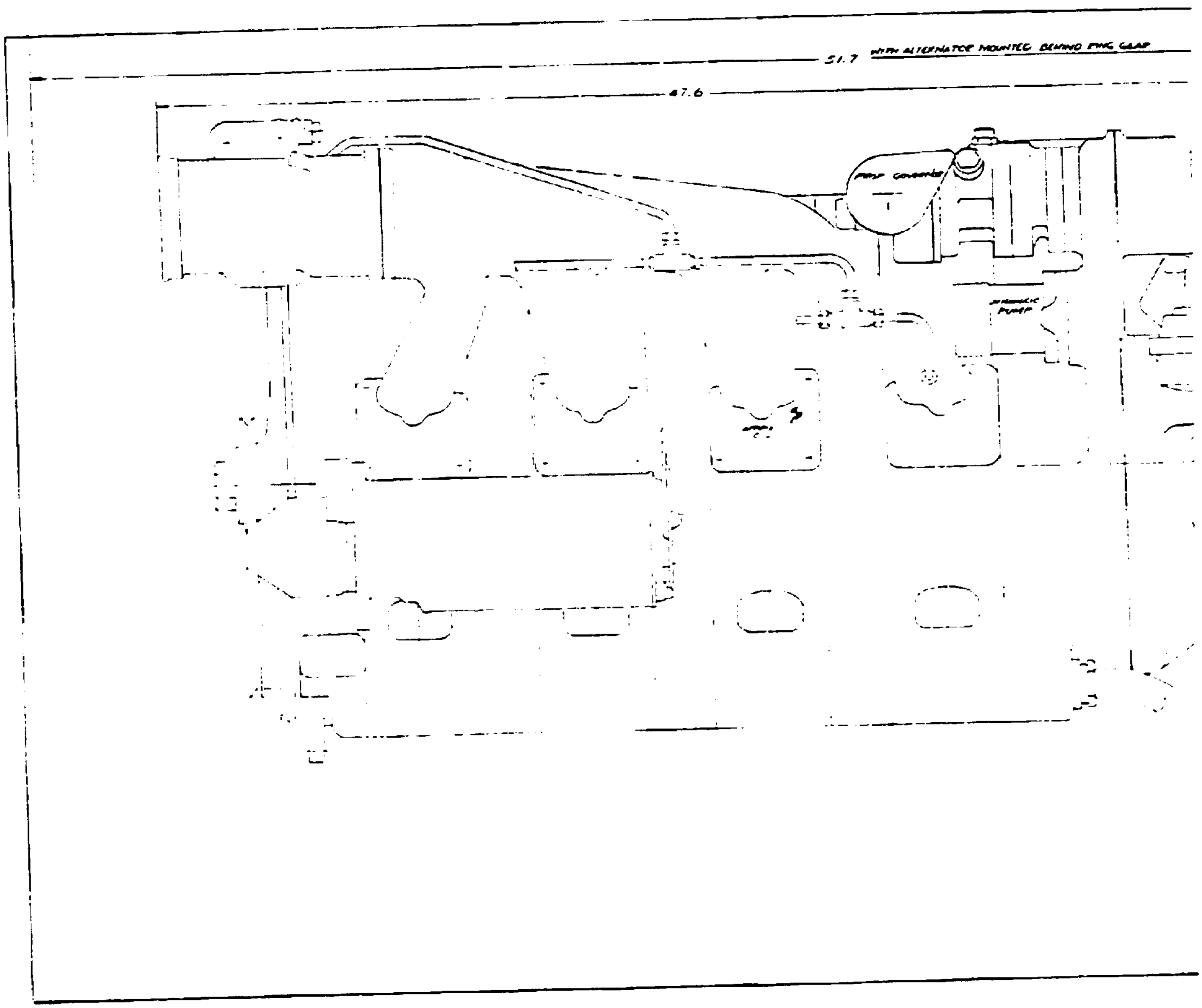

Figure 52. Preliminary Installation Drawing SK 12579 (RC4-75) 425 KW (570 BHP), 6000 RPM.

