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ENGINEERING FLIGHT TEST OF THE YCH-47C MEDIUM TRANSPORT HELICOPTER

ARMY PRELIMINARY EVALUATION I

FINAL REPORT

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SEPTEMBER 1968

US ARMY AVIATION TEST ACTIVITY
Edwards Air Force Base, California 93523

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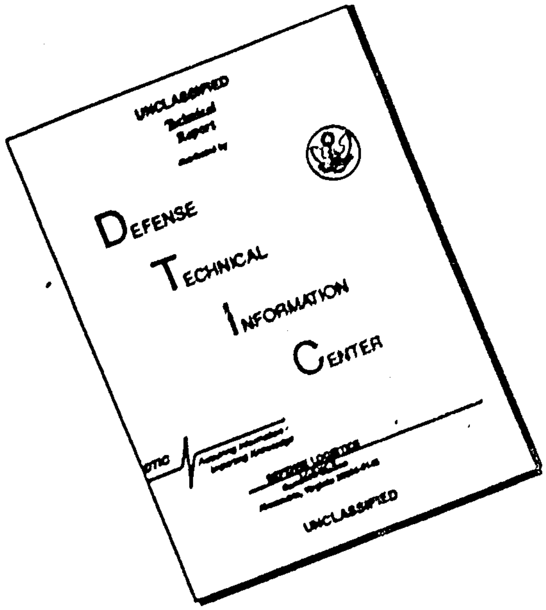

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ABSTRACT

Army Preliminary Evaluation I was conducted to verify the performance guarantees, obtain limited handbook data and evaluate the mission effectiveness of the YCH-47C helicopter. The performance testing was conducted in the vicinity of Philadelphia International Airport, Pa. and Millville Airport, N. J. by the US Army Aviation Test Activity. The testing consisted of nineteen productive flights and 22.1 productive flight hours and was conducted from 19 February through 14 March 1968. Within the scope of this evaluation all performance guarantees were met. The maximum cruise speed capability was 155 KTAS and limited by heavy cockpit vibration. The outstanding 95-degree Fahrenheit day in ground effect and out of ground effect hover capability enhances the mission effectiveness of the aircraft. The flight envelope release V_{NE} for all gross weights tested at 245 rpm rotor speed and low and high altitudes was not attained. The airspeed was limited by as much as 15 KTAS due to heavy cockpit vibration, but not to the extent that the mission effectiveness of the helicopter would be seriously degraded. The V_{NE} was easily exceeded for all gross weights tested at 235 rpm rotor speed-high altitudes with no vibration limitations encountered. There were eleven shortcomings for which correction is desirable for improved Army use. There were no deficiencies noted for which correction would be mandatory for acceptable helicopter operation and/or capabilities as per mission requirements.

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INTRODUCTION

BACKGROUND

1. The hot day-high altitude performance degradation of the CH-47 helicopter in Vietnam has verified the importance of improving the helicopter's payload and speed capabilities. Based on the requirement for an increased payload capability for the CH-47A, a CH-47 Product Improvement Program evolved (ref 1, app I). The CH-47 Product Improvement Program outlines a two-step program to incorporate performance, stability and vibration level improvements in production CH-47 helicopters. The helicopter configured for step one modifications has been designated the CH-47B. The second step in the CH-47 Product Improvement Program provides for the incorporation of higher power for a further increase in payload capability. The helicopter configured for step two modifications has been designated the CH-47C.

2. Authority for the US Army Aviation Test Activity (USAAVNTA) participation in the CH-47 Product Improvement Program test program was provided by the test directive issued by the US Army Test and Evaluation Command (USATECOM) on 17 June 1966 (ref 2, app I). The test plan for the Army Preliminary Evaluation (APE) was approved by the CH-47 Project Manager and the US Army Aviation Materiel Command (USAAVCOM) in February 1968 (ref 3, app I) to be conducted in two phases, APE I and APE II.

TEST OBJECTIVES

3. The purpose of APE I was to furnish the CH-47 Project Manager and the Procuring Activity (USAAVCOM) with preliminary and timely results derived from US Army tests of the YCH-47C helicopter during the contractor's development program. Specific objectives were:

a. Provide quantitative/qualitative engineering flight test data.

b. Serve as a basis for an estimate of the degree to which the aircraft is suitable for its intended mission.

c. To assist in determining the flight envelope to be used by Army pilots for future service and for flight operations.

d. Detect and allow early correction of deficiencies as well as to provide a basis for evaluation of changes incorporated to correct deficiencies.

e. Provide preliminary aircraft performance data for operational use and to determine compliance with performance guarantees.

DESCRIPTION

4. The YCH-47C helicopter flown during APE I, serial number 66-19121 (production tab number B-379), was a prototype CH-47C in external configuration specified in the detail specification (ref 4, app I) less the cargo mirror. Nonstandard items mounted externally were slip ring assemblies on both rotor heads, Rosemont temperature probe on the underside of the fuselage, and a pitot static boom on the nose. Significant changes from the CH-47B that were applicable to the test helicopter are contained in appendix IV. These and other changes are contained in the CH-47 Product Improvement Program document (ref 1, app I).

5. The test helicopter was powered by two prototype YT55-L-11 calibrated engines in lieu of production T55-L-11 engines which are to be incorporated on the production CH-47C helicopter at a later date. Design gross weight was 33,000 pounds and the alternate design gross weight was 44,800 pounds. Cockpit instrumentation was nonstandard and helicopter loading was nonrepresentative due to ballast and instrumentation requirements.

SCOPE OF TEST

6. The YCH-47C was evaluated with respect to its mission as a transport helicopter as defined in the detail specification. Nineteen productive test flights were conducted for a total of 22.1 productive flight hours. Performance results were compared to the guarantees set forth in the detail specification. The YCH-47C was tested under the conditions shown in Table 1.

Table 1. Scope of Test .

Flight Conditions	Hover, level, single and dual engine climb, and autorotation
Airspeed	0 to 158 KTAS
Takeoff gross weight	30,815 lb to 45,983 lb
Rotor speed	223 rpm to 255 rpm
Pressure altitude	S.L. to 11,000 ft
OAT	+7°C to -11.5°C
Fuel	JP-4
Takeoff center of gravity	1.5 in. to 12.4 in. forward
Stability augmentation system	ON
Longitudinal cyclic speed trim	AUTOMATIC/MANUAL
Differential collective pitch	OPERATING

7. The flight restrictions and operating limitations applicable to the evaluation are contained in appendix VII and the Safety-of-Flight Release for the conduct of the evaluation (ref 5, app I).

8. The specific performance requirements against which the YCH-47C was tested are presented in appendix VIII (also see ref 4, app I). Vibration characteristics were qualitatively evaluated as affecting the airspeed capability.

METHOD OF TESTS

9. Performance tests were conducted in the vicinity of Philadelphia International Airport, Pa. and Millville Airport, N. J. Tests were

conducted under stabilized flight conditions. Sensitive and calibrated instruments were used and data were recorded on a photopanel and a magnetic tape recorder. Data were also recorded manually from the cockpit and from the photopanel. Power and fuel flow data, as specified in the T55-L-11 Engine Model Specification (ref 6, app I), were used to derive standard performance conditions. Power required was derived from the YT55-L-11 test engines calibrations based on fuel flow. Power derived from rotor torque was compared with power derived from fuel flow to verify that engine degradation had not occurred.

10. Flying qualities characteristics where appropriate were evaluated during performance tests. Vibration levels were qualitatively evaluated in the cockpit and cabin as affecting operational capability. A Pilot Rating Scale was used to augment qualitative comments. This scale is presented in appendix IX.

11. The test methods used in evaluating the YCH-47C are contained in appendix III.

12. Test instrumentation used on the YCH-47C including a description of parameters recorded is contained in appendix V.

CHRONOLOGY

13. The chronology of testing is as follows:

Test directive received	June 1966
Test aircraft received	17 February 1968
Test started	19 February 1968
Test completed	14 March 1968
Draft report submitted	15 April 1968
Final report forwarded	June 1968

RESULTS and DISCUSSION

PERFORMANCE

General

14. Performance tests were conducted to verify compliance with the detail specification guarantees. Within the scope of the evaluation all performance guarantees were met. The normal power cruise speed guarantee was exceeded based on extrapolated data but the operational speed was limited to 155 KTAS because of heavy cockpit vibration.

15. All generalized performance data presented are based on the generalized parameters, generalized gross weight (GW/δ), generalized shaft horsepower ($SHP/\delta\sqrt{\theta}$), referred airspeed ($V/\sqrt{\theta}$) and referred rotor speed ($N/\sqrt{\theta}$) as specified in reference 7, appendix I. Where the actual $N/\sqrt{\theta}$'s flown varied from the $N/\sqrt{\theta}$'s presented in the generalized performance plots, the compressibility corrections shown in figure I, appendix II, for hover and figures 2 and 3 for level flight were used. Compressibility corrections were based on theory and empirical data obtained during YCH-47B and YCH-47C tests. Those items affecting the external configuration of the helicopter and not a part of the guarantee were accounted for by determining their f_e's and resulting shp required with airspeed. The resulting shp required was applied as a reduction in total shp required for a given airspeed in level flight. The f_e's were based on wind tunnel data provided by the contractor. The items for which f_e corrections were applied are presented in appendix IV.

16. A summary of performance guarantee compliance is presented in table 2.

Hover Performance

17. The 10 ft IGE hover capability at 245 rpm for a standard day and 95-degree Fahrenheit day is presented in figure 4, appendix II, and derived from the nondimensional plot in figure 5. The highest test C_T was 62 X 10^{-4} and obtained at a test G.W. of 44,753 lb at a H_p of -90 ft and -2.3 degrees centigrade. Figure 5 was used to derive the standard day and 95-degree Fahrenheit day hover curves presented in figure 4. Above 3150 ft the hover capability degrades rapidly on the 95-degree Fahrenheit day due to less power available when compared to the standard day.

Table 2. Performance Guarantees Summary.

Condition	Guarantee	Results
Mission I payload, outbound (lb)	12,000	12,000 (1)
Mission I payload, inbound (lb)	6,000	6,000 (1)
Mission II maximum cruise speed at S.L./STD, NP (KTAS)	155	162 (2)
Mission I service ceiling, single engine at NP (ft)	4,000	5,170 (3)
Mission I radius of action (NM)	100	100 (1)
Mission I hover capability OGE 95° F/6,000 ft	6,000	8,180 (4)
Mission III hover capability, OGE S.L./STD (lb)	45,000	45,705

(1) These values fixed to determine the Mission I G.W. of 37,110 lb.

(2) Results obtained from extrapolated data at 245 rpm rotor speed. The maximum acceptable airspeed was 155 KTAS and limited by heavy cockpit vibration.

(3) Results based on level flight performance.

(4) Results obtained from extrapolated data.

18. The OGE hover capability for a standard day at 245 rpm is presented in figure 6, appendix II, and was derived from the nondimensional plot in figure 7. The highest test C_T was 62.05 X 10^{-4} and obtained at a test G.W. of 45,562 pounds at a Hp of 8 ft and 7.0 degrees centigrade. Figure 7 was used to derive the standard day and 95-degrees Fahrenheit day hover curves in figure 6. The YCH-47C has a standard day S.L. hover capability OGE to exceed the alternate design G.W. of 44,800 pounds by 905 pounds (2.0 percent).

19. The OGE hover capability for a 95-degree Fahrenheit day is presented in figure 6, appendix II, and derived from the nondimensional plot in figure 7. Extrapolated data show the helicopter is capable of hovering at 8180 feet on the 95-degree Fahrenheit day at 235 rpm. The OGE hover capability exceeds the Mission I guarantee of 6000

feet 95-degrees Fahrenheit day by 2180 feet (36.4 percent). The Mission I G.W. was 37,110 pounds and was based on the Mission I G.W. computation in table 3. Any increase in the Mission I G.W. up to 40,000 pounds will allow the YCH-47C to meet the 95-degree Fahrenheit day hover guarantee of 6000 feet at 235 rpm. At a 40,000 pound takeoff G.W. the CH-47C will have a useful outbound payload of 14,800 pounds and an inbound payload of 7400 pounds for accomplishing Mission I for a 100 NM radius of action. The outstanding 95-degree Fahrenheit day IGE and OGE hover capability of the YCH-47C enhances mission effectiveness.

Level Flight Performance

20. Level flight performance testing of the YCH-47C was conducted at several referred G.W.'s to determine the best range airspeed, maximum cruise airspeed and power required to verify detail specification compliance. The generalized power required curves derived from the flights are presented in figures 8 and 9, appendix II, for referred rotor speeds of 235 rpm and 245 rpm respectively. The generalized power required curves for 245 rpm were used to develop the nondimensional level flight performance plot presented in figures 12 and 13. The generalized power required curves presented in figures 8 and 9 show that a lower referred rotor speed is more efficient for most values of referred G.W. This is mainly attributable to smaller compressibility power losses at induced blade tip mach number decreases. At above 130 KTAS and below 80 KTAS considerable pilot effort was required to accurately maintain airspeed within ± 5 kt. This was apparently due to weak stability (PRS A5). During VFR and IFR missions a pilot will be required to devote an excessive amount of attention to airspeed. Correction of the apparently weak speed stability characteristics in level flight is desirable for improved Army use.

21. The weight empty, used for accomplishing the Mission I payload radius of action profile, specified in the detail specification was 20,213 pounds. The fixed useful load was determined from the detail specification and is presented in table 3.

Table 3. Fixed Useful Load for Accomplishing Mission I.

Item	Weight (lb)
3 crew members at 200 lb each	600
Unuseable fuel	36
Engine oil	53
Cargo tiedown devices	50
TOTAL	739

22. Determination of the Mission I G.W., was made by fixing the outbound and inbound payloads at 12,000 pounds and 6000 pounds respectively and the radius of action at 100 NM as guaranteed. The range capabilities of the CH-47C are shown in figures 14 and 15, appendix II, for a S.L. standard day. The figures are based on an empty weight of 20,213 pounds plus a fixed useful load of 739 pounds. The level flight range summaries (fig 16), which show NAMPP and airspeed for best range as a function of gross weights were derived from the specific range plots shown in figures 17 and 18. The specific range plots show that the maximum capability of the helicopter is achieved by operating at 235 rpm for gross weights up to 40,000 pounds. At a given gross weight, a decrease from 245 rpm to 235 rpm results in an increase in cruise airspeed and specific range. Additionally, a slight reduction in vibration level was apparent at 235 rpm as compared to 245 rpm for a given airspeed.

23. The curves in figures 17 and 18, appendix II, were plotted from the generalized power required curves presented in figures 8 and 9. Fuel flow as a function of shp was determined from figure 19, which was derived from the T55-L-11 Engine Model Specification. Ram effects and inlet temperature rise were accounted for as outlined in reference 8, appendix I. The ram effects and inlet temperature rise used were extracted from reference 8 and presented as inlet losses in figure 20, appendix II. Figure 14 shows that the YCH-47C met the payload/radius of action guarantees with a Mission I G.W. of 37,110 pounds. Table 4 presents the computations used to compute the Mission I G.W.

24. The maximum cruise speed at SL/STD, NP for accomplishment of Mission III at 33,000 pounds G.W. was 162 KTAS and 166 KTAS at 245 and 235 rpm respectively. The airspeeds are obtained from extrapolated data shown in figures 21 and 22 and based on the transmission limit. The lower compressibility power loss at 235 rpm more than offsets the increase in transmission limited power at 245 rpm yielding the higher speed capability for the lower rotor speed. Actual airspeed reached under test conditions was 157 KTAS. Operation above 155 KTAS resulted in heavy cockpit and cabin vibration levels (para 39). The maximum cruise speed capability exceeded the guarantee of 155 KTAS SL/STD, NP by 7 kt (4.5 percent) at 245 rpm rotor speed.

Table 4. Computation of Mission I G.W. (1)

(1) Based on S.L. standard day, T55-L-11 engines installed, no bleed air off, heater off, all windows and doors closed, cargo mirror not installed and 235 rpm rotor speed.

(2) NAMPP and average cruise speed based on 100 percent maximum specific range for weights shown in computation of Mission I G.W. above.

Item	Weight (lb)
Detail specification weight empty statement	20,420
Troop seats	-169
Engine inlet screen	-38
Mission I empty weight	20,213
Fixed useful load	739
Fuel	4,158
Outbound payload	12,000
Mission I G.W.	37,110
Engine start G.W.	37,110
Warm-up (2 min) at NRP	-107
Outbound fuel	1,848
Landing G.W.	35,155
Average outbound G.W.	36,079
Offload 12,000 lb, load 6,000 lb	29,155
Warm-up (2 min) at NRP	-107
Inbound fuel	-1,680
Landing G.W.	27,368
Average inbound G.W.	28,208
Unload 6,000 lb	21,368
Fixed useful load	-739
Empty weight plus fuel	20,629
Ten percent fuel reserve	-416
Mission I empty weight	20,213
Average NAMPP outbound (2)	0.0542
Outbound fuel	1,848
Outbound range at average 136 KTAS (2)	100 NM
Average NAMPP inbound (2)	0.0596
Inbound fuel	1,680
Inbound range at average 126 KTAS (2)	100 NM

Climb Performance

25. Climbs were conducted both dual engine and single engine. Single engine climbs to service ceiling were conducted at 230 rpm rotor speed at the appropriate Mission I G.W. Dual engine climbs to the envelope limit density altitude were conducted at 245 rpm and 235 rpm rotor speeds at the alternate design gross weight and the Mission I gross weight respectively. Rates of climb were corrected for nonstandard atmospheric conditions, nonstandard power available (K_p, fig 23, app II), and for nonstandard fuel flow. All climbs were conducted using the contractor's recommended airspeed and torque schedules. The contractor climb schedule airspeeds were within 2 kt of the best rate of climb airspeeds obtained from the APE level flight generalized power required curves. Considerable pilot attention was required to accurately maintain airspeed within ±5 kt during climbs, apparently due to weak speed stability (PRS A 5). During VFR or IFR missions a pilot will be required to devote an excessive amount of attention the airspeed indicator. Correction of the apparent weak speed stability characteristics in climbs is desirable for improved Army use.

26. Cockpit vibration levels were satisfactory throughout the climb tests (para 42); however, above 55 percent torque (per engine) a 2/3 per revolution light lateral vibration became apparent which reached a moderate at high power settings. At NP and MP the level of this vibration did not degrade the pilot's ability to control the aircraft but was annoying (PRS A 4). Reduction in the lateral vibrations during climbs is desirable for improved Army use.

27. The single engine MP climb performance was derived from the level flight generalized power required curves and engine power available curves as specified in reference 6, appendix I, to determine compliance with the Mission I, single engine service ceiling guarantee. Additionally, two single engine climbs to service ceiling were conducted to substantiate the results derived from the level flight performance data and the results are presented in figure 24, appendix II. The results indicate a single engine service ceiling of 4900 feet using number 2 engine and 5250 feet using number 1 engine. Based on the results calculated from the level flight generalized power required curves the CH-47C has a single engine service ceiling of 5170 feet which exceeds the Mission I guarantee of 4000 feet H_D by 1170 feet (29.3 percent).

28. The dual engine climb performance of the CH-47C is presented in figures 25 and 26, appendix II. The rate of climb at the 235 rpm envelope limit ceiling of 10,250 feet, (H_D) was 1280 fpm. The extrapolated rate of climb at the 245 rpm envelope ceiling of 7250 feet, (H_D), was 620 fpm. The approximate starting G.W.'s for these climbs were Mission I and Mission III respectively.

Autorotative Performance

29. The allowable rotor speed range specified by the contractor for autorotative descents was 223 rpm to 261 rpm but the maximum useable rotor speed during the test was 255 rpm. Cockpit vibration levels rapidly increased from moderate at 250 rpm to heavy at 255 rpm (para 42) and the pilot experienced difficulty in reading instrument panel gages. Rotor response to thrust lever inputs was rapid between 223 and 255 rpm and rotor rpm rates could be easily controlled; however, precise control of rotor speed within ±5 rpm was difficult. The rotor speed was very sensitive to small variations in airspeed (±2 kt). Rotor speeds for best range or minimum rate of descent were not determined, even though the autorotative flying qualities characteristics of the YCH-47C appeared to be satisfactory for Army use (PRS A 3). It is recommended that further testing be conducted during the CH-47C phase D test to determine autorotative performance characteristics.

Engine Characteristics

30. The NP, MP and maximum power available curves for 235 and 245 rpm used for performance tests were based on the T55-L-11 Engine Model Specification (ref 6, app I) and are presented in figures 27 through 29, appendix II. A one degree centigrade engine inlet temperature rise was used to correct specification powers to installed powers as specified in reference 8, appendix I, and shown in figure 20, appendix II. Ram pressure rise as determined during CH-47A Category II tests was used in calculating the installed power available. Inlet recovery effects used for determining MP available for single engine climbs are presented as figure 30.

31. The power turbine inlet temperature (T.I.T.) of the installed YT55-L-11 engines on the test helicopter generally correlated with test stand calibration results obtained by Lycoming. Figures 31 and 32, appendix II, show T.I.T. presented as a function of fuel flow shp. Temperatures generally ran cooler than obtained during the test stand calibration. Figures 33 and 34 show referred gas producer speed as a function of fuel flow shp. Figure 33 shows that the Lycoming test stand calibration was inaccurate. The fuel flow inaccuracy was substantiated by rotor torque, constant collective checks, and engine torque. Figures 35 and 36 present the calibrated engine torque versus indicated engine torque. Figure 35 indicates that no error existed in the torque system for number one engine. Figure 36 shows that the indicated engine torque was approximately 1.3 percent higher than calibrated engine torque at 78 percent (transmission limit). The data contained in figures 35 and 36 were obtained from Lycoming test stand calibrations. Based on figures 35 and 36 engine shp derived from engine torque was

compared with engine shp derived from fuel flow, (fig 37 and 38). Figure 37 shows the number one engine torque shp to be approximately 100 shp low indicating a one percent inaccuracy in the Lycoming test stand calibration. Figure 38 shows excellent agreement on number two engine torque shp indicating an accurate test stand calibration. Production torque indicators were used in the test helicopter. Figures 35 through 38 show that the ship system torque indicators were reading one percent higher than the actual shp output. The torque measuring system in the test helicopter was satisfactory for Army use. Figure 39 shows that actual engine biasing resulted in lower N_1 speeds than was specified for the YT55-L-11 engine. The number one engine was biasing 0.6 percent N_1 low at -5 degrees centigrade and improved to no error at -10 degrees centigrade. The number two engine biased 0.3 percent N_1 low at -5 degrees centigrade.

32. Thrust lever control was not precise. During the testing the pilot was required to estimate a torque higher than desired. This was necessary because after the thrust and brake switch was released torque would bleed off from 2 percent to 3 percent per engine. The lack of precise torque control resulted in an increase in pilot effort required to perform the precise hover mission by increasing external cargo hookup times (PRS A 4). Correction of the imprecise thrust lever control is desirable for improved Army use.

33. Continued torque balance adjustments between engines when making rotor speed and/or thrust lever changes were required. Pilot attention was therefore distracted from flying the aircraft and resulted in increased pilot effort to precisely control the helicopter. This characteristic also increased the probability of engine overtorques when operating at high power settings (PRS A 5). Correction of the nonuniform torque distribution when making power and/or rotor speed changes is desirable for improved Army use.

