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USATECOM PROJECT NO. 4-3-0150-17

USAAVNTA PROJECT NO. 64-20

ENGINEERING TEST OF UH-1D HELICOPTER WITH XT67 POWER PLANT INSTALLED

FINAL REPORT

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APRIL 1966

U. S. ARMY AVIATION TEST ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA

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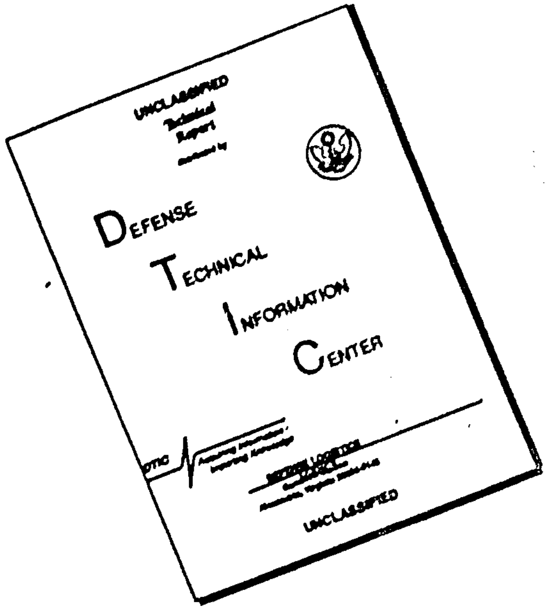

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TEST REPORT

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ABSTRACT

This report presents the results of limited engineering tests conducted to determine the performance characteristics of the XT67 power plant (i.e. two T72 engines) installed in a YUH-1D/48-foot rotor helicopter. Ten productive hours were flown between 14 October 1965 and 22 October 1965. The tests were performed at the airframe contractor's flight test facility located at Greater Southwest Airport, near Fort Worth, Texas.

The U. S. Army Aviation Test Board (USAAVNTBD) was assigned as Executive Test Agency, responsible for coordinating the test plan preparation, executing the limited serviceability testing and coordinating the test reporting. The U. S. Army Aviation Test Activity (USAAVNTA) was assigned the responsibility for coordinating the planning and reporting of the engineering tests with USAAVNTBD and executing the engineering tests.

The XT67 power plant improved the hover and climb performance of the UH-1D/48-foot rotor helicopter by sustaining the helicopter main transmission torque limit to higher altitudes than were possible with the T53-L-11 engine. The XT67 power plant improved the level flight performance by allowing higher cruise speeds for essentially the same range. Increased range could be attained by shutting down one engine. Test installation losses were high but could be reduced significantly through continued development.

The static droop characteristics of the XT67 power plant were acceptable. Static load sharing was excellent; however, load sharing during power transient, although adequate, could be improved. The transient response of the power plant-dynamic system was slow. This shortcoming should be corrected prior to service test.

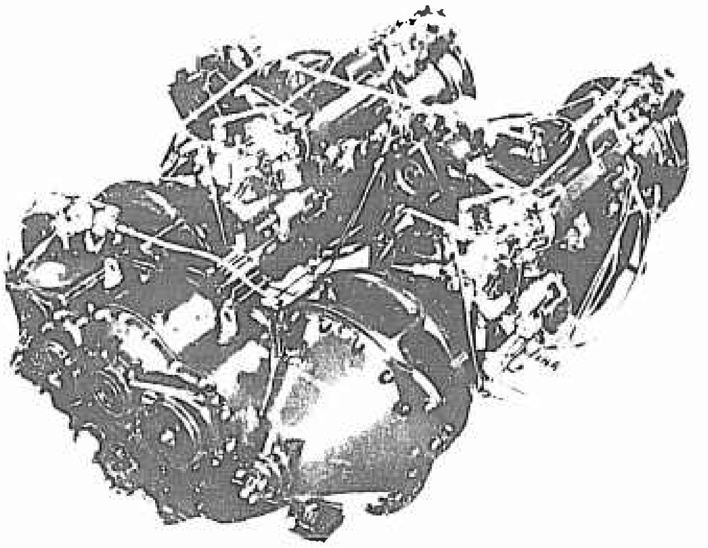


PHOTO NO. 1
XT67 POWER PLANT

FOREWORD

1. AUTHORITY

Letter, AMCPM-IR, Hq, U. S. Army Materiel Command (USAMC), 29 July 1963, subject: "Evaluation of Alternate Engine Installation in the UH-1D Helicopter," with 1st Indorsement, AMSTE-BG, Hq, U. S. Army Test and Evaluation Command (USATECOM), 28 August 1963.

2. REFERENCES

a. Letter, AMCPM-IR-T, Hq, USAMC, 8 July 1964, subject: "USATECOM Plan of Test, Project Number 4-3-0150-10, Evaluation of Alternate Engine Installation in the UH-1D Helicopter," Undated, with 1st Indorsement, AMSTE-BG, Hq, USATECOM, 20 August 1964.

b. Engineering Plan of Test of the LTCIK-4 Engine Installed in the UH-1D Helicopter, USATECOM Project Number 4-3-0150-10, U. S. Army Aviation Test Activity (USAAVNTA), September 1964.

c. Letter, STEBG-TPAC, U. S. Army Aviation Test Board (USAAVNTBD), 24 September 1964, subject: "Change to Evaluation of Alternate Engine Installation Plan of Test for UH-1D Helicopter, USATECOM Project Number 4-4-0150-10."

d. Technical Manual TM 55-1520-210-10, "Operator's Manual Army Model UH-1D Helicopter," Department of the Army, 30 September 1964.

e. Report FTC-TDR-64-27, "Category II Performance Tests of the YUH-1D with a 48-foot Rotor," U. S. Air Force Flight Test Center, November 1964 (AD 452710).

f. Letter, STEAV-PO, USAAVNTA, 3 November 1964, subject: "Evaluation of the Alternate Engine Installation Using the T72 Engine Installed in the UH-1D, USATECOM Project Number 4-3-0150-10."

g. Letter, AMCPM-IR-T, Hq, USAMC, 28 December 1964, subject: "USATECOM Plan of Test, Project Number 4-3-0150-10 Engineering Plan of Test of the LTCIK-4 Engine Installed in the UH [illegible] Helicopter," with 1st Indorsement AMSTE-BG, Hq, USATECOM, 13 Jan[illegible] 1965.

h. Plan of Test, USATECOM Project Number [illegible]50-10, "Evaluation of Alternate Engine Installation in the UH-1D Hel[illegible]opter," USAAVNTBD, 31 March 1965.

i. Engine Specification No. 2252-A, "XT67 Power Plant Aircraft Twin Turboshaft Engine Continental Model 217A-2," Continental Aviation and Engineering Corporation, 15 July 1965.

j. Engine Specification, T53-L-11 Shaft Turbine Engine," Lycoming Division of AVCO Corporation.

k. Letter, 81.JRG:im - 1346, Bell Helicopter Company, 17 July 1965, subject: Proposed Instrumentation for Test of XT67-T-1 Installed in YUH-1D Helicopter with a 48-Foot Diameter Main Rotor.

l. Unclassified Message, SMOSM-EAA 10-1363, U. S. Army Aviation Materiel Command, 14 October 1965, subject: "Safety of Flight Release for Continental Power Plant Installation XT67."

m. AF Technical Report No. 6273, "Flight Test Engineering Handbook," U. S. Air Force Flight Test Center, revised January 1966.

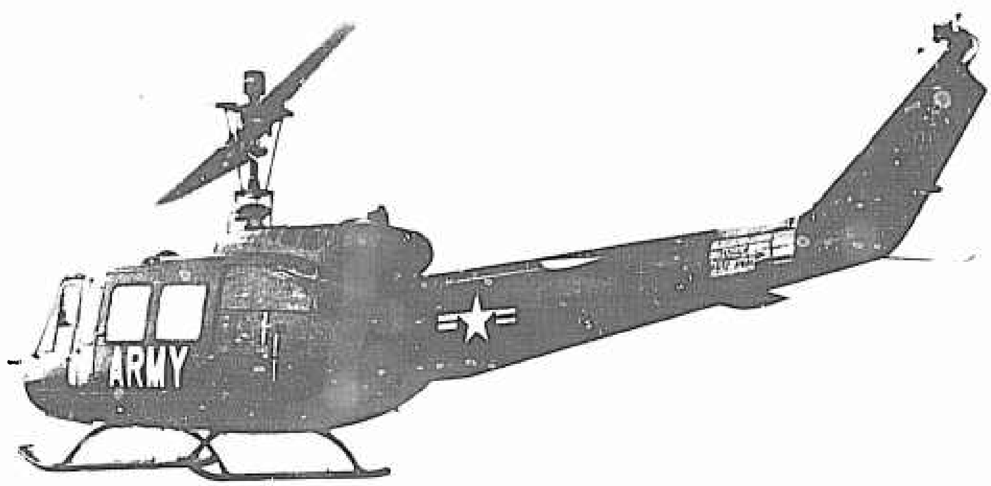


PHOTO NO. 2 - UH-1D WITH XT67 POWER PLANT INSTALLED

SECTION 1 - GENERAL

1.1 OBJECTIVE

To conduct limited engineering tests to determine the performance characteristics of the XT67 power plant installed in the UH-1D helicopter.

1.2 RESPONSIBILITIES

1.2.1 The USAAVNTBD was assigned as Executive Test Agency responsible for coordinating the test plan preparation, executing the limited service testing, and coordinating the test reporting.

1.2.2 The USAAVNTA was assigned responsibility for coordinating the planning and reporting of the engineering portion of the test with USAAVNTBD and executing this portion of the test.

1.3 DESCRIPTION OF MATERIEL

See Section 3, Appendix II.

1.4 BACKGROUND

1.4.1 The Army has a continuing requirement to attain the optimum potential for all equipment in the inventory. The ultimate usefulness of the UH-1D helicopter could be enhanced by an improvement in the hovering and climbing capabilities.

1.4.2 On 2 May 1963, the engine contractor submitted to the Iroquois Project Manager a proposal to install the XT67 in a UH-1D helicopter for evaluation as an alternate power plant. The engine manufacturer's test data indicated that the UH-1D's hovering capability, climb performance, acceleration, and/or throttle response would be improved with the alternate power package.

1.4.3 On 29 July 1963, the Iroquois Project Manager requested USATECOM to evaluate the XT67 power plant installation. USATECOM assigned the program to USAAVNTBD on 28 August 1963. On 8 July 1964, the Iroquois Project Manager requested that USAAVNTA accomplish all engineering tests for this program. USATECOM, on 20 August 1964, assigned USAAVNTA as Participating Agency with responsibilities as described in Paragraph 1.2.2. The scope of the program was enlarged to include limited performance testing of the XT67 power plant in the UH-1D helicopter. An additional requirement for testing at 9500 pounds gross weight was issued by USATECOM on 13 January 1965. A consolidated test plan incorporating the required changes was published by USAAVNTBD on 31 March 1965.

1.5 FINDINGS

1.5.1 GENERAL

The XT67 offered many desirable characteristics as a power plant for the UH-1D helicopter. The airframe contractor had relatively little flight experience with the installation prior to this evaluation. The installation was not optimized or developed. With very little refinement, the performance and engine operating characteristics as described in this report could be significantly improved. The XT67 installation offered significant improvement in the performance of the UH-1D helicopter, particularly in the areas of hovering, climb and level flight. Although the single-engine height-velocity characteristics were not quantitatively evaluated, a significant safety factor over a single-engine helicopter was available.

1.5.2 HOVER

Hovering performance was improved for all ambient conditions; however, the hot-day hovering capability improvement in the test installation was small. The hot-day hover performance could be greatly improved through elimination of the hot-day power-available limitation based on maximum allowable power turbine inlet temperature. In addition, the hot-day shaft horsepower (SHP) available, and thus the hot-day hover performance, could be greatly improved through elimination of the compressor air bleed used to drive cooling blowers in the test installation. The magnitude of the effect of eliminating the bleed could not be calculated because neither the amount of bleed nor its effect upon engine performance was known.

1.5.3 CLIMB

An improvement in climb performance was realized because the transmission limit SHP could be maintained up to an altitude of 6600 feet on a standard day. Sea-level rates of climb were not improved, but a higher rate of climb was possible at higher altitudes.

1.5.4 LEVEL FLIGHT

Level flight performance was improved, even though range was essentially unchanged, because of higher optimum cruise speeds. Optimum cruise speed was the placard limit airspeed in every case. Range was increased approximately 30 percent by shutting down one engine and cruising on the other; however, cruise speed was reduced 15 to 35 knots calibrated airspeed (KCAS). If the second engine was kept at flight-idle rather than shut down, the improvement in range was negligible.

1.5.5 ENGINE OPERATING CHARACTERISTICS AND POWER MANAGEMENT

The static droop characteristics of the XT67 were satisfactory though not optimum. Static load sharing was excellent. No pilot attention was required to maintain equal torque between the two engines. Transient response of the power plant-dynamic system was slow and considered a shortcoming; however, at the time of this evaluation no attempt had been made to optimize this characteristic.

1.5.6 COCKPIT ENGINE CONTROLS AND INFORMATION DISPLAY

The cockpit controls and instrumentation were adequate for the test installation. Many improvements should be incorporated in this area, however, prior to service test.

1.6 CONCLUSIONS ....

1.6.1 The XT67 power plant improved the hover performance of the YUH-1D/48-foot rotor helicopter at all ambient conditions in which maximum SHP available from the T53-L-11 engine was not limited by the main transmission. (Paragraph 2.1.1.4)

1.6.2 The XT67 power plant improved the climb performance of the YUH-1D/48-foot rotor helicopter by sustaining the helicopter main transmission torque limit to 5600 feet. The corresponding increase in power available resulted in higher rates of climb at higher altitudes. (Paragraph 2.1.2.4)

1.6.3 The maximum single-engine rate of climb (sea-level standard day) attained with a climb start gross weight of 7000 pounds was 820 feet per minute. Service ceiling at these conditions was 15,000 feet. (Paragraph 2.1.2.4.2)

1.6.4 The XT67 power plant improved the level flight performance of the YUH-1D/48-foot rotor helicopter by allowing higher cruise speeds for essentially the same range. (Paragraph 2.1.3.4)

1.6.5 By operating the XT67 power plant on a single engine with the second engine shut down, range was increased approximately 30 percent at those conditions in which level flight at single-engine normal rated power was possible. (Paragraph 2.1.3.4.3)

1.6.6 The power losses caused by the test installation were high and particularly detrimental to hot-day performance. (Paragraph 2.2.4)

1.6.7 The high test installation power losses could be reduced significantly through continued development. (Paragraph 2.2.4)

1.6.8 Static droop characteristics of the XT67 power plant were acceptable, although droop cam compensation was not optimum. (Paragraph 2.3.1.4)

1.6.9 Static load sharing was excellent. (Paragraph 2.3.2.4)

1.6.10 Transient response of the power plant-dynamic system was slow. (Paragraph 2.3.3.4)

1.6.11 Load sharing during power transients was adequate but could be improved. (Paragraph 2.3.3.4.3)

1.6.12 The engine cockpit controls and information display were adequate for the test installation. Changes should be incorporated, however, prior to service test. (Paragraph 2.3.4.4)

1.6.13 Engine failure and fuel control malfunction could be readily detected, identified, and compensated for; however, a modified engine torquemeter indicator and collective pitch position indicator would simplify detection, identification and compensation. (Paragraphs 2.3.4.4.4 and 2.3.4.4.5)

1.7 RECOMMENDATIONS

1.7.1 Effort should be initiated by the contractors to correct the following shortcoming:

Inadequate transient response of the power plant-dynamic system. (Paragraph 2.3.3.4)

1.7.2 Developmental effort should be continued by the contractors to correct or improve the following items:

a. Reduce the installation power losses, particularly those affecting hot-day SHP available. (Paragraph 2.2.4)

b. Optimize the static droop characteristics of the power plant for increased compensation at high collective settings. (Paragraph 2.3.1.4.3)

c. Improve the load sharing during power transients. (Paragraph 2.3.3.4.3)

d. Provide better identification of the two modes of operation of the starter button. (Paragraph 2.3.4.4.1)

e. Provide the individual twist-grips with individually adjustable friction. (Paragraph 2.3.4.4.2)

f. Provide the twist-grips with a "dead band" at the full-open position to prevent the fuel control levers from "backing off." Paragraph 2.3.4.4.2)

g. Make both twist-grips the same size and provide a distinctive texture for each to facilitate identification by feel. (Paragraph 2.3.4.4.2)

h. Reduce the distance between the twist-grips and the flight-idle release buttons to reduce hand motion. (Paragraph 2.3.4.4.2)

i. Indicate, on the large and small needles of the dual tachometer, rotor speed and power plant output shaft speed respectively.

j. Provide a three-needle torque indicator, displaying left-engine torque, right-engine torque and total torque. (Paragraph 2.3.4.4.4)

SECTION 2 - DETAILS OF TEST

2.0 INTRODUCTION

2.0.1 Except in climbing flight, no attempt was made during this evaluation to measure directly helicopter performance because the power required in most flight regimes for the YUH-1D/48-foot rotor helicopter was well defined in Reference e, Foreword. The significant parameters measured were the power available and fuel-flow characteristics of the XT67. Based on the results of these measurements, the performance of the YUH-1D/48-foot rotor helicopter with the XT67 installed could be calculated using the data contained in Reference e.

2.0.2 Climb performance was increased due to the increased power available and this performance characteristic was measured directly.

2.0.3 Due to the scope of this evaluation, several limitations were imposed and several assumptions were made. First, no attempt was made to gather information on the effect of engine output speed (rotor speed) upon engine performance. All data presented in this report was valid for a rotor speed of 324 rpm. Second, there was insufficient information available to determine the amount of compressor bleed air used in the test installation to drive cooling blowers. Additionally, the effect of compressor bleed on engine performance was not well established. Because of the ambiguity of the effect of bleed upon engine performance, no attempt was made to standardize the observed data to a zero-bleed condition. Third, the data presented in this report was based on the assumption that both engines of the XT67 power plant had specification torquemeters. Prior to this evaluation, the XT67 power plant was calibrated in a test cell. It, however, was not run in a single-engine configuration sufficiently to define the individual engine torquemeter pressure as a function of engine output torque. There was no dependable method of obtaining this information in the limited flight time available. Any deviation between the test engine torquemeters and the torquemeter characteristics in Engine Specification 2252-A (Reference i) affected the accuracy of the performance data contained in this report. Engine Specification No. 2252-A, Paragraph 3.23, states: "The torquemeter signals shall indicate the torque developed by the engines within the following tolerances:

a. From maximum steady-state torque to normal rated output torque: ± 3 percent of the value being measured.

b. From normal rated output torque to one-third of normal rated output torque: ± 3 percent of the value obtained at normal rated torque."

2.0.4 Engine handling characteristics and power management were briefly but quantitatively evaluated in terms of static droop and transient response in both the twin- and single-engine modes. Static load sharing and transient load sharing were briefly investigated. Cockpit engine controls and engine information display were briefly evaluated. Time did not allow evaluation of the single-engine height-velocity characteristics of the helicopter.

2.1 PERFORMANCE OF YUH-1D/48-FOOT ROTOR HELICOPTER WITH XT67 POWER PLANT INSTALLED

2.1.1 The hovering and level-flight performance characteristics presented in this report were calculated based upon the data presented in Reference e for power required in hovering and level flight.

2.1.2 The climb performance presented in this report was based upon actual flight test data obtained during climb performance tests.

2.1.3 All summary performance for the helicopter with the XT67 power plant installed was based upon observed installed engine characteristics which included the installation losses of the test helicopter.

2.1.4 The helicopter performance with the T53-L-11 engine was calculated for comparison purposes based upon fuel flow and power available obtained from an airframe contractor report. Fuel flow and shaft horsepower available from this report were based upon: a. Engine Model Specification T53-L-11 (Reference j); b. Compressor inlet total pressure loss = 0; c. Compressor inlet total temperature rise = 2 degrees Centigrade (C); d. Percent air bleed = 0.6 percent; and e. Power extracted from gas producer section = 0.

2.1.1 HOVER

2.1.1.1 Objective

The objective of the hover performance tests was to define the hover performance of the UH-1D/48-foot rotor helicopter with the XT67 power plant installed.

2.1.1.2 Method

The shaft horsepower (SHP) required to hover at various gross weights, pressure altitudes and ambient temperatures was obtained from Reference e. The SHP available from the XT67 power plant was obtained from Figure 15, Section 3, Appendix I. Based upon these characteristics, the hover ceiling both in and out of ground effect was calculated for various gross weights and ambient temperatures.

2.1.1.3 Results

The hover performance test results of the YUH-1D/48-foot rotor helicopter with the XT67 power plant installed are presented in Figures 1 and 2, Appendix I.

2.1.1.4 Analysis

2.1.1.4.1 All hover performance was based upon military rated power for both the XT67 power plant and the T53-L-11 engine.

2.1.1.4.2 On a standard day, the out-of-ground effect (OGE) hover performance of the UH-1D/48-foot rotor helicopter was significantly better with the XT67 power plant than with the T53-L-11 engine. With the XT67 power plant, the OGE standard-day hover ceiling was 4000 feet at 9500 pounds gross weight. With the T53-L-11 engine, the maximum gross weight for OGE hover at sea level was 8850 pounds and, at 4000 feet, 8430 pounds. At 8500 pounds gross weight, the OGE hover ceiling with the T53-L-11 was 3690 feet; the XT67 increased the OGE hover ceiling to 10,020 feet. Using only the right single engine of the XT67 power plant, the maximum gross weight for OGE hover at sea level was 6200 pounds.

2.1.1.4.3 The hot-day (35-degree-C) OGE hover performance of the YUH-1D/48-foot rotor helicopter was not as greatly improved with the installation of the XT67 power plant as was the standard-day performance. The reason was that the SHP available on a hot day from the XT67 power plant was low for reasons explained in Paragraph 2.2.4. Maximum gross weight for OGE hover on a 35-degree-C day at sea level was 8360 pounds with the XT67 power plant and 8160 pounds with the T53-L-11 engine. At design gross weight, 6600 pounds, the OGE hover ceiling was 6470 feet pressure altitude with the XT67 power plant and 5900 feet pressure altitude with the T53-L-11 engine.

2.1.1.4.4 The 2-foot skid height in-ground-effect (IGE) hover ceiling is presented in Figure 2, Appendix I. This hovering skid height was approximately the limit from which a satisfactory takeoff could be accomplished with this helicopter without contacting the ground or exceeding engine military power limits. The 2-foot hover ceiling at 9500 pounds gross weight on a standard day was 12,400 feet with the XT67 power plant and 5850 feet with the T53-L-11 engine.

2.1.1.4.5 Using only the right single engine of the XT67 power plant, the maximum gross weight for a 2-foot hover at sea level was 7420 pounds.

2.1.1.4.6 On a 35-degree-C day the 2-foot hover ceiling at 9500 pounds gross weight was 1080 feet pressure altitude with the XT67 power plant and 300 feet pressure altitude with the T53-L-11 engine. Again there was only a small gain in hot-day hover performance due to the low hot-day SHP available from the XT67 power plant for reasons explained in Paragraph 2.2.4.

2.1.2 CLIMB

2.1.2.1 Objective

The objective of the climb performance tests was to define the climb performance of the YUH-1D/48-foot rotor helicopter with the XT67 power plant installed.

2.1.2.2 Method

2.1.2.2.1 Continuous climb performance tests were conducted from minimum attainable altitude to service ceiling at military rated power. One climb was made at a climb-start gross weight of 9500 pounds using both left and right engines. One climb was made at a climb-start gross weight of 7000 pounds using only the left engine. One climb was made at a climb-start gross weight of 7000 pounds using only the right engine.

2.1.2.2.2 A rotor speed of 324 rpm was maintained during the climb tests. SHP was maintained at either the torque limit of the helicopter transmission or the maximum power available at the test conditions using the military power limits.

2.1.2.2.3 The climb performance data was corrected to standard-day conditions and standard climb gross weights of 9500 pounds for the twin-engine climb and 7000 pounds for the single-engine climbs.

2.1.2.3 Results

The results of the climb performance tests are presented in Figures 3, 4 and 5, Appendix I.

2.1.2.4 Analysis

2.1.2.4.1 The climb performance of the YUH-1D/48-foot rotor helicopter was improved by the installation of the XT67 power plant. The sea-level rate of climb was not significantly changed due to the fact that the maximum power available was limited to the torque limit of the main transmission. No flight test climb performance data was available for the T53-L-11 engine; however, sea-level rate of climb at 9500 pounds gross weight was 1560 feet/minute with both the XT67 power plant and the T53-L-9 engine. The increase in climb performance was the result of the capability of the XT67 to maintain the transmission limit power to a higher altitude, with a subsequent increase in power available above the altitude where the main transmission no longer limited maximum power (6600 feet). A higher service ceiling also resulted with the XT67 power plant. The time to climb to 10,000 feet, which was 9.3 minutes with the T53-L-9, was reduced 19.4 percent to 7.5 minutes with the XT67. Service ceiling at 9500 pounds climb-start gross weight was 14,630 feet with the XT67 power plant and 12,550 feet with the T53-L-9 engine.

2.1.2.4.2 With a sea-level climb-start gross weight of 7000 pounds, using only the left engine of the XT67 power plant, the sea-level rate of climb was 660 feet/minute and the service ceiling was 12,680 feet. At the same conditions using only the right single engine, the sea-level rate of climb was 820 feet/minute and the service ceiling was 15,000 feet, because of the higher SHP available.

2.1.3 LEVEL FLIGHT

2.1.3.1 Objective

The objective of the level-flight performance tests was to define the level-flight performance of the YUH-1D/48-foot rotor helicopter with the XT67 power plant installed.

2.1.3.2 Method

The SHP required to maintain level flight with the YUH-1D/48-foot rotor helicopter was defined in Reference e. The curves of SHP required versus true airspeed presented in Figures 8 through 13, Appendix I were obtained directly from Reference e. SHP available and the fuel flow at any SHP for the XT67 were measured during this program as described in Paragraph 2.2. With this information the level flight performance of the YUH-1D/48-foot rotor helicopter was calculated for both single-engine and twin-engine XT67 operation.

2.1.3.3 Results

The results of the level flight performance tests are presented in Figures 6 through 14, Appendix I.

2.1.3.4 Analysis

2.1.3.4.1 The range rformance of the YUH-1D/48-foot rotor helicopter with the XT67 power p.ant was very similar to that with the T53-L-11 engine. A comparison in terms of range factor is shown in Figure 6, Appendix I. At low values of thrust coefficient (C_T), less than .00294, the T53-L-11 showed slightly higher range performance than the XT67. At higher values of C_T, the range performance of the XT67 power plant was slightly superior. The "crossover" C_T of .00294 corresponded to approximately 8380 pounds gross weight at sea level or 7220 pounds gross weight at 5000 feet with a rotor speed of 324 rpm on a standard day.