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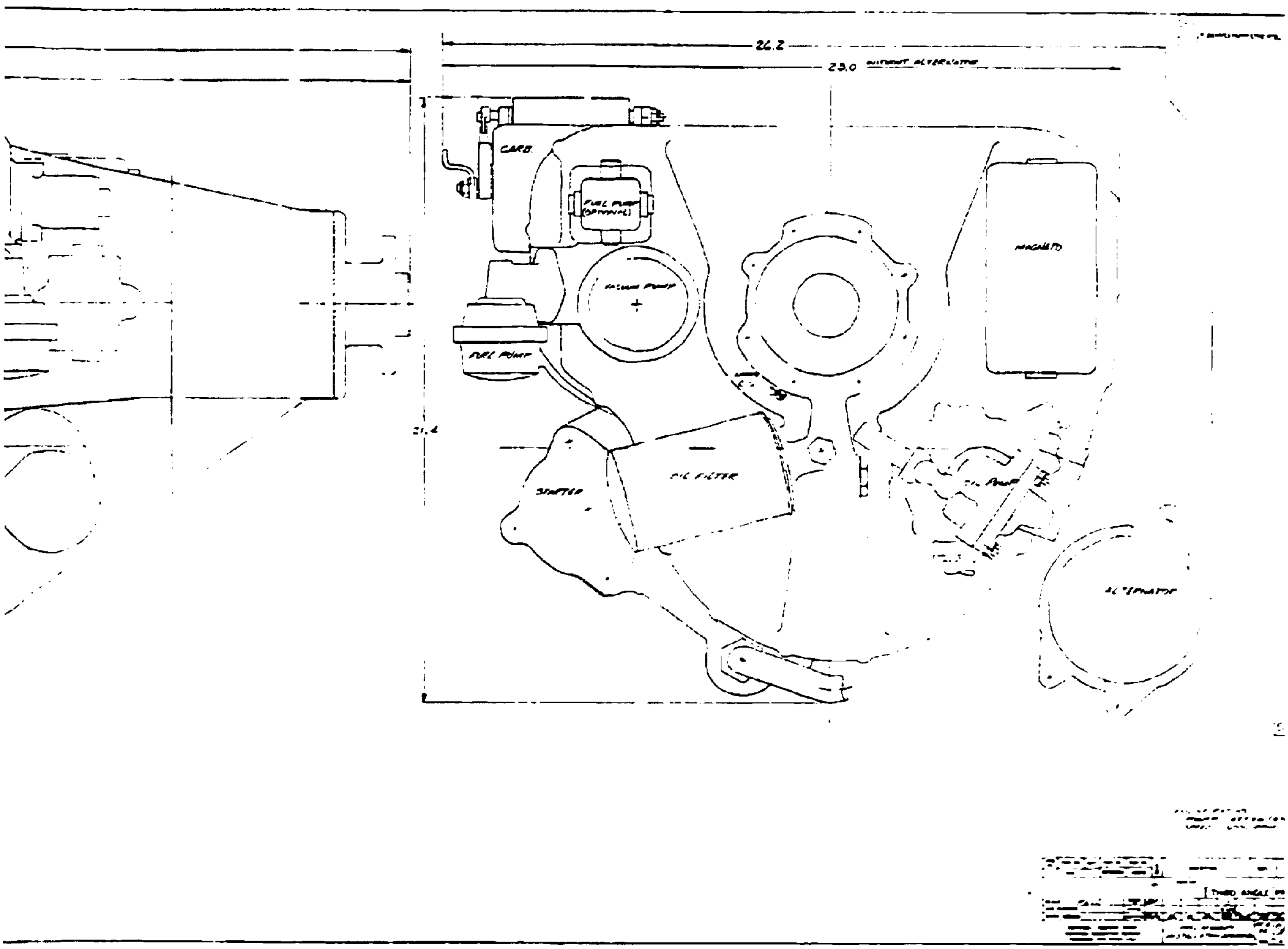