Airspeed Calibration

34. The swivel head pitot-static boom and ship service airspeed systems were calibrated in level flight for position error by the contractor using a surveyed ground speed course. The contractor's airspeed calibrations were verified. The airspeed calibration data are presented in figures 40 and 41.

35. Ship service system position errors varied from +15 kt in NP climbs to -15 kt in autorotation as compared to the ship's system level flight position error. The large position errors associated with climbs and autorotative descents requires the pilot to remember large airspeed calibration corrections to establish optimum airspeeds (PRS A 5). Correction of the large variation in ship's

system position error associated with climbs and descents is desirable for improved Army use. The ship's service airspeed system is satisfactory for Army use in level flight (PRS A 2).

Weight Determination

36. Weight empty for determination of detail specification performance guarantees was based on the contractor's estimated weight statement of 20,213 pounds. The weight of the test helicopter with instrumentation, ballast boxes, and water ballast tanks was verified prior to starting the evaluation. Weight measurements were made with empty fuel cells (24,490 lb) and full fuel cells (31,620 lb). These weights were used for performance computations with actual fuel weight compensated for temperature.

MISCELLANEOUS

General

37. Within the scope of this test heavy cockpit and cabin vibrations limited the maximum obtained airspeeds under all conditions except at high altitudes and 235 rpm. At 235 rpm and high altitudes allowable envelope airspeeds (app VII) could easily be exceeded and indicated a need for a visual display to warn the pilot when aft rotor head limit flight control loads are being exceeded. The fuel quantity selector switch was difficult to manipulate due to its being spring loaded. The revised longitudinal cyclic speed trim schedule did not operate satisfactorily until the last two flights of the test.

Qualitative Vibration Evaluation

38. A limited qualitative evaluation of vibration levels was made during performance tests. The following definitions were used in assessing vibration levels:

a. Light (L): (PRS A 2)

b. Light to moderate (L-M): (PRS A 3 to PRS A 4)

c. Moderate (M): (PRS A 5)

d. Moderate to heavy (M-H): (PRS A 6)

e. Heavy (H): (PRS U 7)

39. Vibration levels were predominantly 3/rev in a vertical plane and appeared to increase in intensity as a function of increased KTAS and rotor speed. Cabin vibration levels generally correlated

with those experienced in the cockpit. Vibration levels were of a sufficient magnitude to restrict the airspeed at all gross weights by as much as 15 kt below the APE envelope V_{NE} airspeeds. The vibration restrictions to airspeeds occurred for all gross weights tested at 235 rpm and 245 rpm rotor speeds at low altitudes and at 245 rpm for high altitudes (high and low altitudes are defined in figs A and B, app VII). Reduction in vibration levels to allow an increased speed capability is desirable for improved Army use.

40. At high altitudes and 235 rpm rotor speed, the APE flight envelope V_{NE} was limited by stress levels on aft rotor flight control components. Density altitude changes affected the V_{NE} (fig A and B app VII) as much as -22 kt per 1000 ft increase at high density altitudes and the pilot was required to recompute V_{NE} whenever altitude or OAT changed (PRS A 5). The pilot had no aerodynamic cues, such as increased vibration levels or buffet onset, that warned of approaching V_{NE}. A visual display, which would allow the pilot to readily remain within the flight envelope airspeed limits and utilize the full capability of the helicopter, is desirable for improved Army use.

41. Under all conditions tested there was a transient increase in vibration levels of one vibration level rating when changing power or rotor speed. Transients were of 3 second to 4 second duration and resulted from the inertia characteristics of the self-tuning absorbers. The transient vibration characteristics were annoying to the pilot (PRS A 4). Reduction of transient vibration levels is desirable for improved Army use.

42. Vibration levels in climbs, autorotation and powered descents were light to moderate at rotor speeds from 235 rpm to 245 rpm. Cockpit vibrations increased rapidly from moderate at 250 rpm speed to heavy at 255 rpm during autorotations. The heavy vibration levels at 255 rotor rpm and above will effectively warn the pilot that the autorotational rotor speed limit of 261 rpm is being approached.

43. A vibration absorber "cycling" characteristic was usually encountered 5 kt to 10 kt prior to the onset of heavy vibrations and accounted for most of the moderate to heavy vibrations reported during the tests (PRS A 6). Correction of the cycling characteristic of the self-tuning absorbers is desirable for improved Army use.

Fuel System

44. The fuel system of the test helicopter was nonstandard, reflecting the engineering change proposal (ECP) 553 configuration in lieu of ECP 553R which is incorporated in the production CH-47C

helicopters. The fuel quantity measuring system was in the standard production configuration and functioned satisfactorily throughout the test with a system accuracy of ± 100 pounds (1.4 percent of total fuel load) at all times. The pilot was required to turn and hold a spring-loaded dial switch to obtain the individual tank reading. Selection of a particular tank required several seconds of the pilot's attention while waiting for the indicator needle to rotate to the appropriate quantity indication. During this time the pilot's attention was distracted from more important cockpit duties (PRS A 4). Elimination of the self-centering feature of the fuel selector switch is desirable for imrpoved Army use.

Longitudinal Cyclic Speed Trim

45. The YCH-47C incorporated a longitudinal cyclic speed trim (LCST) control which automatically programmed the incidence of the forward and aft rotor heads over a speed range of 60 KIAS to 160 KIAS. The actuator movement was programmed as presented in table 5. Performance data obtained using the original aft LCST schedule was corrected to reflect the effect of the revised schedule. During level flight tests, improper programming by the LCST control box permitted full extensions of the actuators at 144 KIAS. Replacement of the control box failed to correct the problem. Recalibration of the control box used during the initial portion of APE I testing was required to achieve an acceptable speed trim schedule. The LCST control boxes used on the test helicopter were -23 models which had been modified to the -26 production configuration by resetting the system voltages. The contractor's tolerance band for the currect production LCST control box is ±13 kt. During the last two flights of the evaluation the LCST schedule was programming properly within the ±13 kt tolerance band.

Table 5. LCST Schedules.

Forward	Aft
$+1.5^{\circ}$ to -3°	-1.5° to -6° (original LCST schedule)
	$+.5^{\circ}$ to -4° (revised LCST schedule)

CONCLUSION

GENERAL

46. Within the scope of this test, the aircraft and engine performance characteristics met all the requirements.

SHORTCOMINGS AFFECTING MISSION ACCOMPLISHMENT

47. Correction of the following shortcomings is desirable for improved helicopter operation and mission capabilities:

a. Cycling characteristic of the self-tuning absorbers (para 42).

b. Lack of a visual display to allow the pilot to remain within the flight envelope limits (para 40).

c. High vibration levels which restricted the helicopter from reaching the envelope airspeed limits at low altitudes (para 39).

d. Apparent weak speed stability characteristics in level flight (para 20).

e. Apparent weak speed stability characteristics in climb (para 25).

f. Imprecise torque control (para 32).

g. Nonuniform torque distribution when making power and/or rotor speed changes (para 33).

h. Lateral vibration characteristic during high powered climbs (para 27).

i. Large variation in ship's system position error associated with climbs and autorotative descents (para 35).

j. Self-centering feature of the fuel selector switch (para 45).

k. Transient increases in vibration when changing power or rotor speeds (para 40).

RECOMMENDATIONS

48. Correct those shortcomings stated in paragraph 47 for which correction is desirable for improved helicopter operation and mission capabilities.

49. Further testing be conducted during the CH-47C Phase D test to define autorotative performance characteristics.

APPENDIX I
REFERENCES

1. Document D8-0315, "CH-47 Product Improvement Program, CH-47B and CH-47C Helicopters," with revision, 13 February 1967, Vertol Division of the Boeing Company.

2. Letter, AMSTE-BG, USATECOM, 17 June 1966, subject: "Test Directive, Product Improvement Test, CH-47C Helicopter."

3. Test Plan, "Engineering Flight Test of the CH-47C Helicopter, Army Preliminary Evaluation," USAAVNTA, January 1968.

4. Document 114-PJ-803, "Detail Specification for the Model CH-47C Helicopter," 7 December 1967, Vertol Division of the Boeing Company.

5. Letter, AMSAV-EF, USAAVCOM, 16 February 1968, subject: "Preliminary Flight Envelope, CH-47C," with revision 1 dated 21 February 1968.

6. Lycoming Model Specification T55-L-11, "Shaft Turbine Engine Lycoming LTC 43-11B Specification number 124.27," amended 12 October 1966.

7. Document 114-TN-601, "Procedures for Demonstrating Compliance to CH-47B and CH-47C Helicopter Structural and Performance Guarantees," November 1966.

8. Report FTC 66-2, "Category II Performance Tests of the CH-47A Helicopter," AFFTC, May 1966.

APPENDIX II
TEST DATA

Figure No. 1
Compressibility Correction Curve
Hover
CH-47C Helicopter

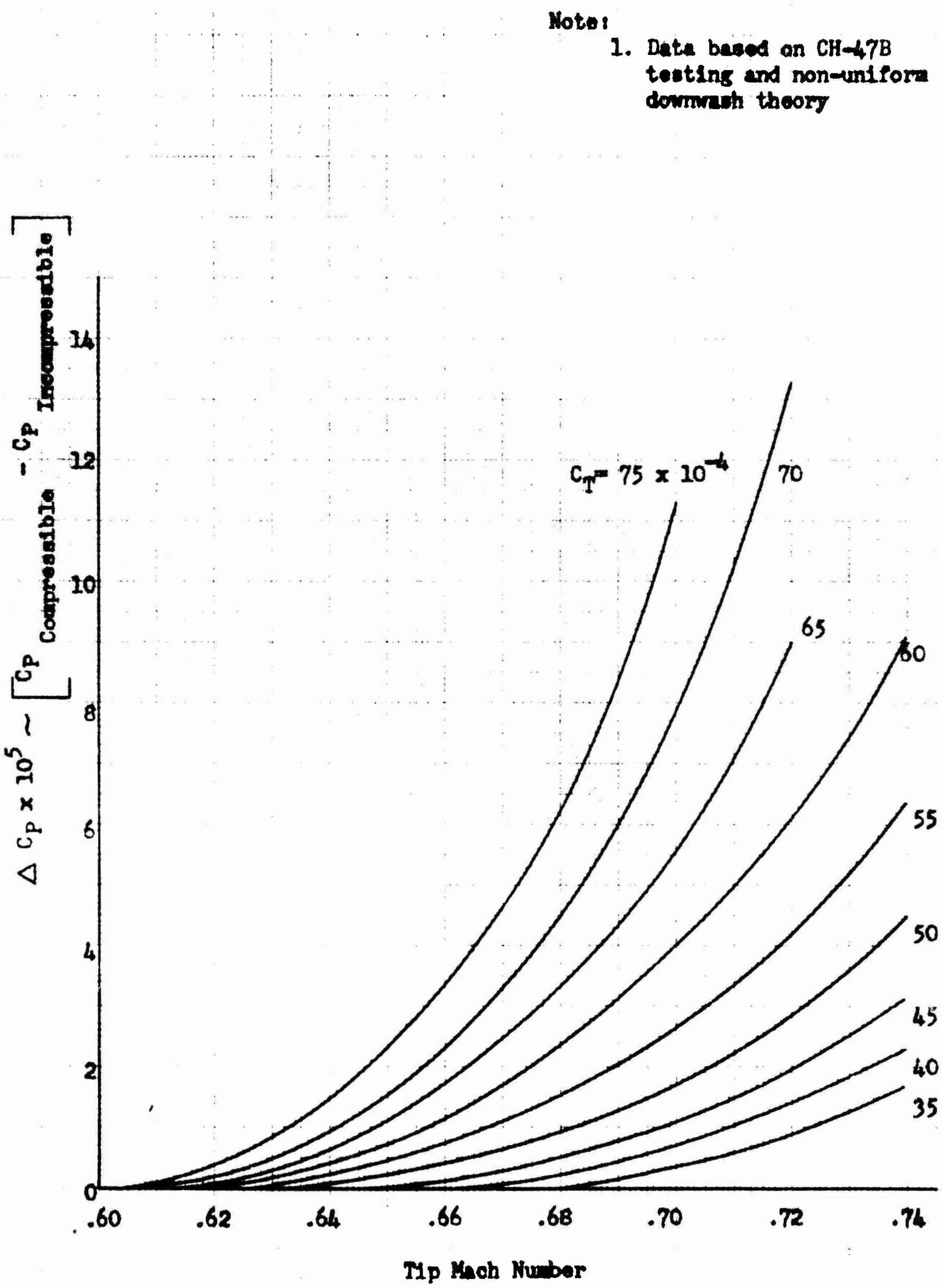


Figure No. 2
Corrections for Non-constant Referred Rotor Speeds
in Level Flight
CH-47C Helicopter

$N/\sqrt{\theta} = 235$ R.P.M.

Note:
1. Based on CH-47B Testing and non-uniform downwash theory
2. Not valid for Δ R.P.M. $> \pm 2$ R.P.M.

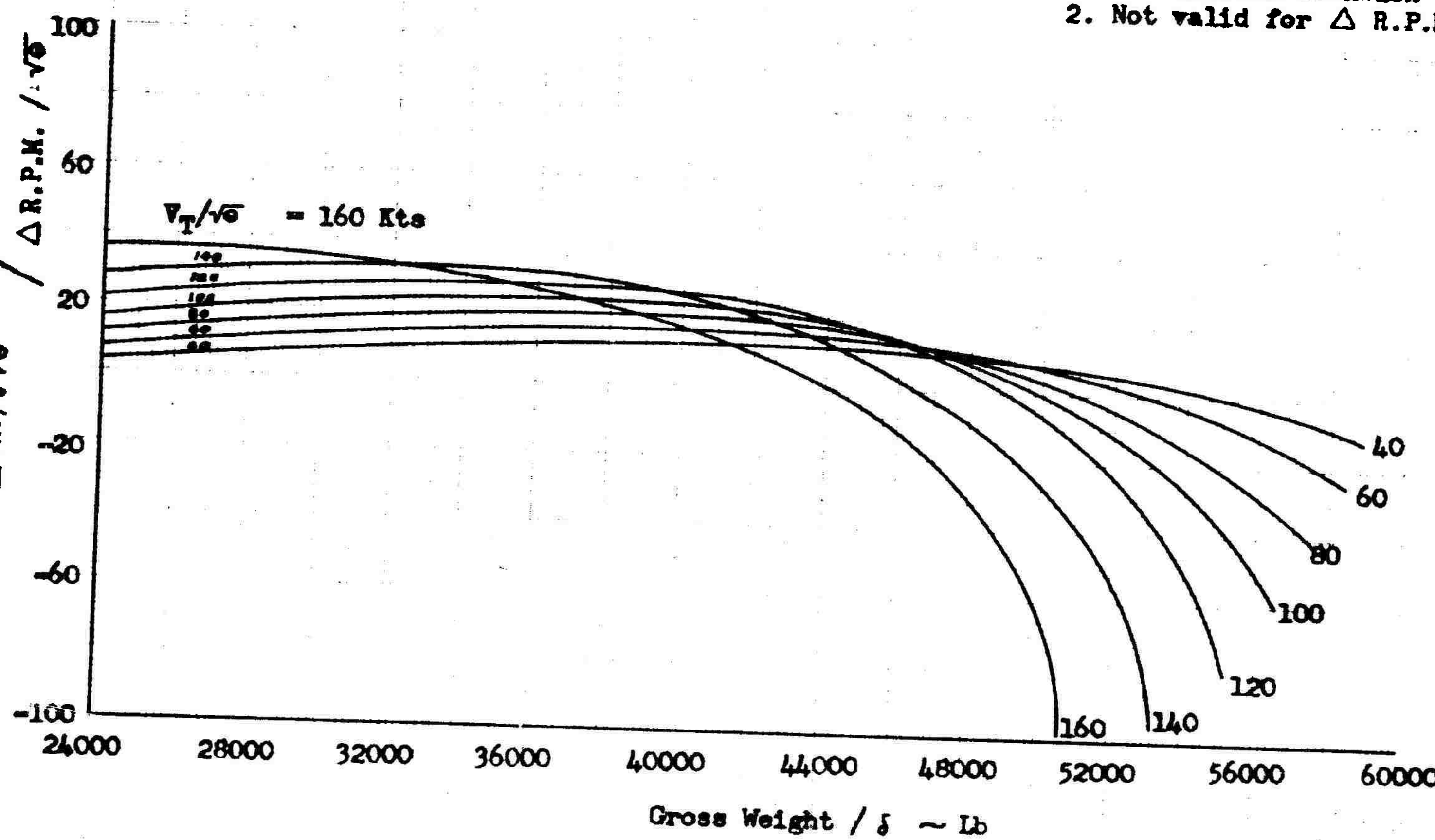


Figure No. 3
Corrections for Non-constant Referred
Rotor Speeds in Level Flight
CH-47C Helicopter
$N/\sqrt{\sigma} = 243$ R.P.M.

Note:
1. Based on CH-47B testing and non-uniform downwash theory
2. Not valid for ΔR.P.M. $> \pm 2$ R.P.M.

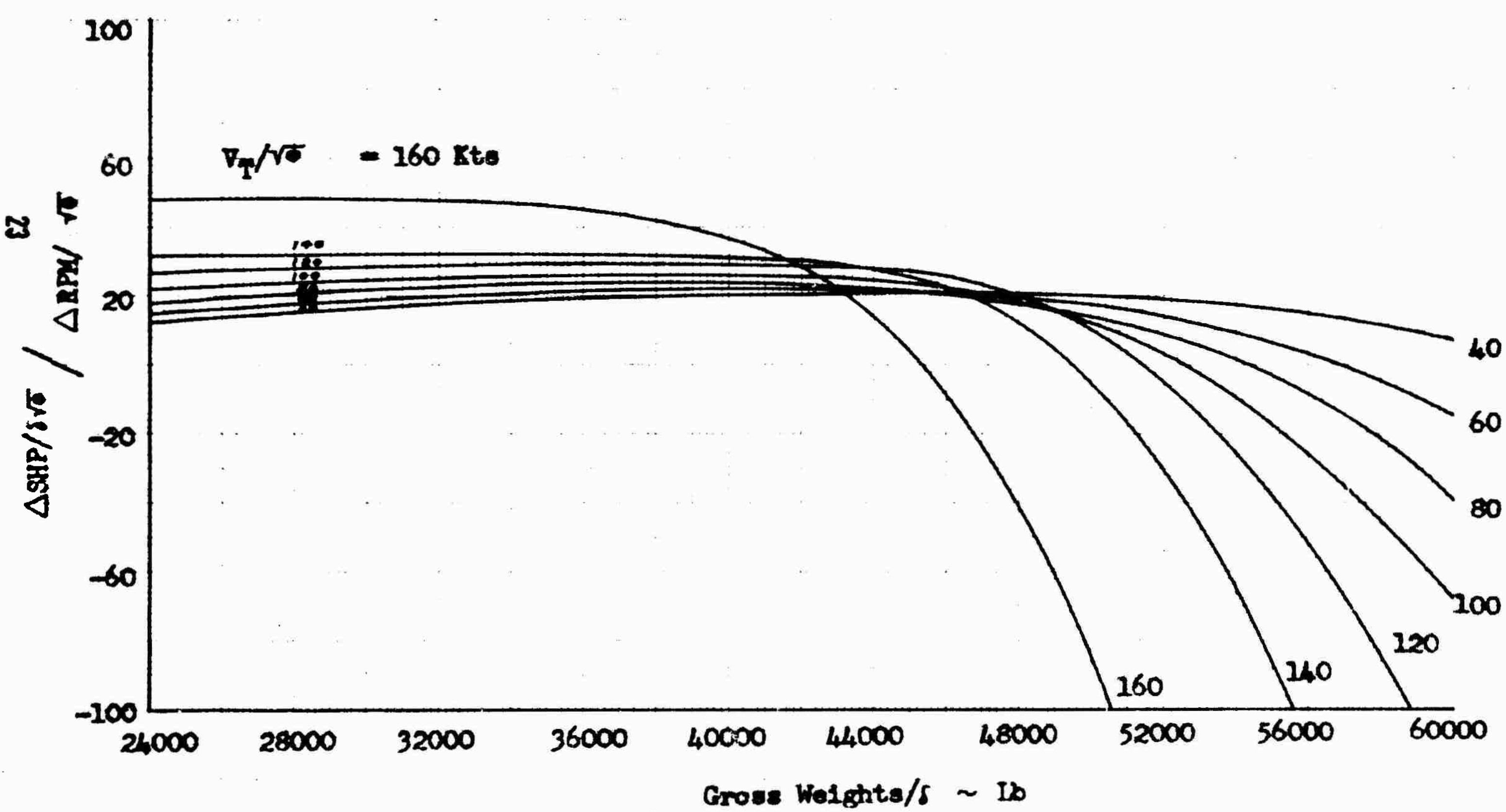


Figure No. 4
Hover Ceiling in Ground Effect
CH-47C
Maximum Power: Two T55-L-11 Engines
Rotor Speed = 245 R.P.M.
Wheel Height = 10 Ft

Note:
1. Curve based on Figure 5
2. Figure 1 used to adjust for compressibility effects due to varying referred rotor speeds
3. Transmission limited power based on 1015 ft.-lbs.
4. Dashed lines based on extrapolated data.