2.1.3.4.2 The airspeed for maximum range with the XT67 power plant was always greater than or equal to the airspeed for maximum range with the T53-L-11. Recommended cruise speed for maximum range with the XT67 was the placard limit airspeed for all conditions. Recommended cruise speed with the T53-L-11 was the airspeed at .99 maximum nautical air miles per pound of fuel (.99 max NAMPP). With the T53-L-11, .99 max NAMPP occurred at or below placard limit airspeed. In general, the YUH-1D/48-foot rotor helicopter traveled approximately the same distance with the XT67 power plant as with the T53-L-11 engine; it would arrive sooner, however, with the XT67 power plant installed.

2.1.3.4.3 There was a considerable increase in range to be gained by cruising on a single engine of the XT67 power plant with the second engine shut down. Range was increased approximately 30 percent in this manner; however, the decrease in cruise speed necessary to gain this increase in range was 15 to 35 knots true airspeed (KTAS) depending upon the combination of gross weight and altitude as shown in Figure 6, Section 3, Appendix I. The airspeed for maximum single-engine range was the airspeed at maximum continuous power available (normal rated power limit).

2.1.3.4.4 If the second engine of the XT67 power plant was operated at flight-idle instead of shut down to maintain twin-engine reliability, the range advantage was lost. The 15-to-35-KTAS cruise speed sacrifice, however, still resulted. The flight-idle fuel consumption of the second engine canceled the advantage of operating a single engine in its high-power, low-specific-fuel-consumption range.

2.1.3.4.5 Single-engine level flight was not possible for all conditions of gross weight and density altitude. The single-engine absolute ceiling of the YUH-1D/48-foot rotor helicopter with the XT67 power plant is shown in Figure 7, Appendix I. The curve of this figure, based upon normal rated power on a standard day at a rotor speed of 324 rpm, shows the maximum altitude at which the helicopter was capable of level flight at the airspeed for minimum power required. At 8500 pounds gross weight, level flight could be maintained on one engine at normal rated power at a standard-day altitude of 5200 feet.

2.1.3.4.6 A calculated range mission is presented in Figure 14, Appendix I. This figure shows a comparison of range performance of the YUH-1D/48-foot rotor helicopter with the T53-L-11 engine, XT67 power plant, XT67 right single engine with the second engine shut down, and XT67 right single engine with the second engine at flight-idle. The conditions chosen for the comparative range mission, listed in Figure 14, Appendix I, were chosen as being typically representative, rather than purposely favoring a particular power plant. The results of the comparative range mission are summarized in table on the following page.

2.2 POWER AVAILABLE AND FUEL FLOW

2.2.1 OBJECTIVE

The objective of the power-available and fuel-flow tests was to define through flight test data the parameters required to calculate maximum SHP available from the XT67 power plant and the fuel flow at any conditions of SHP pressure altitude and ambient temperature.

2.2.2 METHOD

During stabilized flight all pertinent engine parameters, including SHP, fuel flow (W_f), gas producer speed (N_1), and power turbine inlet temperature (T_{T_6}) were recorded. By means of standard engineering methods (Reference m), these readings were reduced to standard-day, sea-level, static conditions, resulting in a single curve expressing the relationship of any two parameters for a single engine on a "referred" basis. These referred engine characteristics for both the left and right engines of the XT67 power plant are presented in Figures 20 through 22 and 25 through 27, Appendix I. With these referred characteristics, it was possible to calculate at any pressure altitude, ambient temperature, and airspeed, the SHP at any N_1 or T_{T_6}. Then, by knowing the maximum N_1 available, as defined in Figures 19 and 24, and the maximum T_{T_6} allowable as given in Engine Model Specification No. 2252A(Reference i), the SHP available could be calculated. In a similar fashion, the W_f required for any available SHP at any pressure altitude, ambient temperature or airspeed could be calculated.

2.2.3 RESULTS

The results of the power-available and fuel-flow tests are presented in Figures 15 through 27, Appendix I.

2.2.4 ANALYSIS

2.2.4.1 Due to the limited scope of this test, no effort was made to determine the effect of engine output shaft speed (rotor speed) upon

RESULTS OF THE COMPARATIVE RANGE MISSION

Configuration	Nautical Air Miles Traveled	Elapsed Time For Maximum Nautical Air Miles Traveled hr	Elapsed Time For 200 Nautical Air Miles hr	Average Cruise Airspeed KTAS
XT67 Power Plant	230	2.064	1.815	111.4
T53-L-11 Engine	235.7	2.227	1.900	105.8
XT67 Right Single Engine with Left Engine Shut Down	306.3	3.538	2.36	86.6
XT67 Right Single Engine with Left Engine at Flight-Idle	209.5	2.445	2.36	85.7

engine performance. All data presented in this report, therefore, was for an engine output shaft speed of 6600 rpm (324 rpm rotor speed). The data for the referred engine characteristics was not corrected for non-optimum power turbine speed. Similarly, the effects of compressor air bleed and power extracted from the gas producer section were not defined and no bleed correction was made. The data presented in the referred engine characteristics curves, therefore, reflects the performance of the XT67 power plant as installed in the test helicopter with all the installation losses included with the exception of compressor inlet duct losses.

2.2.4.2 The maximum SHP available at military power limits was limited either by maximum allowable T_{T_6}, 677 degrees C, or by maximum N_1 available ("topping" N_1) as limited by the fuel control. As a general rule, power was limited by "topping" N_1 on a standard day or cooler and by maximum T_{T_6} on a hotter than standard day.

2.2.4.3 Although the exact effect of bleed air upon a single engine of the XT67 power plant was not known quantitatively, its general effect was to raise the T_{T_6} for a given SHP. This effect was greater at high ambient temperatures than at low ambient temperatures. This meant that, with bleed air being extracted, not only would the SHP available at T_{T_6} limit be lowered, but the ambient temperature range over which SHP available was limited by maximum T_{T_6} would be extended to lower ambient temperatures for any pressure altitude. The fact that maximum SHP available was limited by maximum T_{T_6} at high ambient temperatures was of particular significance with the XT67 power plant. The power plant should be configured to be limited by "topping" N_1 over as large a span of ambient temperatures as possible.

2.2.4.4 With a twin-engine installation, the two engines are never precisely matched. There is always a relatively "strong" and a relatively "weak" engine. Likewise, the static droop characteristics are not the same. To overcome this, the XT67 power plant employed a torque matching device which "beeped up" the low engine, or shifted its static droop line to the point where the engine torquemeter output pressures would be equal at any load or rotor speed.

2.2.4.5 When increasing power was demanded by increasing collective pitch, the engine supplied an equal torque to the rotor until the "weak" engine reached its maximum output, limited by either "topping" N_1 or maximum T_{T_6}. If the "weak" engine was limited by "topping" N_1, a further increase in collective pitch resulted in the "weak" engine's continuing to put out an essentially constant power. The "strong" engine then continued to increase its power output until the limit of the "strong" engine was reached.

2.2.4.6 On the other hand, if the "weak" engine was limited by maximum T_{T6}, a further increase in load resulted in the torque matching device's "beeping" the "weak" engine into an unacceptable overtemp condition in an effort to match torque output.

2.2.4.7 The effect was that when the "weak" engine was limited by "topping" N_1 the SHP available from the XT67 power plant was the total of the SHP available from the left engine and the SHP available from the right engine. When the "weak" engine was limited by maximum allowable T_{T6}, the SHP available from the XT67 power plant was limited to twice that available from the "weak" engine. An example of the conditions in which the weak engine was limited by maximum T_{T6} may be seen in Figures 15 through 17, Appendix I. At 5000-foot pressure altitude and +35-degree-C ambient temperature, SHP available from the left engine was 393 and SHP available from the right engine was 423. The combined SHP available from the XT67 power plant was 786, twice that available from the "weak" left engine. The 30 SHP remaining in the right engine was not available without either overtemping the left engine or switching into the manual mode of the fuel control on the left engine. This took the "weak" engine governor off line and allowed the twist-grip selection of maximum power on that engine while collective pitch was increased to absorb remaining power on the right engine.

2.3 ENGINE OPERATING CHARACTERISTICS AND POWER MANAGEMENT

2.3.1 STATIC DROOP

2.3.1.1 Objective

The objective of the static droop tests was to define the static droop characteristics of the XT67 power plant in both the twin-engine and single-engine configurations.

2.3.1.2 Method

Rotor speed was established on the ground prior to the static droop tests at 324 rpm. The power turbine speed select (beep) switch setting was not changed for the remainder of the test at two airspeeds and the power demand was increased in increments by increasing collective pitch. The resulting relationship between engine output torque and rotor speed was recorded.

2.3.1.3 Results

The results of the twin-engine and single-engine XT67 static droop tests are presented in Figures 28 and 29, Appendix I.

2.3.1.4 Analysis

2.3.1.4.1 The test installation had a collective "compensator cam" installed, so the basic governor droop was not evaluated. The compensated droop for both single- and twin-engine operation was adequate but not optimum. Figure 28, Appendix I shows that with both engines operating during a vertical takeoff and climb the rotor speed stayed constant to within 2 rpm without beep adjustment. Slight over-compensation of droop occurred in the mid power range. This is a desirable feature in vertical flight since it helps maintain a high rotor speed as a safety margin and aids in preventing rotor overspeed during power reduction during a landing.

2.3.1.4.2 At 72 knots calibrated airspeed (KCAS), when the collective pitch settings for a constant power were higher than at zero airspeed, compensation was less ideal. Total static droop from a "needles-joined" to maximum power was approximately 5 rpm. This value was certainly acceptable; however, hysteresis of approximately 2 rpm made the apparent static droop appear somewhat larger.

2.3.1.4.3 The single-engine static droop is shown in Figure 29, Appendix I. As would be expected, static droop of the single engine was approximately double that of the twin engine. An increase in compensation at higher collective settings not only improved the single-engine static droop characteristics, but also improved the high-speed (and high-altitude) twin-engine static droop characteristics. At torque outputs greater than approximately 350 pounds-foot, the static droop characteristics of the left and right engines were not matched. A single compensator cam was fitted, so this mismatch was the result of the different fuel control characteristics of the two engines.

2.3.2 STATIC LOAD SHARING

2.3.2.1 Objective

The objective of the static load sharing tests was to determine the static load sharing characteristics of the two engines of the XT67 power plant.

2.3.2.2 Method

At minimum collective pitch on the ground, a stabilized rotor speed was selected. The power demand was increased by increasing collective pitch in increments, allowing the engines to stabilize, then recording the individual engine output torques.

2.3.2.3 Results

The results of the static load sharing tests are presented in Figure 30, Appendix I.

2.3.2.4 Analysis

2.3.2.4.1 The static load sharing of the XT67 power plant was better than that of any other helicopter twin-engine installation tested to date. Differences in torquemeter readings were generally small enough to be unreadable on the standard instruments and well within their accuracy. Only at maximum torque output, when one engine was "topped" and could deliver no more power, was there any significant deviation from ideal static load sharing.

2.3.2.4.2 It should be noted that the torque matching device adjusts the relative power of the engines to match the torquemeter output hydraulic pressure. It does not actually match torque. If the torquemeter of one engine were to transmit a higher hydraulic pressure for a given torque output, that engine would produce less torque when the torque matching device was satisfied that the load was being equally shared by the engines. The load sharing characteristics of the XT67 power plant were only as accurate, reliable, and repeatable as the torquemeters of the individual engines. Without the automatic torque matching device of the XT67 power plant, the load sharing characteristics of these engines would probably have been poor. A high degree of pilot attention would have been required to keep the power output of the engines equal.

2.3.2.4.3 The single-engine static droop characteristics of the test installation were described in Paragraph 2.3.1.4. The single-engine static droop characteristics of the left and right engines were not well matched, especially at high torque output.

2.3.3 TRANSIENT RESPONSE

2.3.3.1 Objective

The objective of the transient response tests was to determine quantitatively the response of the XT67 power plant-dynamic system to abrupt power changes.

2.3.3.2 Method

2.3.3.2.1 The helicopter was loaded to normal mission gross weight, 8500 pounds. At the test altitude, approximately 1900 feet pressure altitude, 85 percent military rated power was selected at approximately

67 KCAS and the collective position noted. The collective was then lowered to a stabilized autorotation in which the needles were just joined at a rotor speed of approximately 332 rpm. Collective pitch was then increased at varying rates to the setting previously noted. Photo panel records were taken of the resulting transient response to the demands.

2.3.3.2.2 Single-engine transient response was also briefly evaluated, first as described above, then by recording the reaction of one engine as it assumed the load imposed when the second engine was "chopped" simulating a single-engine power failure.

2.3.3.3 Results

The results of the transient response tests are presented in Figures 31 through 36, Appendix I.

2.3.3.4 Analysis

2.3.3.4.1 Oscillograph recording of transient response data was not available, so a detailed analysis of the XT67 power plant's transient response, including system lags and time constants, could not be made. The results obtained through photo panel recording presented here are, however, representative of the results that could have been obtained more accurately through the use of an oscillograph.

2.3.3.4.2 Twin-engine transient response was poor and considered a shortcoming. The minimum allowable power-on rotor speed of 299 rpm was reached during torque demand rates of approximately 211 pounds-foot/second. With the T53-L-11 engine installed, this minimum transient droop was not reached at torque demand rates of 289 pounds-foot/second at approximately the same ambient conditions. Maximum XT67 gas-producer accelerations were approximately 5 percent/second. The engine acceleration, although slow, was very uniform. Torque changes were uniform and easily anticipated with directional control to avoid helicopter yawing. The engine manufacturer stated that acceleration could be easily increased through fuel control adjustments and that acceleration was purposely kept to a low value in the experimental installation to provide a highly damped torsionally stable dynamic system.

2.3.3.4.3 The load sharing during transient power demands was inferior to the static load sharing. The torque-matching device incorporated a variable damper which was set for very high damping to avoid any possible engine instability or hunting. There was room for considerable improvement in the test installation in the transient load sharing area. The difference in torque between the left and right engines during transient response reached as high as 72 pounds-foot, or approximately 20 percent.

2.3.3.4.4 The simulated single-engine power failure presented in Figure 36, Appendix I shows the only evidence of engine instability observed during the evaluation. Three oscillations in torque were observed while the right engine was accelerating to assume the load of the "chopped" engine. Although the peak oscillation was approximately 18 percent of the mean torque, this oscillation was not objectionable or even noted in flight. It should be noted that if a single-engine failure were to occur at a high combined power plant output power setting on a cold day at low pressure altitude, the operating engine would accelerate and exceed its limit torque if collective pitch were not lowered. For example, a left-engine failure at a combined power plant output of 800 SHP at sea level on a -10-degree-C day would result in a right-engine overtorque if corrective action were not taken by the pilot.

2.3.4 COCKPIT ENGINE CONTROLS AND INFORMATION DISPLAY

2.3.4.1 Objective

The objective of the cockpit engine controls and information display evaluation was to present specific comments concerning this aspect of the test installation.

2.3.4.2 Method

This evaluation is based upon the comments of an experienced engineering test pilot.

2.3.4.3 Results

The results of this evaluation are presented and discussed in Paragraph 2.3.4.4.

2.3.4.4 Analysis

2.3.4.4.1 The two-position starter button on the cyclic control stick was satisfactory, but better identification of the two modes of operation seemed desirable. During air starts, it was easy to release the button fully; this took the starter motor off the line and resulted in a hot start.

2.3.4.4.2 The tandem twist-grip arrangement should be improved by incorporating the following changes:

a. Provide the individual twist-grips with individually adjustable friction.

b. Incorporate a "dead band" at the full-open position to prevent the fuel control levers from "backing off."

c. Make both twist-grips the same size and provide a distinctive texture for each to facilitate identification by feel.

d. Reduce, if possible, the distance between the twist-grips and the flight-idle release buttons to reduce hand motion.

2.3.4.4.3 The practice of displaying the power turbine speed (N_2) on the large needle and rotor speed (N_R) on the small needle of the dual tachometer is undesirable. Rotor speed is the primary parameter and should be displayed more prominently. The small needle is difficult to read and subject to considerable parallax. The pilot is not normally interested in N_2 except for monitoring during needle-split operation.

2.3.4.4.4 A three-needle torque indicator displaying left-engine torque, right-engine torque and total power plant torque is desirable. The total torque indication is desirable because over a large range of altitude and ambient temperature conditions the power output of the XT67 power plant is limited by helicopter main transmission torque limit. With a separate indicator for each engine, the total torque must be summed by a pilot. Having individual left- and right-engine output torque on one indicator would aid the pilot in identifying an engine failure or torque matching device malfunction.

2.3.4.4.5 The fuel control incorporated a manual mode by which fuel flow to the engine could be regulated directly by twist-grip rotation. This manual mode would restore full power should a fuel control malfunction restrict fuel flow to either engine. A fuel control failure resulting in a reduction in fuel flow could be identified by the decrease in rotor speed due to single-engine static droop and the reduction of torque on one engine. The recommended three-needle torque indicator would simplify identification of the failed engine. Were a fuel control failure to result in an increase in fuel flow to either engine, this could be identified by an increase in rotor speed and an increase in torque on the engine with the malfunctioning system. Again, the recommended torque indicator would simplify identification of the malfunctioning engine.

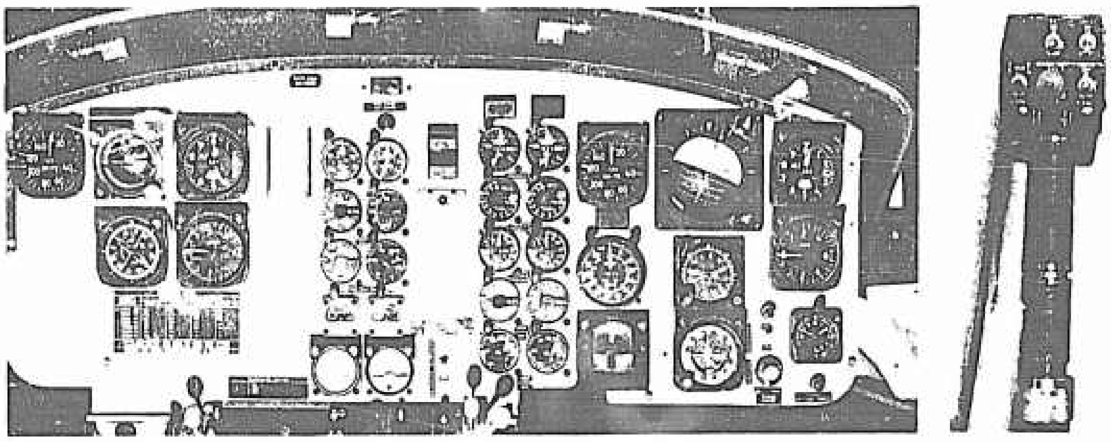


PHOTO NO. 3 and 4 - UH-1D COCKPIT DISPLAY and THROTTLE CONTROL STICK

SECTION 3 - APPENDICES

APPENDIX I

TEST DATA

FIGURE NO. 1
HOVERING CEILING OUT OF GROUND EFFECT
YUH-1D/48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
MILITARY RATED POWER
ROTOR SPEED = 324 RPM

NOTES:

1. SHAFT HORSEPOWER REQUIRED TO HOVER OUT OF GROUND EFFECT OBTAINED FROM FTC-TDR-64-27
2. SHAFT HORSEPOWER AVAILABLE, XT-67, FROM FIGURES NO 15 AND 17.
3. SHAFT HORSEPOWER AVAILABLE, T-53-L-11, FROM BHC. RPT. 205-099-705

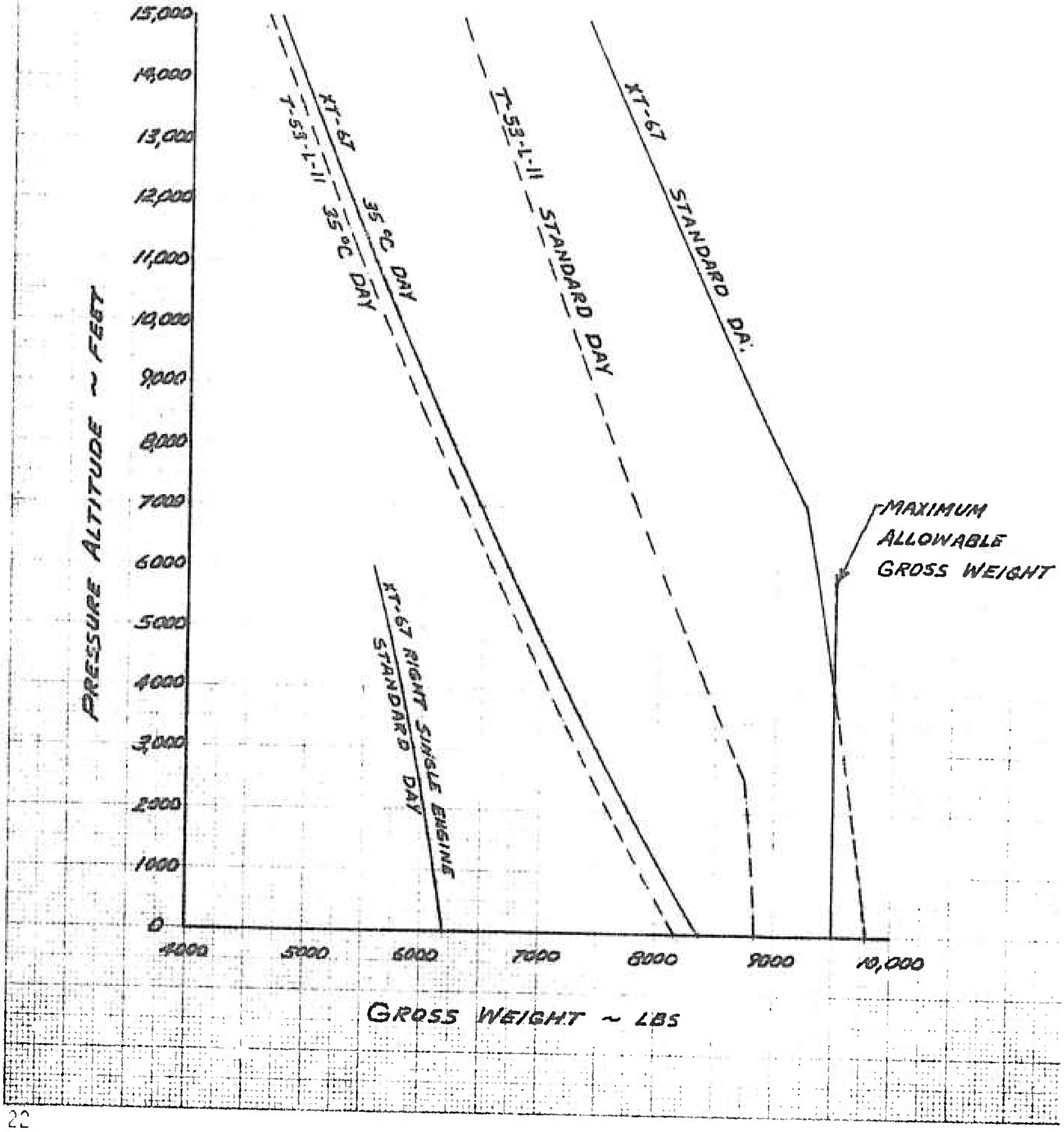


FIGURE NO. 2
HOVERING CEILING IN GROUND EFFECT
YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

MILITARY RATED POWER

ROTOR SPEED = 324 RPM

2 FOOT SKID HEIGHT

NOTES:

1. SHAFT HORSEPOWER REQUIRED TO HOVER WITH A 2 FOOT SKID HEIGHT OBTAINED FROM FTC-TDR-64-27.
2. SHAFT HORSEPOWER AVAILABLE, XT-67 FROM FIGURES NO 15 AND 17.
3. SHAFT HORSEPOWER AVAILABLE, T-53-L-11, FROM BHC RPT 205-099-705

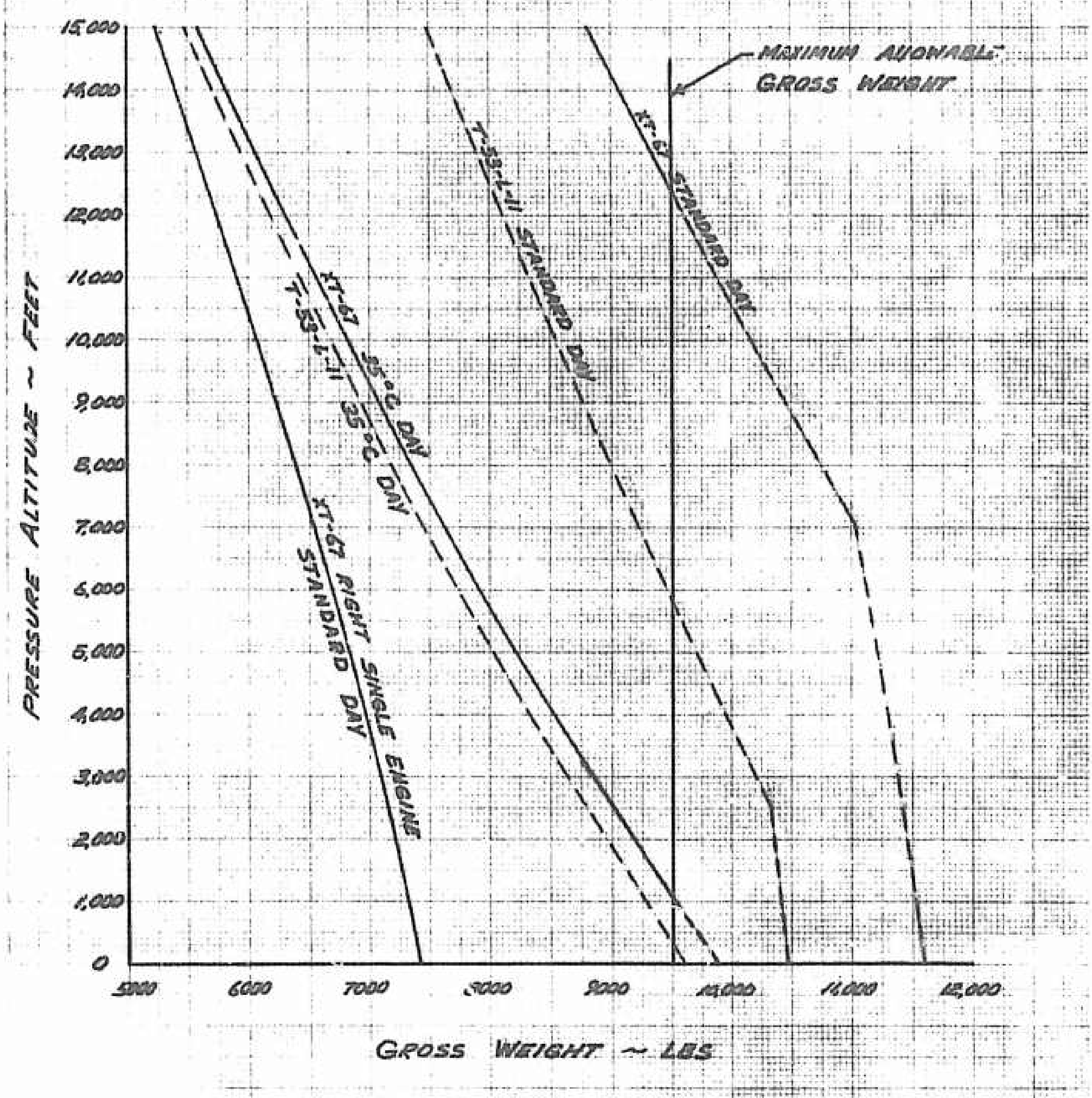


FIGURE NO. 3
TWIN ENGINE CLIMB PERFORMANCE
YUH-1D/48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2

STANDARD DAY
MILITARY RATED POWER
SEA LEVEL CLIMB START GROSS WEIGHT = 9500 LBS
ROTOR SPEED = 324 RPM
CG = 137.7 INCHES (MID)