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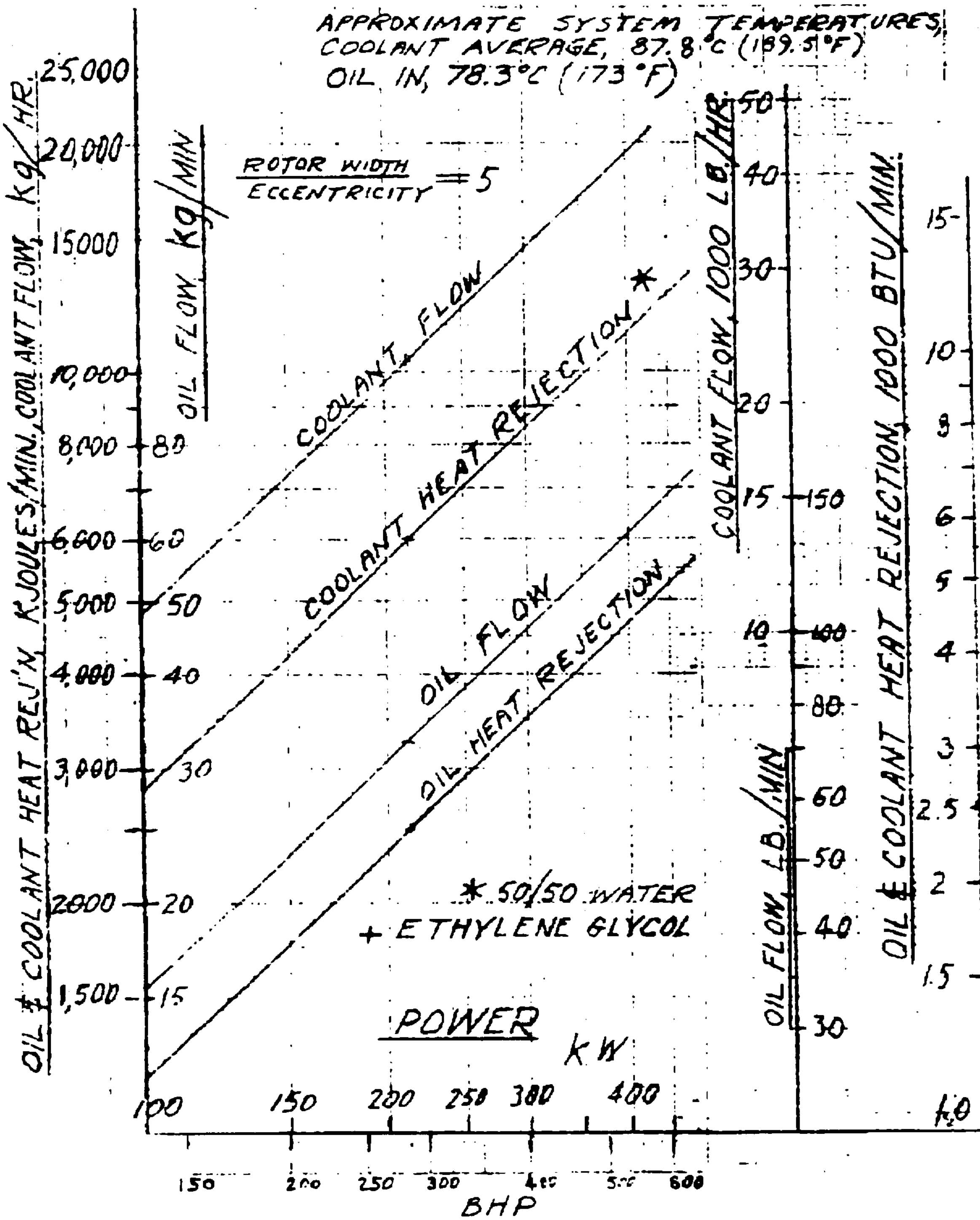


Figure 53. Oil and Coolant Flows and Heat Rejection vs Power.