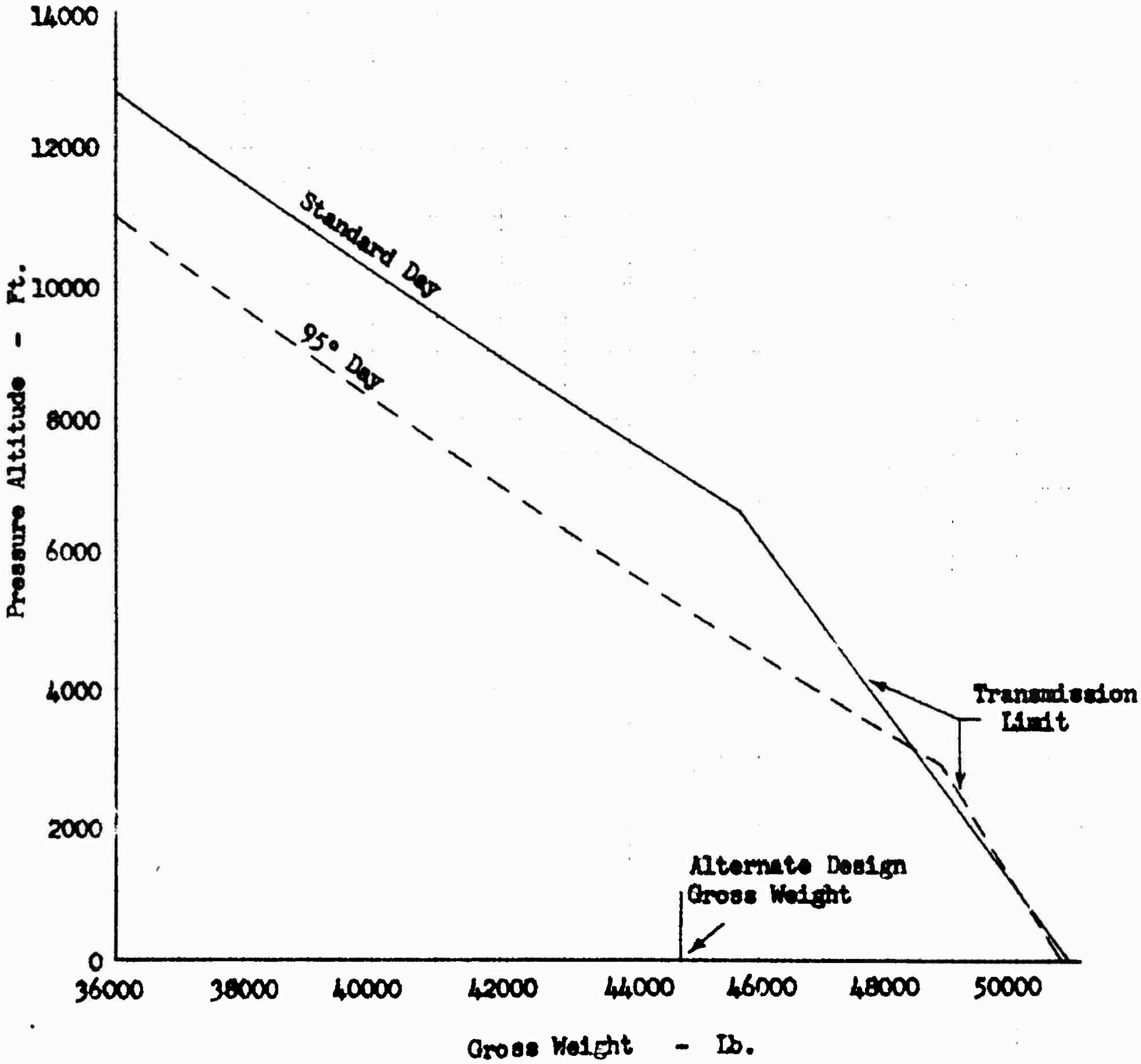


Figure No. 5
IGE Non-dimensional Hovering Performance
YCH-47C U.S.A. S/N 66-19121
Free Flight Hover
Wheel Height=10 Ft.
$N/\sqrt{\sigma}$ = 245 R.P.M.

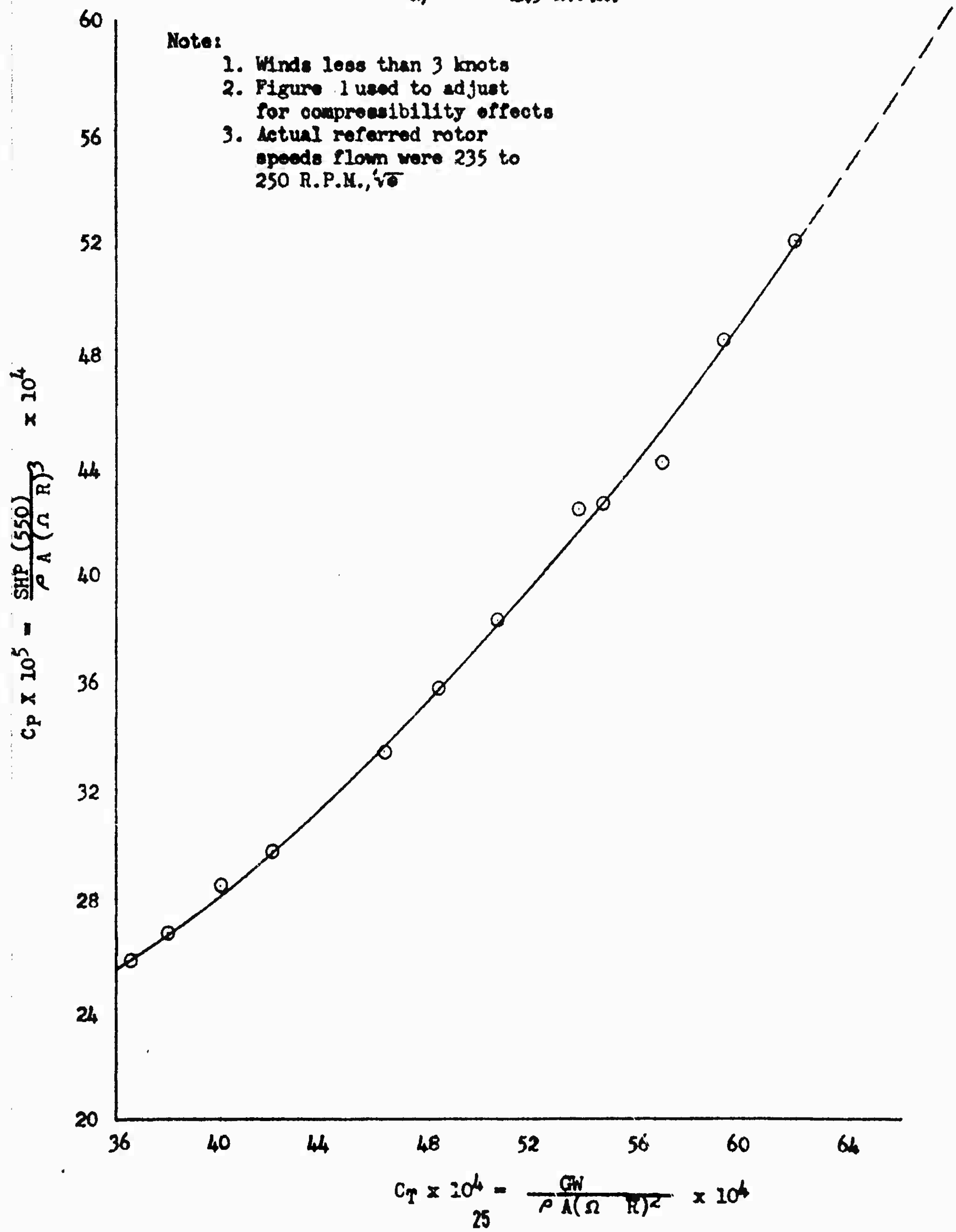


Figure No. 6
Hover Ceiling Out of Ground Effect
CH-47C
Maximum Power - Two T55-L-11-Engines

Note:
1. Curve based on Figure
2. Figure 1 used to adjust for compressibility
3. effects due to varying referred rotor speeds
3. 40000 lbs is the 235 RPM APE envelope limit
4. Dashed lines based on extrapolated data
5. Transmission limited power based on 1015 ft-lbs.

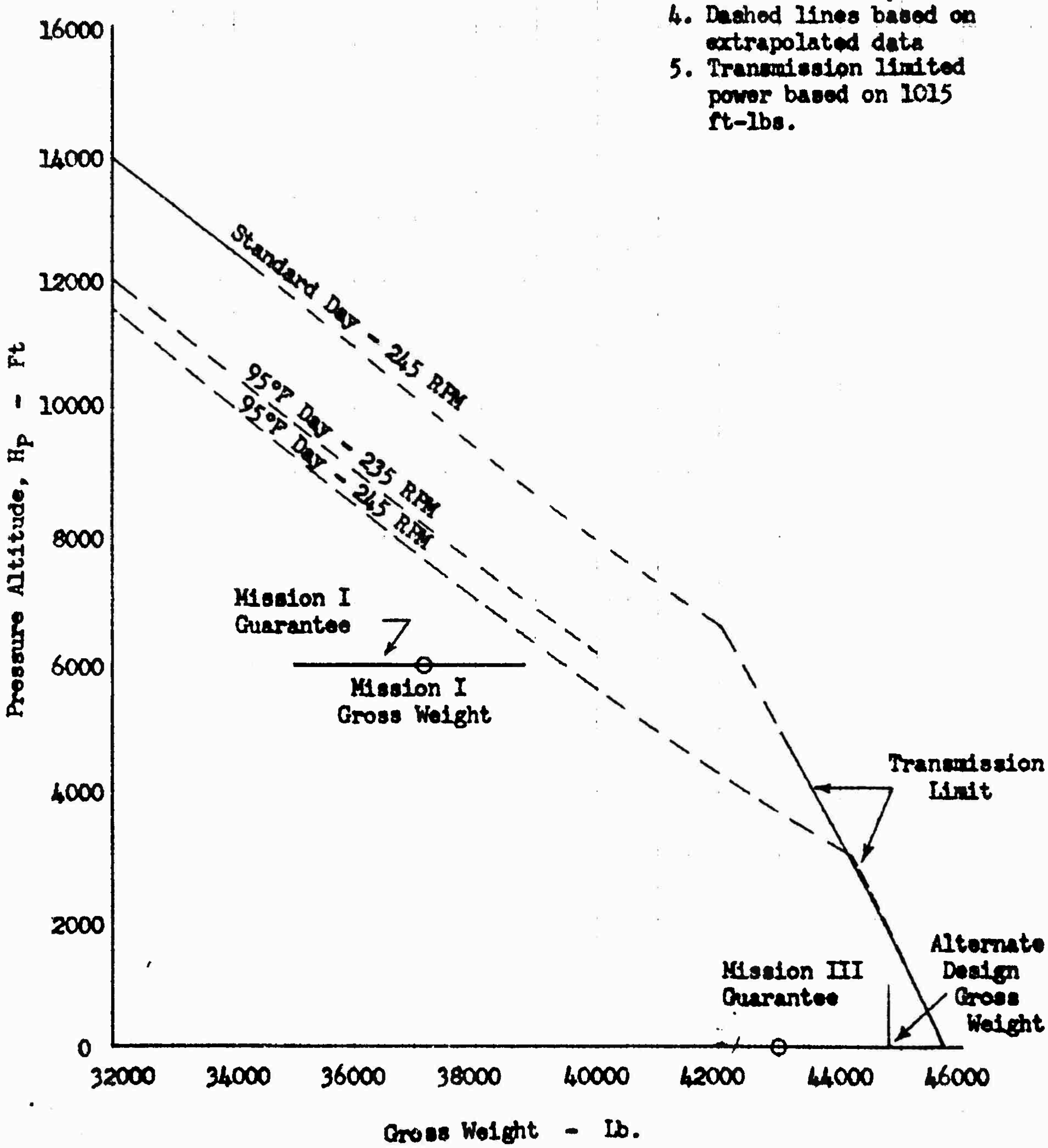


Figure No. 7
OGE Non-dimensional Hovering Performance
YCH-47C U.S.A. S/N 66-19121
Free Flight Hover
Radar Height = 150 Feet
$N/\sqrt{\theta}$ = 245 R.P.M.

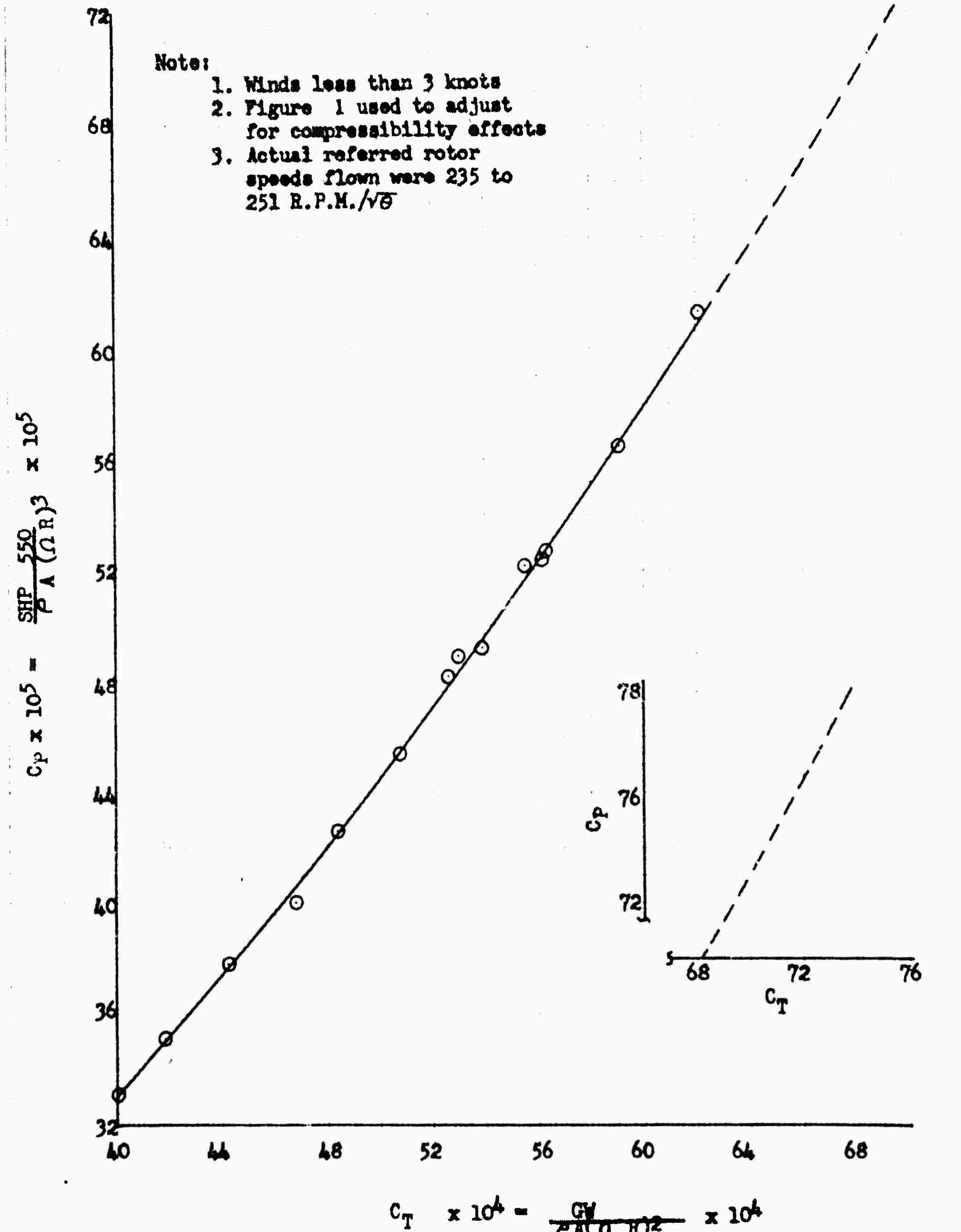


Figure No. 8
Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
Mid C.G.
N/√θ = 235 R.P.M.

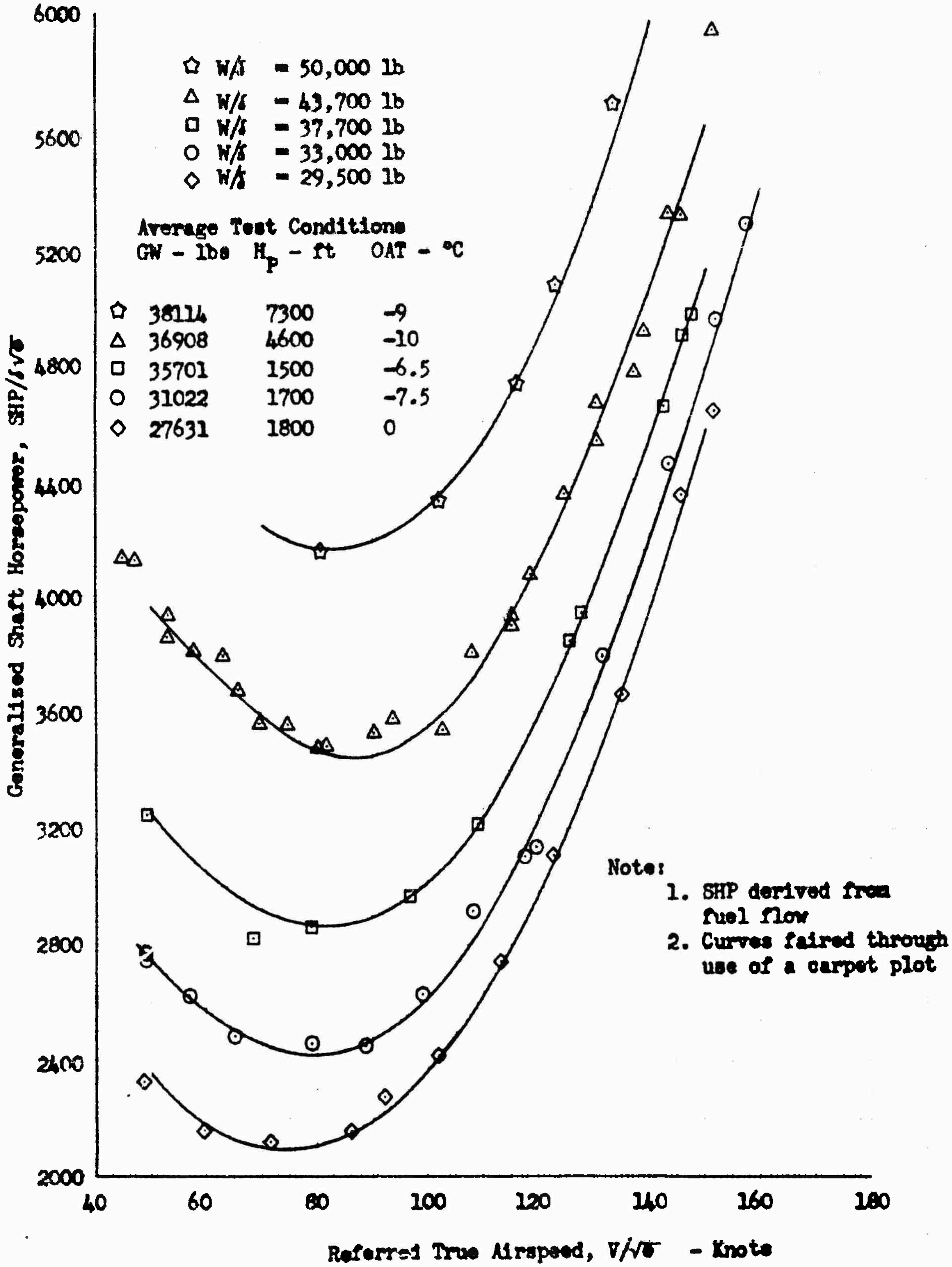


Figure No. 9
Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
Mid C.G.
$N/\sqrt{\theta}$ = 245 RPM

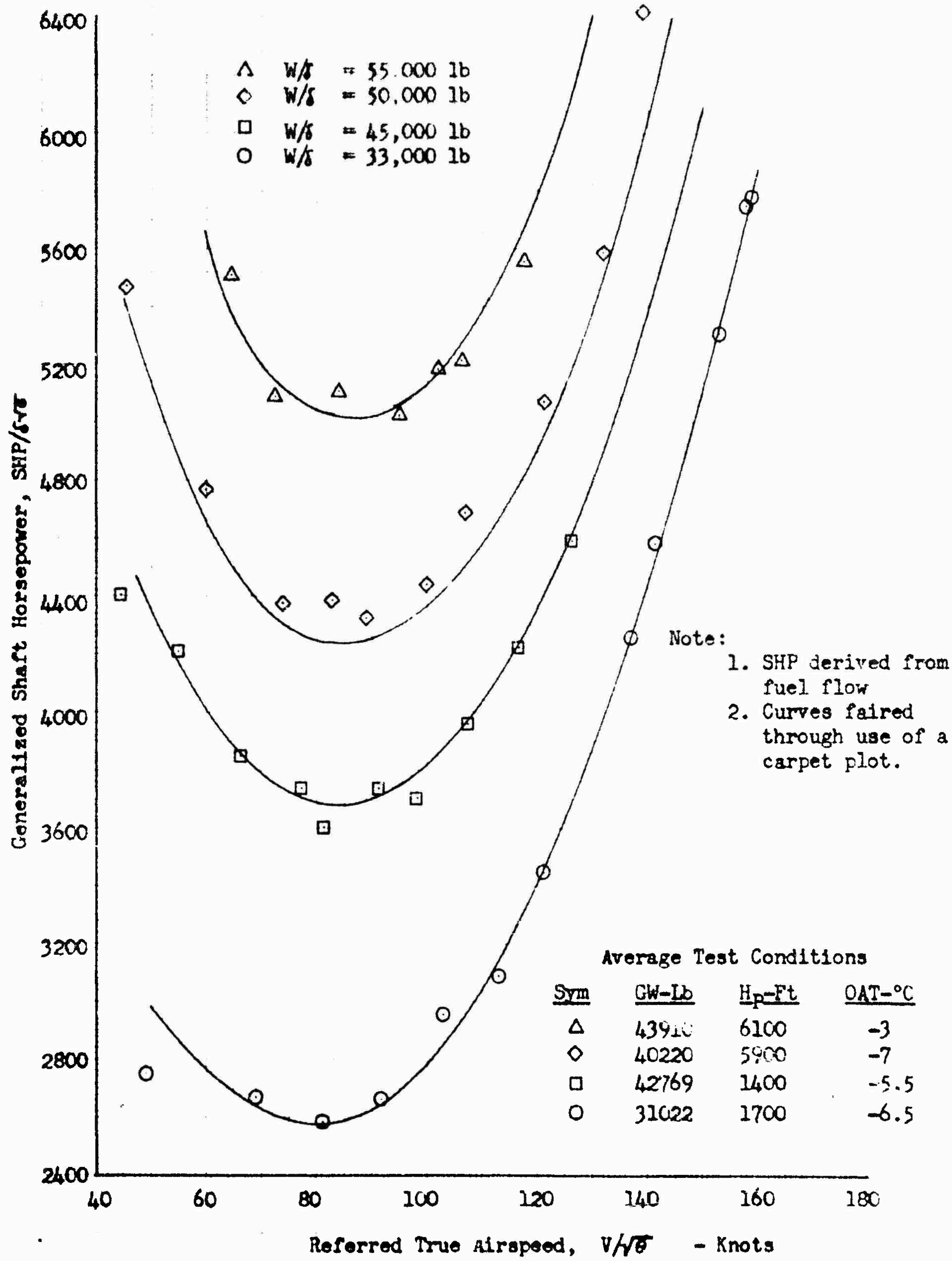


Figure No. 10
Non-dimensional Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
$N/\sqrt{\sigma}$ = 235