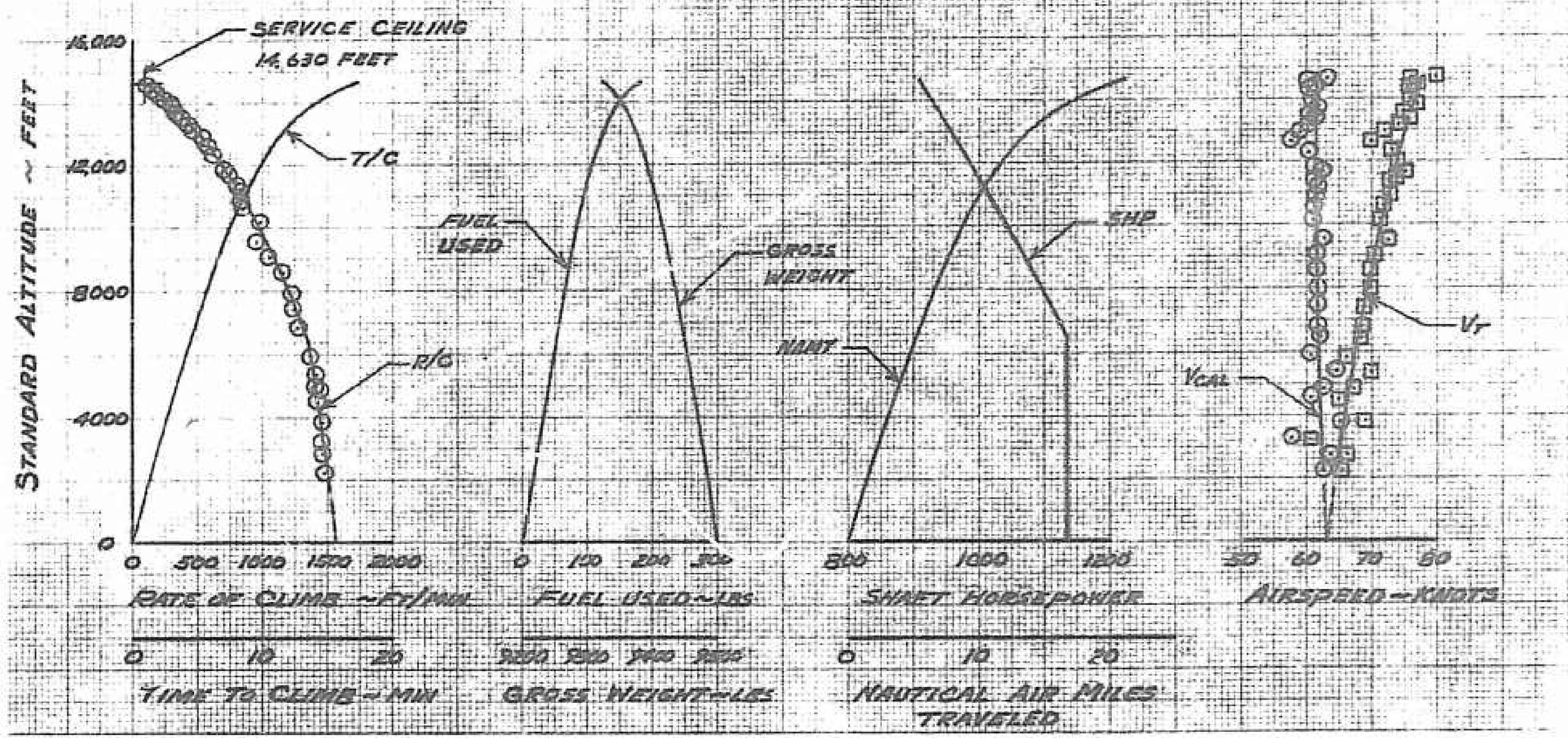


FIGURE NO. 4
LEFT SINGLE ENGINE CLIMB PERFORMANCE
YUH-1D/48 FOOT ROTOR USA S/N 61-6030
XT-67 POWERPLANT S/N 2
LEFT ENGINE S/N X-6

STANDARD DAY
MILITARY RATED POWER
SEA LEVEL CLIMB START GROSS WEIGHT = 7000 LBS.
ROTOR SPEED = 324 RPM
C.G. = 137.3 INCHES (MID)

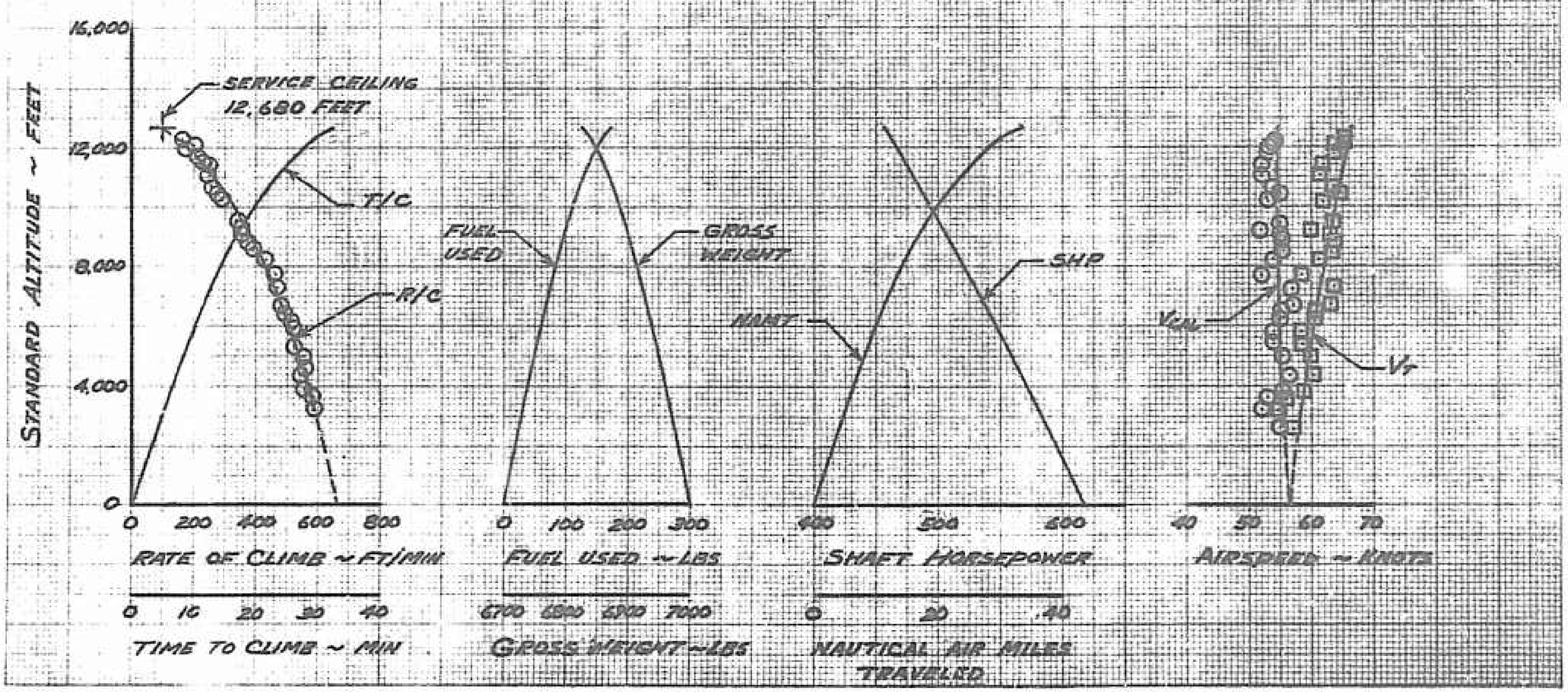


FIGURE No. 5

RIGHT SINGLE ENGINE CLIMB PERFORMANCE

YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

RIGHT ENGINE S/N X-5

STANDARD DAY

MILITARY RATED POWER

SEA LEVEL CLIMB START GROSS WEIGHT = 7000 LBS

ROTOR SPEED = 324 RPM

C.G. = 137.3 INCHES (MID)

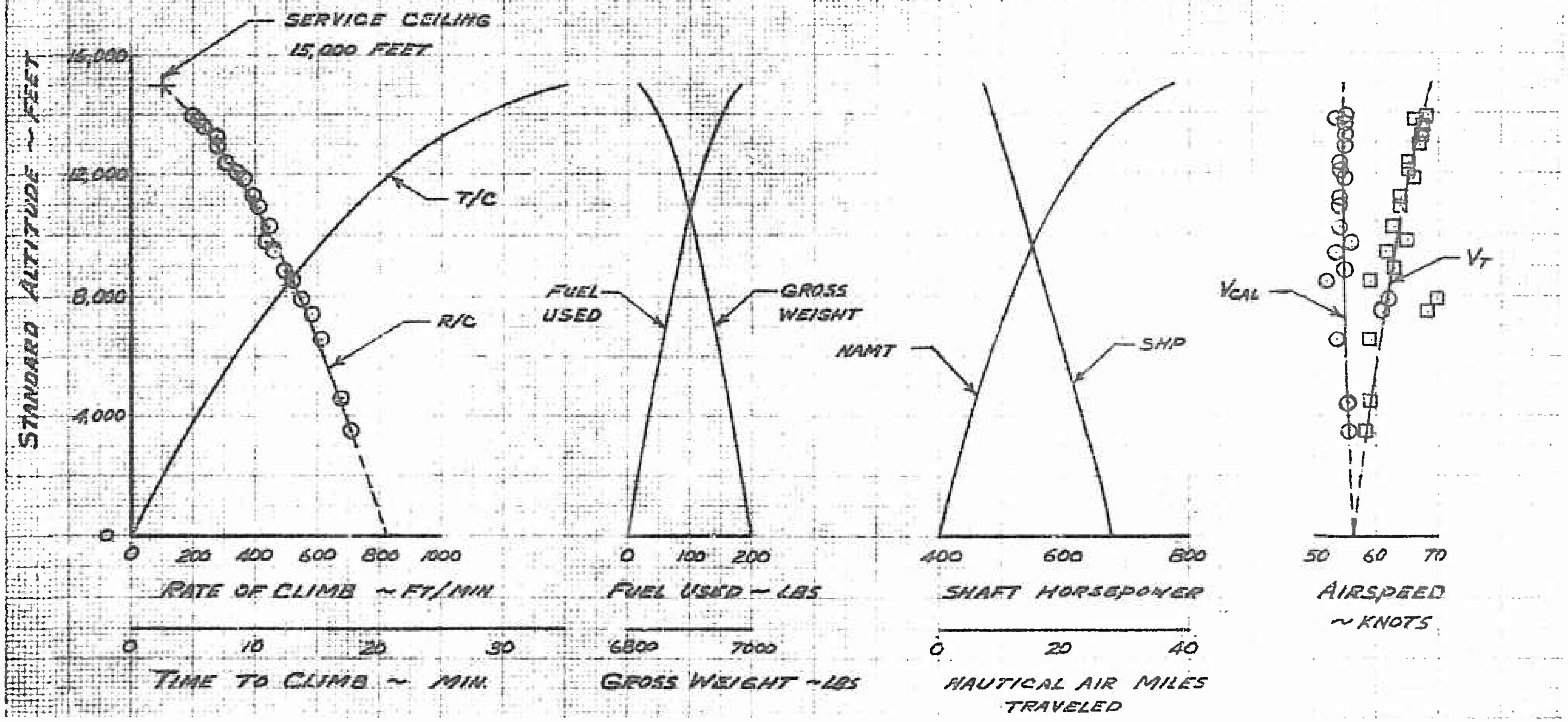


FIGURE NO 6

LEVEL FLIGHT RANGE SUMMARY

YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

ROTOR SPEED = 324 RPM

NOTES:

1. DERIVED FROM FIGURES NO 8 THROUGH 13.
2. RECOMMENDED CRUISE SPEED WITH XT-67 ENGINES BOTH OPERATING WAS PLACARD LIMIT AIRSPEED.
3. RECOMMENDED CRUISE SPEED WITH XT-67 RIGHT ENGINE ONLY OPERATING WAS THE AIRSPEED AT NORMAL RATED POWER.
4. FUEL FLOW DATA FOR T-53-L-11 OBTAINED FROM BHC RPT 205-099-705.

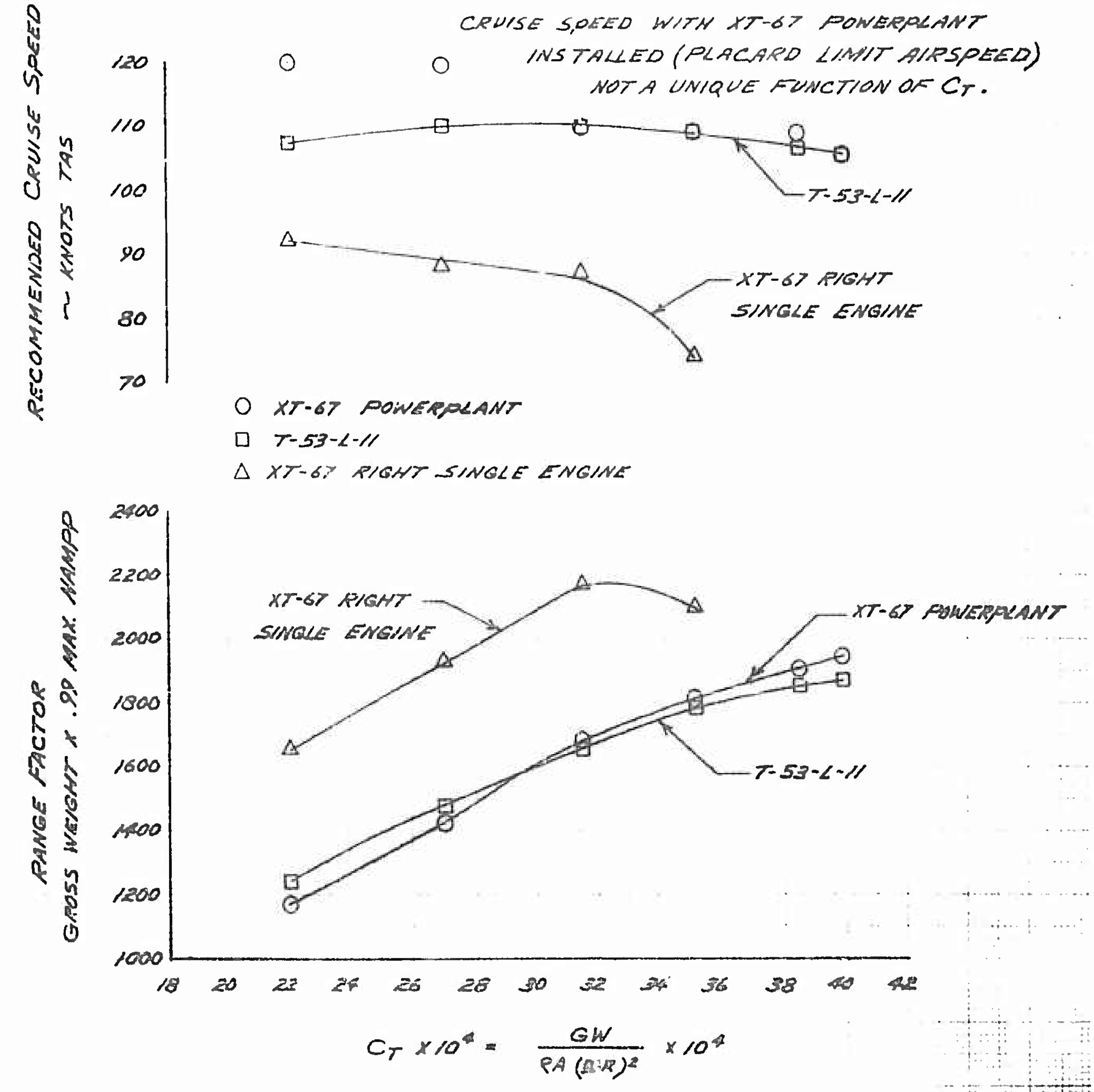


FIGURE NO. 7
SINGLE ENGINE ABSOLUTE CEILING
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
RIGHT ENGINE S/N X-5
ROTOR SPEED = 324 RPM
STANDARD DAY

NOTE:

1. SHAFT HORSEPOWER REQUIRED TO MAINTAIN LEVEL FLIGHT AT THE AIRSPEED FOR MINIMUM POWER REQUIRED WAS DERIVED FROM FTC-TDR-64-27.

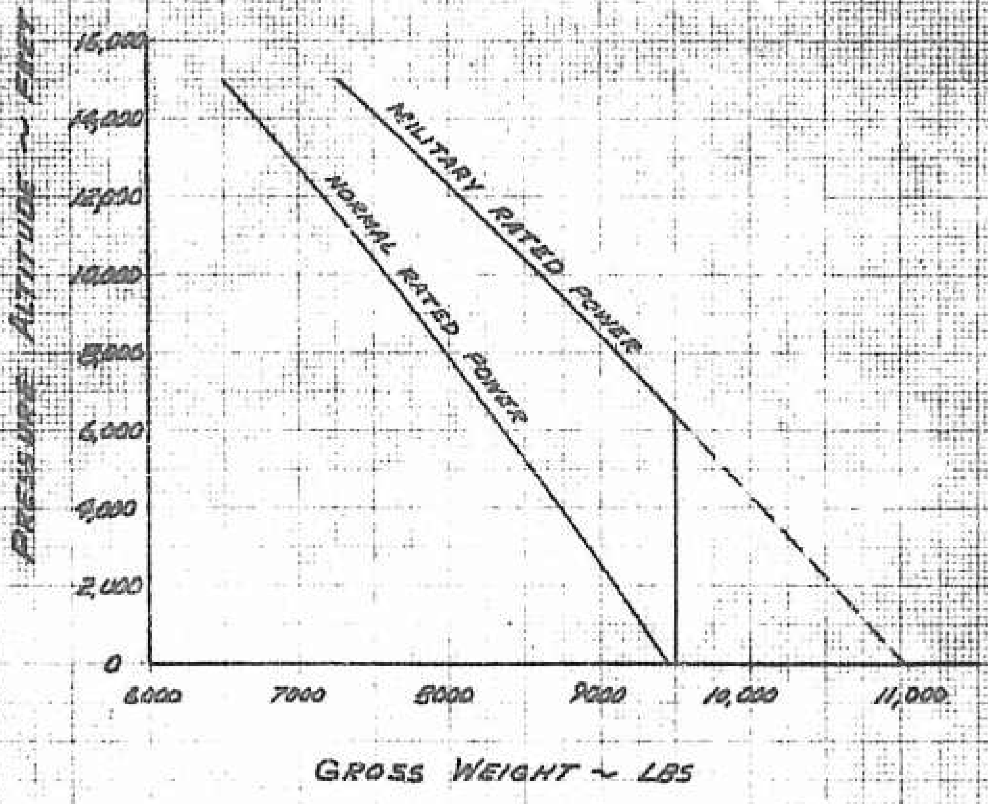


FIGURE NO. 8
LEVEL FLIGHT PERFORMANCE
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
GROSS WEIGHT = 6270 LBS
DENSITY ALTITUDE = SEA LEVEL
ROTOR SPEED = 324 RPM
CG = 136.5 INCHES (MID)
C_T = .002209

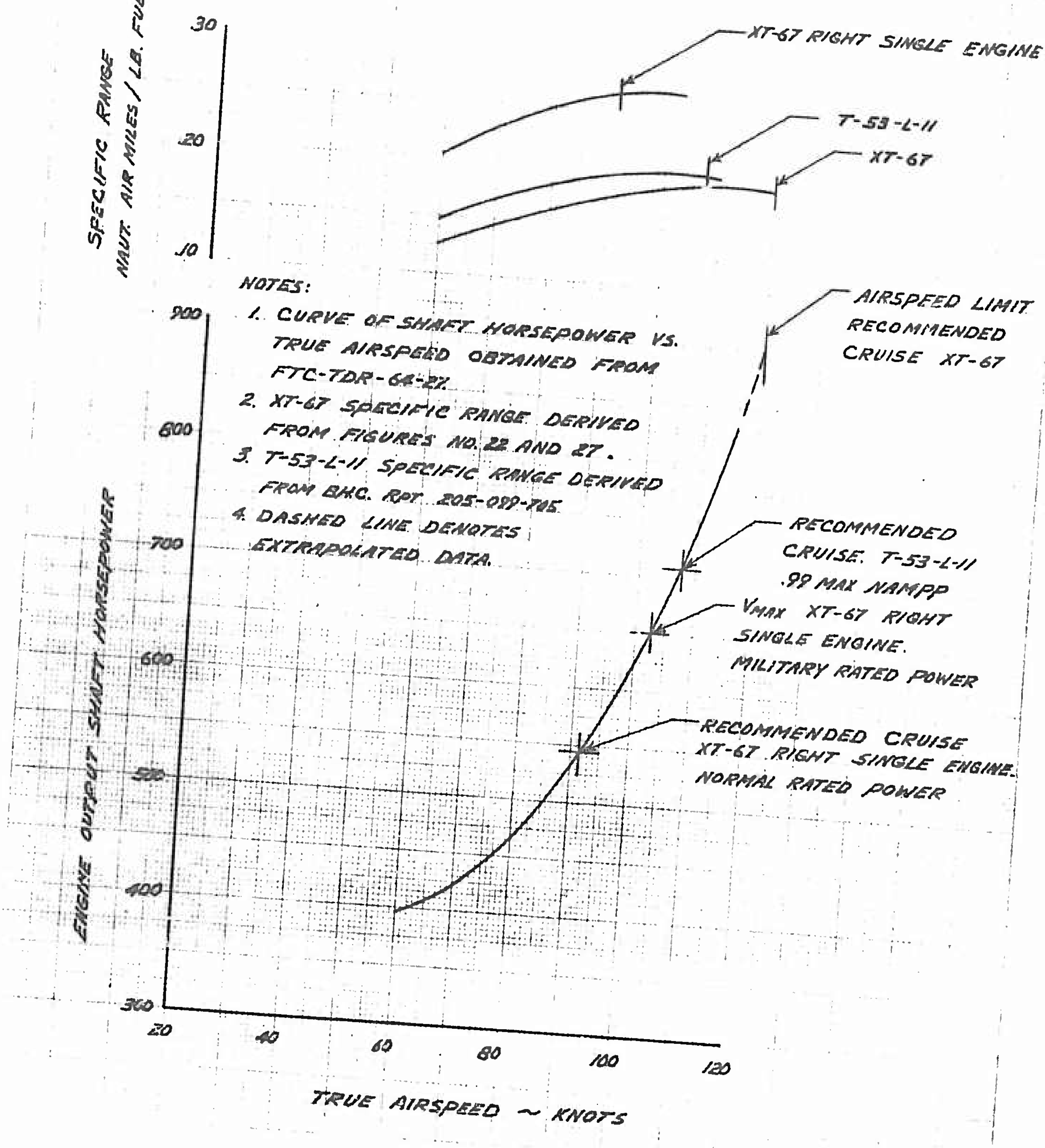


FIGURE NO. 9
LEVEL FLIGHT PERFORMANCE
YUH-1D/48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
GROSS WEIGHT = 6635 LBS
DENSITY ALTITUDE = 5000 FEET
ROTOR SPEED = 324 RPM
CG = 136.5 INCHES (MID)
C_T = .002700

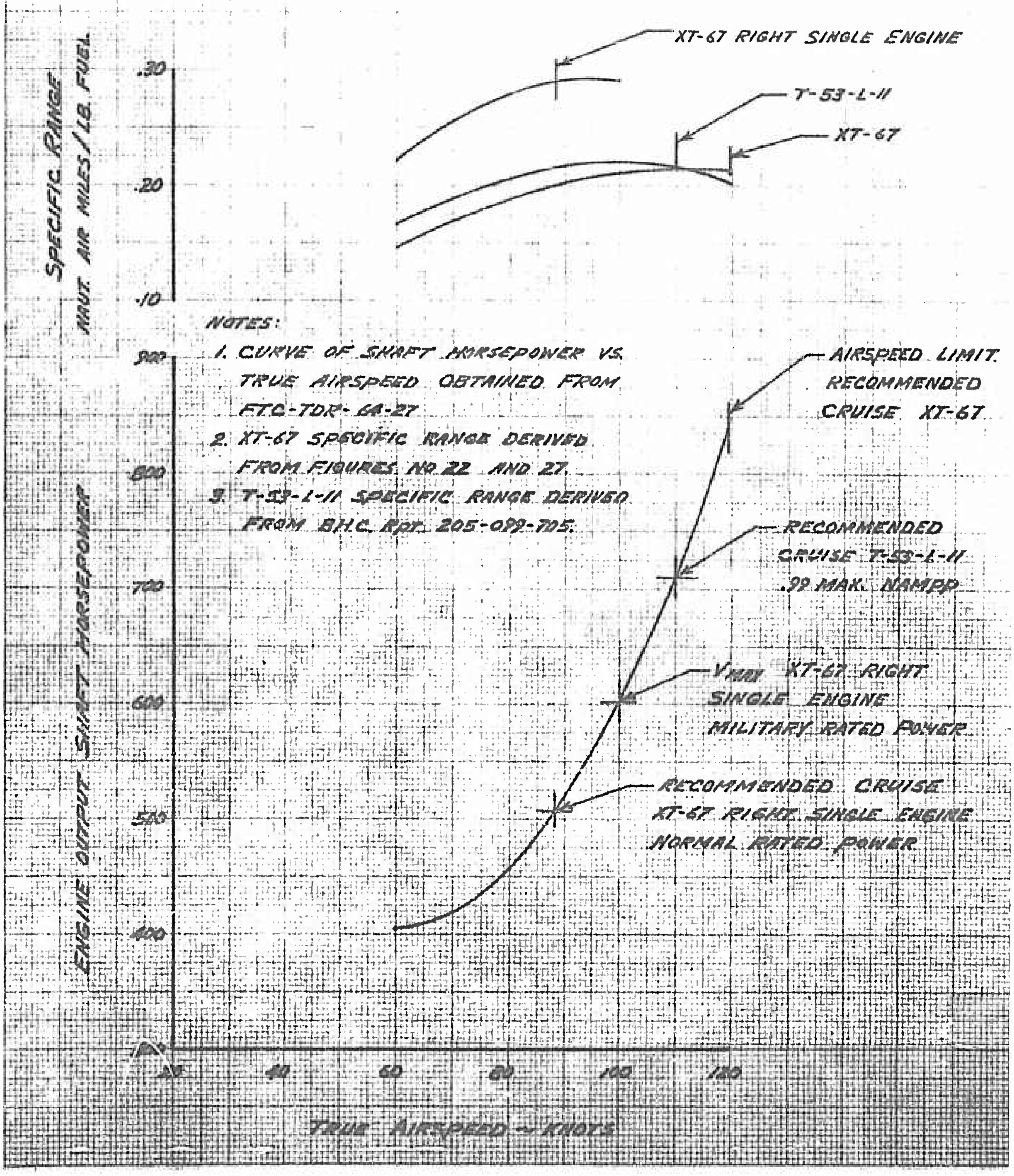


FIGURE No. 10
LEVEL FLIGHT PERFORMANCE
YUH-1D/48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
GROSS WEIGHT = 6630 LBS
DENSITY ALTITUDE = 10,000 FEET
ROTOR SPEED = 324 RPM
CG = 136.0 INCHES (MID)
C_T = .003150