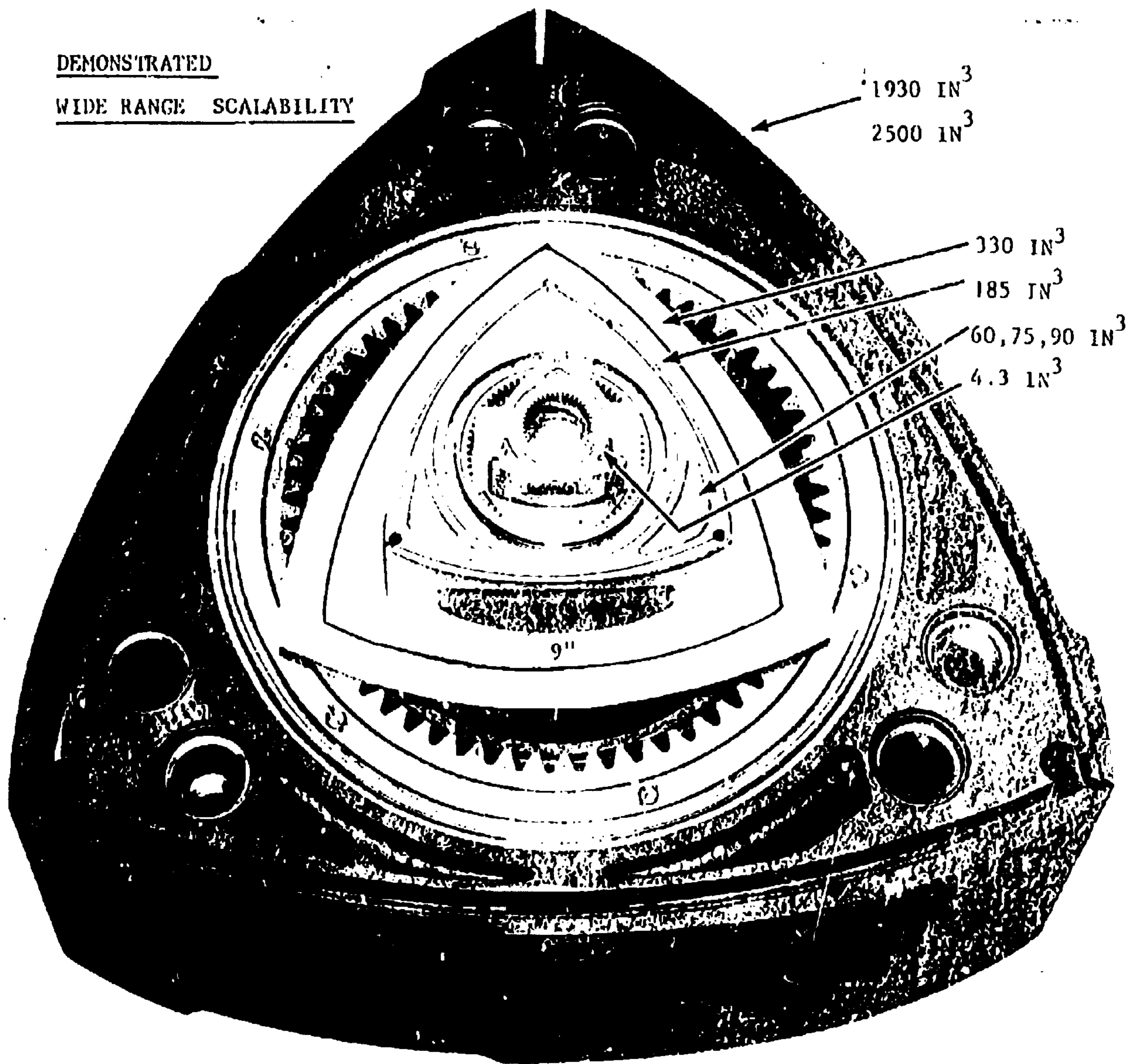
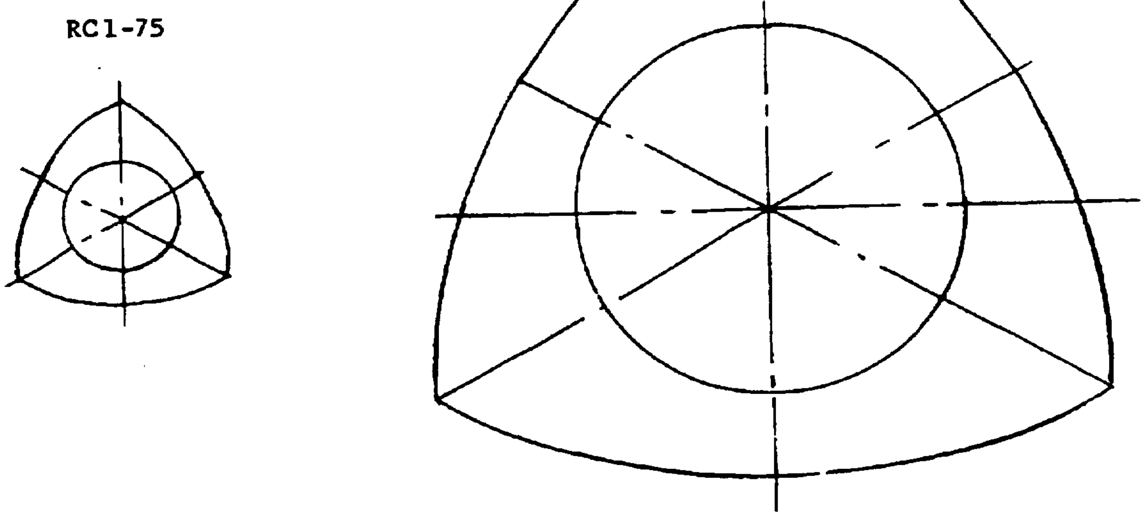


Figure 54 Size Comparison of Rotors Used in Range of Curtiss-Wright Tested Engines - 4.3 Through 2,500 Cubic Inches Displacement Per Rotor.

SHAFT TORSIONAL SHEAR STRESS COMPARISON			
ENGINE MODEL	RC1-75	RC1-185	RC1-330
SHAFT SIZE	2.3" Dia.	3.1" Dia.	3.8" Dia.
Horsepower	138	250	375
SPEED, RPM	6000	4400	3600
AV. TORQUE, FT-LBS	120	298	547
AV. STRESS, PSI	600	600	600

Figure 55. Shaft Torsional Shear Stress Comparison for Varied Engine Sizes.