Note:
1. Curves based on Figure 8

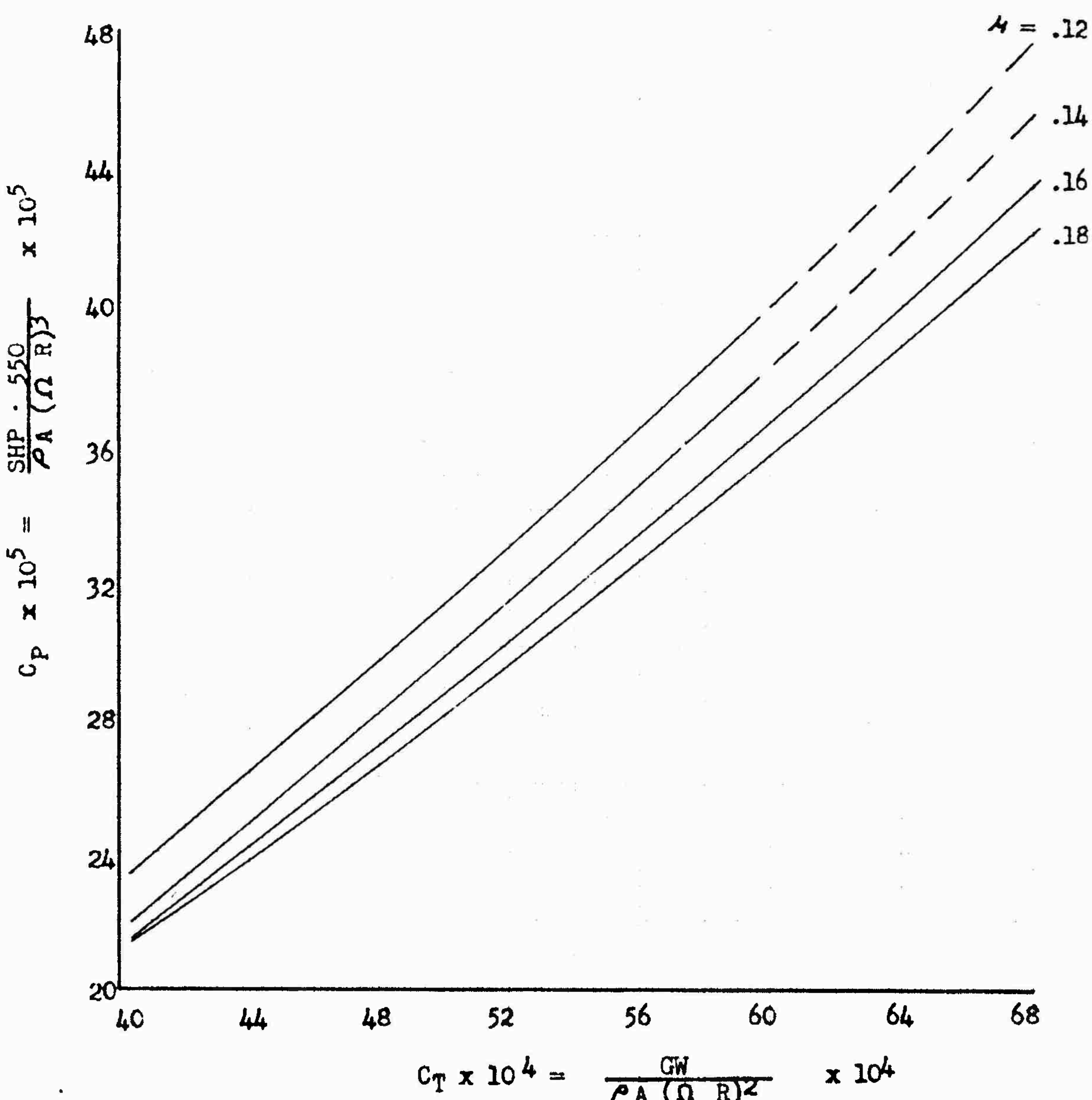


Figure No. 11
Non-Dimensional Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
$N/\sqrt{\sigma} = 235$

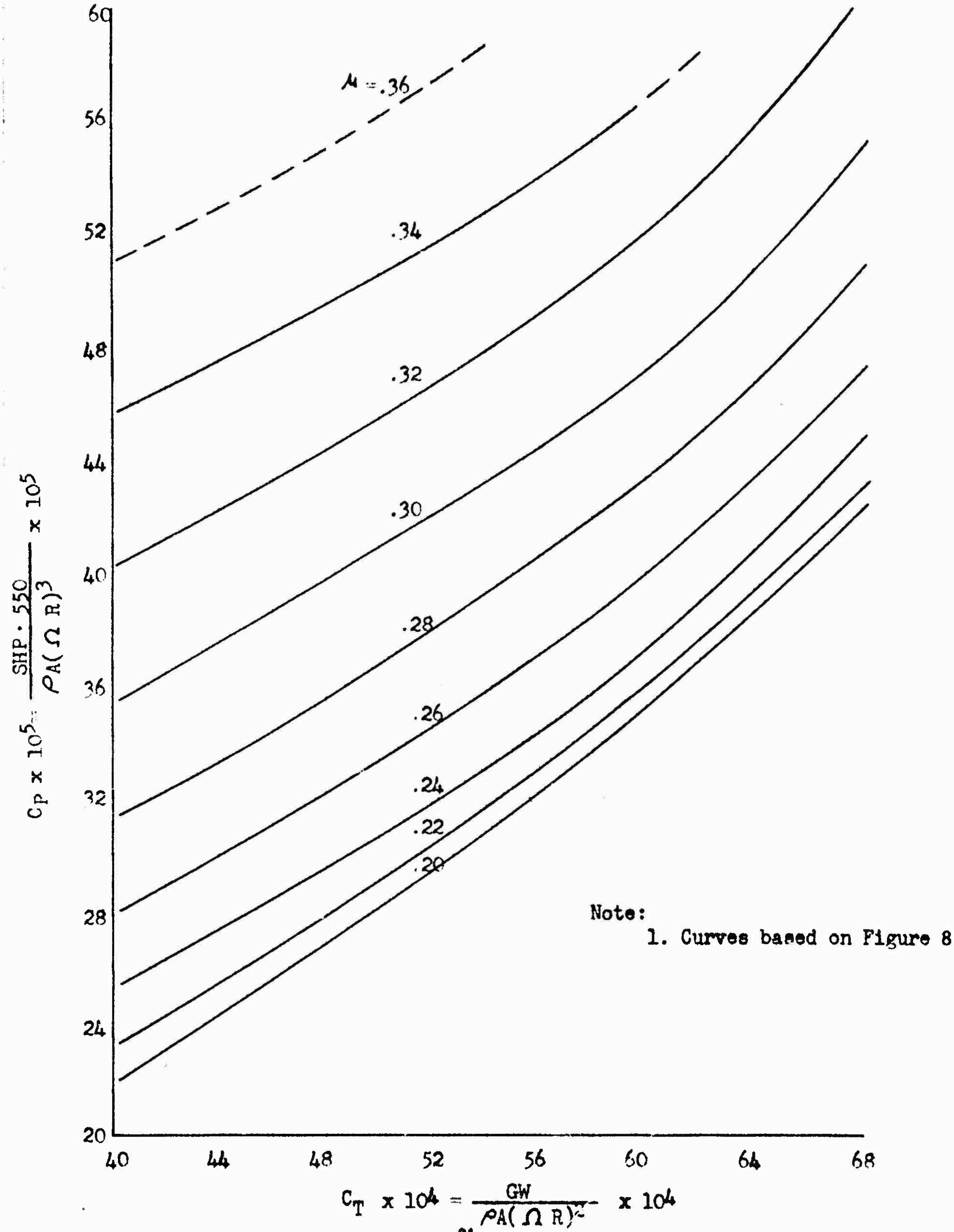


Figure No. 12
Non-dimensional Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
$N/\sqrt{\sigma} = 245$

Note:
1. Curves based on Figure 9

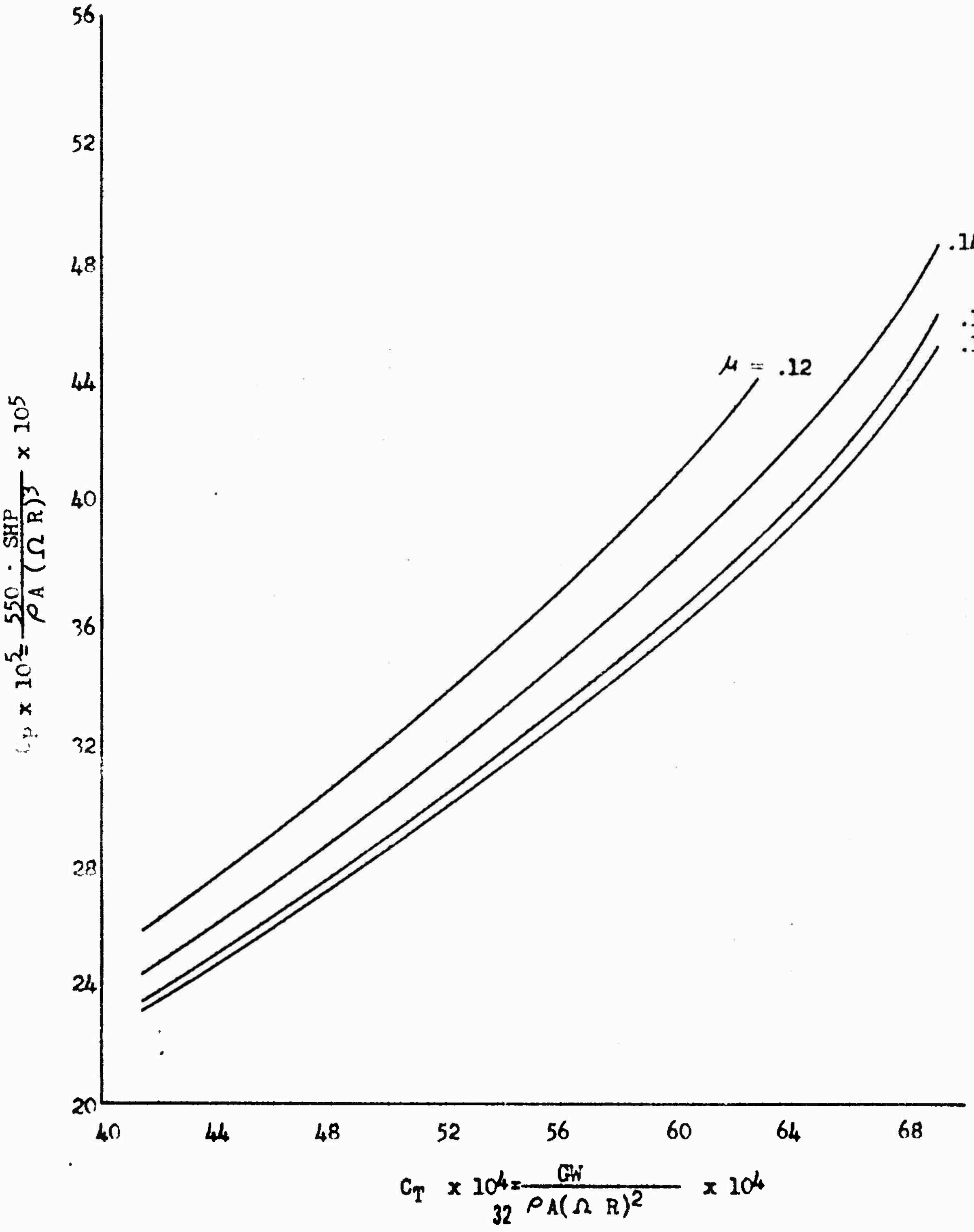


Figure No. 13
Non-dimensional Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
$N/\sqrt{\theta} = 245$

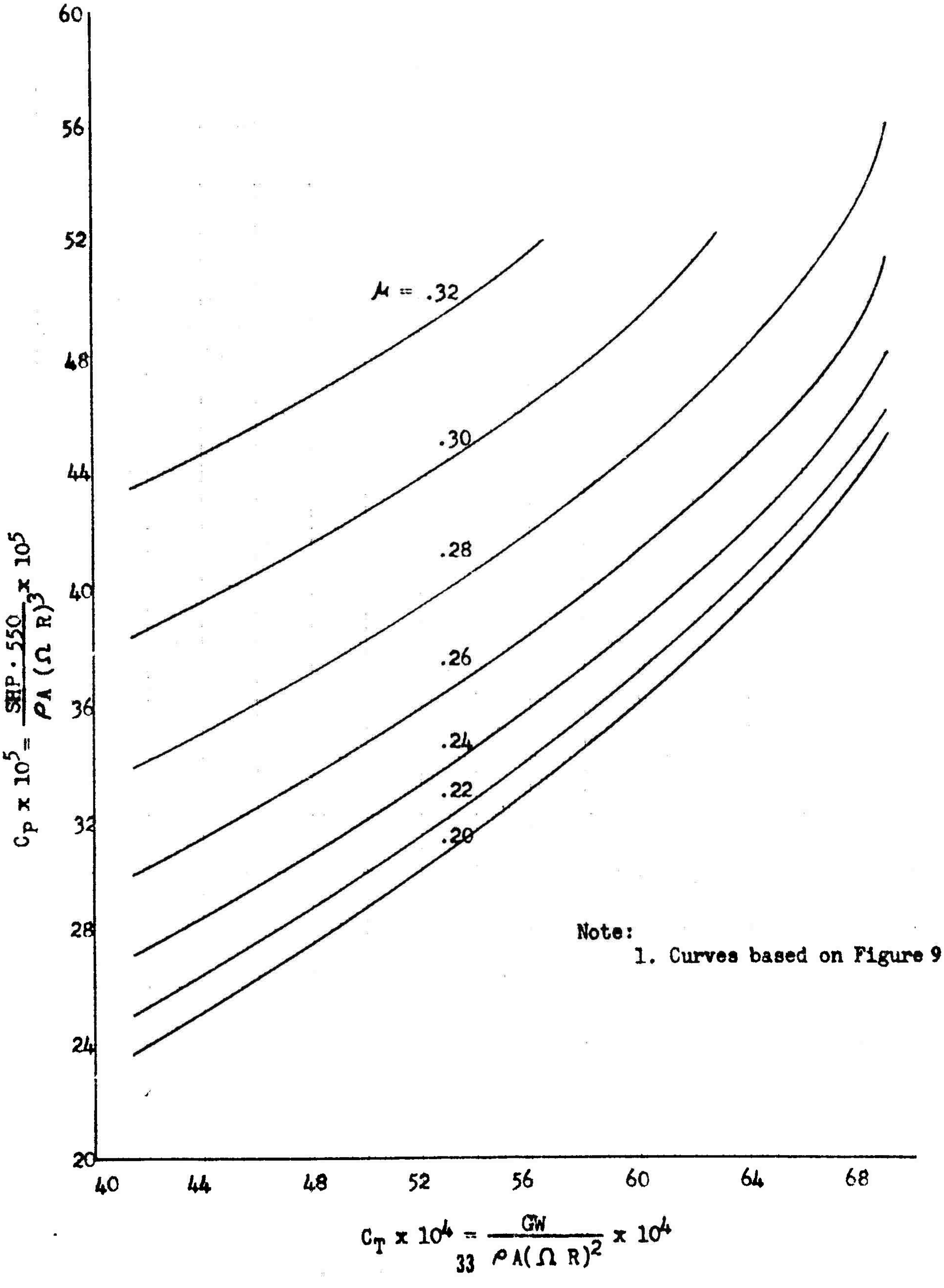


Figure No. 14
Range Summary
CH-47C
Sea Level Standard Day
Rotor Speed = 235 RPM

Note:
1. Based on Figure 16
2. Mission Profile: 2 min at NRP, outbound at best cruise speed, 2 min at NRP, inbound at best cruise speed with ½ outbound load, arrive with 10% initial fuel
3. Take-off gross weight consists of empty weight, fixed useful load, outbound load, and initial fuel
4. 40,000 lb is 235 RPM envelope limit
5. Fixed useful load contains 36 lb of unusable fuel

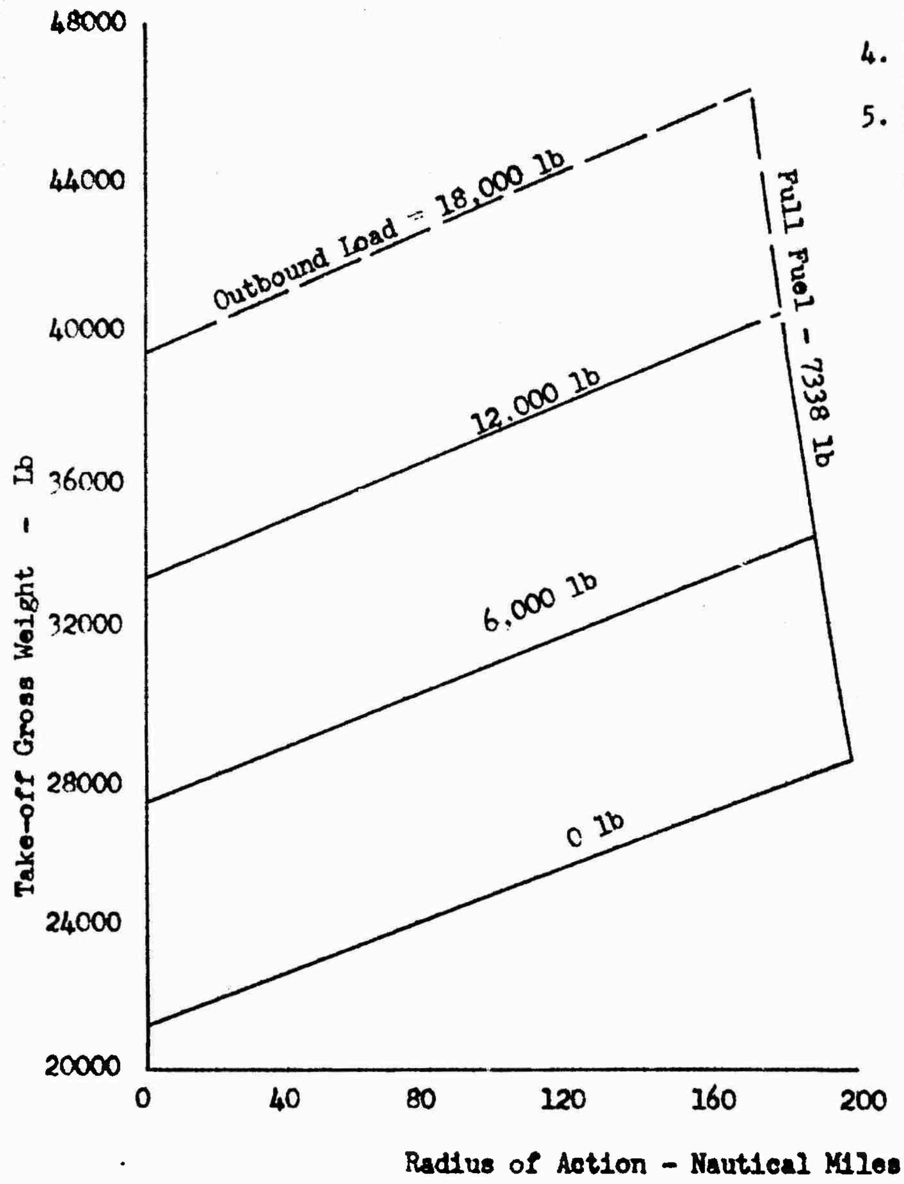


Figure No. 15
Range Summary
CH-47
Sea Level Standard Day
Rotor Speed=245 RPM

Note:

1. Based on Figure 16
2. Mission Profile: 2 min at NRP outbound at best cruise speed, 2 min at NRP inbound at best cruise speed with ½ outbound load, arrive with 10% initial fuel
3. Take off gross weight consists of empty weight, fixed useful load, initial fuel, and outbound load.
4. Fixed useful load contains 36 lb of unusable fuel
5. 46,000 lb is 245 RPM envelope limit

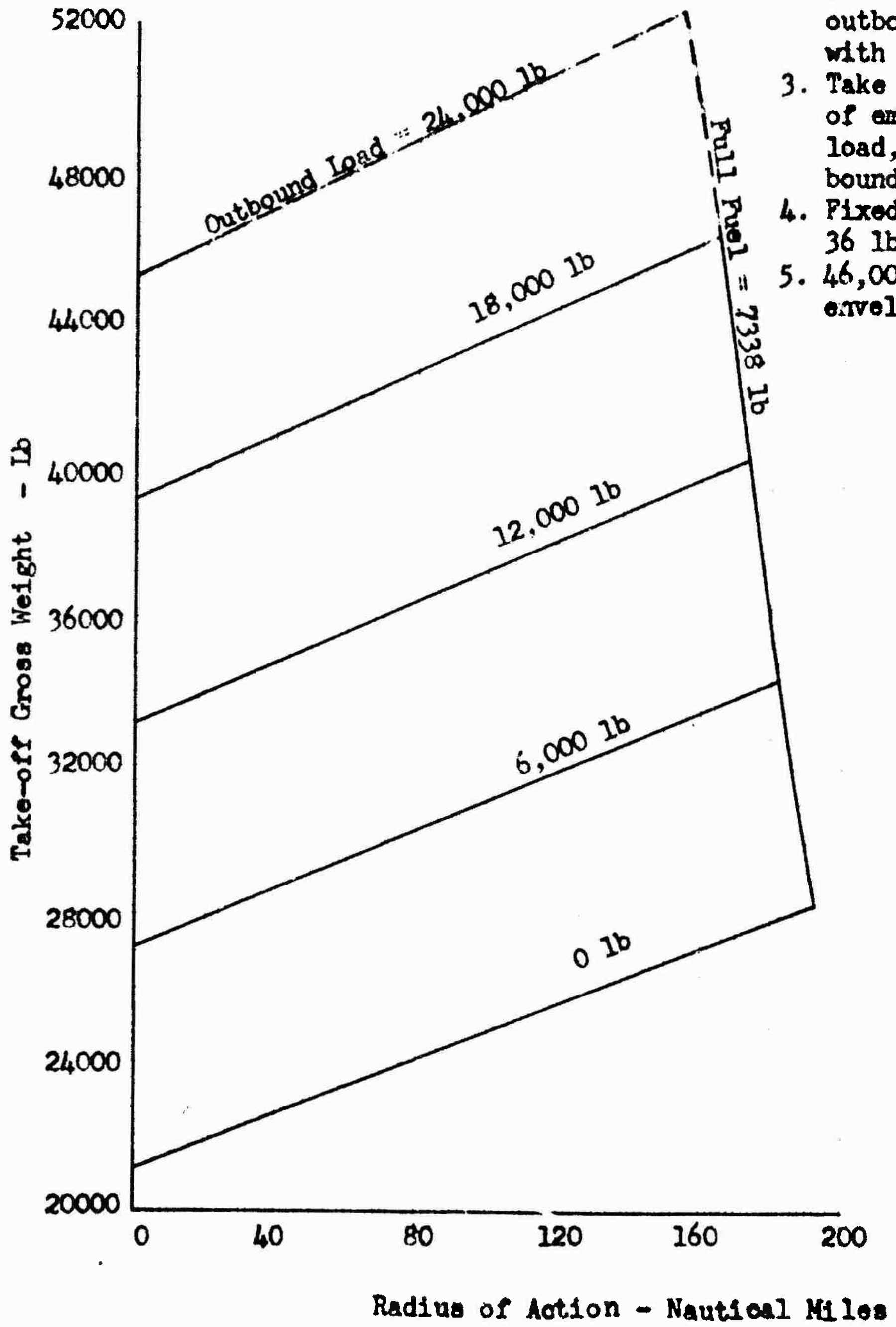


Figure No. 16
Level Flight Range Summary
CH-47C
Sea Level Standard Day

Note:
1. Curves derived from Figures 17 and 18
2. Specific range based on max. NAMPP
3. T55-L-11 Specification fuel flow
4. 40,000 lb is 235 RPM envelope limit