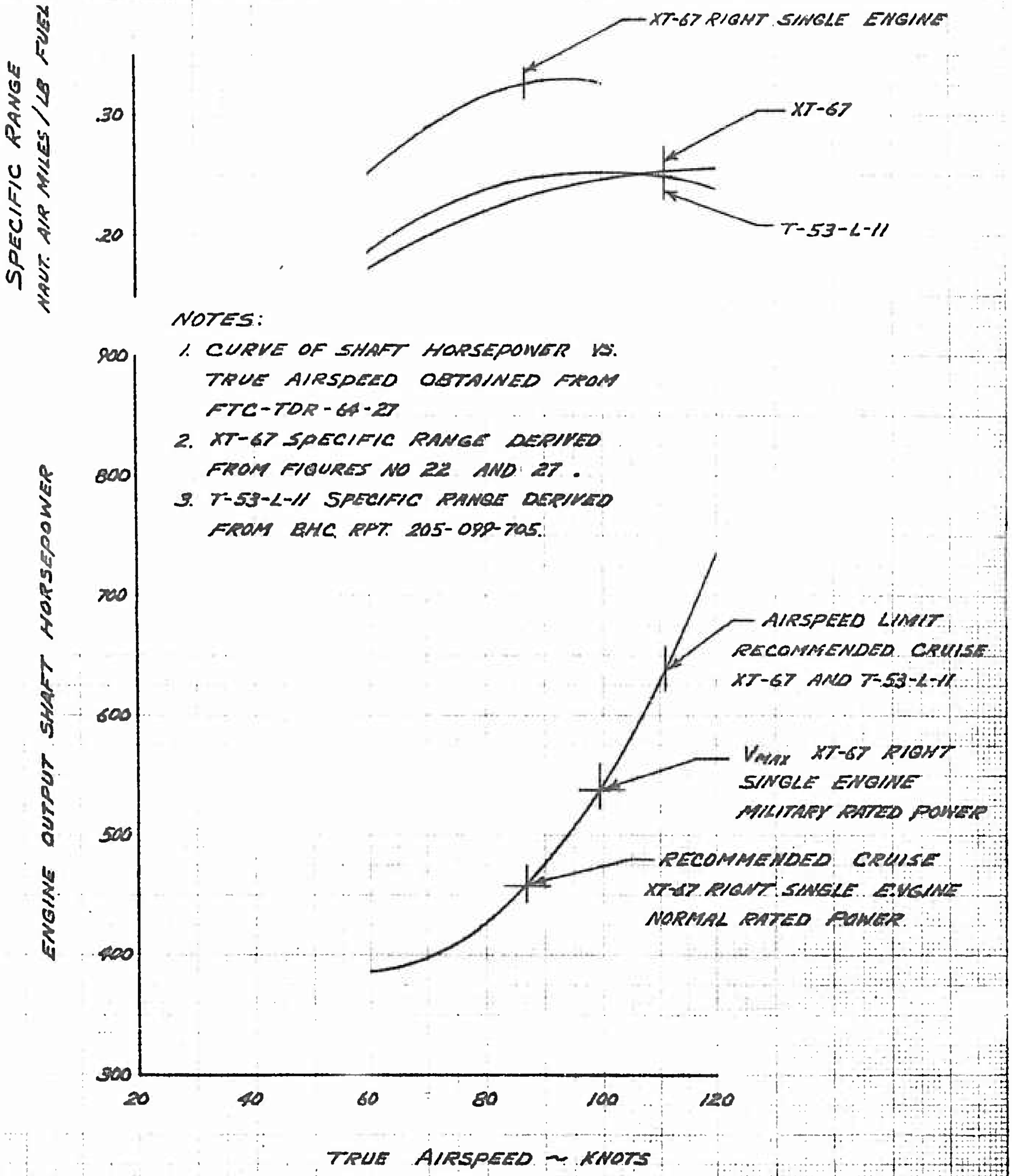


FIGURE NO. 11

LEVEL FLIGHT PERFORMANCE

YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N. 2

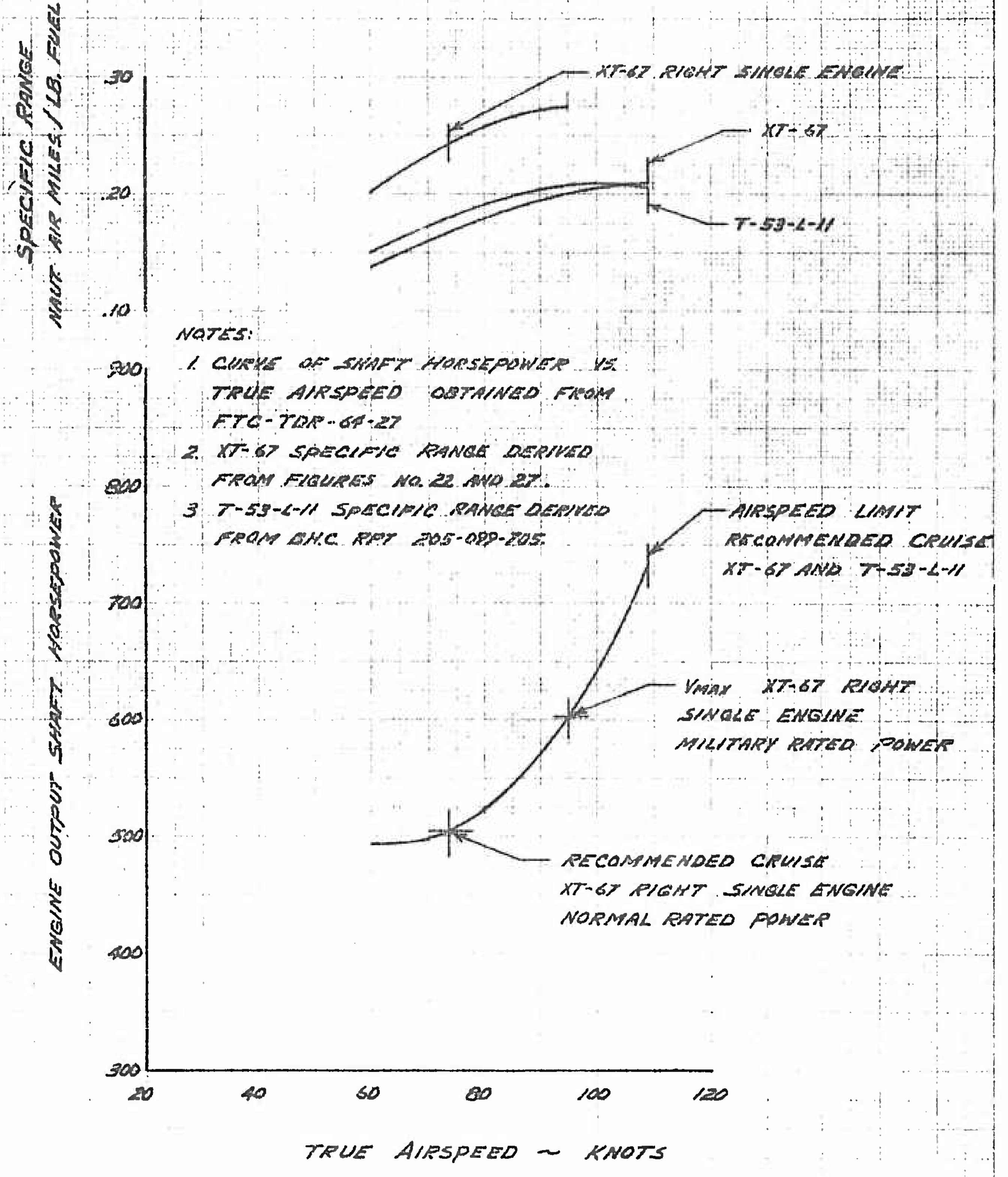
GROSS WEIGHT = 8630 LBS

DENSITY ALTITUDE = 5000 FEET

ROTOR SPEED = 324 RPM

CG = 136.3 INCHES (MID)

C_T = .003523



NOTES:

1. CURVE OF SHAFT HORSEPOWER VS. TRUE AIRSPEED OBTAINED FROM FTC-TDR-64-27
2. XT-67 SPECIFIC RANGE DERIVED FROM FIGURES NO. 22 AND 27.
3. T-53-L-11 SPECIFIC RANGE DERIVED FROM B.H.C. RPT 205-099-205.

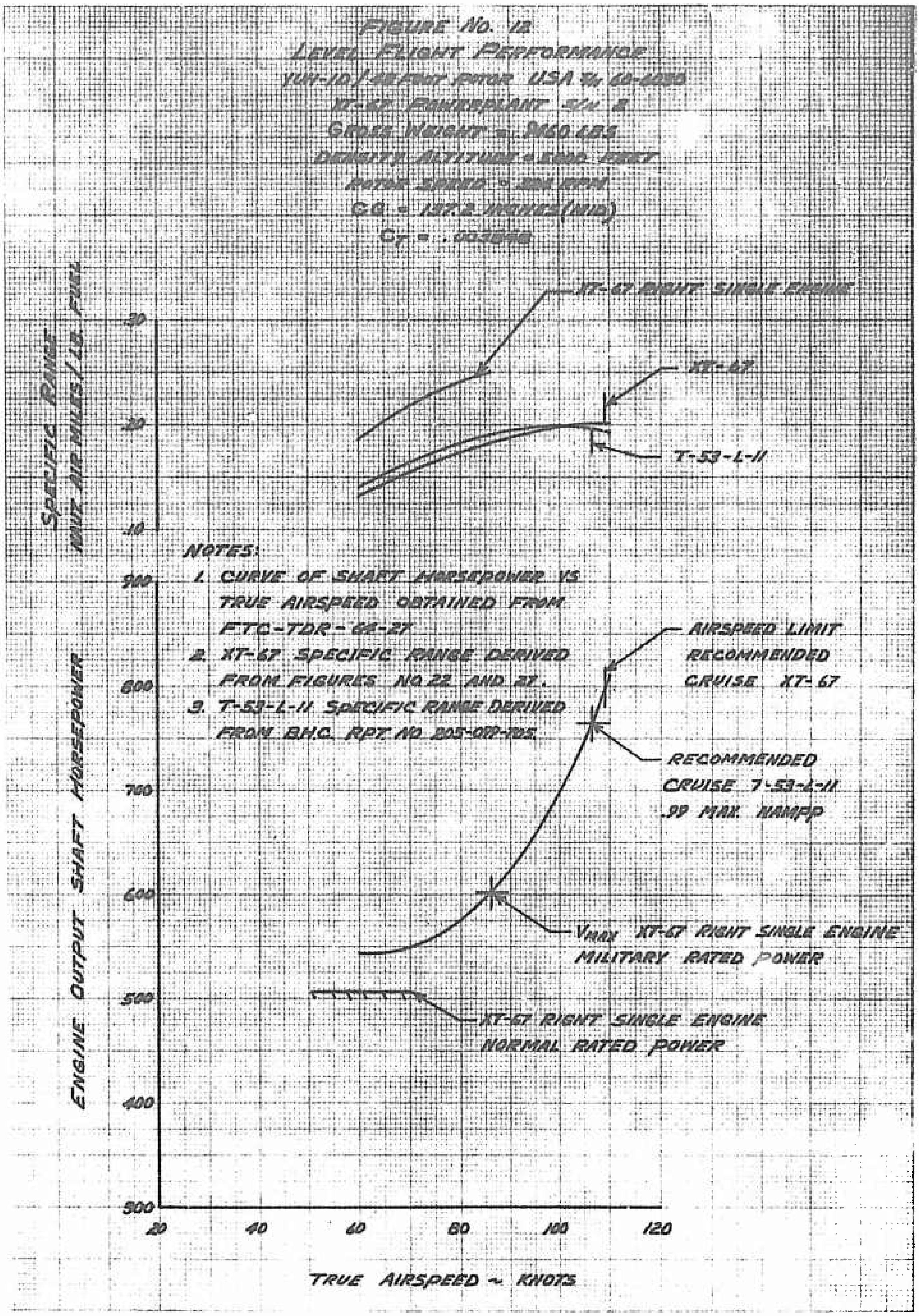


FIGURE NO. 12
LEVEL FLIGHT PERFORMANCE
SPECIFIC RANGE
NAUT. AIR MILES / LB. FUEL
XT-67 RIGHT SINGLE ENGINE
XT-67
T-53-L-11
NOTES:
1. CURVE OF SHAFT HORSEPOWER VS TRUE AIRSPEED OBTAINED FROM FTC-TDR-62-27
2. XT-67 SPECIFIC RANGE DERIVED FROM FIGURES NO 22 AND 27.
3. T-53-L-11 SPECIFIC RANGE DERIVED FROM BHC RPT NO 205-099-105
AIRSPEED LIMIT RECOMMENDED CRUISE XT-67
RECOMMENDED CRUISE T-53-L-11 .99 MAX NAMPP
VMAX XT-67 RIGHT SINGLE ENGINE MILITARY RATED POWER
XT-67 RIGHT SINGLE ENGINE NORMAL RATED POWER
ENGINE OUTPUT SHAFT HORSEPOWER
TRUE AIRSPEED ~ KNOTS

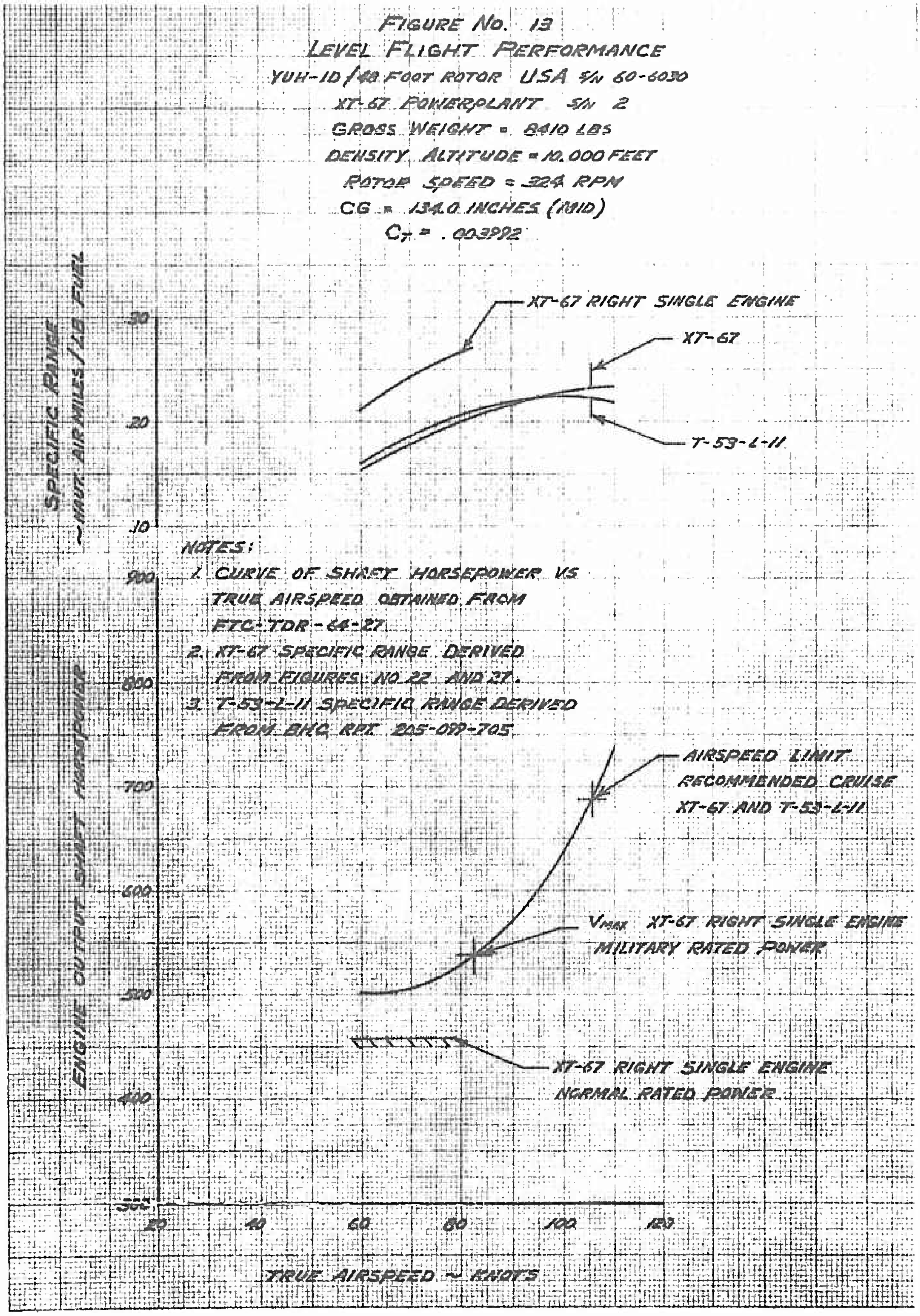


FIGURE No. 13
LEVEL FLIGHT PERFORMANCE
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
GROSS WEIGHT = 8410 LBS
DENSITY ALTITUDE = 10,000 FEET
ROTOR SPEED = 324 RPM
CG = 134.0 INCHES (MID)
CT = .003992
XT-67 RIGHT SINGLE ENGINE
XT-67
T-53-L-11
SPECIFIC RANGE ~ NAUT. AIR MILES / LB FUEL
NOTES:
1. CURVE OF SHAFT HORSEPOWER VS TRUE AIRSPEED OBTAINED FROM FTC-TDR-64-27
2. XT-67 SPECIFIC RANGE DERIVED FROM FIGURES NO 22 AND 27.
3. T-53-L-11 SPECIFIC RANGE DERIVED FROM BHC RPT 205-099-705
AIRSPEED LIMIT RECOMMENDED CRUISE XT-67 AND T-53-L-11
VMAX XT-67 RIGHT SINGLE ENGINE MILITARY RATED POWER
XT-67 RIGHT SINGLE ENGINE NORMAL RATED POWER
ENGINE OUTPUT SHAFT HORSEPOWER
TRUE AIRSPEED ~ KNOTS

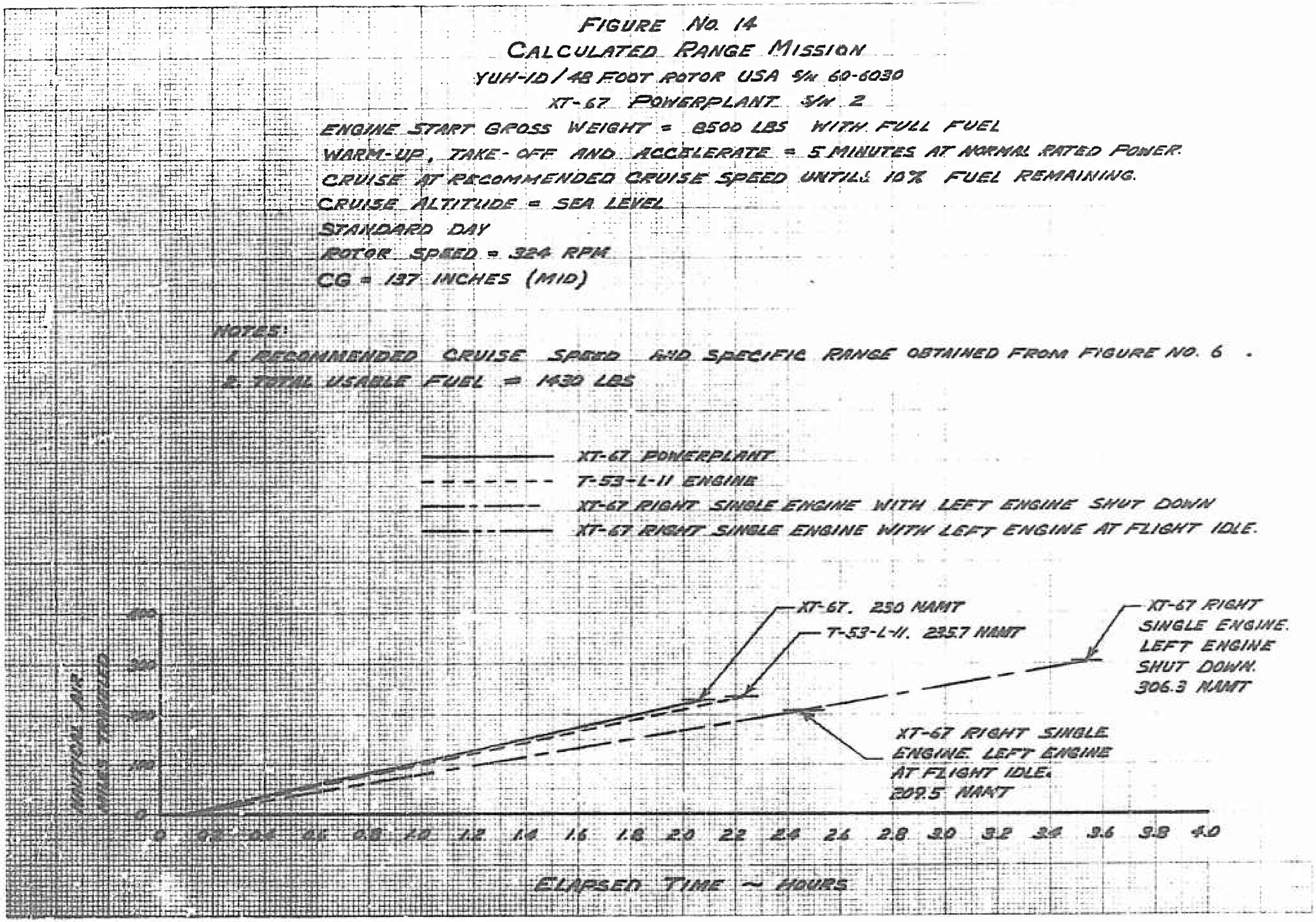


FIGURE No. 14
CALCULATED RANGE MISSION
YUH-1D/48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
ENGINE START GROSS WEIGHT = 8500 LBS WITH FULL FUEL
WARM-UP, TAKE-OFF AND ACCELERATE = 5 MINUTES AT NORMAL RATED POWER.
CRUISE AT RECOMMENDED CRUISE SPEED UNTILL 10% FUEL REMAINING.
CRUISE ALTITUDE = SEA LEVEL
STANDARD DAY
ROTOR SPEED = 324 RPM
CG = 137 INCHES (MID)
NOTES:
1. RECOMMENDED CRUISE SPEED AND SPECIFIC RANGE OBTAINED FROM FIGURE NO. 6.
2. TOTAL USABLE FUEL = 1430 LBS
XT-67 POWERPLANT
T-53-L-11 ENGINE
XT-67 RIGHT SINGLE ENGINE WITH LEFT ENGINE SHUT DOWN
XT-67 RIGHT SINGLE ENGINE WITH LEFT ENGINE AT FLIGHT IDLE.
XT-67. 250 NAMT
T-53-L-11. 235.7 NAMT
XT-67 RIGHT SINGLE ENGINE. LEFT ENGINE SHUT DOWN. 306.3 NAMT
XT-67 RIGHT SINGLE ENGINE. LEFT ENGINE AT FLIGHT IDLE. 209.5 NAMT
0
100
200
300
400
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
ELAPSED TIME ~ HOURS

FIGURE No. 14 (CONT.)