EXAMPLE OF COMPONENT WEIGHT
SCALING EXPONENT-USING
ACTUAL HARDWARE



WT = 19.3 lbs.

WT = 500 lbs.

$$\text{SCALE FACTOR, } L = \left(\frac{2500}{75}\right)^{\frac{1}{3}} = 3.218$$

$$\text{ROTOR} \quad WT_{75} \times L^{2.785} = WT_{2500}$$

$$19.3 \times 3.218^{2.785} = 500 \text{ lb.}$$

Figure 56. Example of Component Weight Scaling From Actual Hardware.

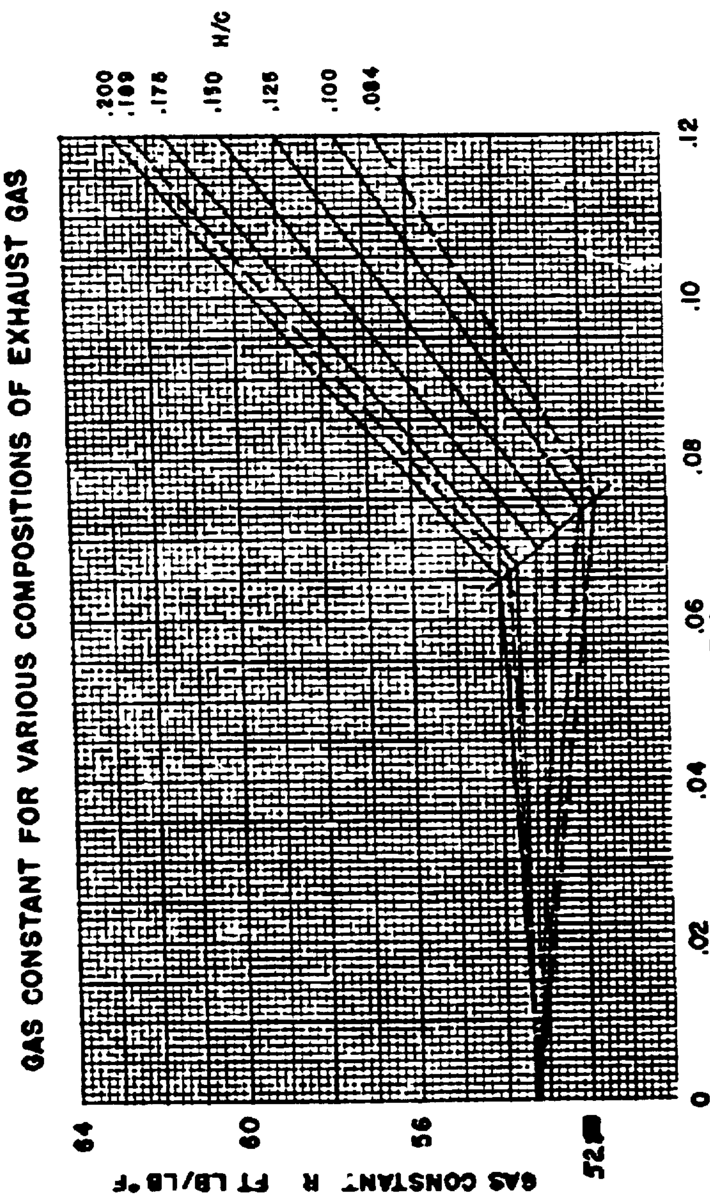


Figure 57. Gas Constant For Various Compositions of Exhaust Gas.

VI. APPENDICES

A. Curtiss-Wright Projected F.A.A. Type Certification Activity

B. Aviation Gas 100/130 with 1% AD 65 Oil, Laboratory Analysis Report

C. Formulas for Full Throttle Performance Corrections to Standard Day Sea Level Conditions

D. Exhaust Emissions Calculation Formulae

E. Excerpts from the RC2-75 Engine Specification

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APPENDIX A

CURTISS-WRIGHT RC2-75 ROTARY ENGINE

PROJECTED F.A.A. TYPE CERTIFICATION ACTIVITY

RC1-75 Engines

1. Extended endurance
2. Endurance and performance effects of cooling changes
3. Ignition system evaluation
4. Spark plug location closer to trochoid
5. Combination peripheral and side ports
6. Rotor modifications (Rokide coating, higher compression ratios)