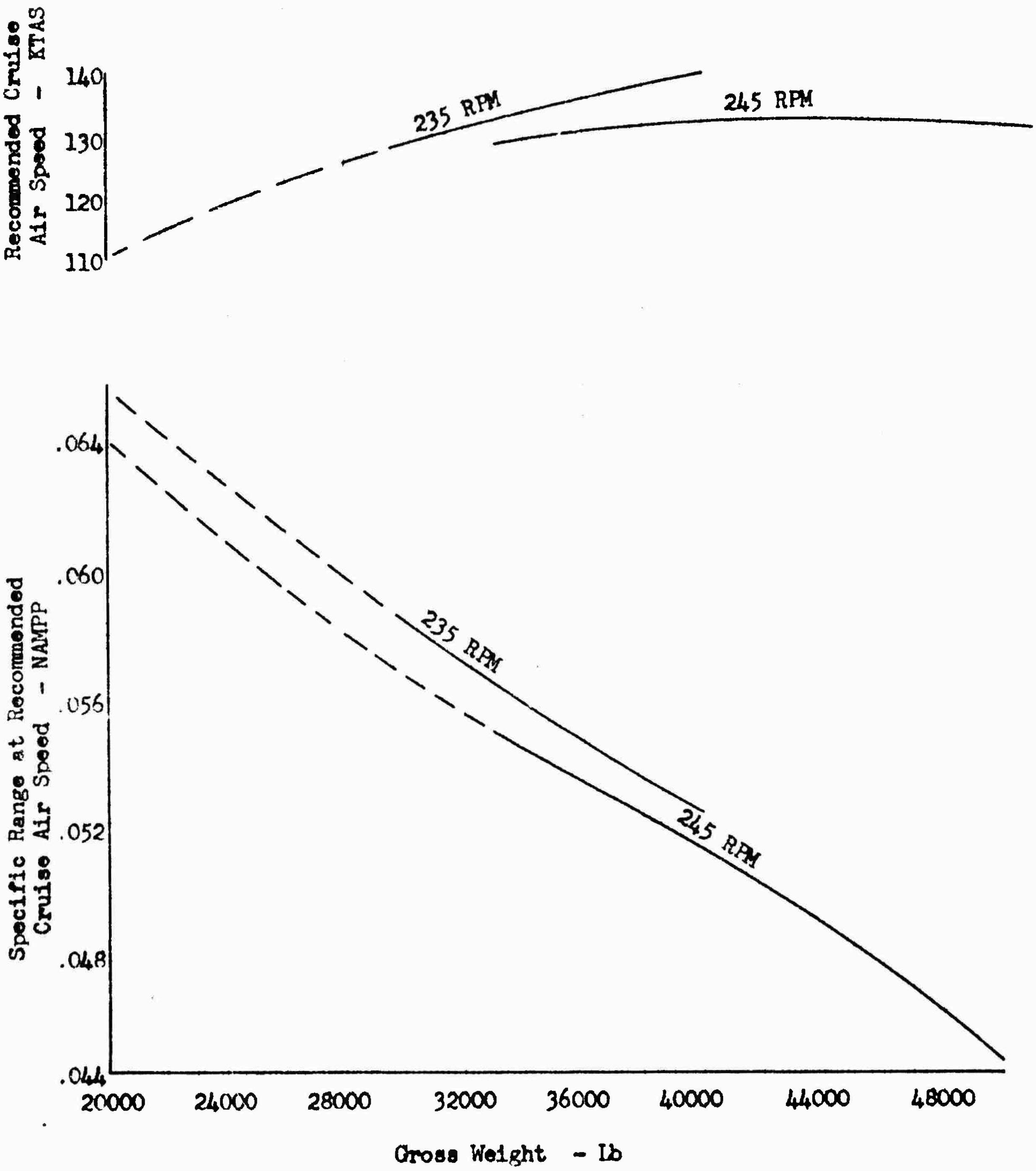


Figure No. 17
Level Flight Specific Range
CH-47C
Sea Level Standard Day
Rotor Speed = 235 RPM

Note:
1. Curves based on level flight data and T55-L-11 engine specification. (Figures 8 and 19
2. 40.000 lb is 235 RPM envelope limit

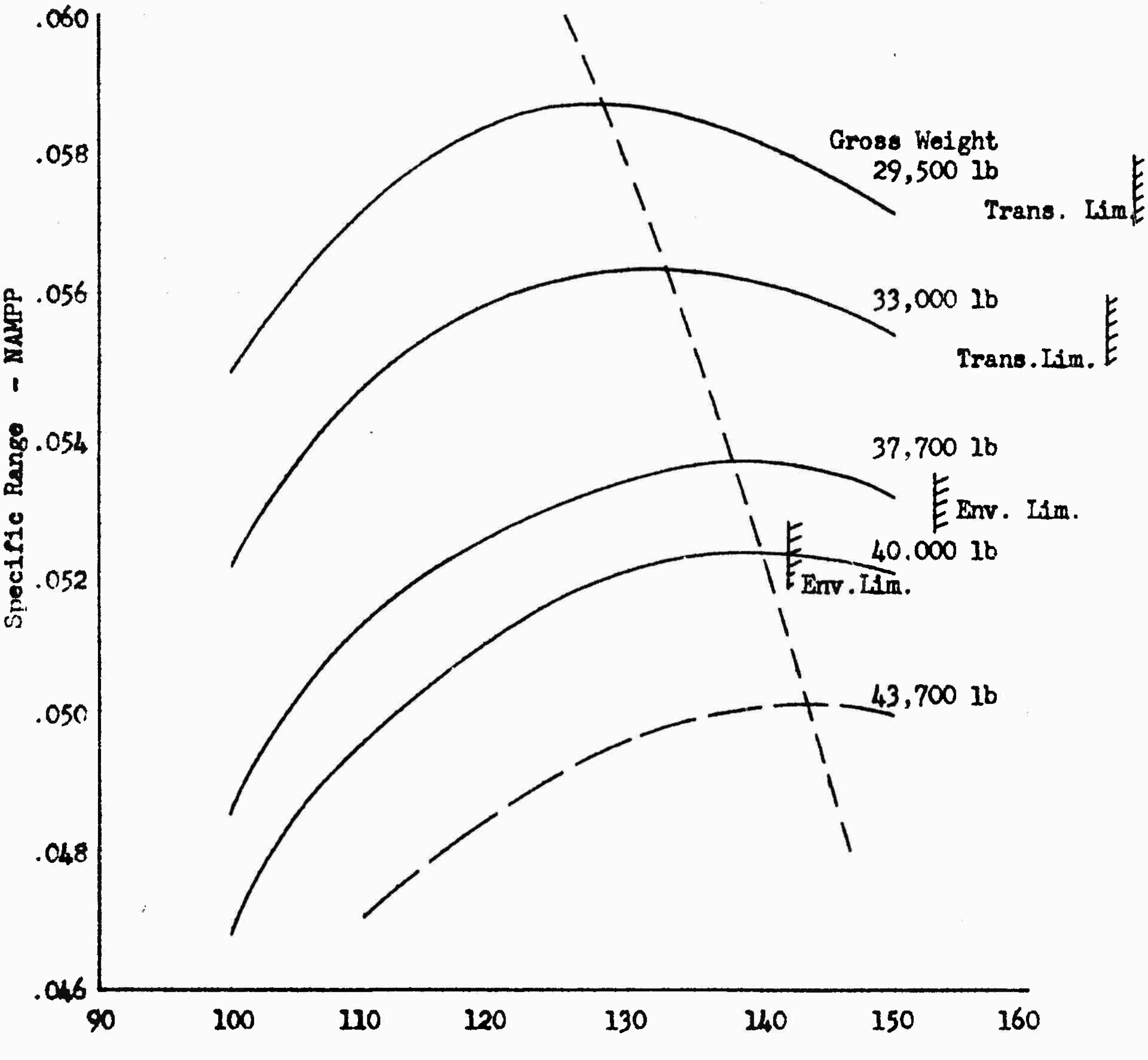


Figure No. 18
Level Flight Specific Range
CH-47C
Sea Level Standard Day
Rotor Speed - 245 RPM

Note:

Curves based on level flight data and T55-L-11 engine Specification. (Figures 9 and 19).

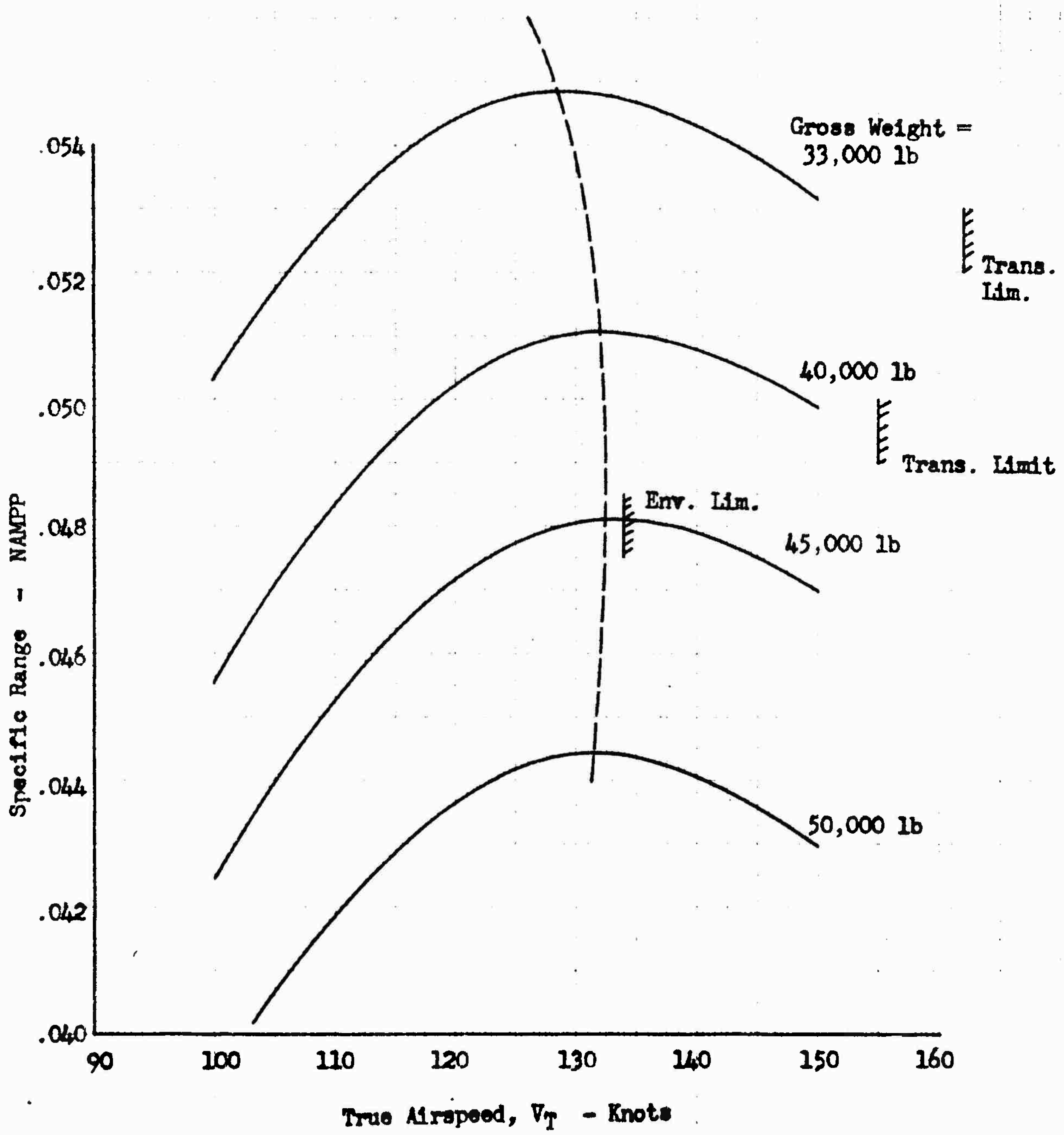


Figure No. 19
Fuel Flow vs Power and Airspeed
Lycoming T55-L-11 Engine
Sea Level - Standard Day
N_{II} = 15,550 RPM

Note:
1. No bleed air or power take off
2. No heat rise in inlet
3. Based on T55-L-11 engine specification