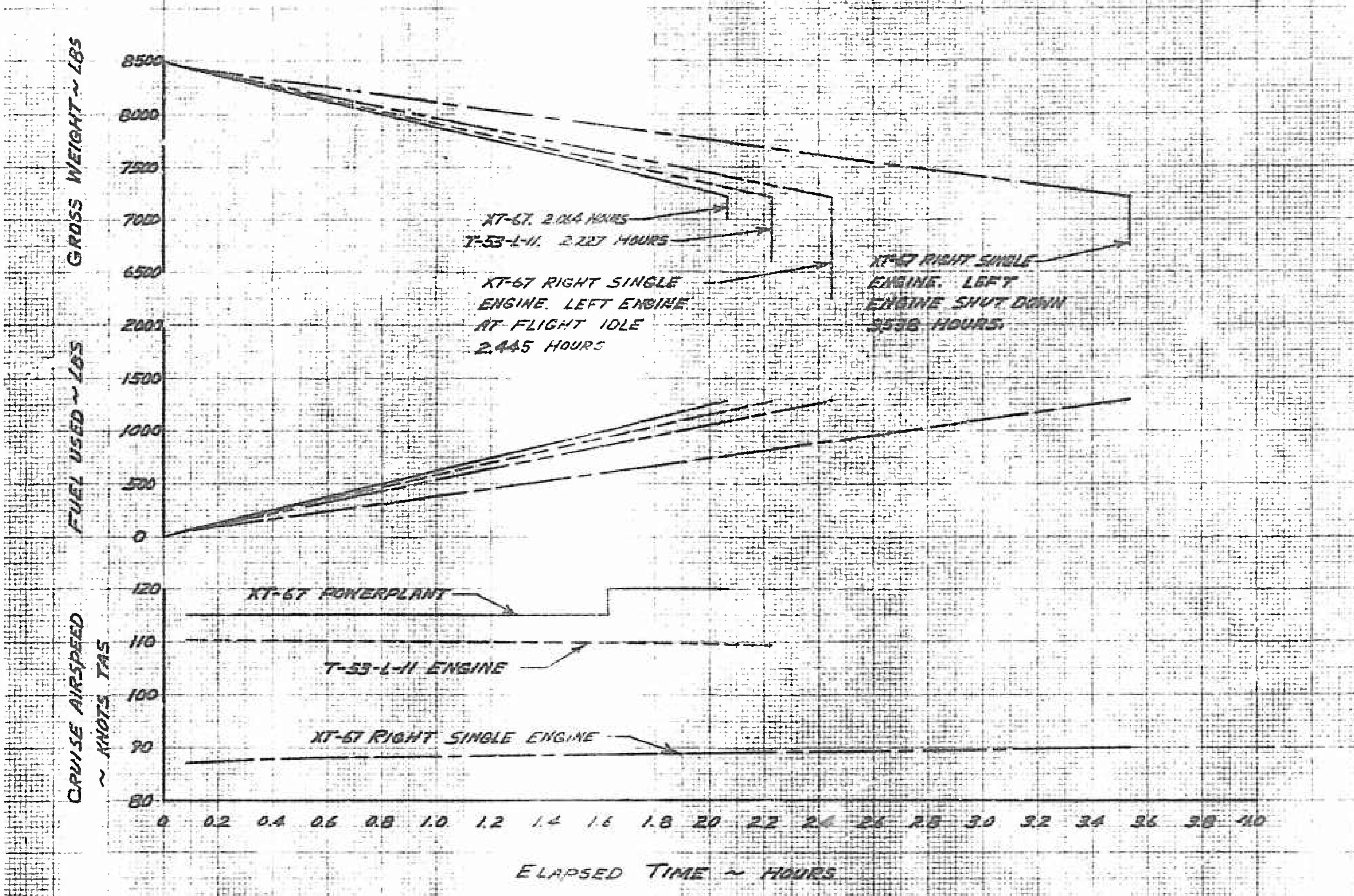


FIGURE [illegible]

SHAFT HORSEPOWER AVAILABLE

YUH-1D / 48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

MILITARY POWER LIMITS

ZERO AIRSPEED

NOTE

DERIVED FROM FIGURES NO 18 THROUGH [illegible]

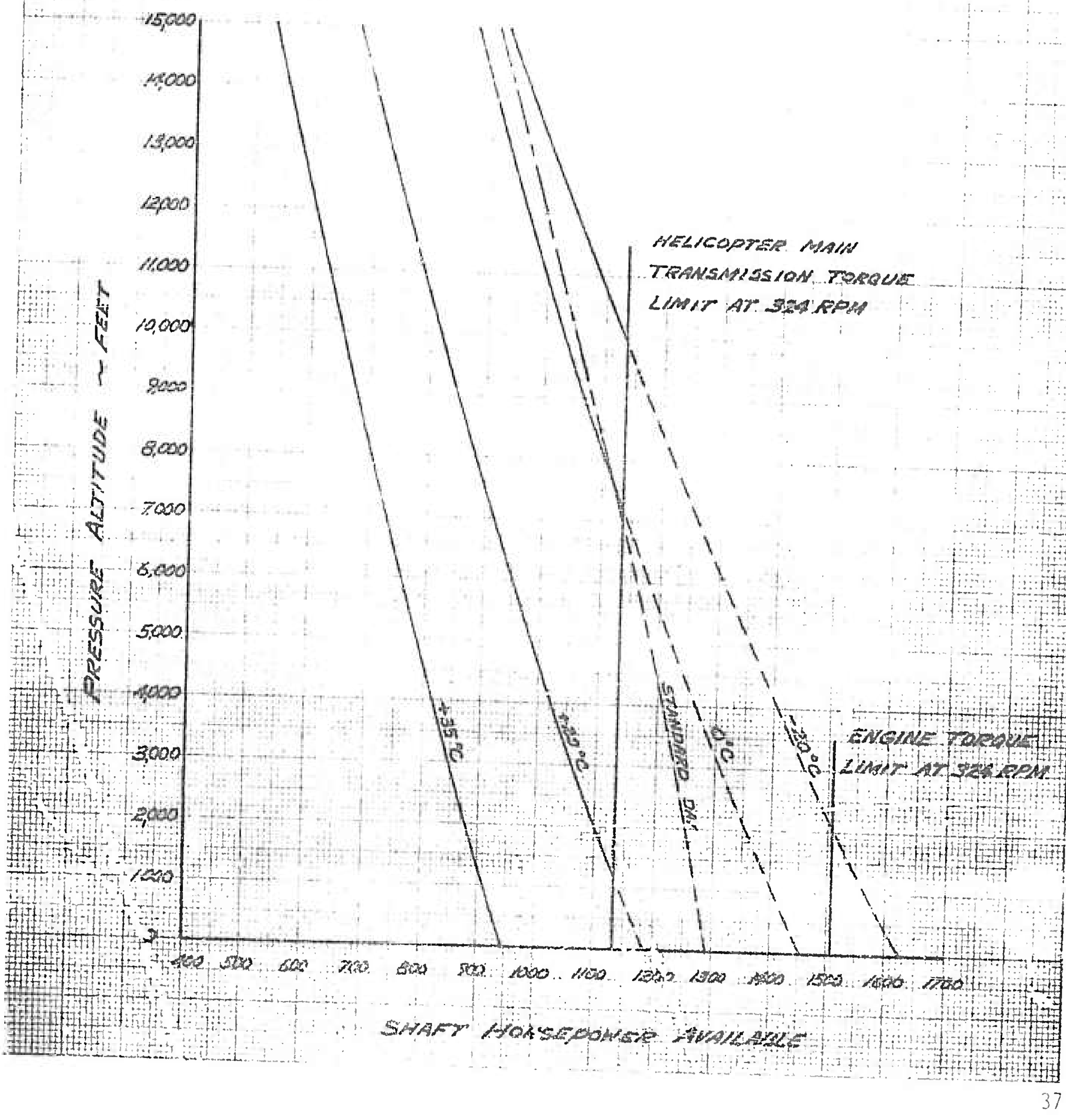


FIGURE NO. 16
LEFT ENGINE SHAFT HORSEPOWER AVAILABLE
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
LEFT ENGINE S/N X-6
MILITARY POWER LIMITS
ZERO AIRSPEED

NOTES:

1. BASED ON COMPRESSOR INLET PRESSURE RATIO AND TEMPERATURE RISE AS DEFINED IN FIGURE NO. 18 AT ZERO AIRSPEED.
2. SHAFT HORSEPOWER LIMITED BY EITHER MAXIMUM T_{T_6} (677 °C) OR MAXIMUM N_1 AVAILABLE.
3. MAXIMUM N_1 AVAILABLE VARIES AS SHOWN IN FIGURE NO. 19
4. SHAFT HORSEPOWER DETERMINED FROM CURVE OF $SHP/\delta\sqrt{\theta}$ VS $N_1/\sqrt{\theta}$ (FIGURE NO. 20) OR $SHP/\delta\sqrt{\theta}$ VS T_{T_6}/θ (FIGURE NO. 21).

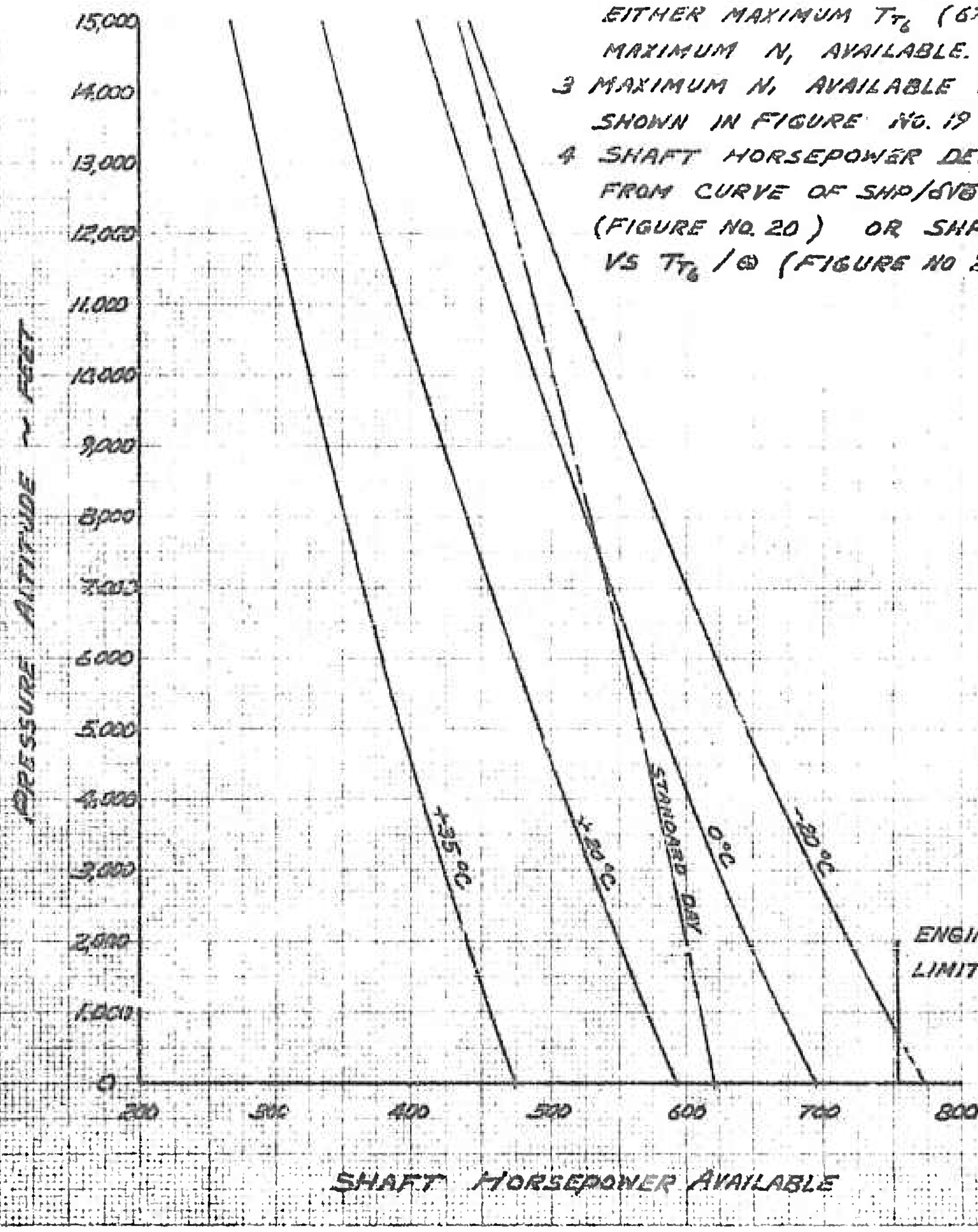


FIGURE No 17
RIGHT ENGINE SHAFT HORSEPOWER AVAILABLE
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
RIGHT ENGINE S/N X-5
MILITARY POWER LIMITS
ZERO AIRSPEED

NOTES:

1. BASED ON COMPRESSOR INLET PRESSURE RATIO AND TEMPERATURE RISE AS DEFINED IN FIGURE NO. 23 AT ZERO AIRSPEED.
2. SHAFT HORSEPOWER LIMITED BY EITHER MAXIMUM T_{T_6} (677 °C) OR MAXIMUM N_1 AVAILABLE.
3. MAXIMUM N_1 AVAILABLE VARRIES AS SHOWN IN FIGURE No 24.
4. SHAFT HORSEPOWER DETERMINED FROM CURVE OF SHP/$\delta\sqrt{\theta}$ VS $N_1/\sqrt{\theta}$ (FIGURE No 25) OR SHP/$\delta\sqrt{\theta}$ VS T_{T_6}/θ (FIGURE No 26).

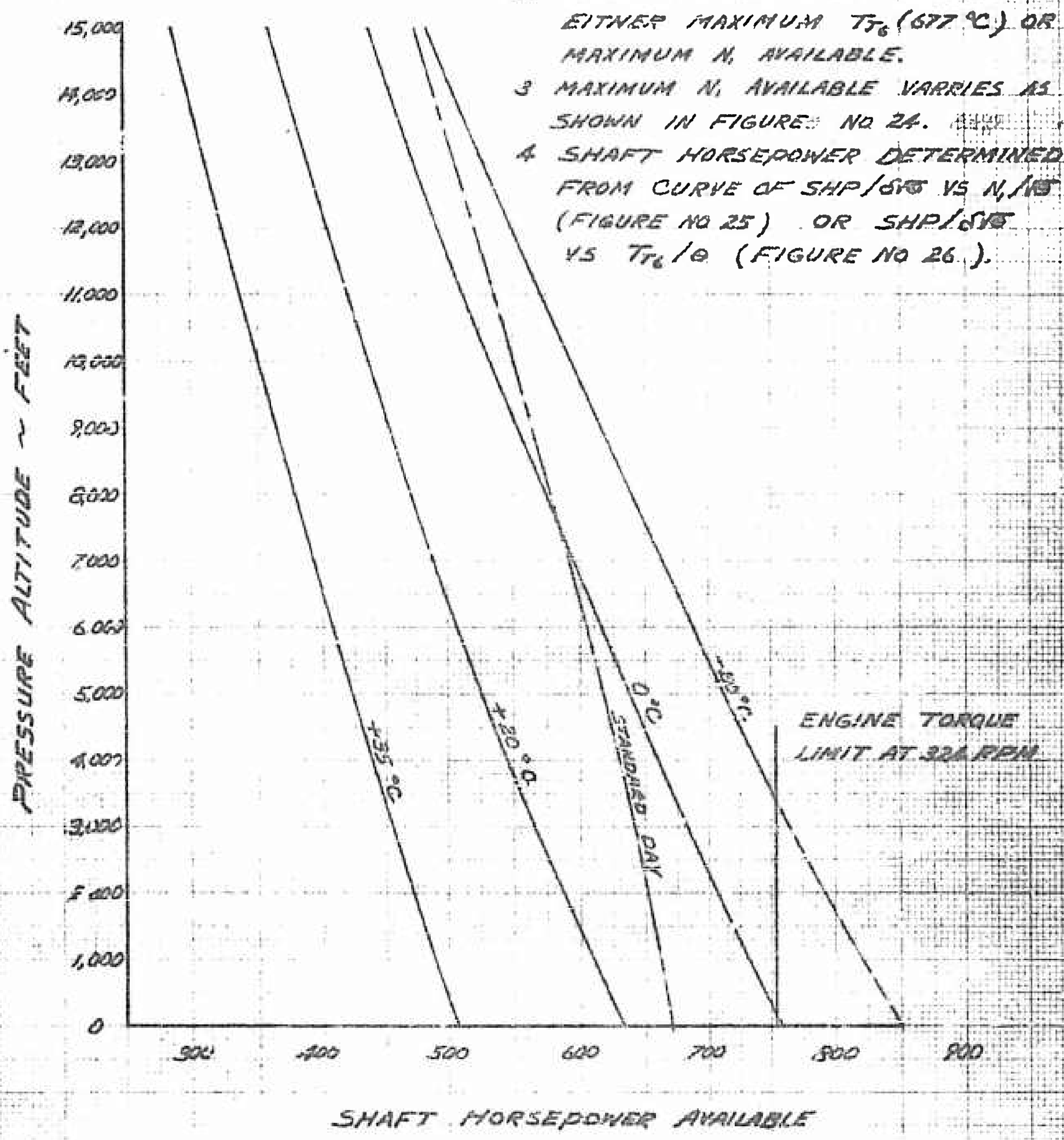


FIGURE NO 18

LEFT ENGINE INLET CHARACTERISTICS

YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

LEFT ENGINE S/N X-6

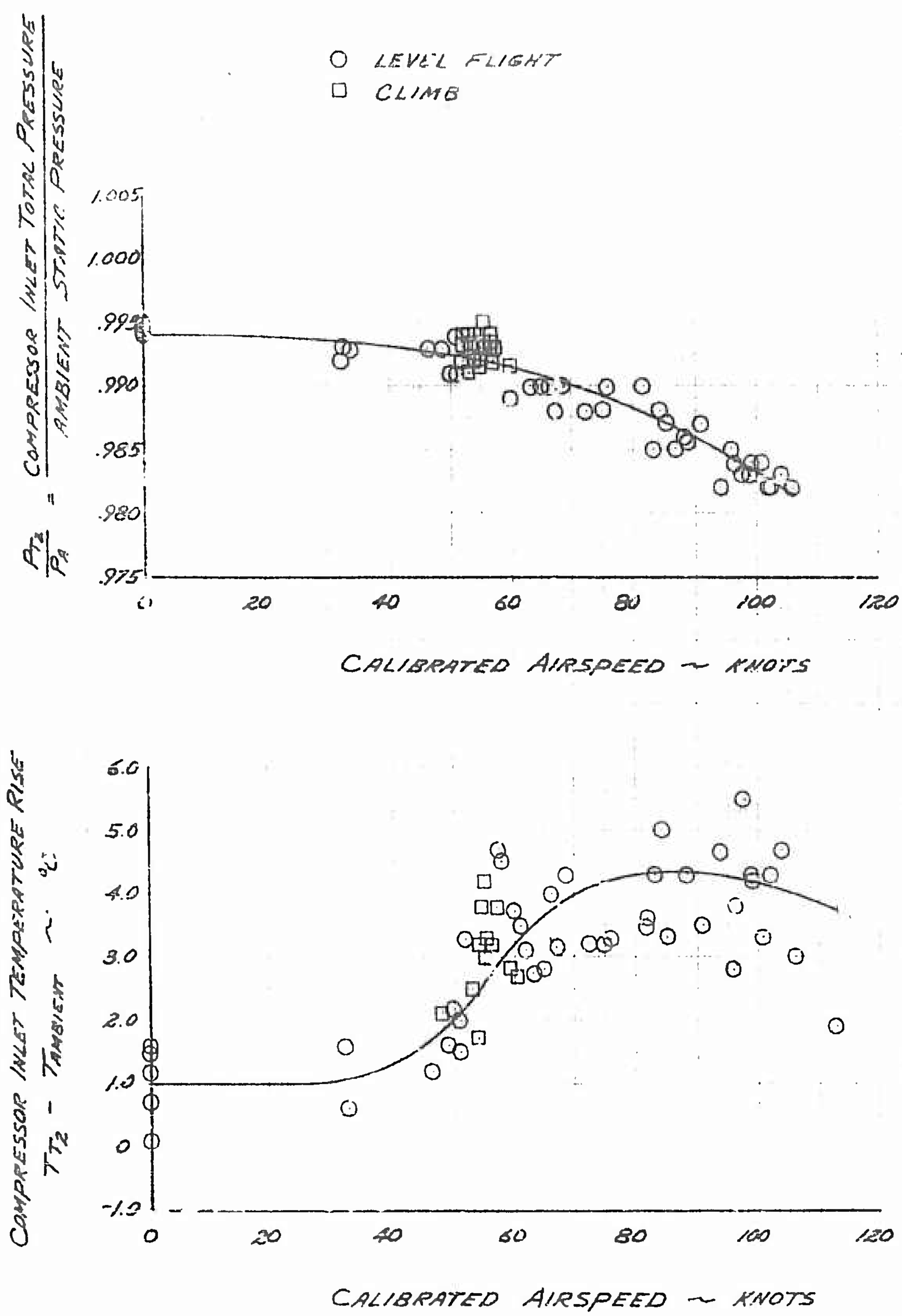
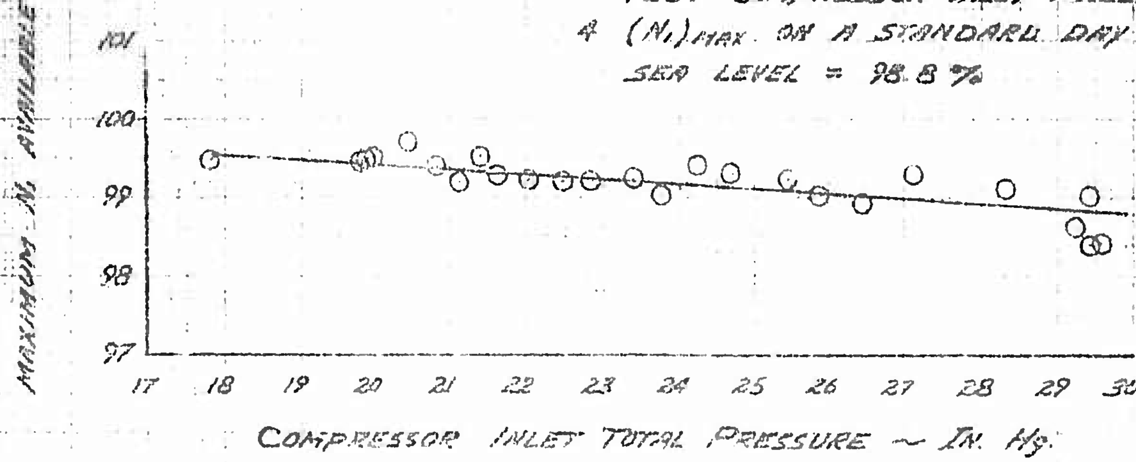


FIGURE NO 17
LEFT ENGINE VARIATION OF MAXIMUM
GAS PRODUCER SPEED AVAILABLE
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
LEFT ENGINE S/N X-6

VARIATION OF $(N_1)_{MAX}$ WITH COMPRESSOR INLET TOTAL PRESSURE ON A STANDARD DAY

NOTES:
1. $(N_1)_{MAX}$ = MAXIMUM GAS PRODUCER SPEED AVAILABLE
2. 100% N_1 = 40,100 RPM
3. $(N_1)_{MAX}$ TEST POINTS CORRECTED TO STANDARD DAY TEMPERATURE AT TEST COMPRESSOR INLET PRESSURE
4. $(N_1)_{MAX}$ ON A STANDARD DAY AT SEA LEVEL = 98.8 %



VARIATION OF $(N_1)_{MAX}$ WITH NON-STANDARD COMPRESSOR INLET TEMPERATURE FOR ANY COMPRESSOR INLET PRESSURE

NOTE:
BASED ON PRELIMINARY INFORMATION PROVIDED BY ENGINE MANUFACTURER

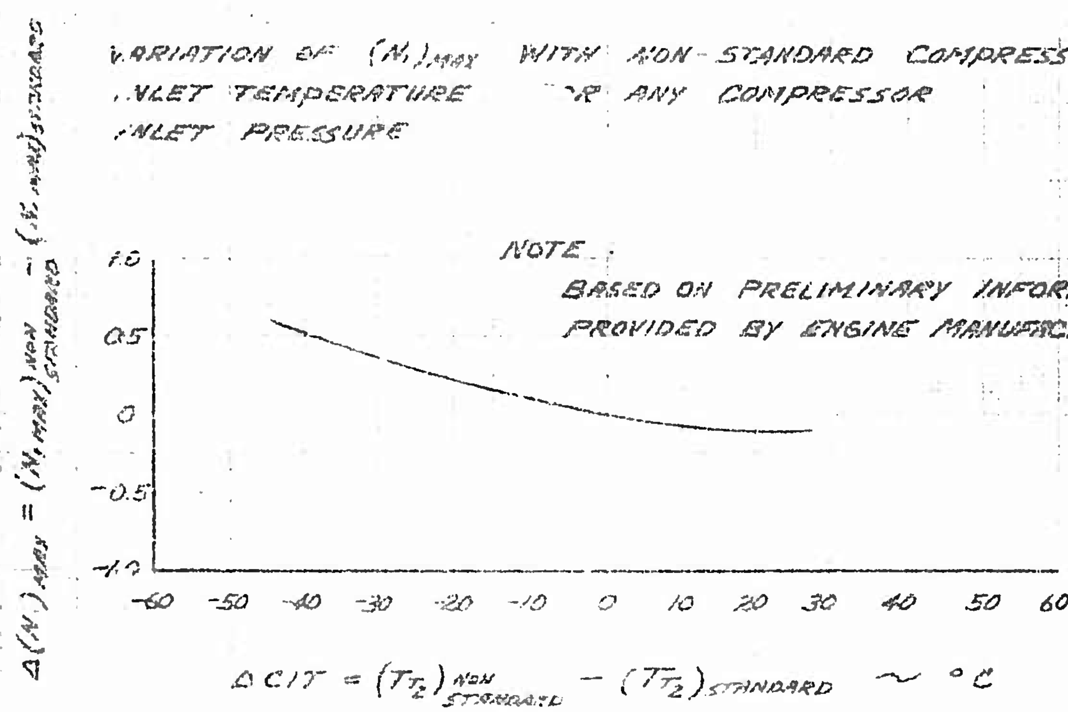


FIGURE No. 20

LEFT ENGINE CHARACTERISTICS

YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

LEFT ENGINE S/N X-6

NOTES:

1. δ AND $\sqrt{\theta}$ BASED UPON MEASURED COMPRESSOR INLET TOTAL PRESSURE AND TEMPERATURE.
2. 100% N_1 = 40,100 RPM
3. SHP BASED UPON SPECIFICATION RELATIONSHIP BETWEEN TORQUEMETER PRESSURE AND ENGINE OUTPUT SHAFT TORQUE.