RC2-75 Engines

1. Evaluation of alternate vibration dampers
2. Starting tests (normal and low temperatures)
3. Extended endurance
4. Fuel metering, and manifold development
5. Accessory and control system endurance and performance testing
6. Flight evaluation coordination
7. First unofficial type certification test
8. Flight instrumentation and ground checks
9. Second unofficial type certification test
10. Flight tests
11. Official type certification test

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LABORATORY ANALYSIS REPORT

SEPTEMBER 24, 1976
LAB. NO. J 9525

SAMPLE DESIGNATED BY CLIENT AS AVIATION GAS 100/130 WITH 1% AD 65

FROM SUBMITTED: 9-13-76

FOR CURTISS WRIGHT CORP.
ONE ROTARY DRIVE
WOOD RIDGE, N. J.

(IL)2297

TESTS	RESULTS
GRAVITY API @60°F	67.7
HYDROGEN CARBON RATIO	6.286
COLOR	GREEN
CORROSION 2 HRS. @212°F	PASSES #1A
SULFUR, ASTM	0.018%
VAPOR PRESSURE, REID @100°F	6.1 LBS.
ANALINE POINT	150°F
LEAD	2.17 G/GAL.
NET HEAT OF COMBUSTION	18,933 BTU/#
POTENTIAL GUM	3.8 MGS.
FREEZING POINT	BELOW MINUS 72°F
WATER REACTION	0.5 ML #1
OCTANE NO. MOTOR D2700	102.7
I.B.P.	104°F
10% EVAP. @	146°F
40% EVAP. @	208°F
50% EVAP. @	216°F
90% EVAP. @	238°F
END POINT	298°F
RECOVERY	98.0%
RES.	1.5%
LOSS	0.5%
RESIDUAL ACIDITY	NEUTRAL
SUM OF 10 & 50% EVAP.	362°F

E. W. SAYBOLT & CO., INC.

[signature]

BY

MEMBERS OF A. S. T. M. – A. P. I. – S. A. E.

ND

APPENDIX C

FULL THROTTLE PERFORMANCE CORRECTIONS

TO STANDARD DAY SEA LEVEL CONDITIONS

A. Brake Horsepower

1. $$BHP_{std} = (BHP_{obs} + FHP)\left(\frac{29.92}{B_D - \Delta_p}\right)\sqrt{\frac{CAT + 459.4}{518.4}} - FHP$$

where FHP = friction horsepower

B_D = true barometer – vapor pressure, in. Hg

Δp = airflow system pressure drop, in. Hg

CAT = carburetor air temperature, °F

B. Airflow

2. $$Airflow_{std} = (airflow_{obs})\left(\frac{29.92}{B_T - p}\right)\sqrt{\frac{CAT + 459.4}{518.4}}$$

where B_T = true barometer, in. Hg

C. Brake Specific Fuel Consumption

3. $$BSFC_{std} = (f/a_{act})\left(\frac{AF_{std}}{BHP_{std}}\right)$$

where $$f/a_{actual} = (f/A_{obs})\sqrt{\frac{1 - .377\,\frac{P_v}{P_w}}{1 - \frac{P_v}{P_w}}}$$

and $$\frac{P_v}{P_w} = \frac{B_D}{B_T} - 1$$

where the correction factor accounts for the water vapor in the measured wet airflow

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APPENDIX D

EXHAUST EMISSIONS CALCULATION FORMULAE

A. Wet Correction Factor for Water of Combustion and Ambient Humidity

A procedure used in the general aviation industry was utilized as follows:

1. $$\frac{H_2O}{1-H_2O} = \left[2+7.67478\left(\frac{W}{a}\right)\right]$$

$$\left[\frac{\frac{(CO_2)+(CO)+(THC)}{100}\ (12.01 + 1.008y)}{138.2689\ (f/a)}\right] - \left[\frac{2[(CO_2+O_2)]+(CO)+(NO)}{100}\right]$$

where ( ) = % concentration of exhaust constituents

with CO, CO_2 and O_2 dry and NO and HC wet as measured

f/a = measured fuel air ratio

y = hydrogen carbon ratio

and w/a, the inlet air specific humidity

$$w/a = .622\ \frac{(\text{true barometer} - \text{dry barometer})}{\text{dry barometer}}$$

2. From the above, the correction factor, Cf_w, derives as

$$Cf_w = \frac{1}{1 + \frac{H_2O}{1-H_2O}}$$

B. Calculation of Air-Fuel Ratio

The Spindt carbon balance procedure, reference 3, was utilized as follows:

3. $$A/F = Fb\left[11.492\ Fc\left(\frac{1 + \frac{R}{2} + Q}{1 + R}\right) + \frac{120\ (1-Fc)}{3.5 + R}\right]$$

where $R = \frac{(CO)}{(CO_2)}$ $\quad Q = \frac{(O\ )}{(CO_2)}$ $\quad F_b = \frac{(CO) + (CO_2)}{(CO) + (CO_2) + (THC)}$

and $Fc = \frac{12.01}{12.01 + 1.008y}$

An oxygen balance calculation procedure for air-fuel ratio by Stivender, reference 4, was also utilized

4. $$A/F = 4.76 \left(\frac{\frac{(H_2O) + (NO_x) + (CO)}{2} + (CO_2) + (O_2)}{(CO) + (CO_2) + (THC)} \right) \frac{28.96}{M_f}$$

where $(H_2O) = 100\ (1 - Cf_w)$

and $M_f = 12.01 + 1.008y$

a carbon balance procedure of calculating air-fuel ratio, also by Stivender, reference 4, was also utilized

5. $$A/F = \frac{28.96}{M_f} \left(\frac{\frac{3(H_2O) - (CO)}{2} + (THC) + 100}{(CO) + (CO_2) + (THC)} - \frac{y}{2} \right)$$

C. Calculation of Exhaust Gas Density

From Figure 57 (Curtiss-Wright Engineering Handbook, 1965) showing the gas constant, R, versus f/A for varying hydrogen carbon ratio the following was derived to determine exhaust gas density for the exhaust volume mass emissions calculations.

6. $f/a_t = (.9558 - F_h)\ .086$

where $F_h = \frac{1.008y}{12.01}$

if the observed f/A is equal to or less than f/a_t the gas constant is calculated

7. $R_1 = \left[(F_h - .1)\ 453.33 + 120 \right] f/a + 43.2$

if the observed f/A is greater than f/a_t the gas constant is calculated

$$8.\quad R_r = \left\{ \left[\left(\frac{R_1}{53.345} - 1 \right) \frac{f/a}{f/a_t} \right] + 1 \right\} 53.345$$

the exhaust gas density results from

$$9.\quad d_{exh} = \frac{(14.7)(144)}{(528)\ R} = \frac{4.009}{R}, \quad lb/ft^3$$

D. Mass Emission Rates

Exhaust Volume Method

$$10.\quad X,\ lb/hr = \left(\frac{FF + AF}{d_{exh}} \right) (X) \quad (d_x)$$

where FF = fuel flow, lb/hr

AF = airflow, lb/hr

(X) = concentration of pollutant wet

d_{exh} = exhaust gas density at 68°F, 760 mm Hg

d_x = density of pollutant

Carbon Balance Method, reference 5

$$11.\quad X,\ lb/hr = \frac{(X)\ (\dot{V})(d_x)}{100}$$

where $\dot{V}$ = exhaust flow, lb/hr

$$= \left(\frac{100}{(THC) + (CO) + (CO_2)} \right) \left(\frac{FF}{M_f} \right) (N)$$

where ( ) = % concentration of pollutant wet

M_f = 12.01 + 1.008y

N = 385 ft^3/lb mol at 68°F, 760 mm Hg

APPENDIX E

EXCERPTS FROM THE RC2-75 ENGINE SPECIFICATION

Displacement

The engine incorporates two rotors with a total displacement of 152.4 cubic inches.

Reduction Gear and Propeller Shaft

The reduction gear is a spur gear drive having a ratio of 27:74 (.365:1). The propeller shaft is provided with a 4.875 inch O.D. propeller mounting flange having a 4.000 inch diameter bolt circle in accordance with ARP-50?. Rotation of the propeller shaft is clockwise viewed from the anti-propeller end of the engine.

Overall Dimensions

The overall dimensions of the engine including the carburetor, magnetos, and starter ring gear but less the alternator, and external oil and coolant cooling equipment are as follows:

Height, in.	21.5
Width, in.	23.7
Length, in.	31.4

Center of Gravity Location

The approximate center of gravity of the dry engine is as follows:

> 4.0 inches below propeller shaft centerline, in a vertical plane passing through the propeller shaft centerline, and 18.0 inches aft of the propeller mounting flange.

Fuel Inlet Connection

The carburetor is provided with a .250 x 18 NPSF pipe tap hole for installation of the fuel inlet connection.

Fuel Pressure Connection

A .125 x NPTF tapped hole is provided at the carburetor to measure fuel pressure.

Oil Pressure

The operating main engine oil pressure shall be:

20 psi minimum	idle to 2000 RPM
55 - 65 psi	above 2000 RPM

Oil Drain

An oil drain is provided at the bottom of the anti-propeller end housing in accordance with Part 23.1021 of Federal Aviation Regulations for drainage of the engine only. An additional drain is provided in the external lubrication system to drain the oil tank.