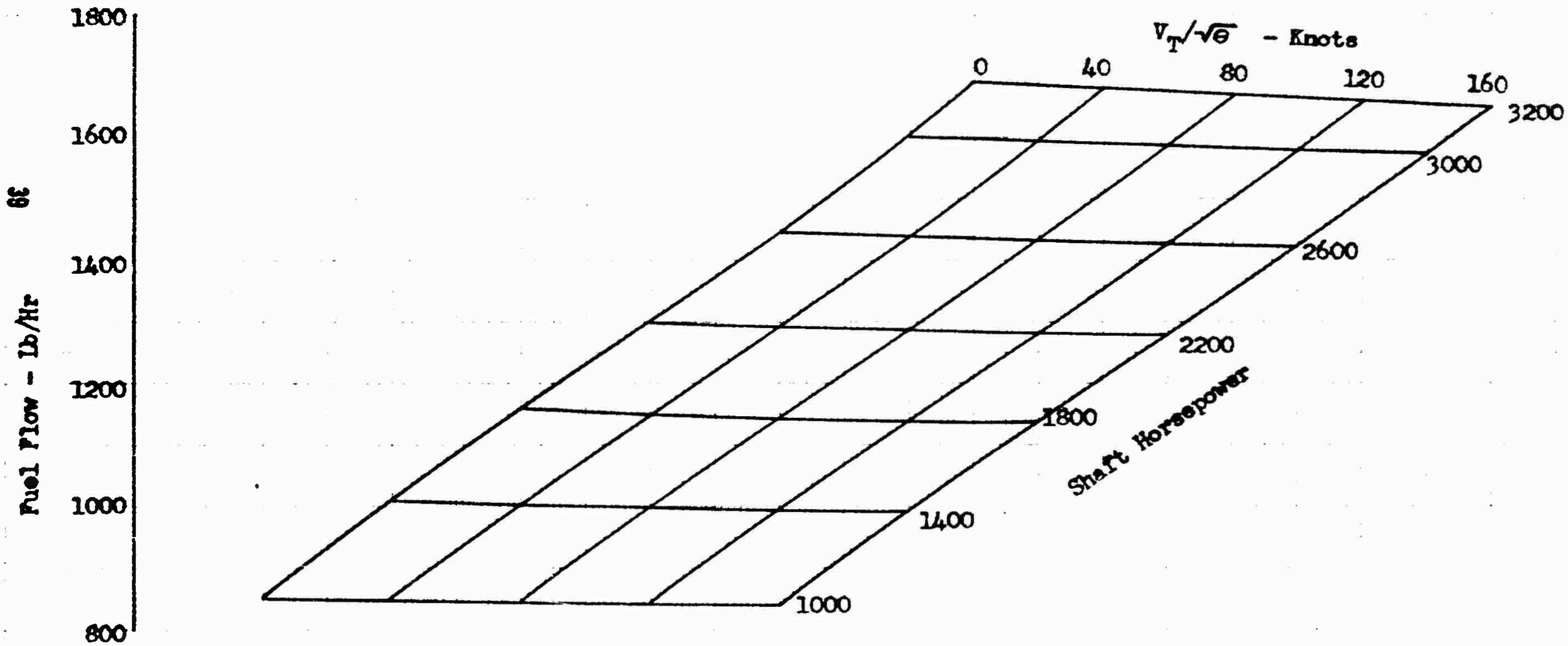


Figure No. 20
Inlet Losses
CH-47A U.S.A. S/N 60-3448

Note:
Curves taken from AFFTC CH-47A
Cat II Technical Report No. 66-2
May 1966

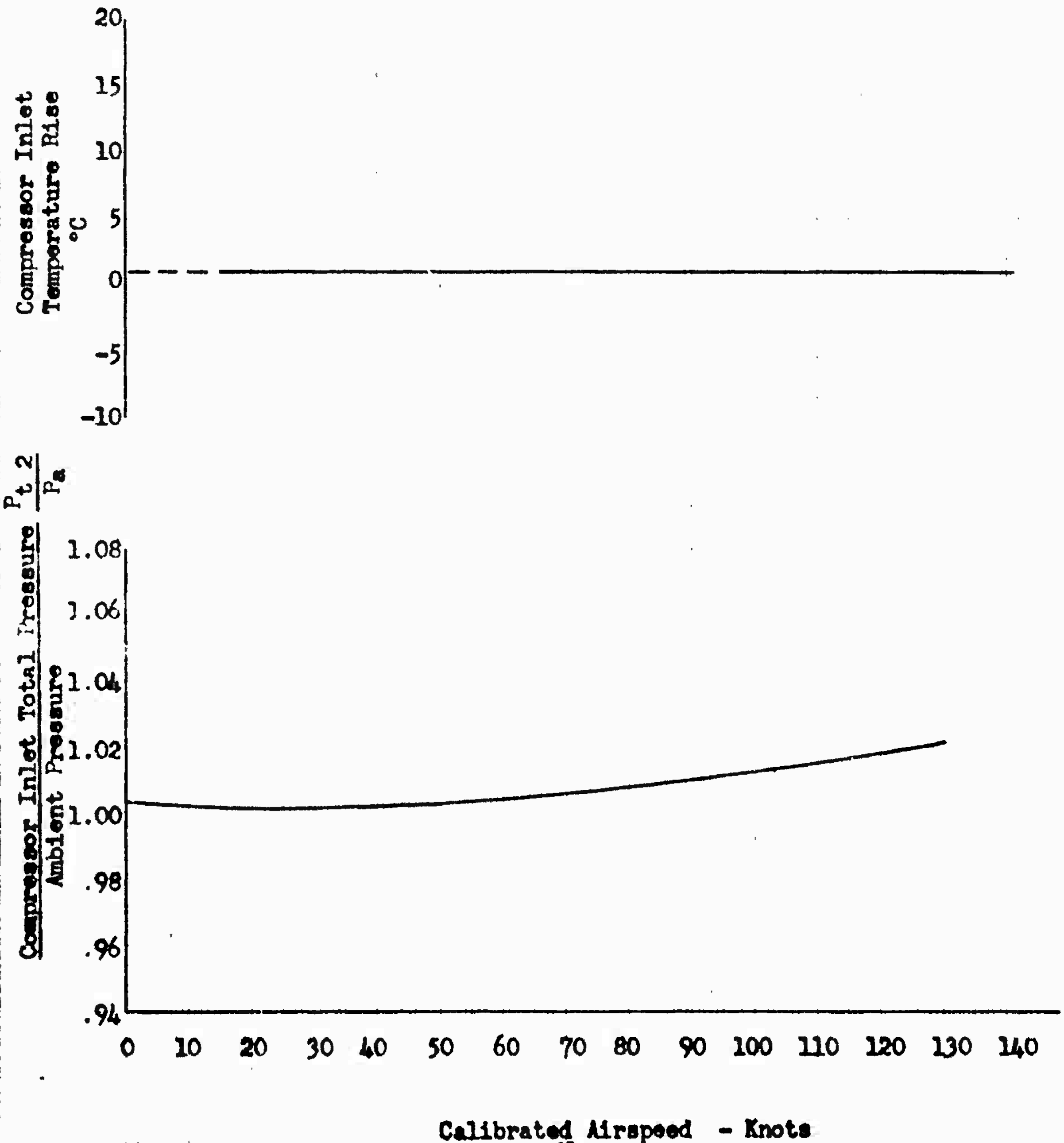


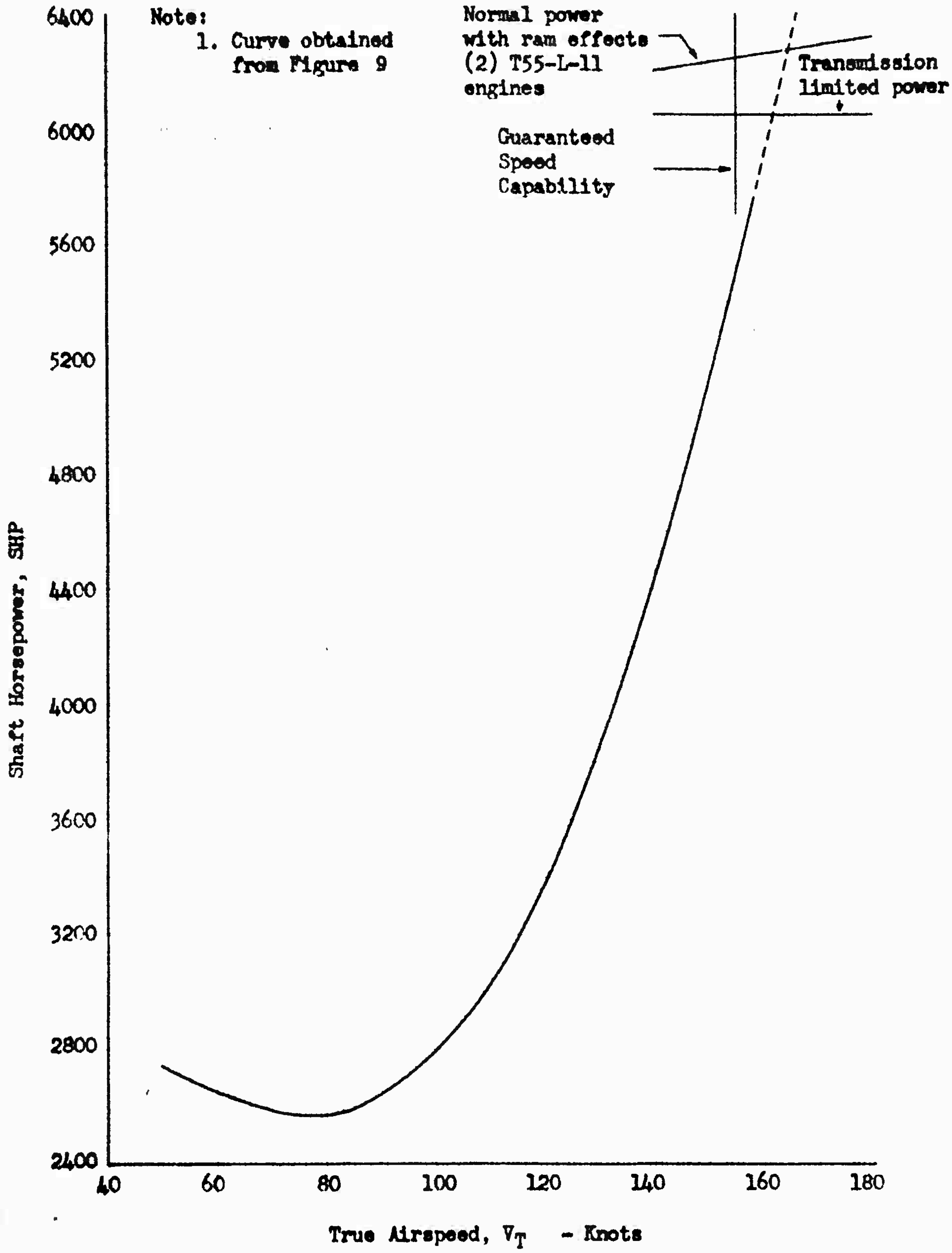
Figure No. 21

Sea Level Standard Day Level Flight Performance

YCH-47C U.S.A. S/N 66-19121

Gross Weight = 33,000 Lb

Rotor Speed = 245 RPM



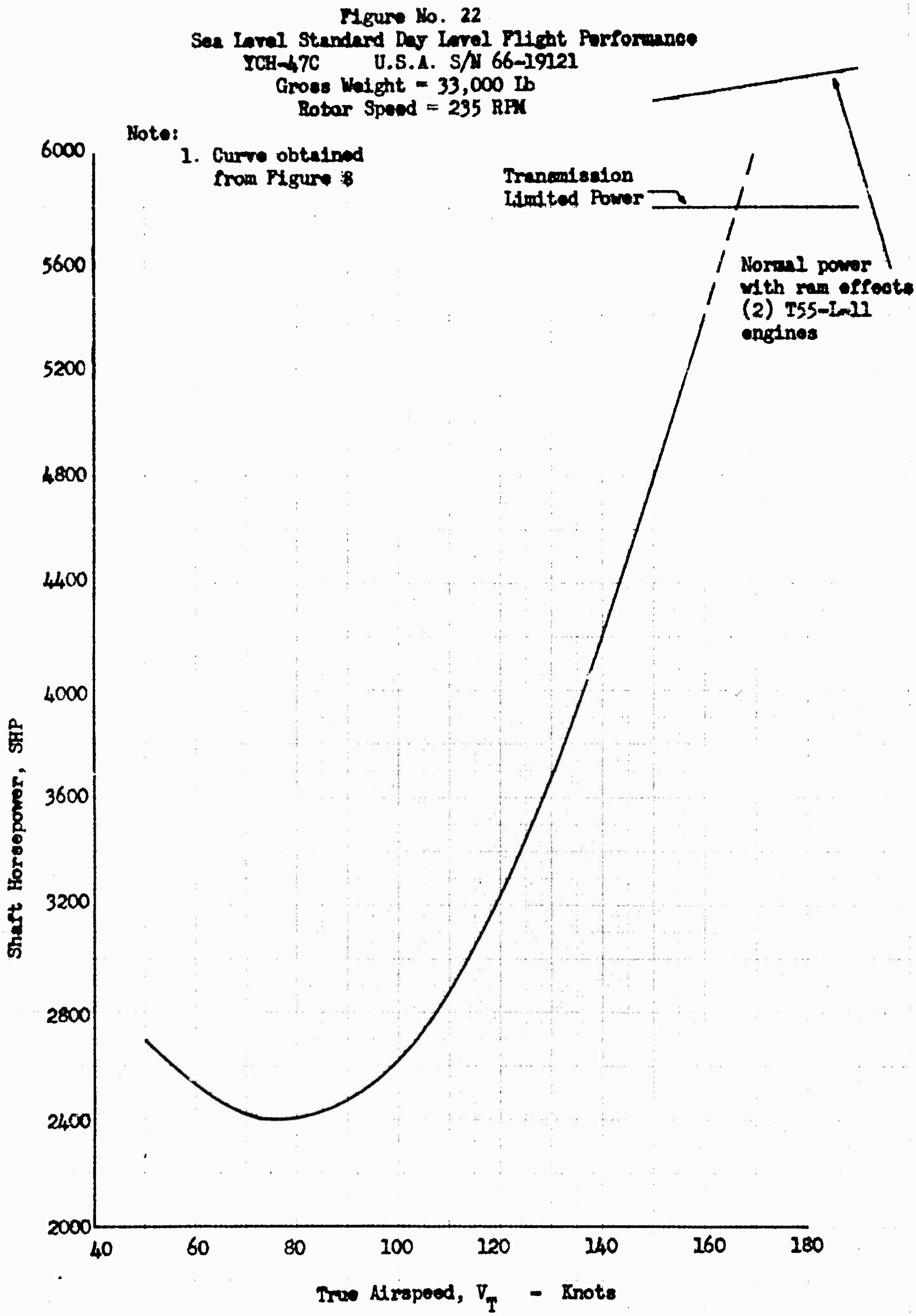


Figure No. 22
Sea Level Standard Day Level Flight Performance
YCH-47C U.S.A. S/N 66-19121
Gross Weight = 33,000 lb
Rotor Speed = 235 RPM
Note:
1. Curve obtained from Figure 8
Transmission Limited Power
Normal power with ram effects (2) T55-L-11 engines
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
Shaft Horsepower, SHP
40
60
80
100
120
140
160
180
True Airspeed, V_T - Knots

Figure No. 23
Power Correction Factor
YCH-47C U.S.A. S/N 66-19121

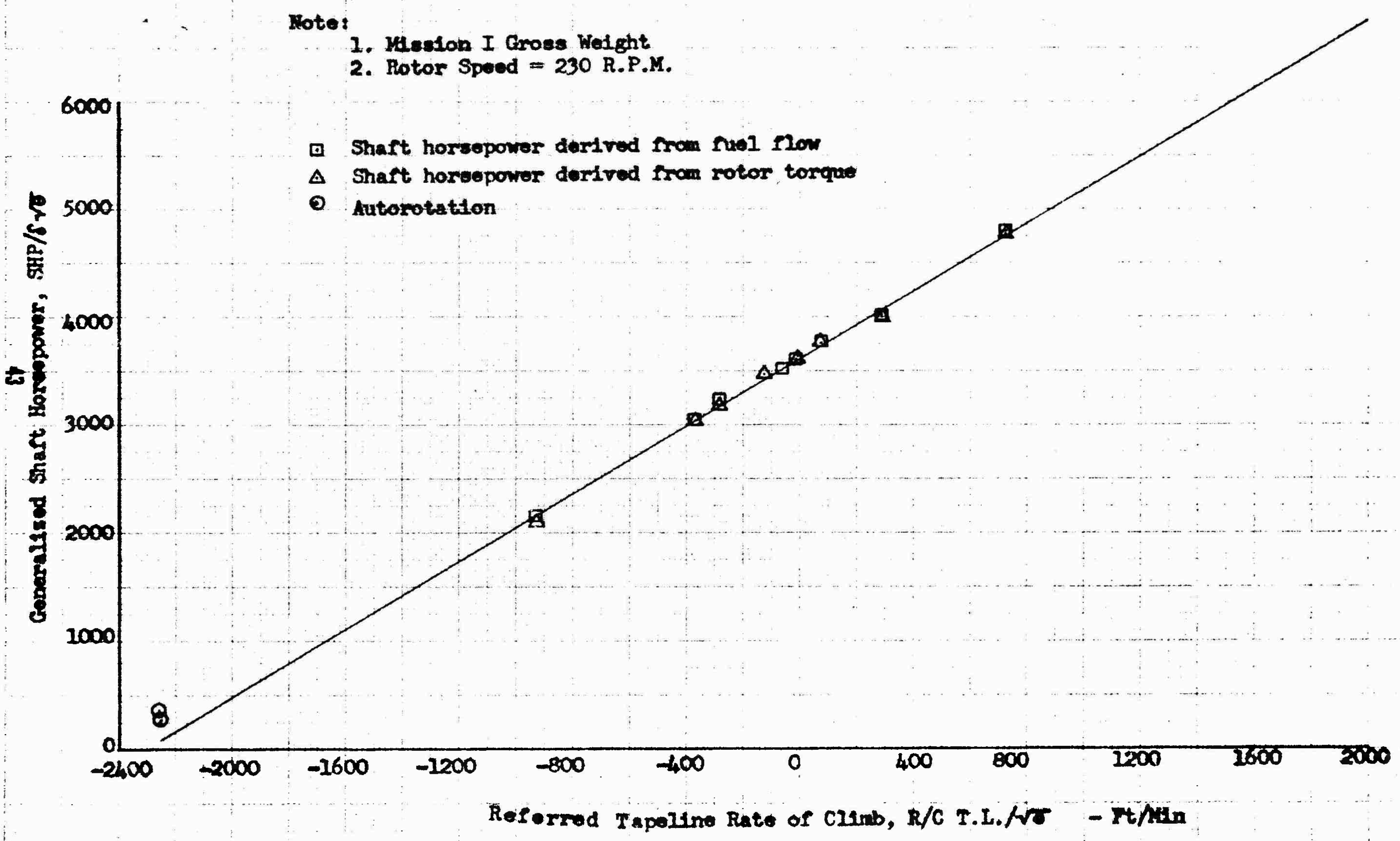
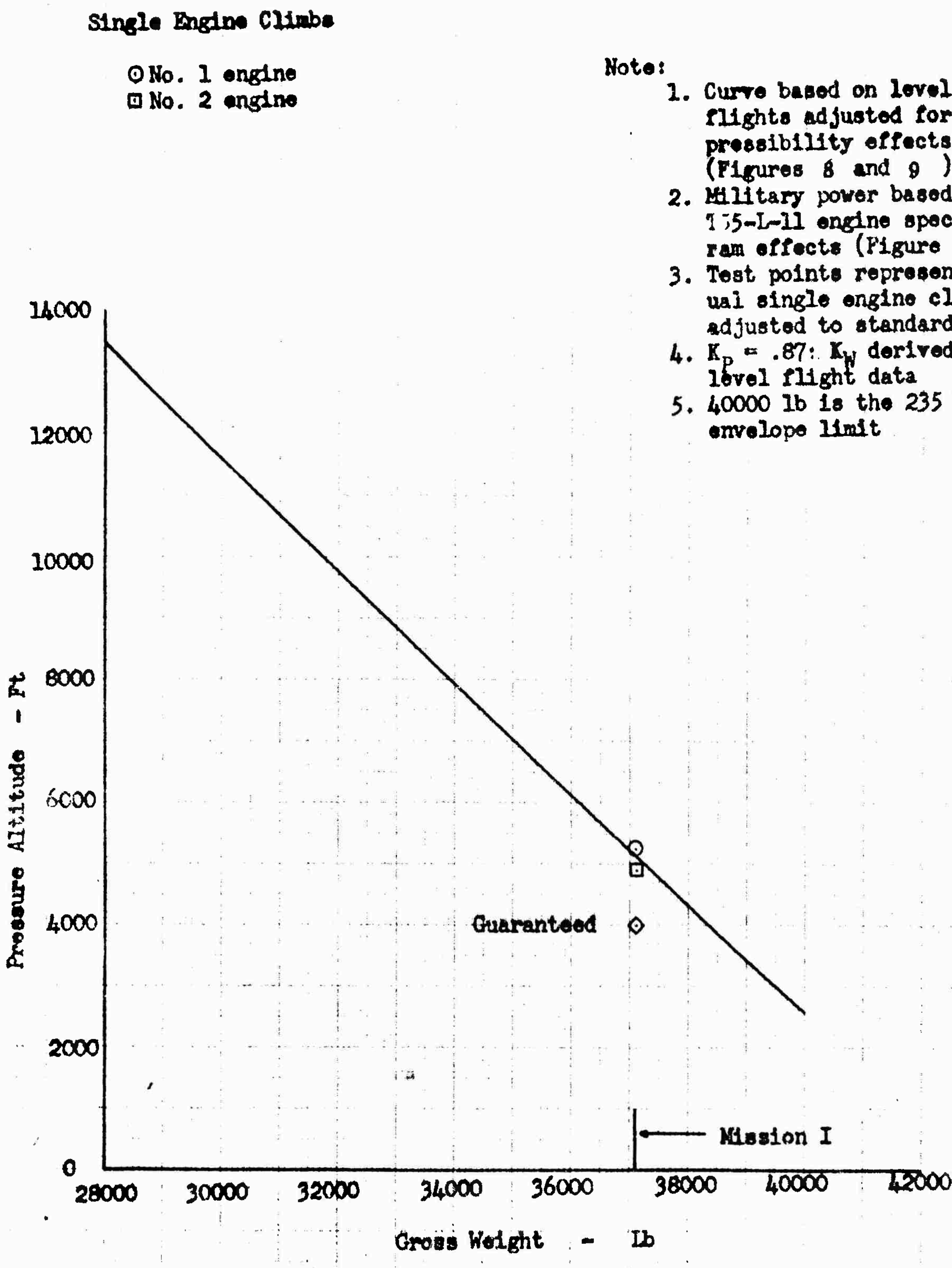


Figure No. 24
Single Engine Service Ceiling
CH-47C
Standard Day
Military Power
Rotor Speed = 230 RPM
Mid C.G.



Note:

1. Curve based on level flights adjusted for compressibility effects (Figures 8 and 9)
2. Military power based on T55-L-11 engine spec. plus ram effects (Figure 30)
3. Test points represent actual single engine climbs adjusted to standard day
4. K_p = .87: K_W derived from level flight data
5. 40000 lb is the 235 RPM envelope limit

Figure No. 25
Climb Performance
CH-47C
Standard Day Dual Engine
(2) T55-L-11 @ Normal Power Mid C.G. Rotor Speed = 235 RPM

Note: YCH-47C, U.S.A. S/N 66-19121 R/C test points shown are adjusted to standard conditions and CH-47C power and fuel flow. The V_T test points are the actual speeds flown.

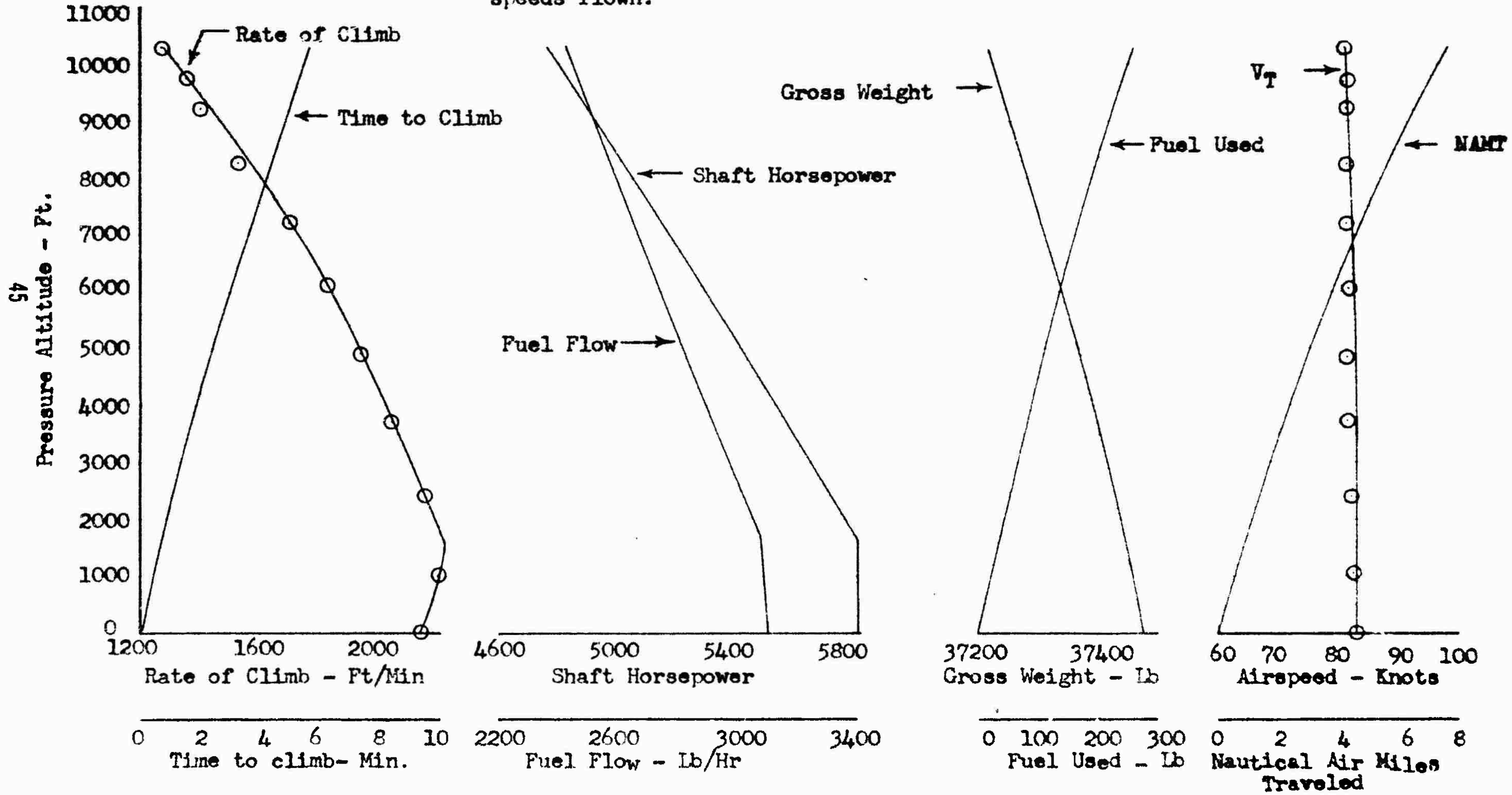


Figure No. 26
Climb Performance
CH-47C
Standard Day   Dual Engine
(2) T55-L-11 @ Normal Power   Mid C.G.   Rotor Speed = 245 RPM

Note: YCH-47C, U.S.A. S/N 66-19121 R/C test points shown are adjusted to standard conditions and CH-47C power and fuel flow. The V_T test points are the actual speeds flown.

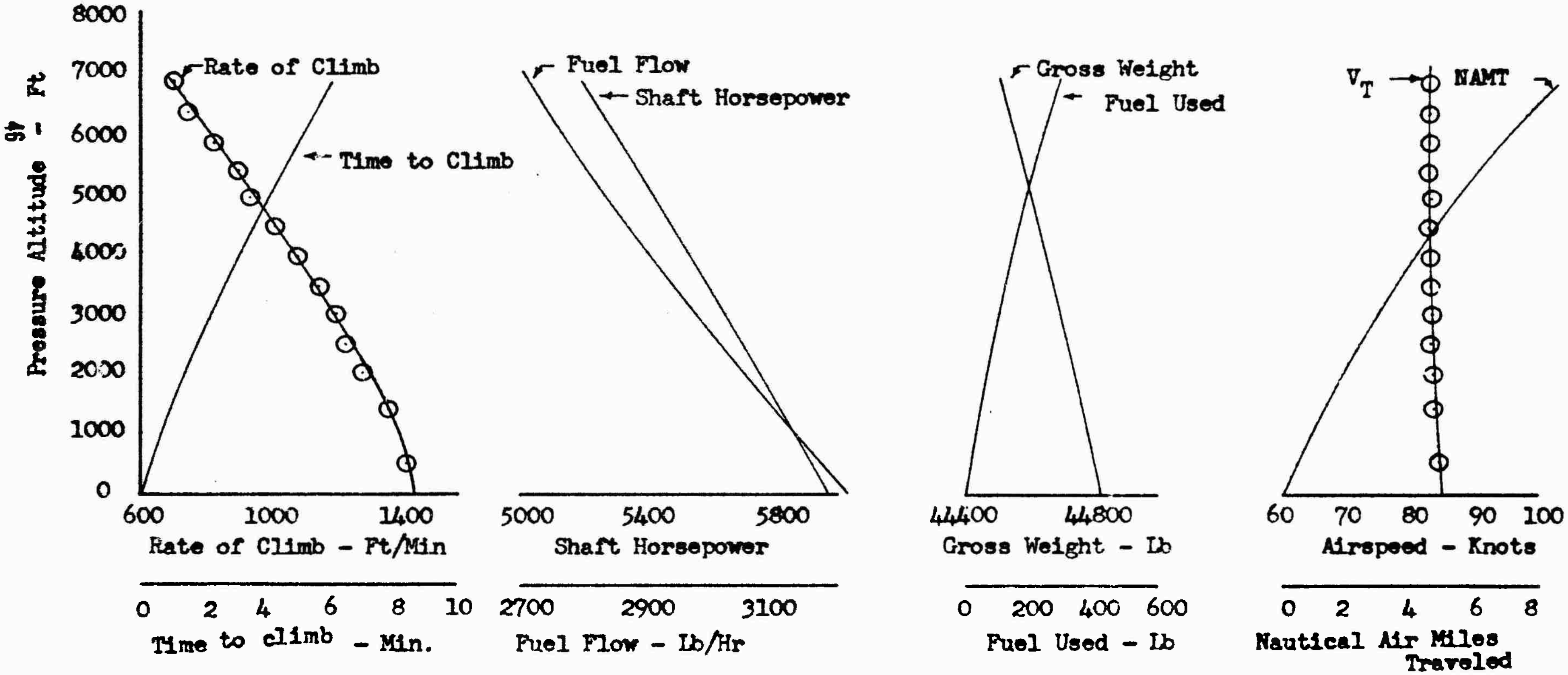
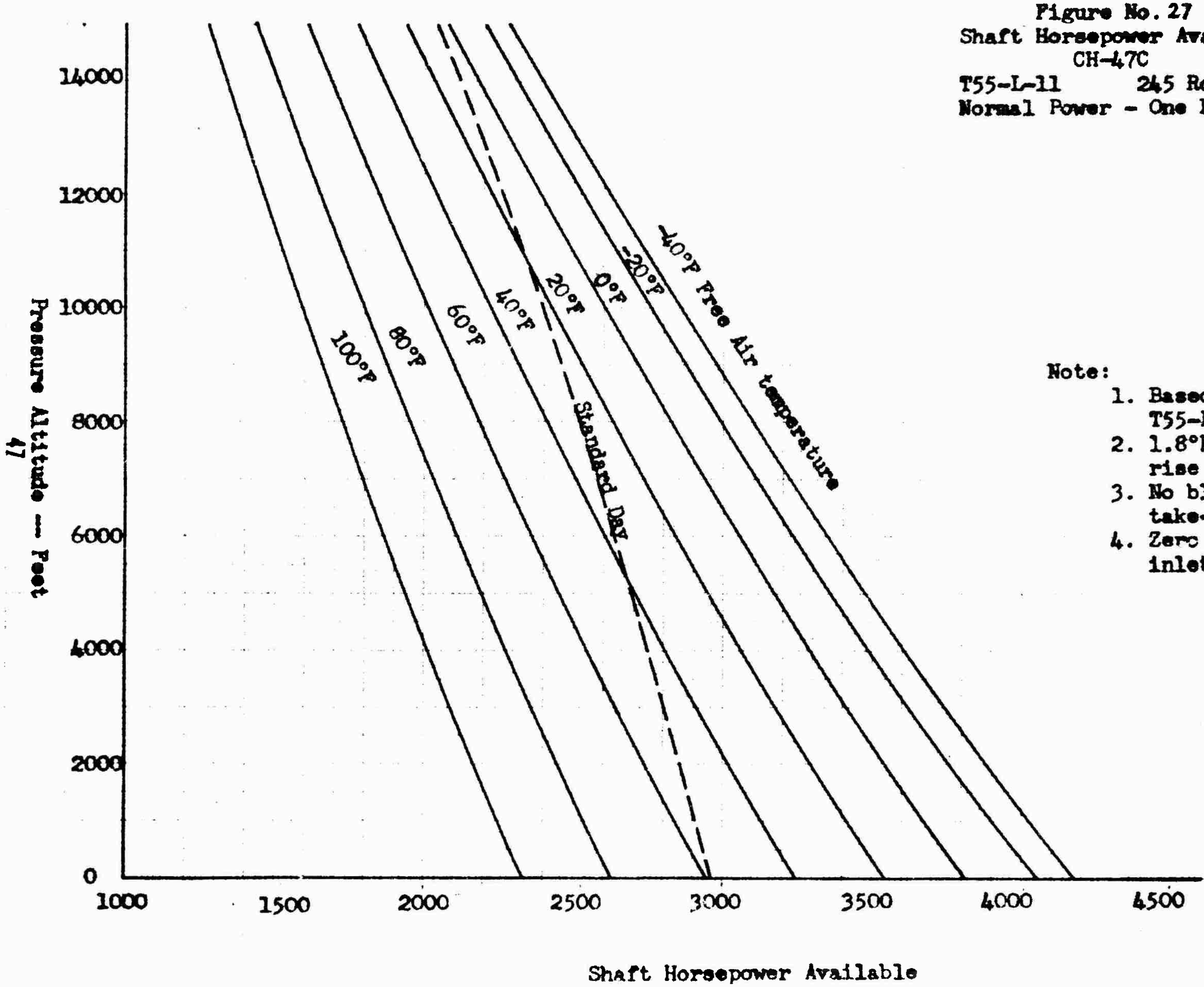
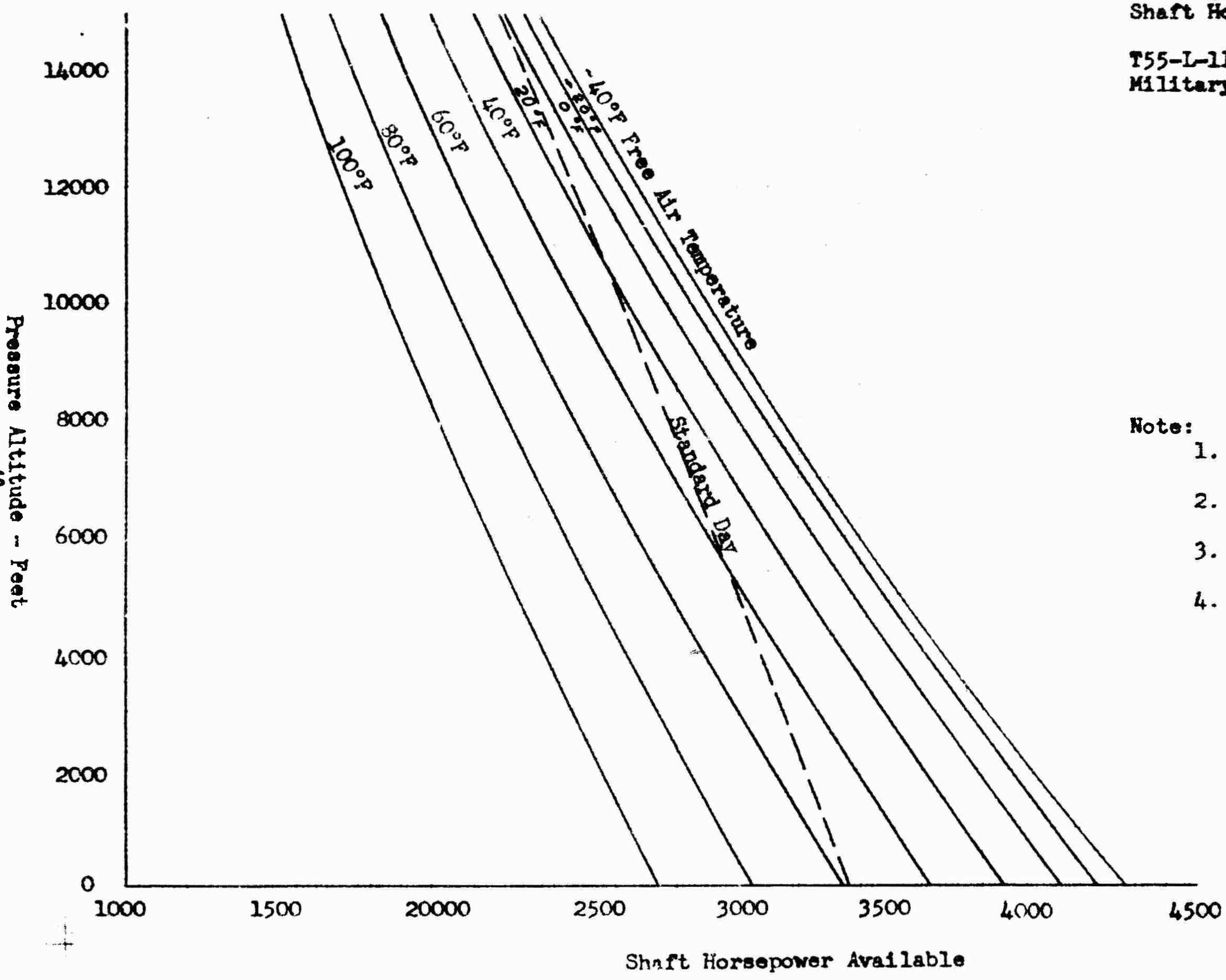