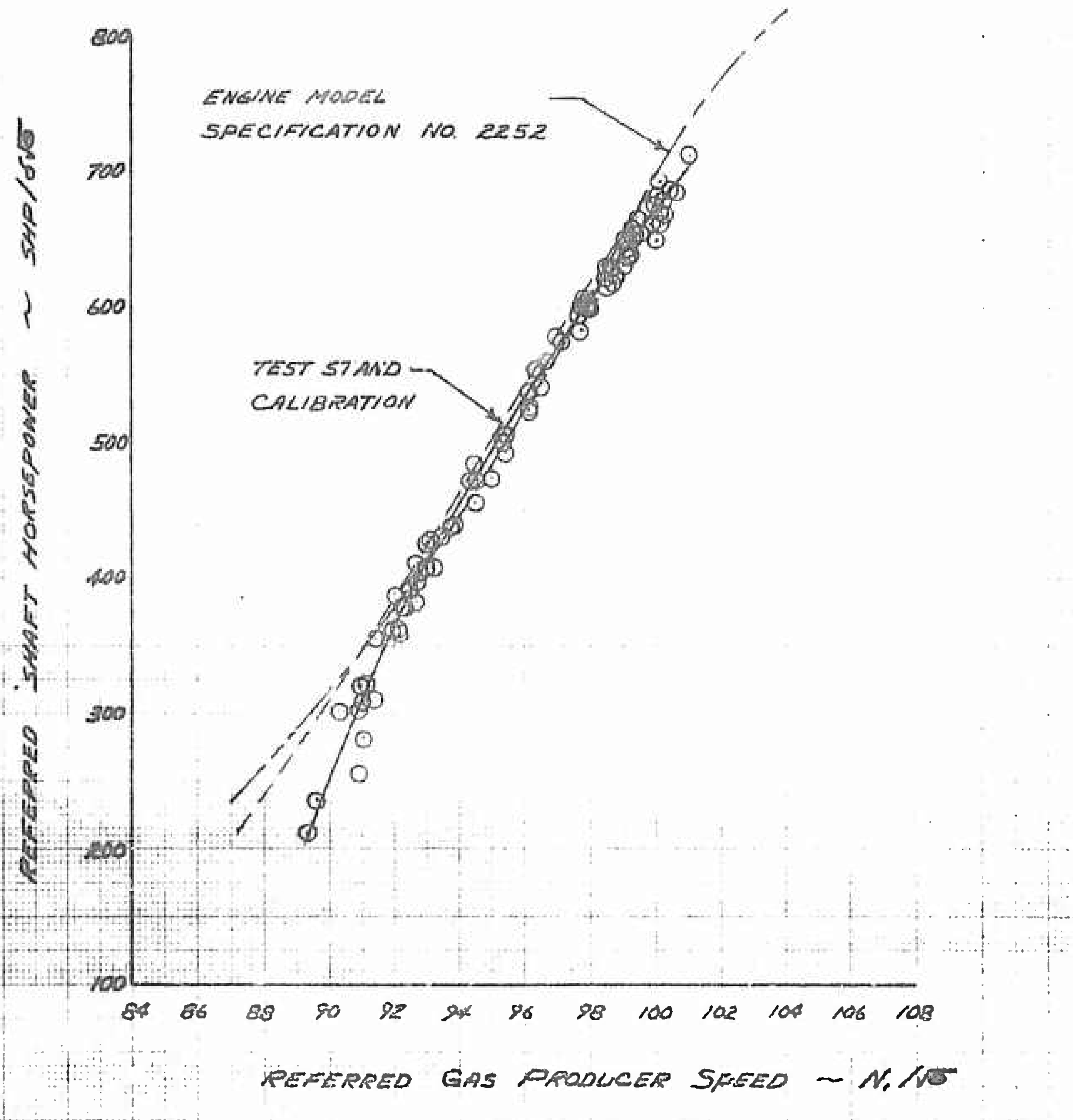


FIGURE NO. 21

LEFT ENGINE CHARACTERISTICS

YUH-1D / 48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

LEFT ENGINE S/N X-6

NOTES:

1. δ AND θ BASED UPON MEASURED COMPRESSOR INLET TOTAL PRESSURE AND TEMPERATURE.
2. SHP BASED UPON SPECIFICATION RELATIONSHIP BETWEEN TORQUEMETER PRESSURE AND ENGINE OUTPUT SHAFT TORQUE.

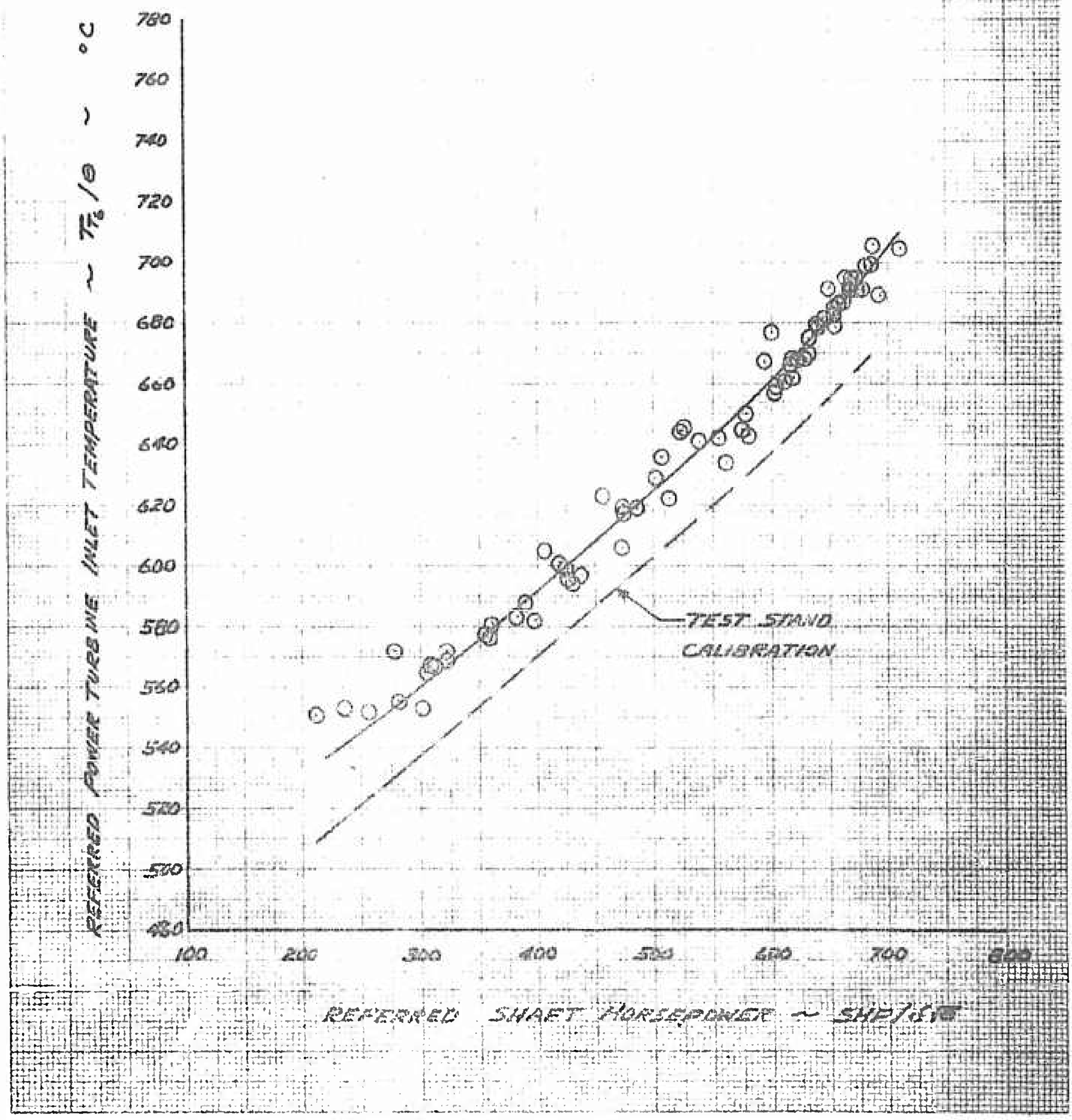


FIGURE NO. 22

LEFT ENGINE CHARACTERISTICS

YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

LEFT ENGINE S/N X-6

NOTES:

1. δ AND $\sqrt{\theta}$ BASED UPON MEASURED COMPRESSOR INLET TOTAL PRESSURE AND TEMPERATURE.
2. SHP BASED UPON SPECIFICATION RELATIONSHIP BETWEEN TORQUEMETER PRESSURE AND ENGINE OUTPUT SHAFT TORQUE.

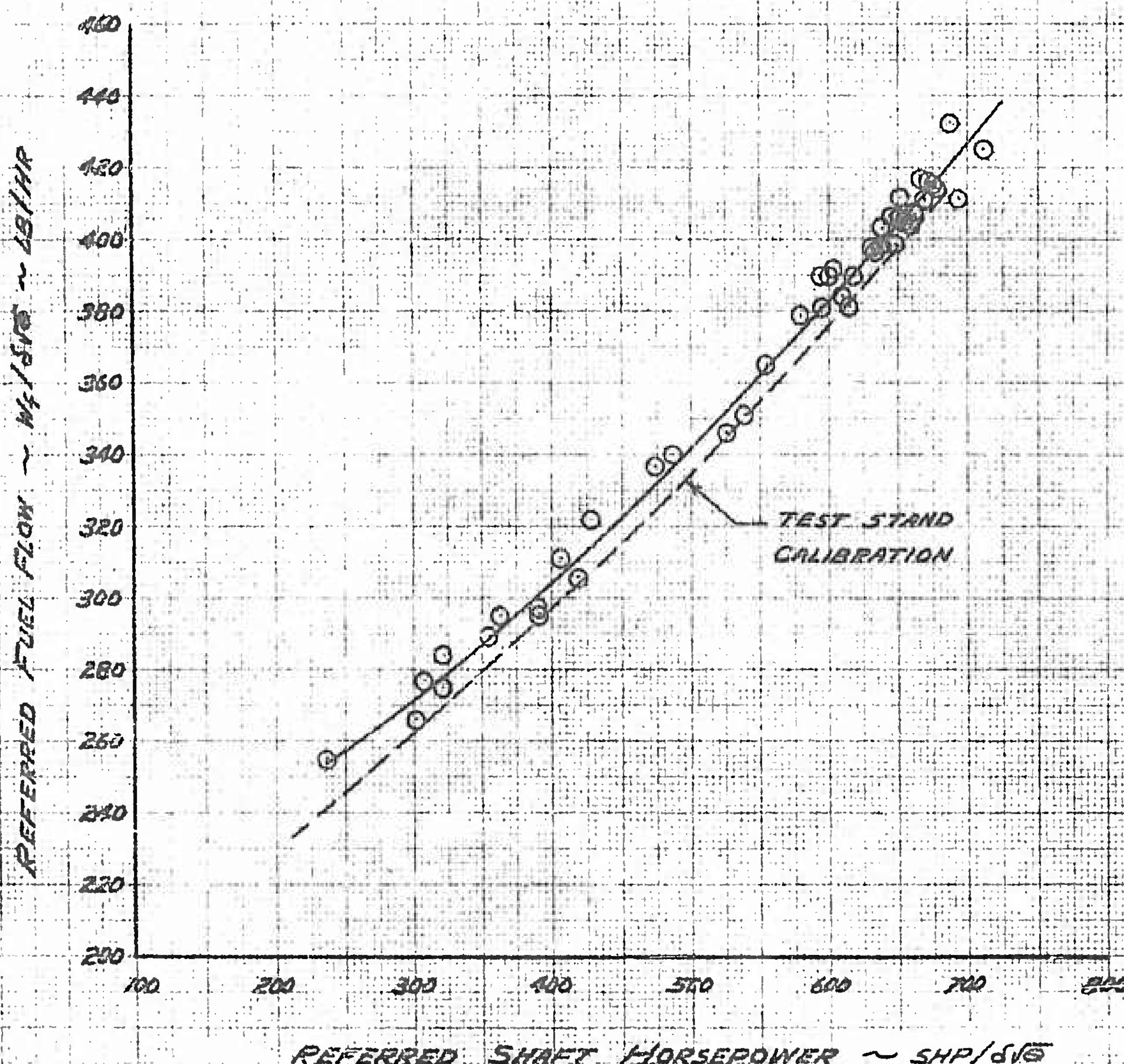


FIGURE No. 23
RIGHT ENGINE INLET CHARACTERISTICS
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
RIGHT ENGINE S/N X-5

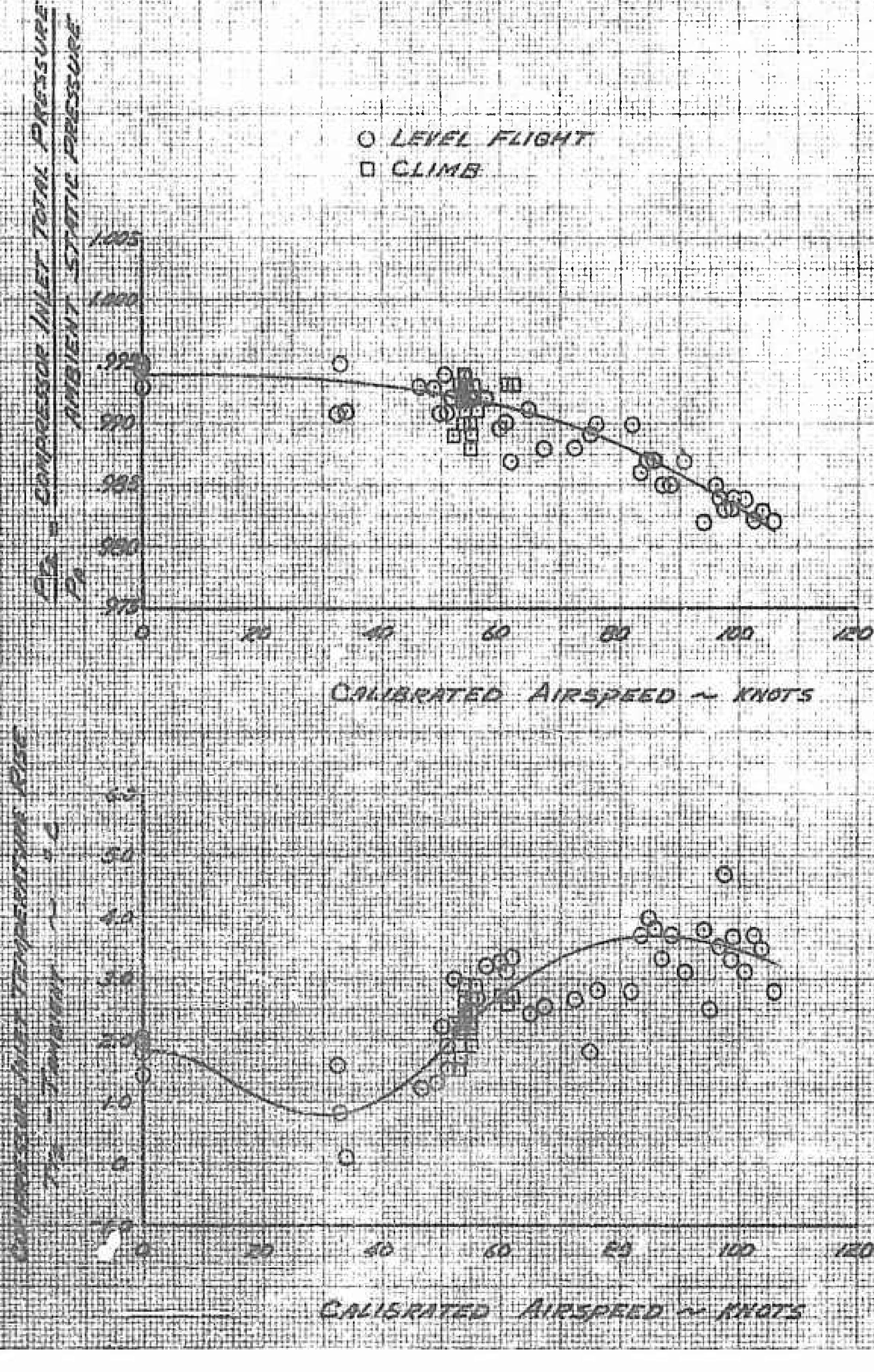
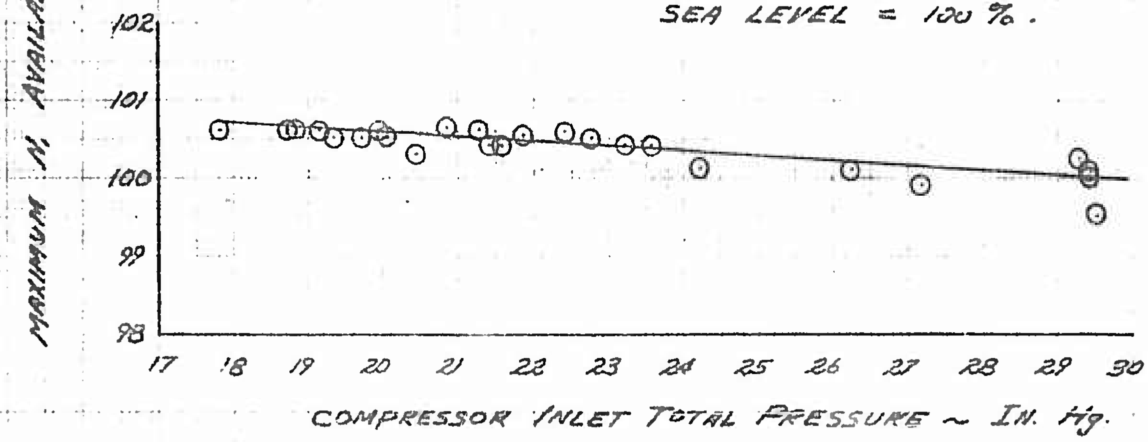


FIGURE NO 24
RIGHT ENGINE VARIATION OF MAXIMUM
GAS PRODUCER SPEED AVAILABLE
YUH-1D/48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT S/N 2
RIGHT ENGINE S/N X-5

VARIATION OF $(N_1)_{MAX}$ WITH COMPRESSOR INLET TOTAL PRESSURE ON A STANDARD DAY.

NOTES:

1. $(N_1)_{MAX}$ = MAXIMUM GAS PRODUCER SPEED AVAILABLE.
2. 100 % N_1 = 40, 100 RPM
3. $(N_1)_{MAX}$ TEST POINTS CORRECTED TO STANDARD DAY TEMPERATURE AT TEST COMPRESSOR INLET PRESSURE.
4. $(N_1)_{MAX}$ ON A STANDARD DAY AT SEA LEVEL = 100 %.



VARIATION OF $(N_1)_{MAX}$ WITH NON-STANDARD COMPRESSOR INLET TEMPERATURE FOR ANY COMPRESSOR INLET PRESSURE.

NOTE:
BASED ON PRELIMINARY INFORMATION PROVIDED BY ENGINE MANUFACTURER.

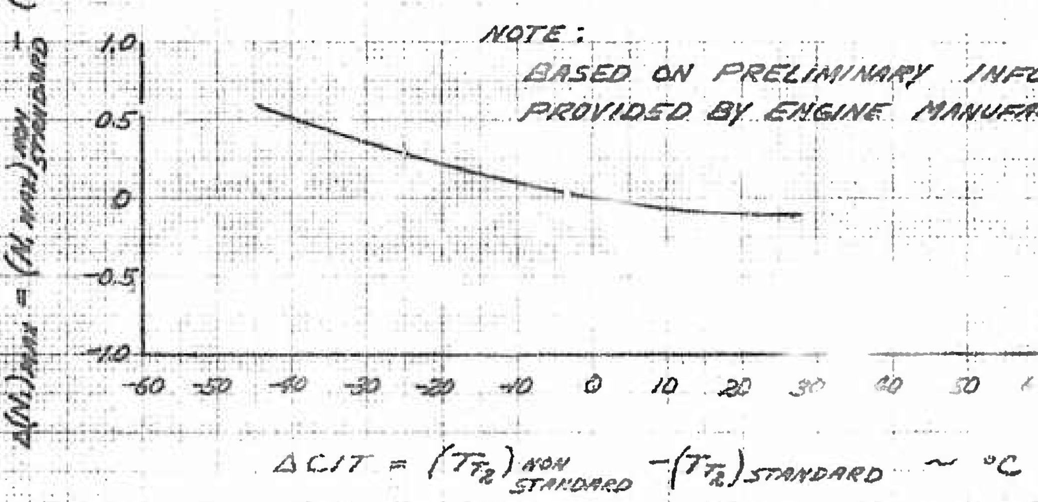


FIGURE NO. 25

RIGHT ENGINE CHARACTERISTICS

YUH-1D/48 FOOT ROTOR USA S/N 60 6070

XT-67 POWERPLANT S/N 2

RIGHT ENGINE S/N X-5

NOTES

1. δ AND $\sqrt{\theta}$ BASED UPON MEASURED COMPRESSOR INLET TOTAL PRESSURE AND TEMPERATURE
2. 100 % N_1 = 40,100 RPM
3. SHP BASED UPON SPECIFICATION RELATIONSHIP BETWEEN TORQUEMETER PRESSURE AND ENGINE OUTPUT SHAFT TORQUE.

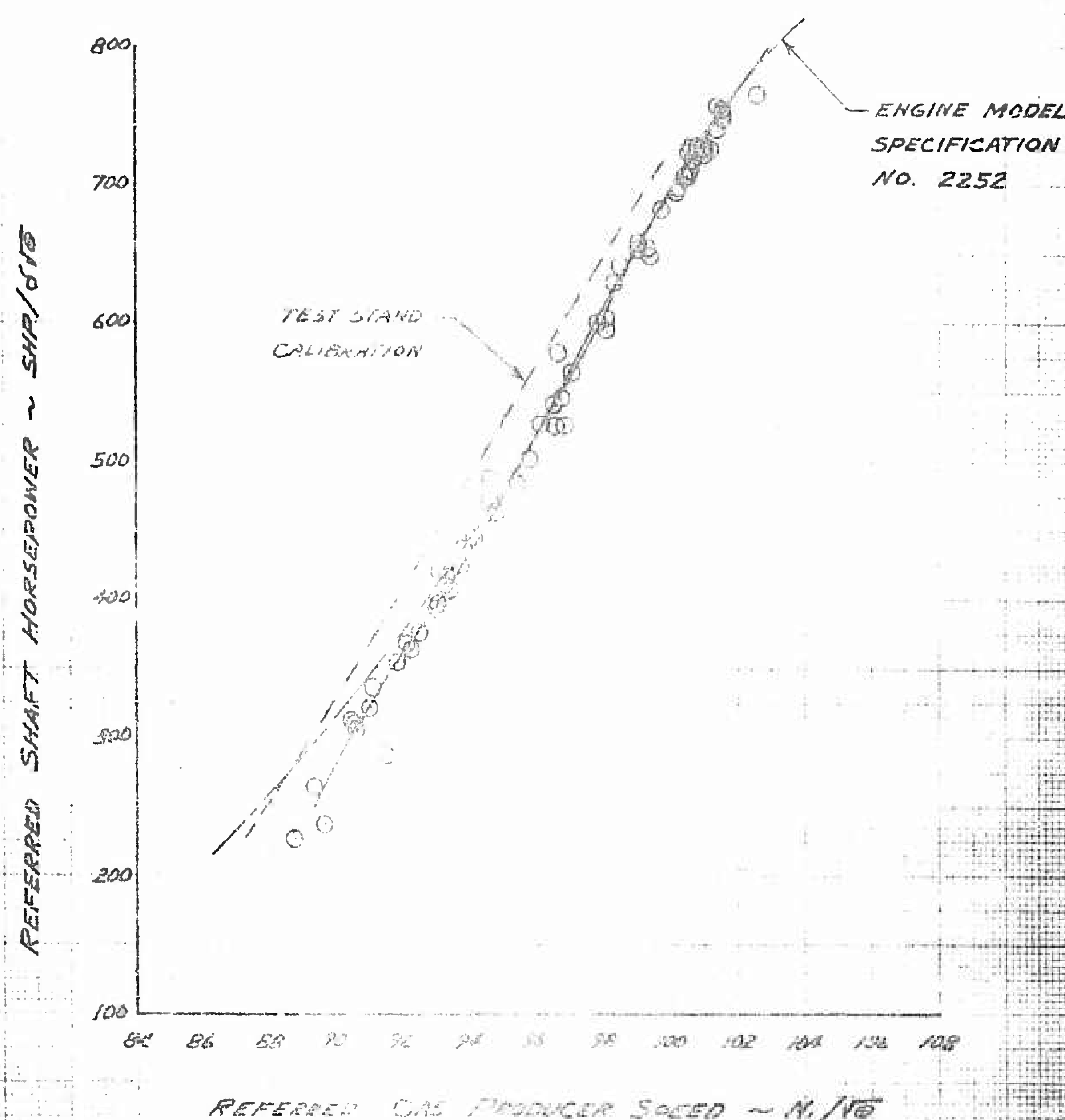


FIGURE No. 26

RIGHT ENGINE CHARACTERISTICS

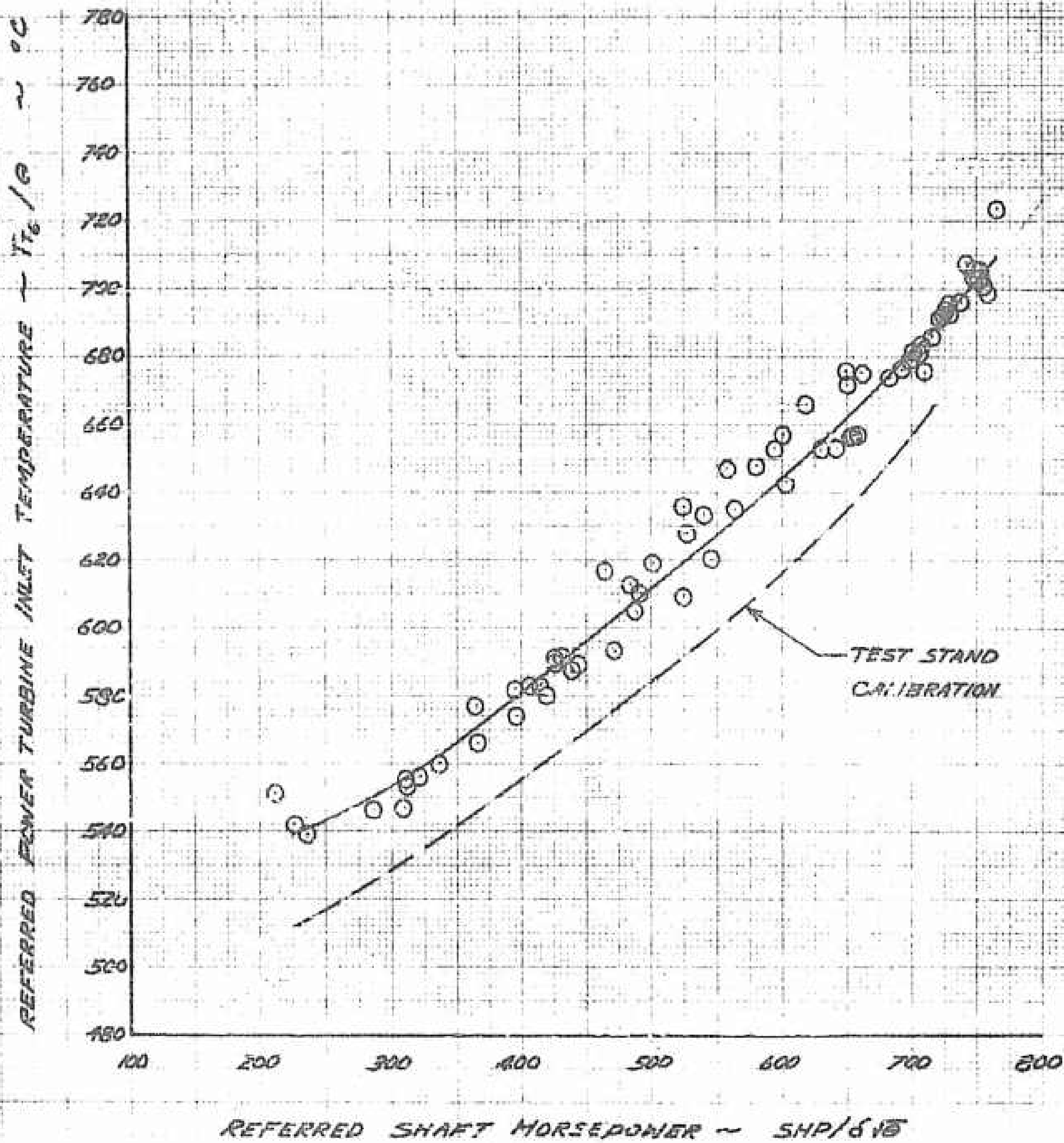
YUH-1D/48 FOOT ROTOR USA S/N 60-6030

XT-67 POWERPLANT S/N 2

RIGHT ENGINE S/N X-5

NOTES:

1. δ AND θ BASED UPON MEASURED COMPRESSOR INLET TOTAL PRESSURE AND TEMPERATURE.
2. SHP BASED UPON SPECIFICATION RELATIONSHIP BETWEEN TORQUEMETER PRESSURE AND ENGINE OUTPUT SHAFT TORQUE.