Breather

The engine is provided with a threaded connector for a .75" diameter hose for venting the engine case to the oil tank.

Oil Inlet and Outlet Connection

The following tapped holes are provided for oil inlet and outlet connections:

Oil Inlet to Pressure Pump	.750 NPTF
Oil Outlet from Pressure Pump	.500 NPTF
Oil Inlet into Engine	.500 NPTF
Oil Outlet from Scavenge Pump	.500 NPTF

Oil Pressure Gage Connection

A .250 x 18 NPTF tapped hole is provided for the installation of an oil pressure gage connection.

Oil Temperature Gage Connection

A .500 x 14 NPTF tapped hole is provided for the installation of an oil temperature gage connection.

Coolant

The coolant for the engine shall be a mix by volume of 50% Prestone (or Curtiss-Wright approved equivalent) anti-freeze and 50% tap water.

Coolant Inlet and Outlet Connections

The engine is provided with two four-bolt attaching pads for AN 756 flanges for the installation of the coolant inlet and outlet connections.

Coolant Outlet Temperature Gage Connection

A .500 x 14 NPTF tapped hole is provided for installation of the coolant outlet temperature gage connection.

Starter Drive

The engine incorporates a ring gear with 10 D.P. and 160 teeth as standard equipment. A starter mounting pad is provided to accommodate starters with mounting flanges conforming to SAE Specification J642a type 1.

Diaphragm Type Drive

This drive operating at 0.394 engine speed is available with a double diaphragm AC Spark Plug Division type JT fuel pump.

Rotary Type Drive

This drive operates at 0.394 engine speed and conforms to Specification AND 20003 Type XIIIA. Rotation is counterclockwise when viewed facing the pad. Lear Romec rotary vane fuel pump No. RG 17989 is available for this drive.

Accessory Drive Ratios

ENGINE ACCESSORY DRIVES

Item	Type Drive	Rotation	Speed RPM	Speed Ratio	Cont. Torque lb-in.	O'Hung Moment lb-in.	Remarks
Magneto	Special (Gear)	CCW	3000	.500	-	-	Scintilla D2000 Ser.
Oil Pump	Special (Gear)	CCW	3600	.600	-	-	
Water Pump	Special (Gear)	CCW	4909	.818	-	-	
OPTIONAL ACCESSORY DRIVES							
Tachometer	SAE J678C 3/16 H.D.	CCW	3000	.500	7	5	
Hydraulic Pump	AND 20000 Type XA	CCW	3000	.500	100	25	NY Air Brake Model 67-B025 or 67-A025
Vacuum Pump	AND 20000 Type XA	CW	3000	.500	100	25	
Prop. Governor	AND 20010 Type XXA	CW	2364	.394	125	-	
Fuel Pump or	Plunger	-	2364	.394	*	10	*Peak Arm Load 33 lbs
Fuel Pump	AND 20003	CCW	2364	.394	25	25	

Item	Type Drive	Rotation	Speed RPM	Speed Ratio	Cont. Torque lb-in.	O'Hung Moment lb-in.	Remarks
Alternator	"V" Belt Polyflex 60°	CCW	12000	2.00	-	-	12 volt 60 amp
or							
Alternator	"V" Belt Polyflex 60°	CCW	12000	2.00	-	-	24 volt 70 amp
Starter	Direct Drive	CCW	-	17.5:1	-	-	9 Tooth Pinion
Air Conditioner	"V" Belt	CCW	4000	.667	-	-	Ref. Weston Hydraulics HE 81000 Series Compressor

DETAIL WEIGHTS

1. Engine (Standard)

   Basic Engine
   Carburetor, Marvel-Schebler
   Magneto
   Spark Plugs (4)
   Ignition Leads
   Starter Drive (Flywheel & Ring Gear)
   Accessory Substituting Cover Plates
   Coolant in Engine

   Standard Engine Weight — 296 lbs

2. Normal Engine Weight

   Standard Engine — 296
   Starter
   Oil Cooler) Dry
   Oil Tank)
   Coolant Cooler
   Coolant in External System

   Normal Engine Weight — 358 lbs

3. Accessories and Drives (Optional)

   Fuel Pump
   Fuel Pump Drive
   Engine Mounting Brackets
   Alternator and Drive Parts
   Governor Drive
   Propeller Beta Control
   Air Conditioning Drive
   Vacuum Pump Drive
   Hydraulic Pump Drive

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