Figure No. 27
Shaft Horsepower Available
CH-47C
T55-L-11 245 Rotor RPM
Normal Power - One Engine



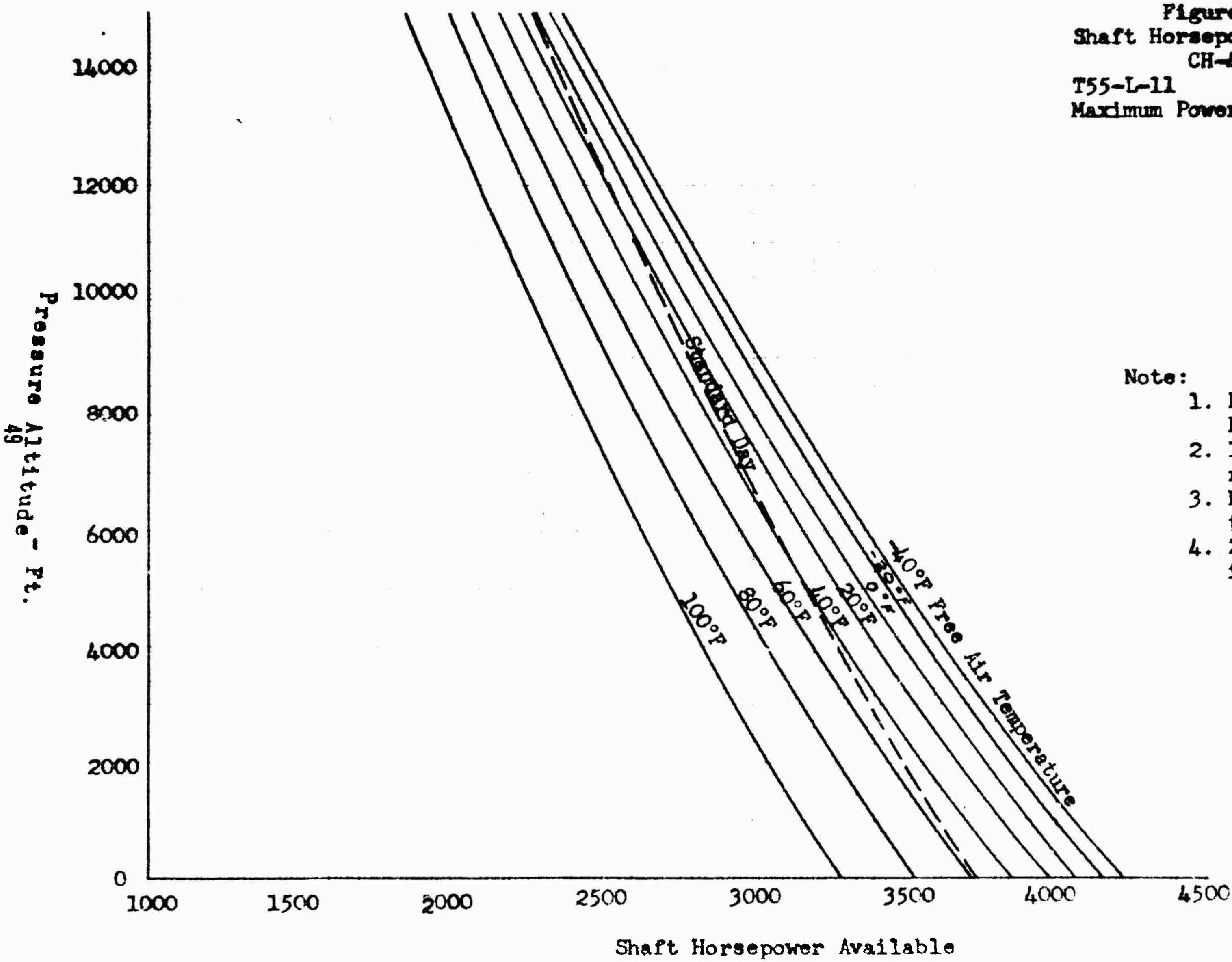
Note:
1. Based on Lycoming T55-L-11 Engine Spec.
2. 1.8°F inlet temperature rise assumed
3. No bleed air or power take-off
4. Zero velocity and no inlet pressure loss

Figure No. 28
Shaft Horsepower Available
CH-47C
T55-L-11   245 Rotor RPM
Military Power - One Engine



Note:
1. Based on Lycoming T55-L-11 Engine Spec.
2. 1.8°F inlet temperature rise assumed
3. No Bleed Air or power take-off
4. Zero velocity and no inlet pressure loss

Figure No. 29
Shaft Horsepower Available
CH-47C
T55-L-11 245 Rotor RPM
Maximum Power - One Engine



Note:
1. Based on Lycoming T55-L-11 Engine Spec.
2. 1.8°F inlet temperature rise assumed
3. No bleed air or power takeoff
4. Zero velocity and no inlet pressure loss

Figure No. 30
Inlet Recovery Effects
Military Power Available
Lycoming T55-L-11
Engine
Standard Day
$V_T/\sqrt{\theta}$ = 85 Knots
N_{II} = 14720 RPM

Note:

1. No bleed air or power take off
2. No heat rise in inlet. A 1°C temperature gain in inlet corresponds to an approximate reduction of 20 SHP in available power
3. Based on T55-L-11 engine spec.

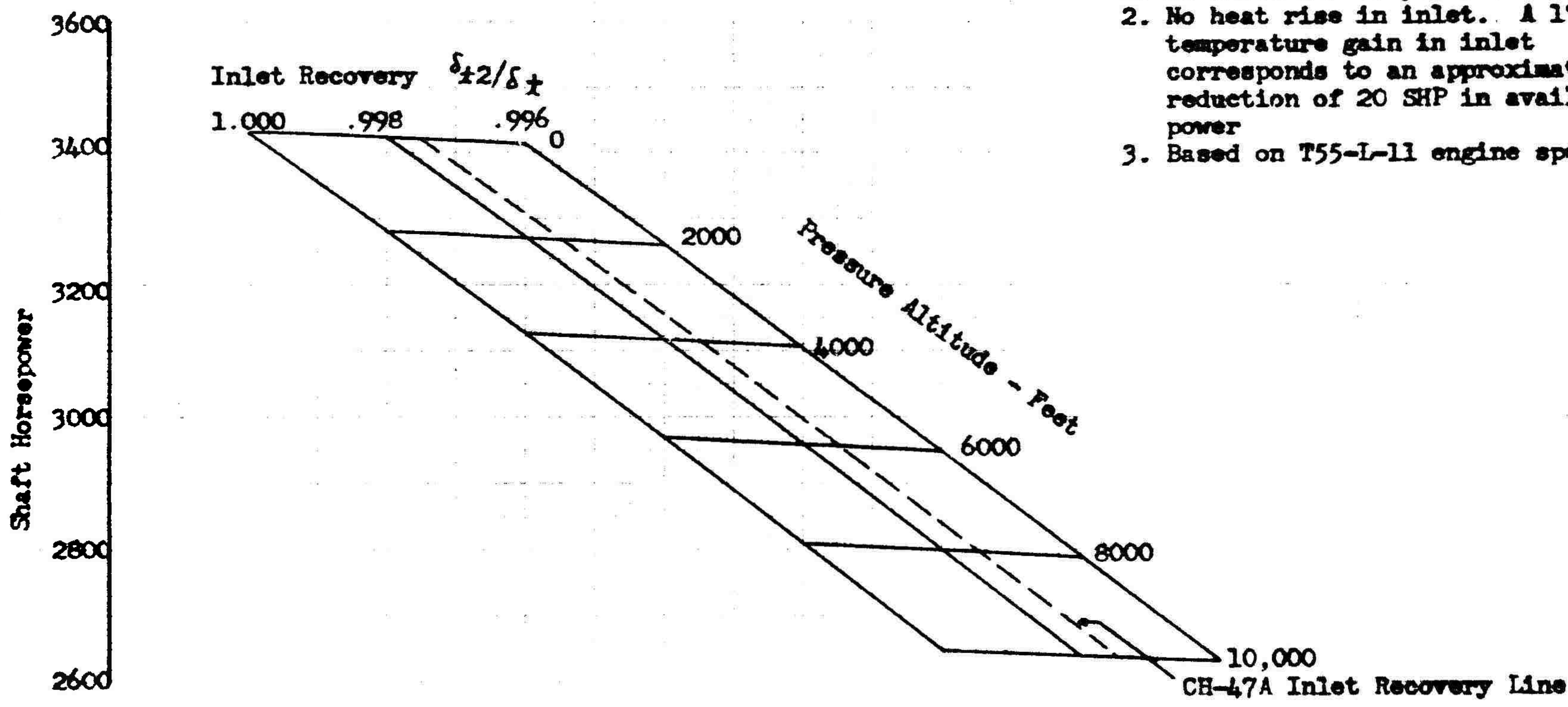


Figure No. 31
Engine Characteristics
Lycoming T55-L-11 S/N LE19106

Note:
1. Shaft horsepower based on fuel flow
2. Referred values based on a 1°C compressor inlet temperature rise
3. Faired line obtained from Lycoming test stand calibration
4. T.I.T. measured at power turbine entrance

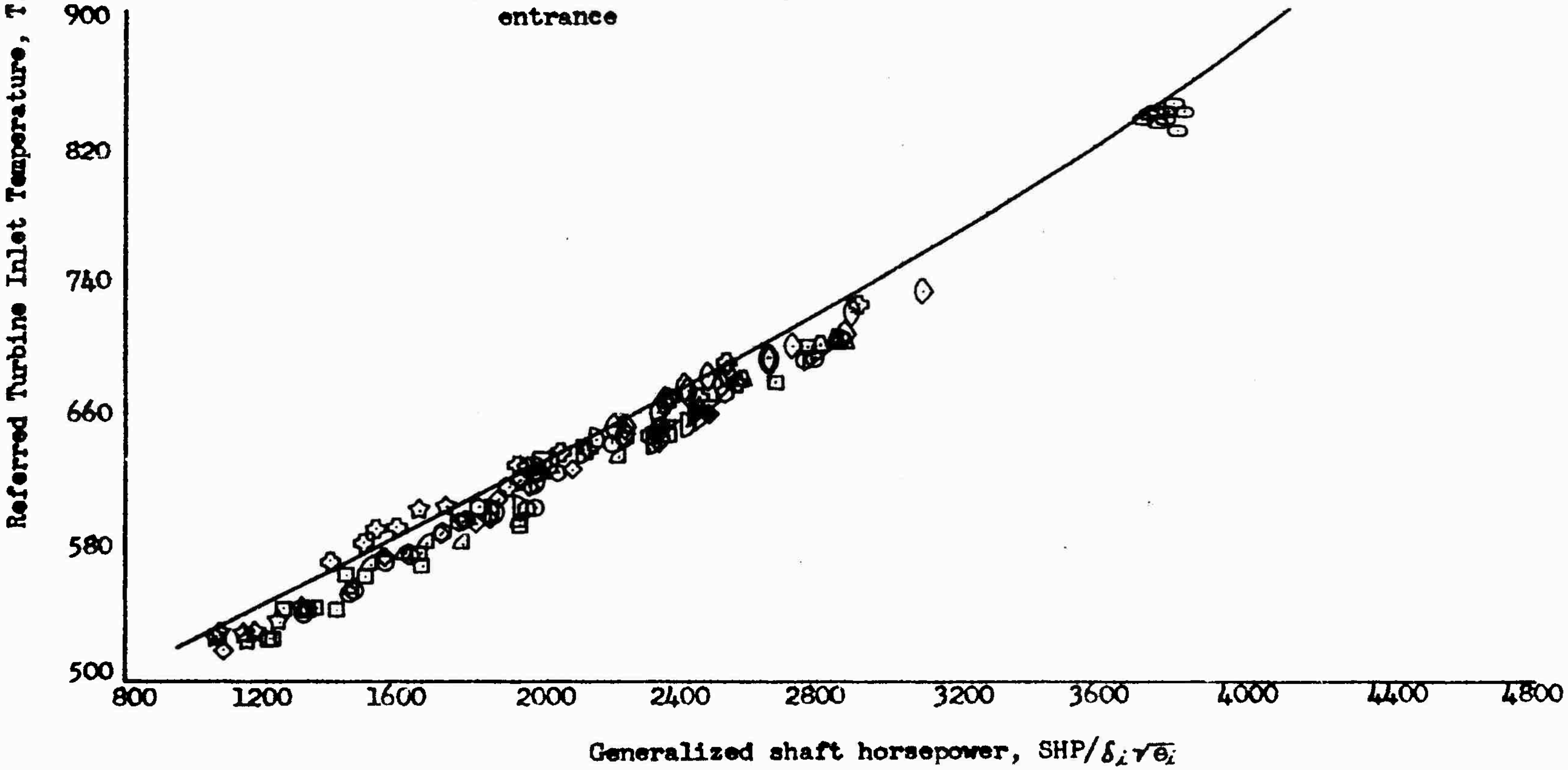


Figure No. 32
Engine Characteristics
Lycoming T55-L-11 S/N LE 19108

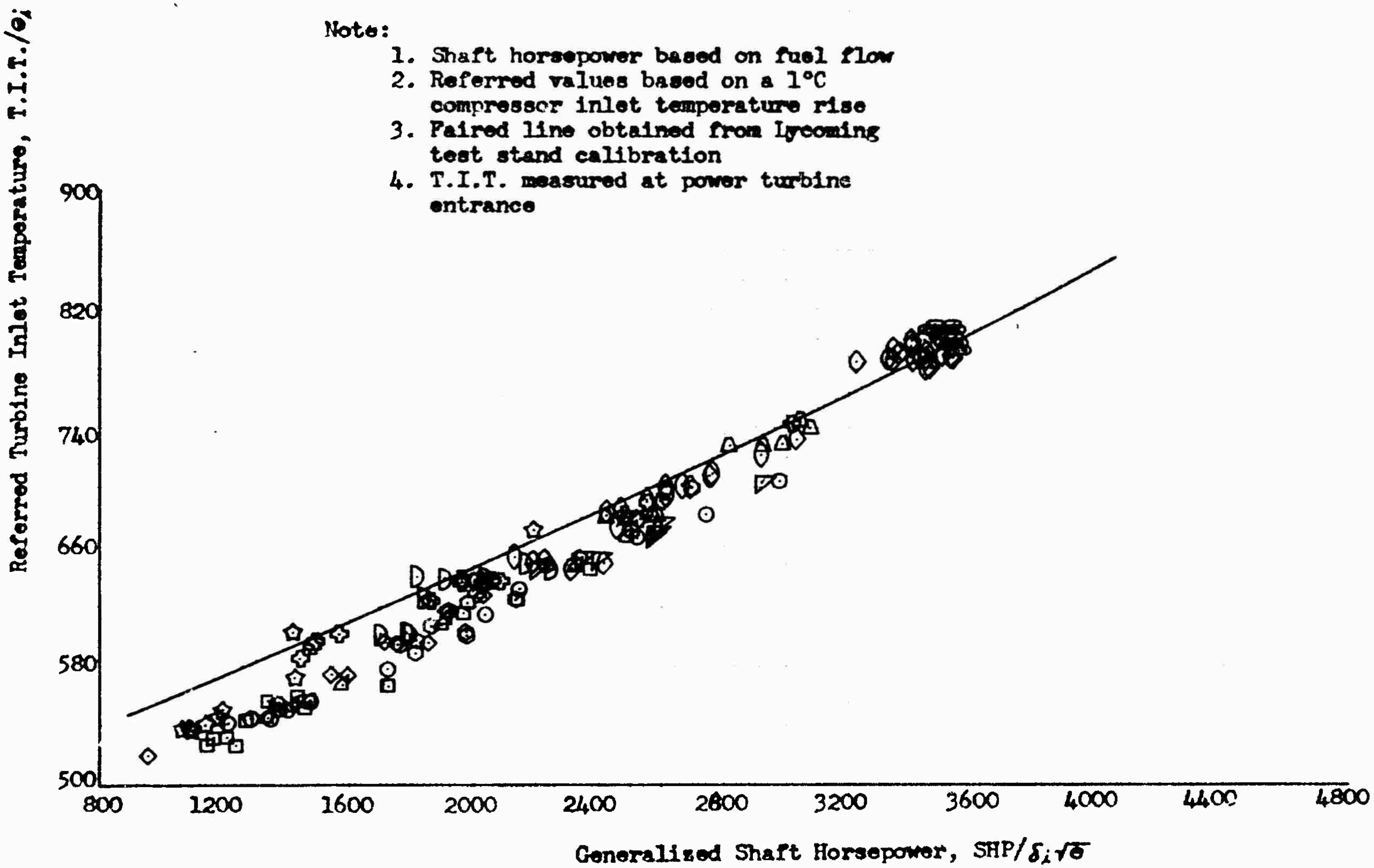


Figure No. 33
Engine Characteristics
Lycoming T55-L-11 S/N LE19106

Note:
1. Shaft horsepower based on fuel flow
2. Referred values based on a 1°C compressor inlet temperature rise
3. Faired line obtained from Lycoming test stand calibration