[illegible] CHARACTERISTICS
[illegible] 48 FOOT ROTOR USA S/N 60-6030
[illegible]-67 POWERPLANT S/N 2
[illegible] ENGINE S/N X-5

NOTES:

1. [illegible] BASED UPON MEASURED COMPRESSOR [illegible] TOTAL PRESSURE AND TEMPERATURE.
3. SHP BASED UPON SPECIFICATION RELATIONSHIP BETWEEN TORQUEMETER PRESSURE AND [illegible] OUTPUT SHAFT TORQUE.

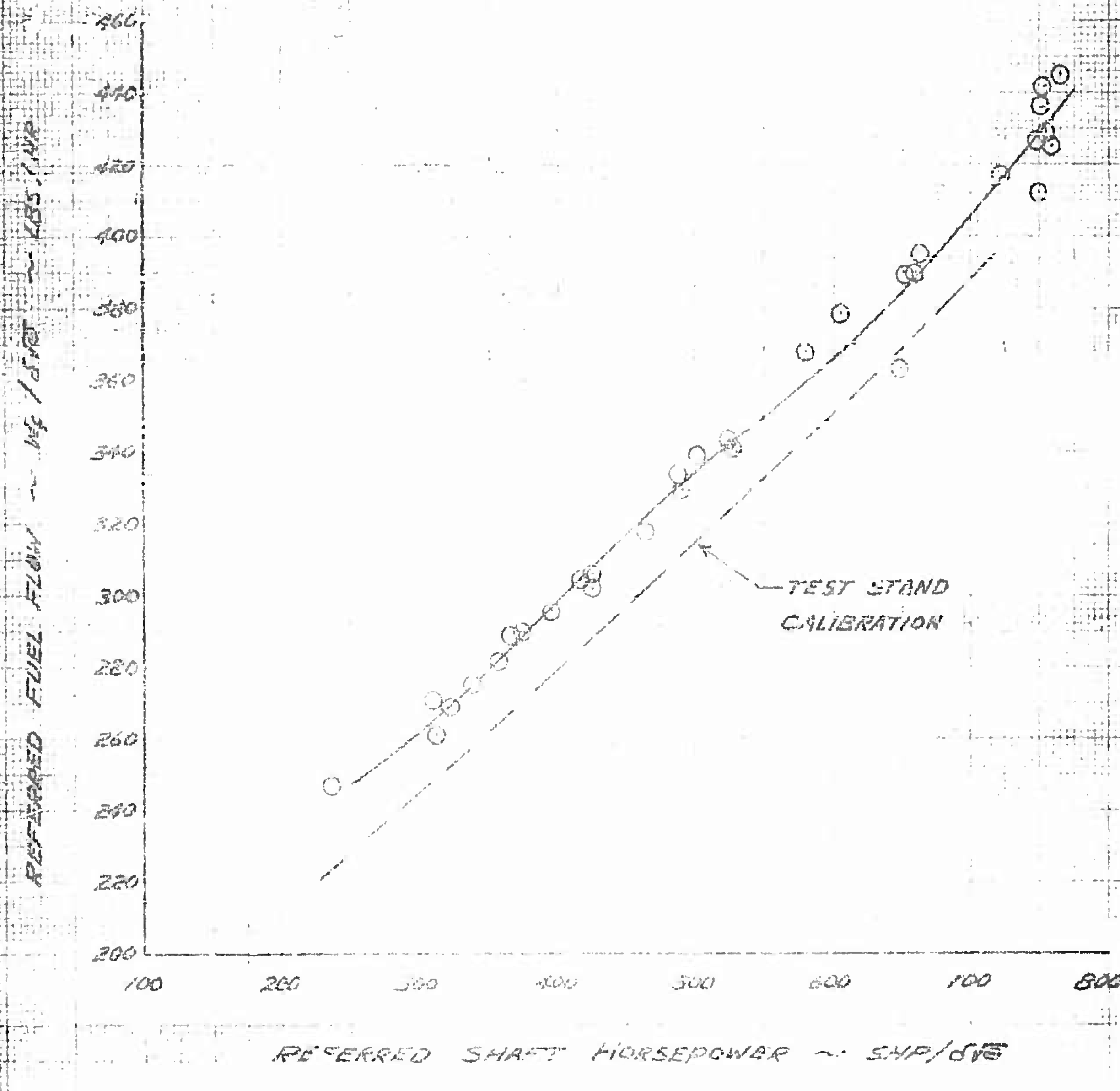
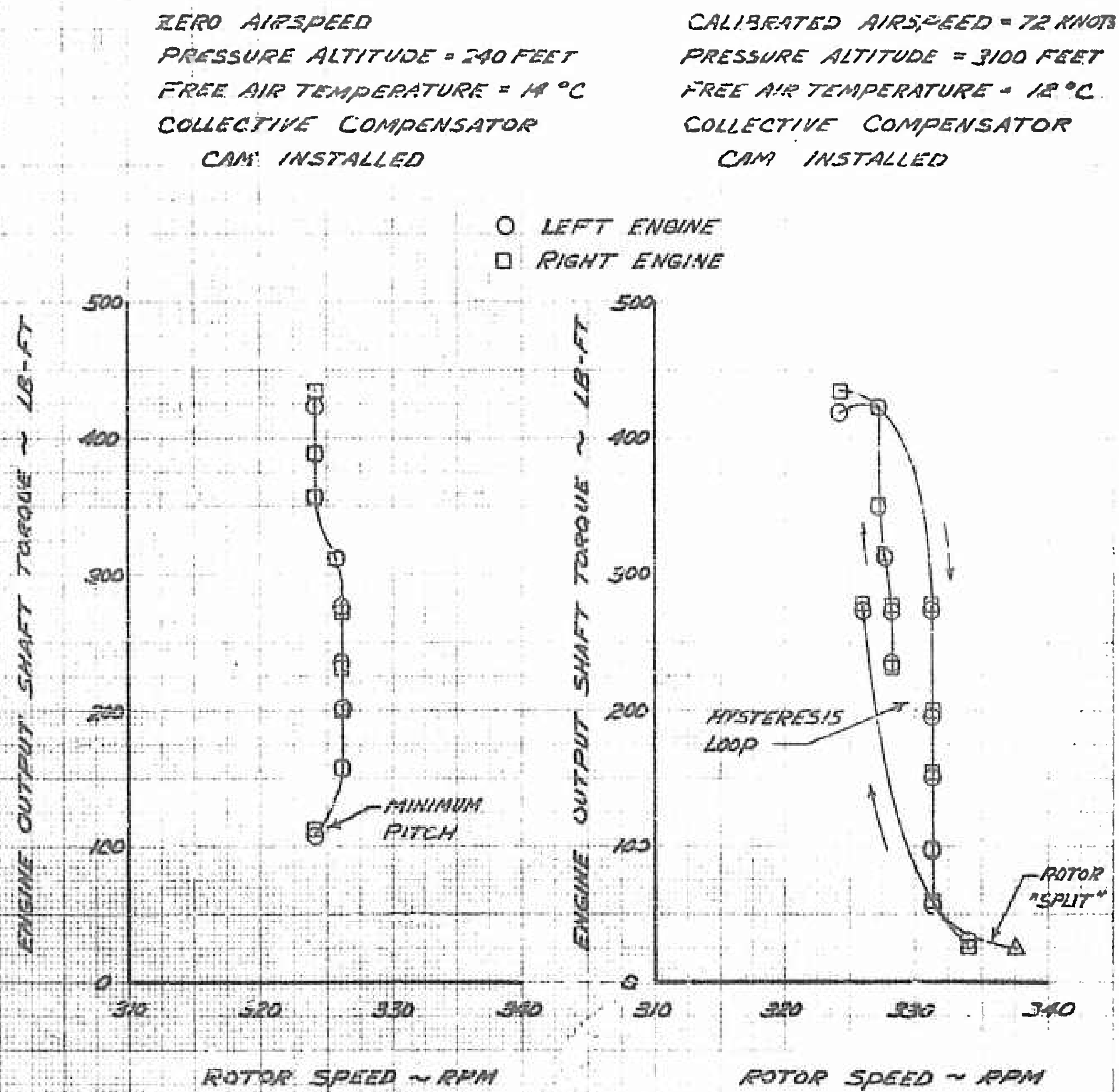


FIGURE No 28
TWIN ENGINE STATIC DROOP
YUH-1D /48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT



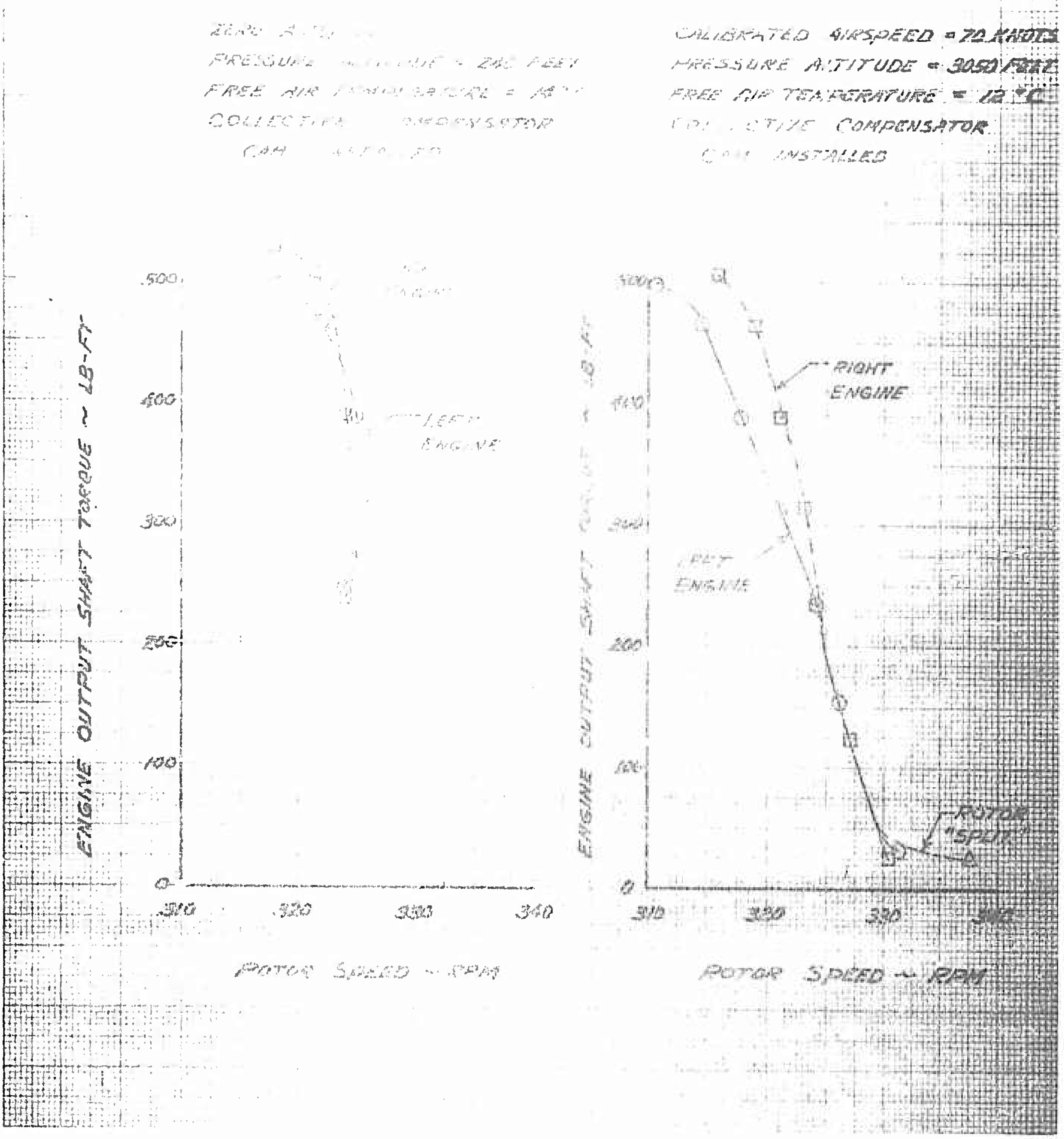
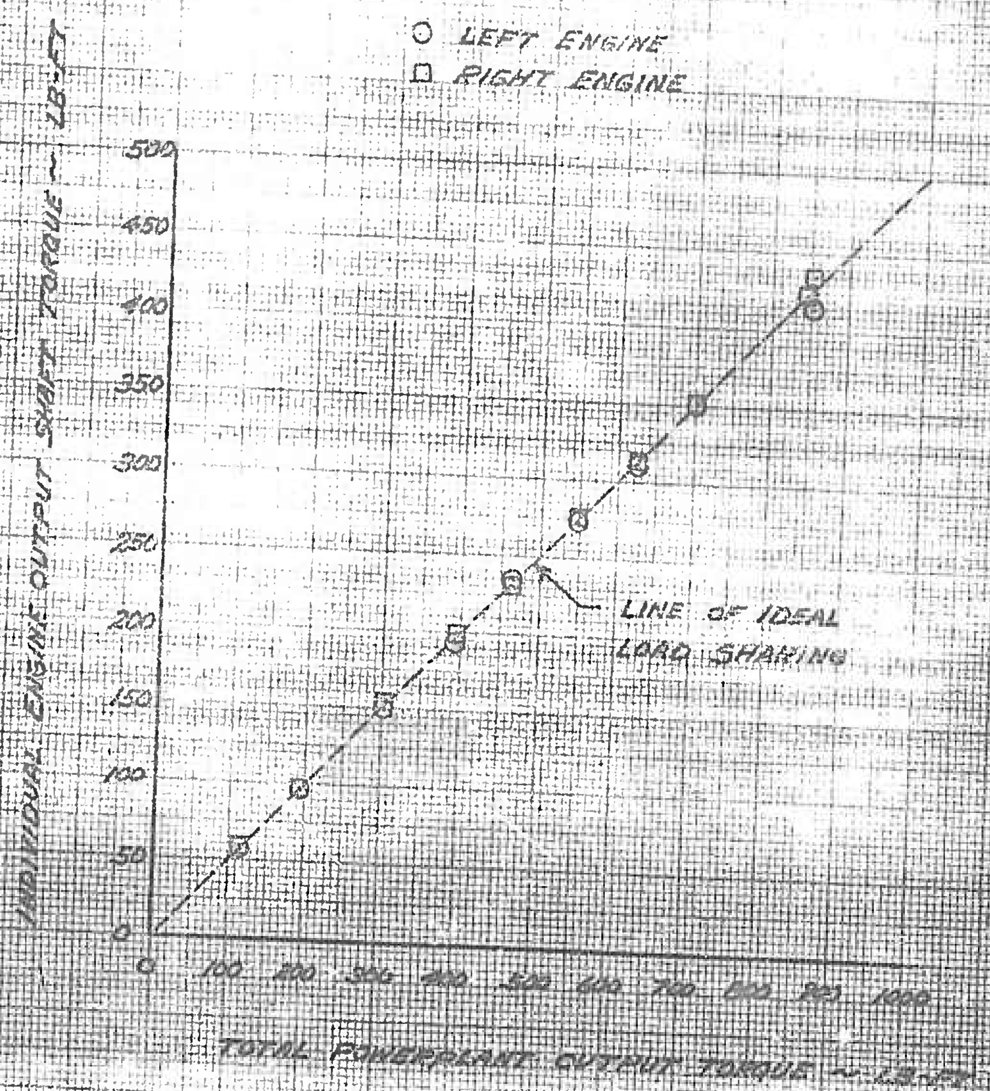

CALIBRATED AIRSPEED = 70 KNOTS
PRESSURE ALTITUDE = 3050 FEET
FREE AIR TEMPERATURE = 12 °C
COLLECTIVE COMPENSATOR
CAM INSTALLED
ENGINE OUTPUT SHAFT TORQUE ~ LB-FT
500
400
300
200
100
0
310
320
330
340
LEFT
ENGINE
ROTOR SPEED ~ RPM
RIGHT
ENGINE
ROTOR
"SPLIT"
ROTOR SPEED ~ RPM

FIGURE No. 30

TWIN ENGINE LOAD SHARING
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT



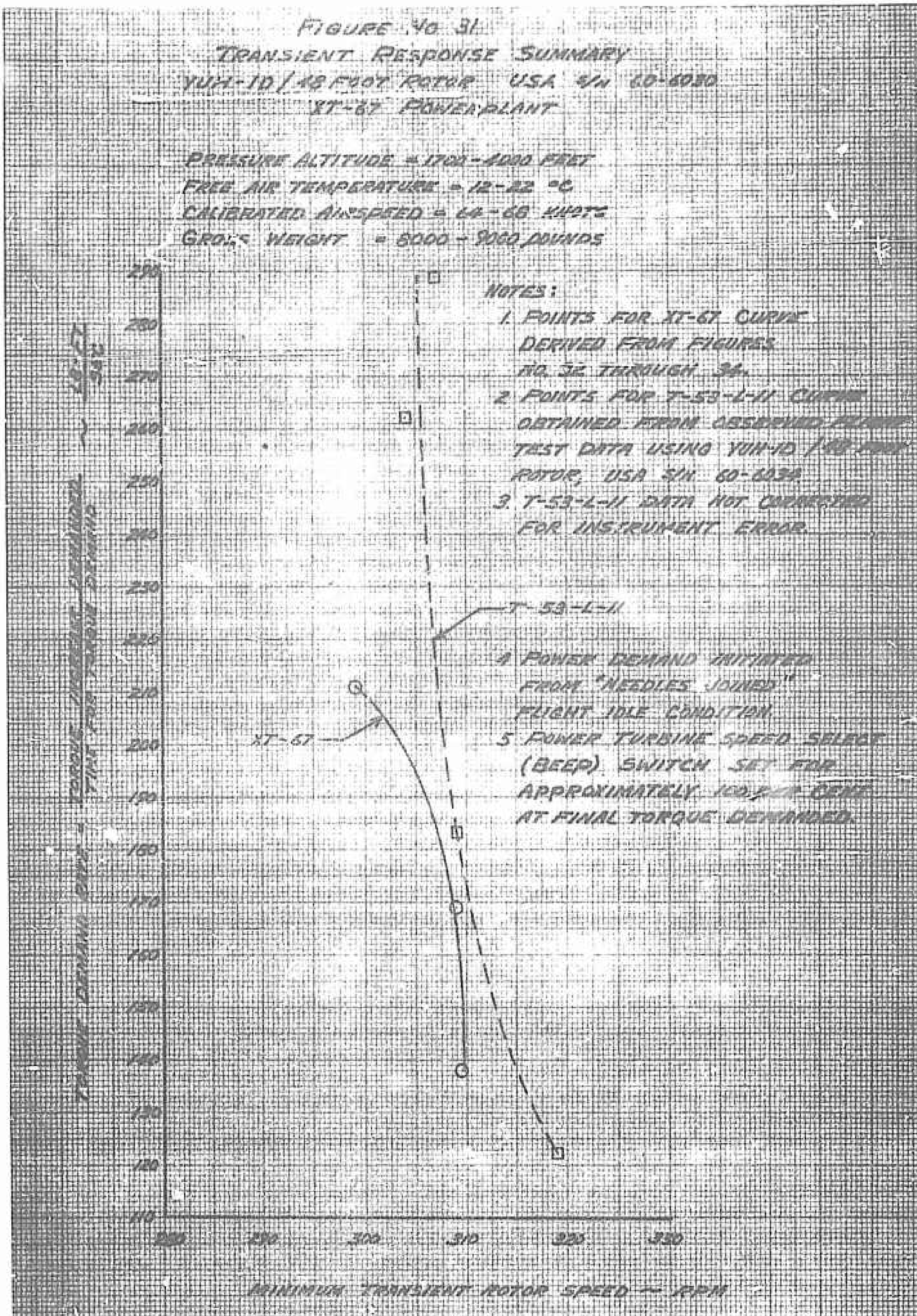


FIGURE NO 31
TRANSIENT RESPONSE SUMMARY
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT
PRESSURE ALTITUDE = 1700-4000 FEET
FREE AIR TEMPERATURE = 12-22 °C
CALIBRATED AIRSPEED = 64-66 KNOTS
GROSS WEIGHT = 8000 - 9000 POUNDS
NOTES:
1. POINTS FOR XT-67 CURVE DERIVED FROM FIGURES NO. 32 THROUGH 34.
2. POINTS FOR T-53-L-11 CURVE OBTAINED FROM OBSERVED FLIGHT TEST DATA USING YUH-1D / 48 FOOT ROTOR, USA S/N 60-6034
3. T-53-L-11 DATA NOT CORRECTED FOR INSTRUMENT ERROR.
4. POWER DEMAND INITIATED FROM "NEEDLES JOINED" FLIGHT IDLE CONDITION.
5. POWER TURBINE SPEED SELECT (BEEP) SWITCH SET FOR APPROXIMATELY 100 PER CENT AT FINAL TORQUE DEMANDED.
T-53-L-11
XT-67
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
290
300
310
320
330
MINIMUM TRANSIENT ROTOR SPEED ~ RPM
TORQUE

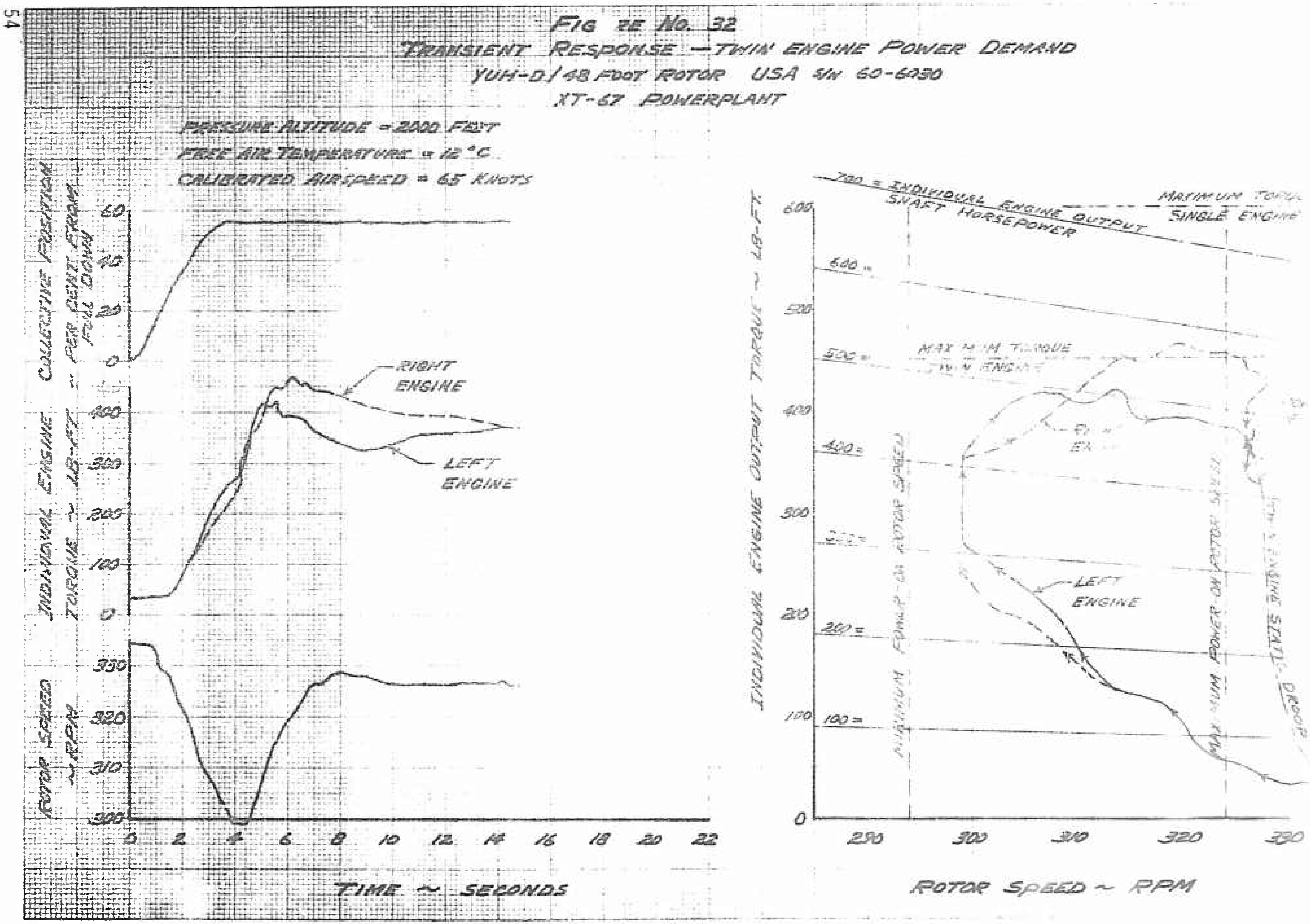
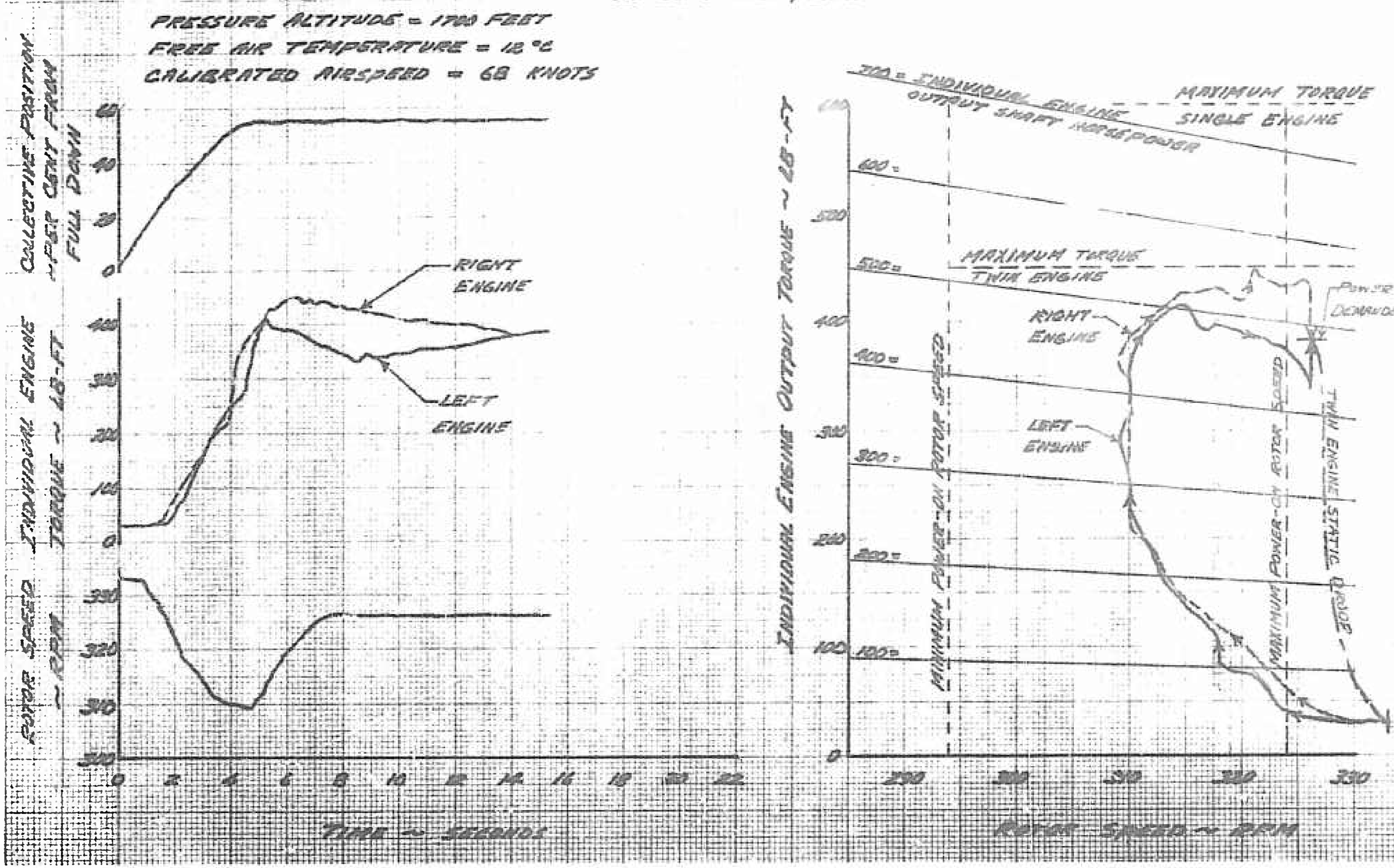


FIGURE No. 32
TRANSIENT RESPONSE — TWIN ENGINE POWER DEMAND
YUH-D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT
PRESSURE ALTITUDE = 2000 FEET
FREE AIR TEMPERATURE = 12 °C
CALIBRATED AIRSPEED = 65 KNOTS
COLLECTIVE POSITION ~ PER CENT FROM FULL DOWN
INDIVIDUAL ENGINE TORQUE ~ LB-FT
ROTOR SPEED ~ RPM
RIGHT ENGINE
LEFT ENGINE
TIME ~ SECONDS
INDIVIDUAL ENGINE OUTPUT TORQUE ~ LB-FT
700 = INDIVIDUAL ENGINE OUTPUT SHAFT HORSEPOWER
MAXIMUM TORQUE SINGLE ENGINE
MINIMUM POWER-ON ROTOR SPEED
MAXIMUM POWER-ON ROTOR SPEED
LEFT ENGINE
ROTOR SPEED ~ RPM

FIGURE NO. 33
TRANSIENT RESPONSE - TWIN ENGINE POWER DEMAND
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT



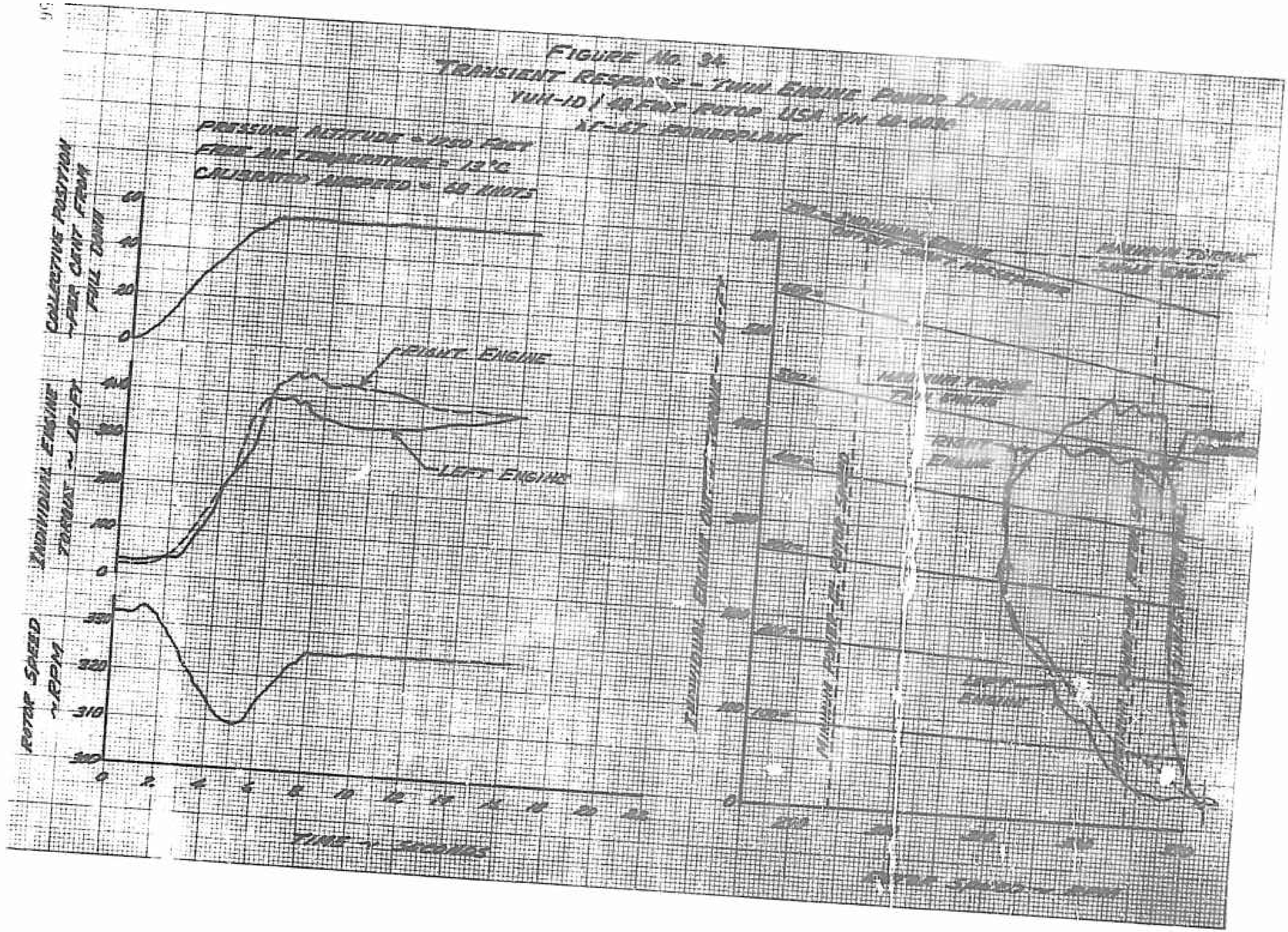


FIGURE No. 34
TRANSIENT RESPONSE – TWIN ENGINE POWER DEMAND
PRESSURE ALTITUDE = 1750 FEET
FREE AIR TEMPERATURE = 13°C
CALIBRATED AIRSPEED = 68 KNOTS
COLLECTIVE POSITION ~PER CENT FROM FULL DOWN
INDIVIDUAL ENGINE TORQUE ~ LB-FT
ROTOR SPEED ~RPM
RIGHT ENGINE
LEFT ENGINE
TIME ~ SECONDS
MAXIMUM TORQUE SINGLE ENGINE
MAXIMUM TORQUE TWIN ENGINE
MINIMUM POWER-ON ROTOR SPEED
ROTOR SPEED ~ RPM

FIGURE NO 35
TRANSIENT RESPONSE – SINGLE ENGINE POWER DEMAND
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT

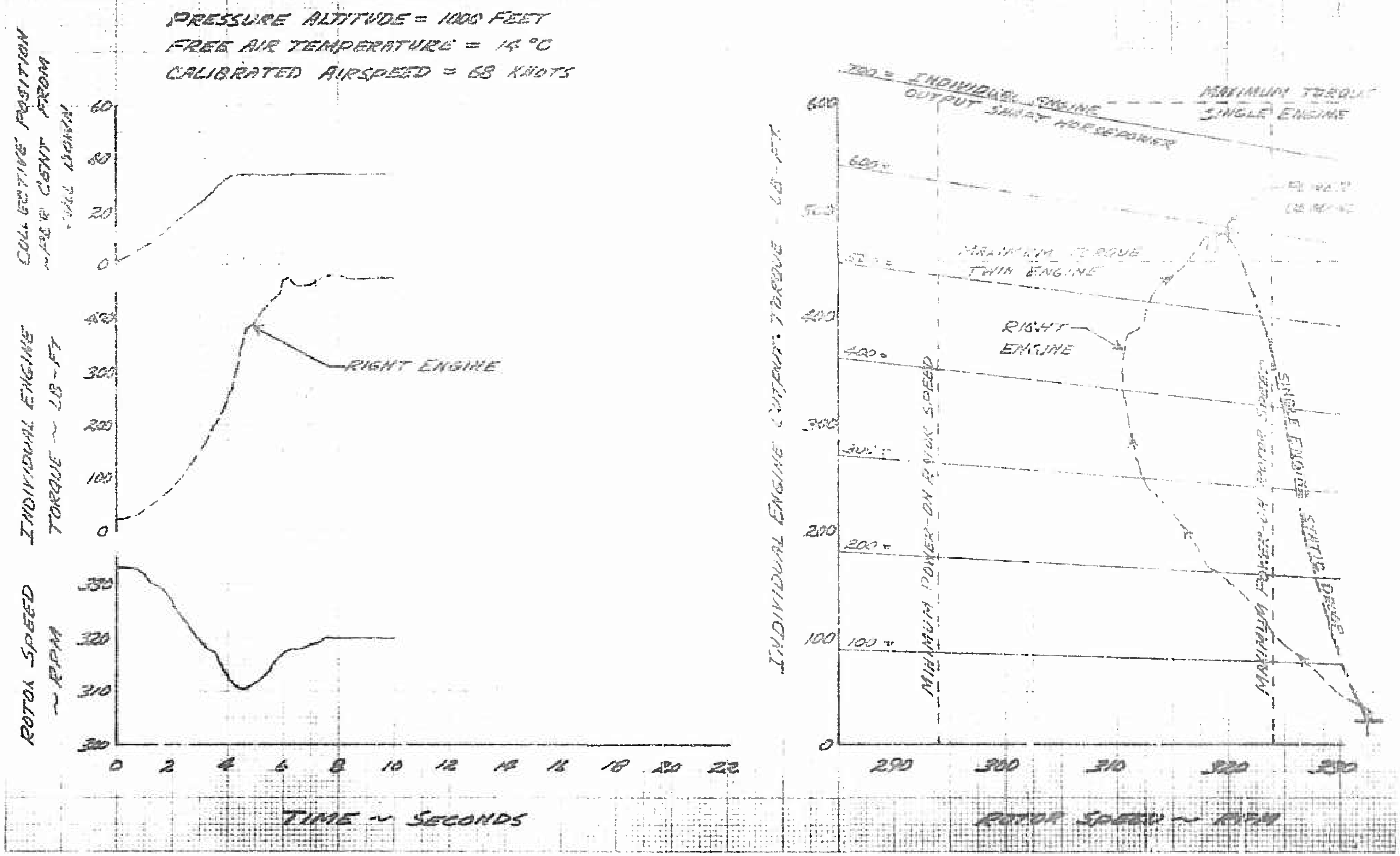
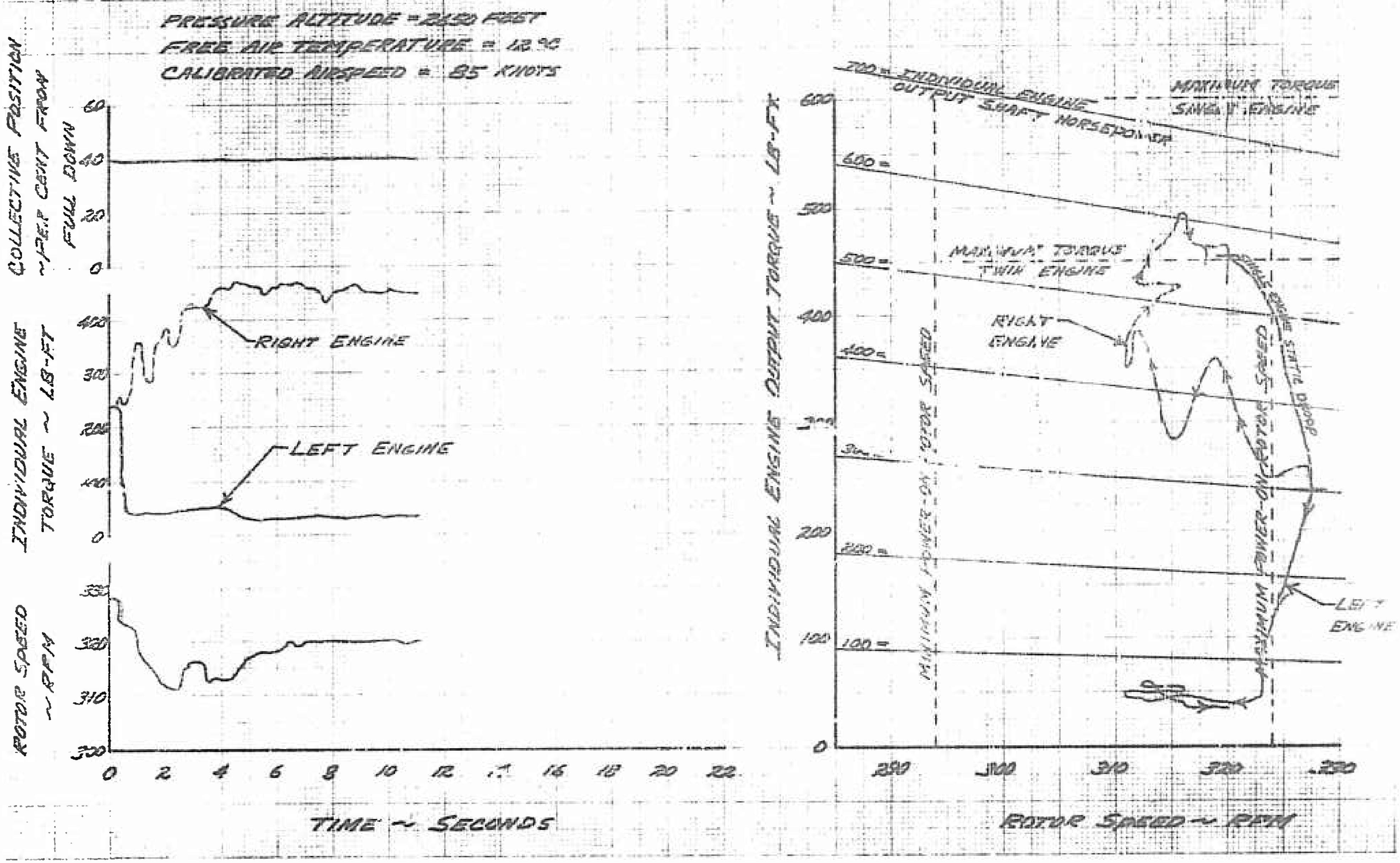


FIGURE No 36
TRANSIENT RESPONSE – SIMULATED LEFT ENGINE FAILURE
YUH-1D / 48 FOOT ROTOR USA S/N 60-6030
XT-67 POWERPLANT



[illegible]

[illegible] POWER PLANT

The [illegible] power plant consisted of two [illegible] gas turbine engines joined in a single [illegible] gearbox.

Tables, extracted [illegible], showing the performance ratings of the [illegible] power plant at [illegible] sea-level static conditions and the engine operating [illegible] on the following page.

The combining gearbox [illegible] the torque output of the two engines and reduced the rotational speed of the power turbines from 32,400 rpm at 100 percent N_2 to a power plant output shaft speed of 6600 rpm. The power plant output shaft [illegible] range was the same as that of the T53-L-11 engine, so no changes were [illegible] in the standard UH-1 main transmission. The power train for each [illegible] through the combining gearbox had a torquemeter [illegible]. The torquemeter design was based on the use of hydraulic [illegible] pressure to balance the axial thrust from a helical idler gear in the reduction [illegible] train. The axial thrust on the idler gear was [illegible] proportional [illegible] engine output torque, so the oil pressure required to balance the thrust was also proportional to torque and was indicated on [illegible] pressure gage. The overrunning clutch, also in the reduction gear train of each engine, allowed transmission of torque in only one direction, providing single-engine operation either at pilot's selection or in case of a single-engine failure.

Each engine of the [illegible] power plant was a free turbine turboshaft engine, with a [illegible] limit) rating of 700 SHP. The gas generator [illegible] inlet, located aft of the combining gearbox, [illegible] one-stage centrifugal compressor. The compressor design [illegible] appeared to offer considerable advantage in resistance to [illegible] damage. Each axial compressor rotor had only seven [illegible] resistance of the engine to damage from solid object [illegible] the engine contractor and susceptibility to sand erosion and power deterioration in dust environment should prove to be relatively low. A two-stage axial flow turbine was coupled directly to the compressor section. The combustor section was compact and of a design similar to that of other engines produced by the engine contractor. Compressor discharge airflow entered the combustor through three air [illegible] to create the desired combustion pattern. One of these airpaths passed over the combustor chamber, providing combustor discharge cooling. Fuel was injected through a centrifugal slinger rotating at gas producer speed. The power turbine was a single-stage axial turbine coupled, through a shaft concentric to the gas producer shaft, to the combining gearbox.

PERFORMANCE RATINGS OF THE YT67 POWER PLANT
AT STANDARD SEA-LEVEL STATIC CONDITIONS

Ratings	Shaft Horsepower	Gas Generator rpm(max)	Output Shaft rpm	Fuel Consumption lb/hp-hr (max)	Rated Output Torque lb-ft	Power Turbine Inlet Temperature °F (max)
Maximum (30 min)	1400	39,250	6600	0.57	1113	1220
Normal	1200	38,360	6600	0.59	955	1151
90% Normal	1080	37,830	6600	0.61	860	1114
75% Normal	900	36,950	6600	0.65	716	1055
Flight-idle	0	27,500	6600	330 lb/hr	---	---
Ground-idle	0	19,600	3640	190 lb/hr	--	---

ENGINE OPERATING LIMITS

	Torque lb-ft	Power Turbine Inlet Temperature °F
Maximum (30 min)	1200	1250
Normal	1113	1220
Max Transient	1300	1750

The fuel control was hydromechanically operated. It provided control for engine-start fuel metering, engine-acceleration scheduling, gas-producer-speed governing and power-turbine-speed governing. A manual or "open loop" control system was also provided. Three control levers were provided for each fuel control. The gas generator condition lever determined the set point of the gas generator governor. Any setting less than fully open would lower the maximum fuel flow, or "topping" of the engine. This lever was connected directly to the pilot's twist-grip. The power turbine speed set lever determined the power turbine speed about which the engine would govern. A two-position switch placed the engine under either automatic or manual mode. When the manual mode was selected, fuel flow to the engine was regulated directly by rotation of the pilot's twist-grip.

A hydro-mechanical torque matching device was used to maintain equal output torque for each engine. Hydraulic pressure from each engine torquemeter was applied across a load sharing piston. Any imbalance in torquemeter pressure would cause the load sharing piston to slew. Through a mechanical linkage this would cause engine with low torquemeter pressure to increase torque output. The linkage was designed so that the torque output of the high engine would not be reduced. The torque output of the low engine was increased by changing the power turbine speed set lever position. When output torquemeter pressure of the low engine was increased to the point where it was equal to that of the other engine, the pressure differential across the load sharing piston would go to zero and the piston would center in a trimmed condition. The sensitivity and response of the torque matching device could be varied through changing hydraulic orifice sizes.

During preliminary flight test of the XT67 power plant in the YUH-1D/48-foot rotor helicopter, it was found that additional cooling of the engine and combining gearbox lubricants was required. Heat exchangers and blowers were installed in the test helicopter. For convenience in installation, the cooling blowers were powered by air turbine motors powered by high pressure engine compressor discharge bleed air. The airflow required to drive the cooling blowers, and thus the compressor air bleed, was not known; and the effect of the airflow upon engine performance could not be defined.

For the one-of-a-kind power plant installation of the test helicopter, no concentrated effort was made toward weight reduction. The gross weight of the empty test helicopter was 936 pounds heavier than that of a production UH-1D/48-foot rotor helicopter. This increase in gross weight included flight test instrumentation. The helicopter manufacturer estimated that on a production basis the gross weight of the empty UH-1D/48-foot rotor helicopter with the XT67 power plant installed would be approximately 160 pounds greater than with the T53-L-11 engine installed.

APPENDIX III

TEST INSTRUMENTATION

The instrumentation required to measure the following parameters was supplied, calibrated and maintained by the airframe contractor:

a. Photo Panel

(1) Record Number

(2) Pressure Altitude

(3) Airspeed

(4) Ambient Temperature

(5) Collective Stick Position

(6) Combining Gearbox Oil Pressure

(7) Cabin Pressure

(8) Time of Day

(9) Compressor Inlet Pressure - Left and Right Engine

(10) Engine Torque - Left and Right Engine

(11) Engine Output Shaft Speed - Left and Right Engine

(12) Gas Producer Speed - Left and Right Engine

(13) Total Fuel Used - Left and Right Engine

b. Pilot Panel

(1) Record Number

(2) Pressure Altitude

(3) Airspeed

(4) Ambient Temperature

(5) Collective Stick Position

(6) Rotor Speed

(7) Compressor Inlet Temperature - Left and Right Engine

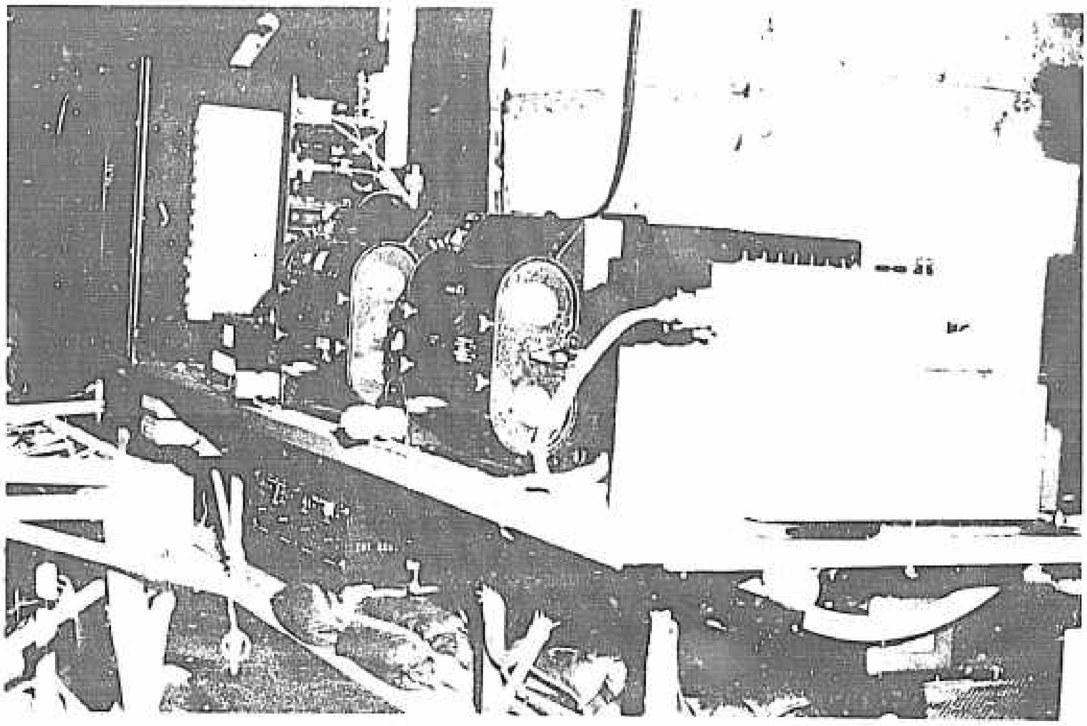
(8) Engine Torque - Left and Right Engine

(9) Gas Producer Speed - Left and Right Engine

(10) Power Turbine Inlet Temperature - Left and Right Engine

(11) Total Fuel Used - Left and Right Engine

(12) Fuel Flow Rate - Left and Right Engine



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11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Materiel Command (AMCPM-IRFO-T)

13 ABSTRACT

This report presents the results of limited engineering tests conducted to determine the performance characteristics of the XT67 power plant (i.e. two T72 engines) installed in a YUH-1D/48-foot rotor helicopter. Ten productive hours were flown between 14 Oct 65 and 22 Oct 65. The tests were performed at the airframe contractor's flight test facility located at Greater Southwest Airport, near Fort Worth, Texas. The U. S. Army Avn Test Board (USAAVNTBD) was assigned as Executive Test Agency, responsible for coordinating the test plan preparation, executing the limited serviceability testing and coordinating the test reporting. The U. S. Army Aviation Test Activity (USAAVNTA) was assigned the responsibility for coordinating the planning and reporting of the engineering tests with USAAVNTBD and executing the engineering tests. The XT67 power plant improved the hover and climb performance of the UH-1D/48-foot rotor helicopter by sustaining the helicopter main transmission torque limit to higher altitudes than were possible with the T53-L-11 engine. The XT67 power plant improved the level flight performance by allowing higher cruise speeds for essentially the same range. Increased range could be attained by shutting down one engine. Test installation losses were high but could be reduced significantly through continued development. The static droop characteristics of the XT67 power plant were acceptable. Static load sharing was excellent; however, load sharing during power transient, although adequate, could be improved. The transient response of the power plant-dynamic system was slow. This shortcoming should be corrected prior to service test.

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