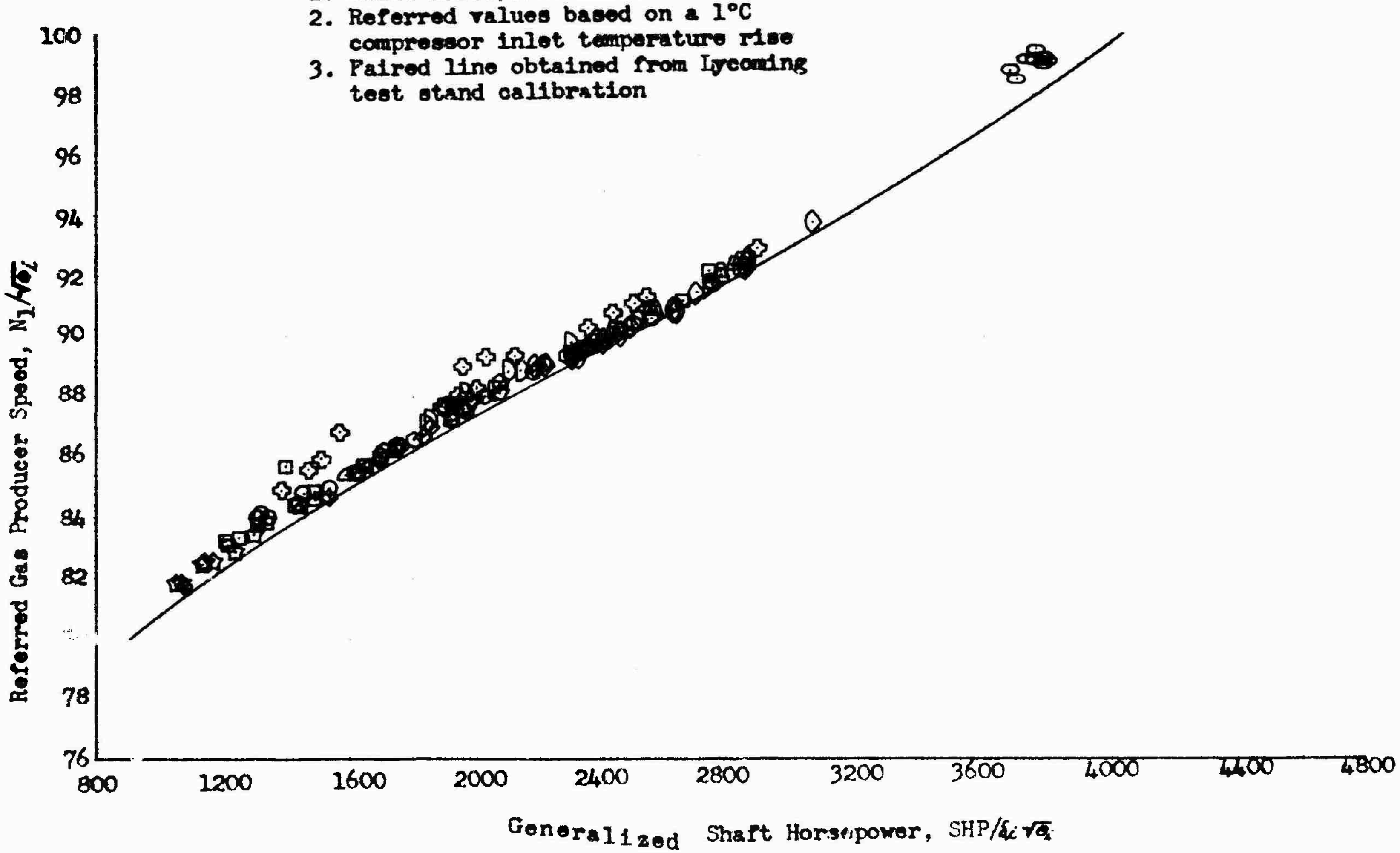


Figure No. 34
Engine Characteristics
Lycoming T55-L-11 S/N LE 19108

Note:
1. Shaft horsepower based on fuel flow
2. Referred values based on a 1°C compressor inlet temperature rise
3. Faired line obtained from Lycoming test stand calibration

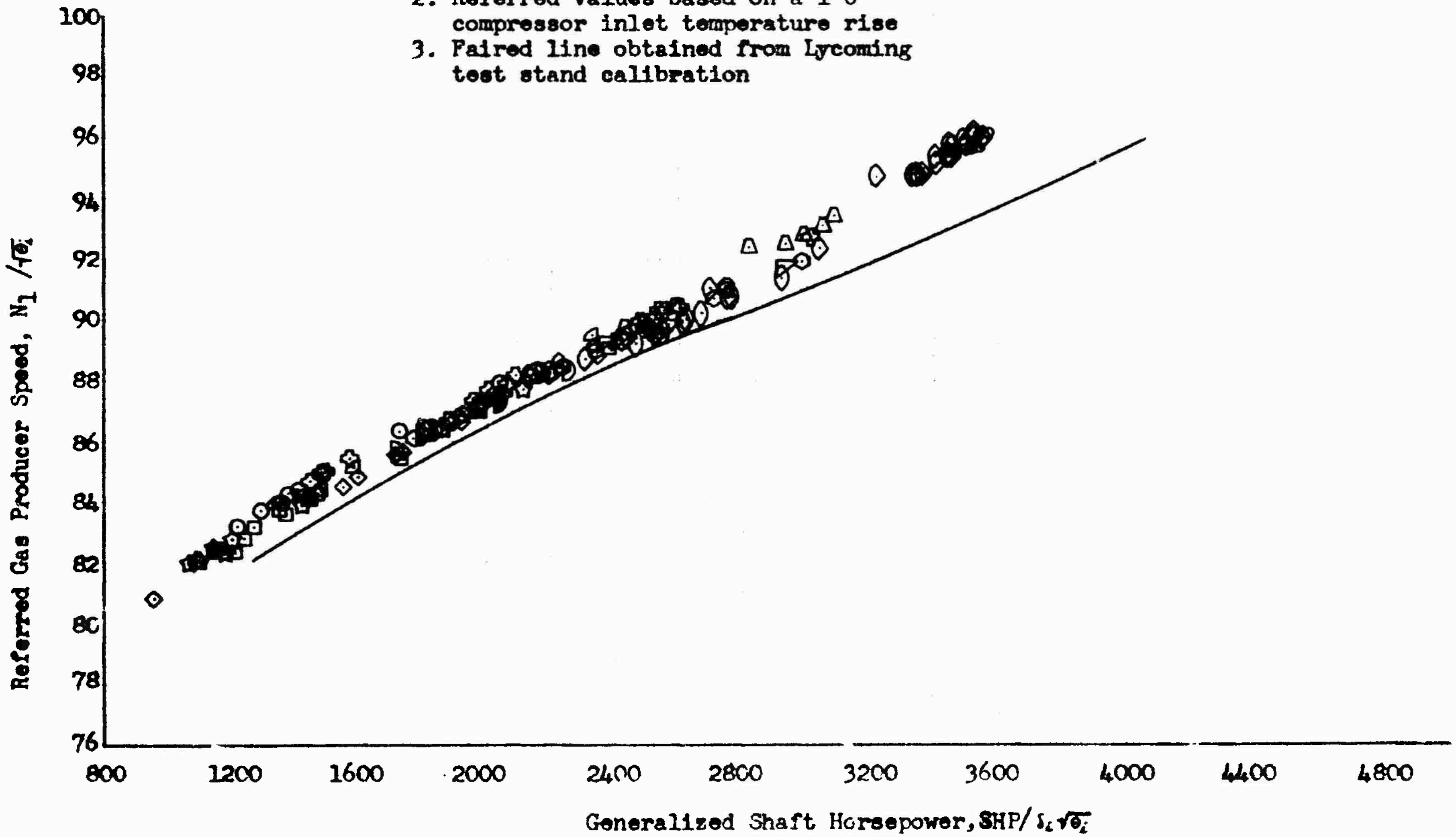


Figure No. 35
Engine Characteristics
Lycoming T55-L-11 S/N LE19106

Note:
1. Lycoming Test Cell Calibration

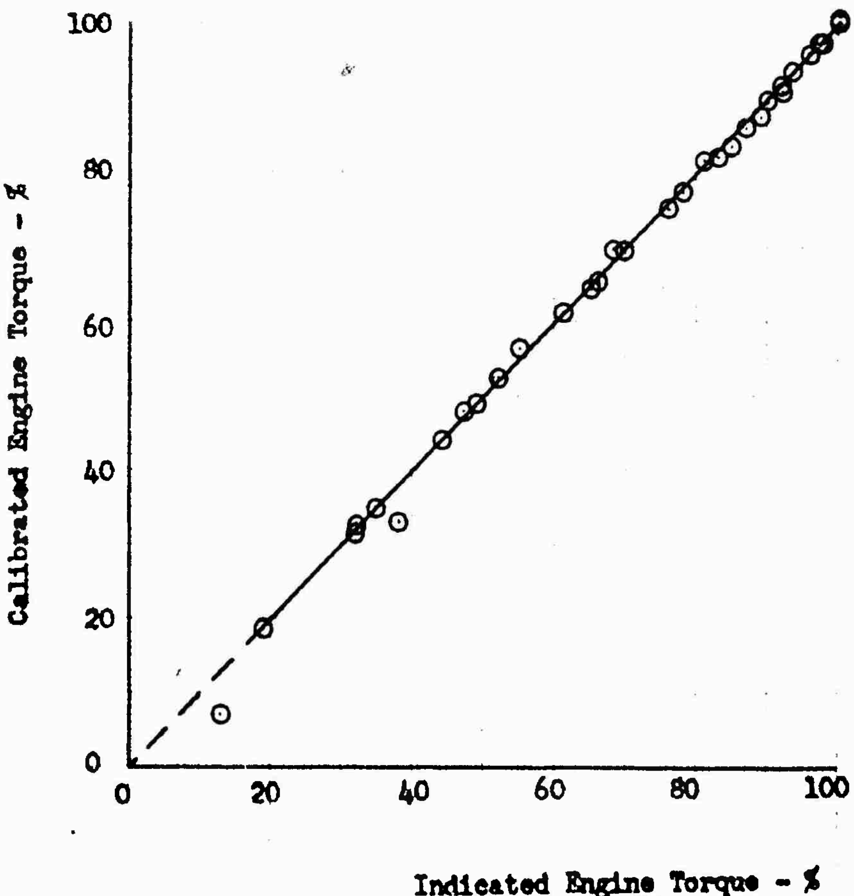


Figure No. 36
Engine Characteristics
Lycoming T55-L-11   S/N LE19108

Note:
1. Lycoming Test Cell Calibration

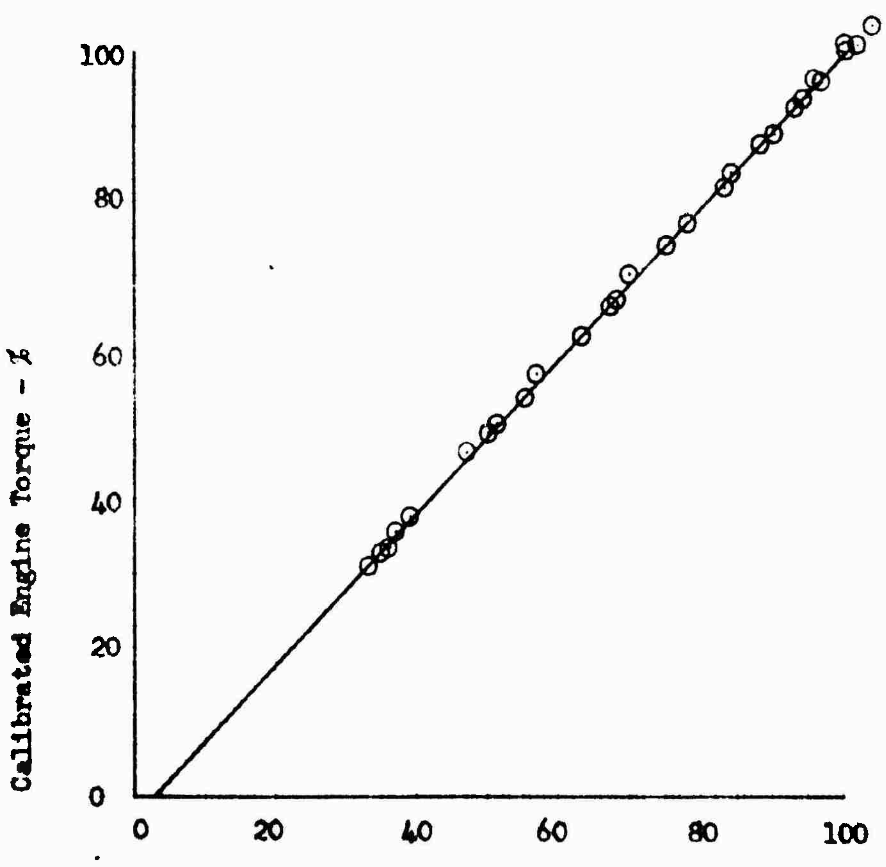


Figure No.37
Engine Characteristics
Lycoming T55-L-11   S/N LE19106

Note:
1. Solid line denotes ideal

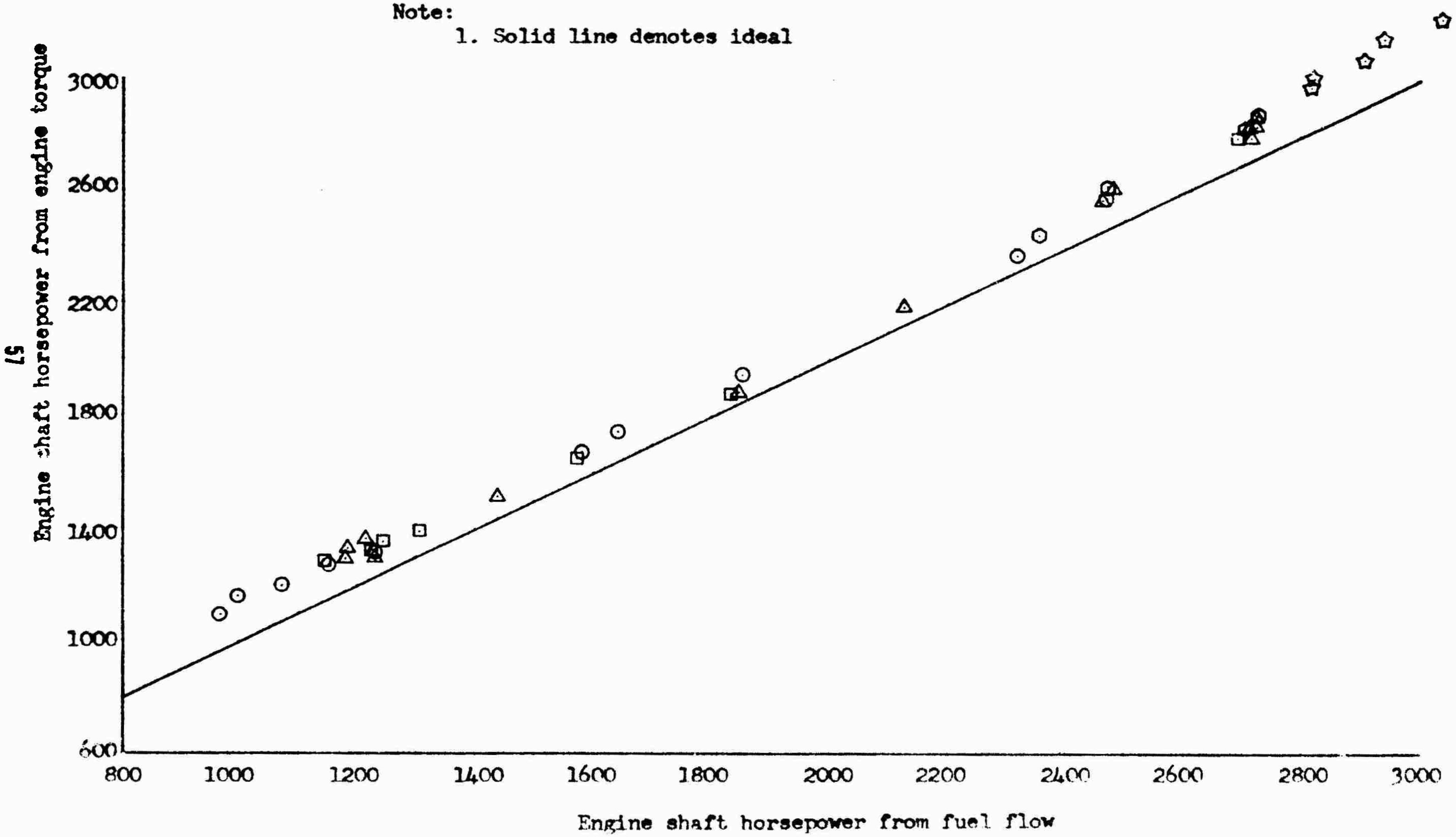


Figure No. 38
Engine Characteristics
Lycoming T55-L-11 S/N LE 19108

Note:
1. Solid line denotes ideal

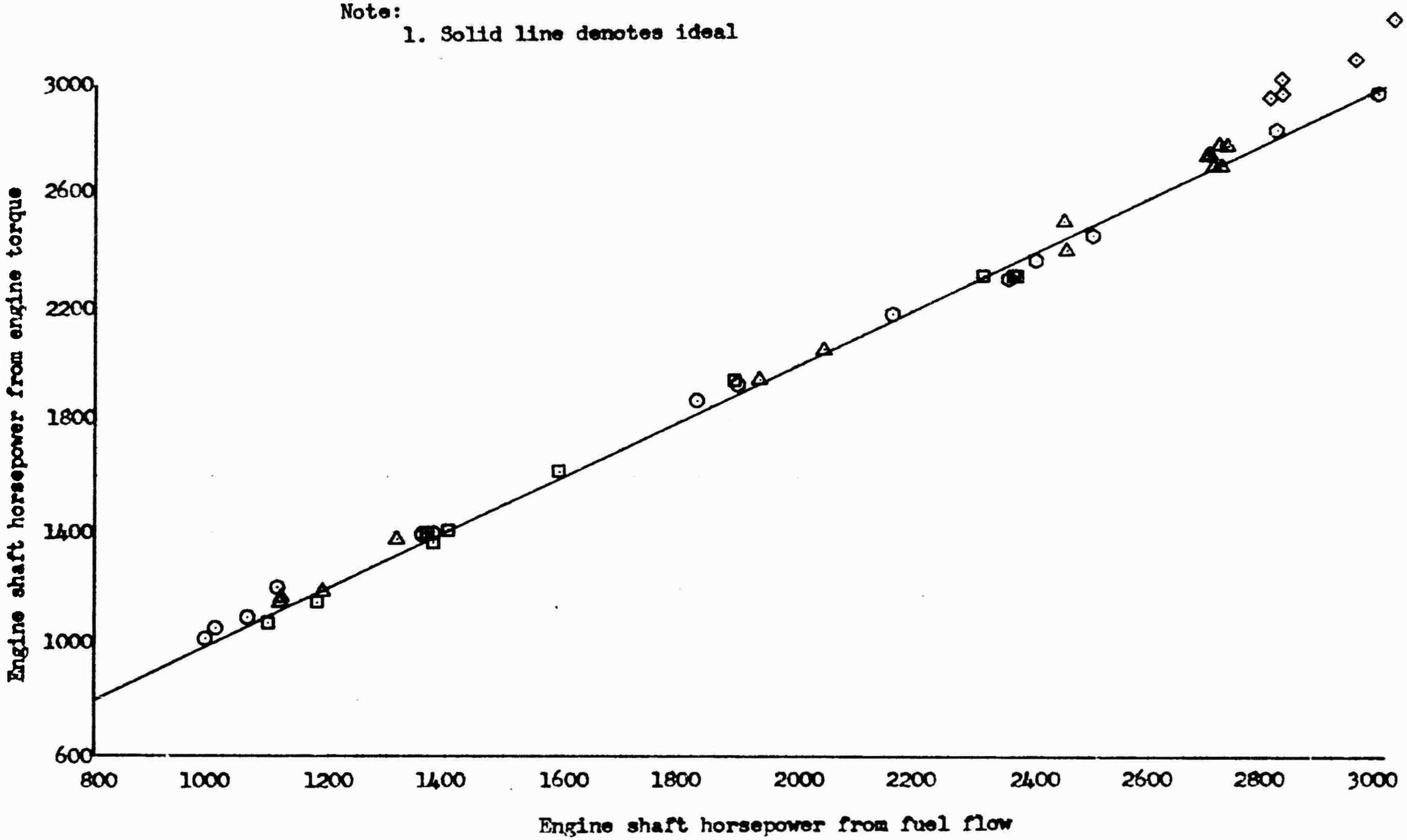


Figure No. 39
Temperature BIAS Curve
T55-L-11 Engine

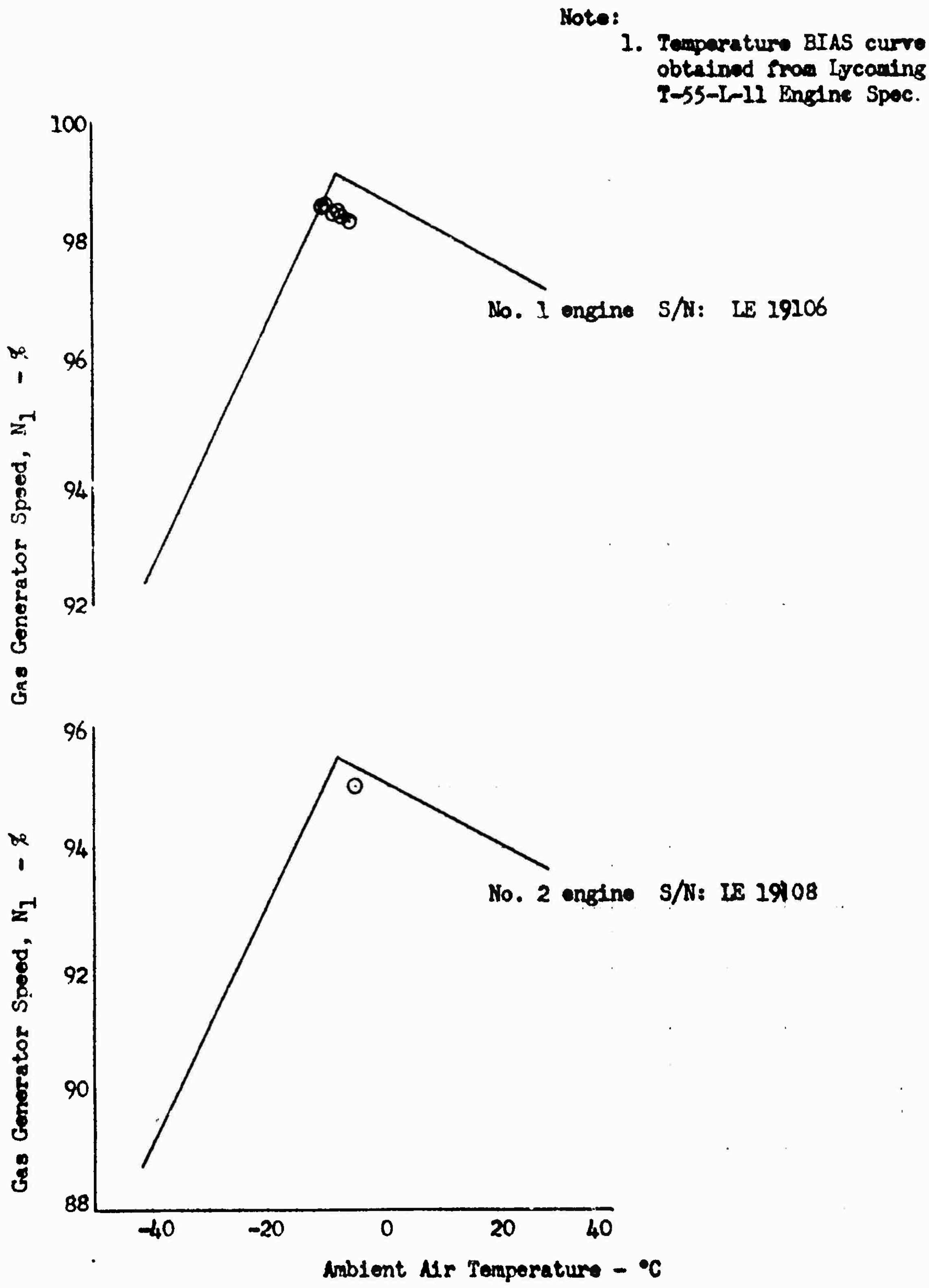


Figure No. 40
Boom System Airspeed Calibration
YCH-47C U.S.A. S/N 66-19121
Level Flight
Mid C.G.

Note:

1. Solid line is Vertol data
2. Test points are APE verification
3. Ground speed course methods
4. Average Gross Weight = 29000 lb
5. Average density altitude = Sea Level
6. Average rotor speed = 235 R.P.M.

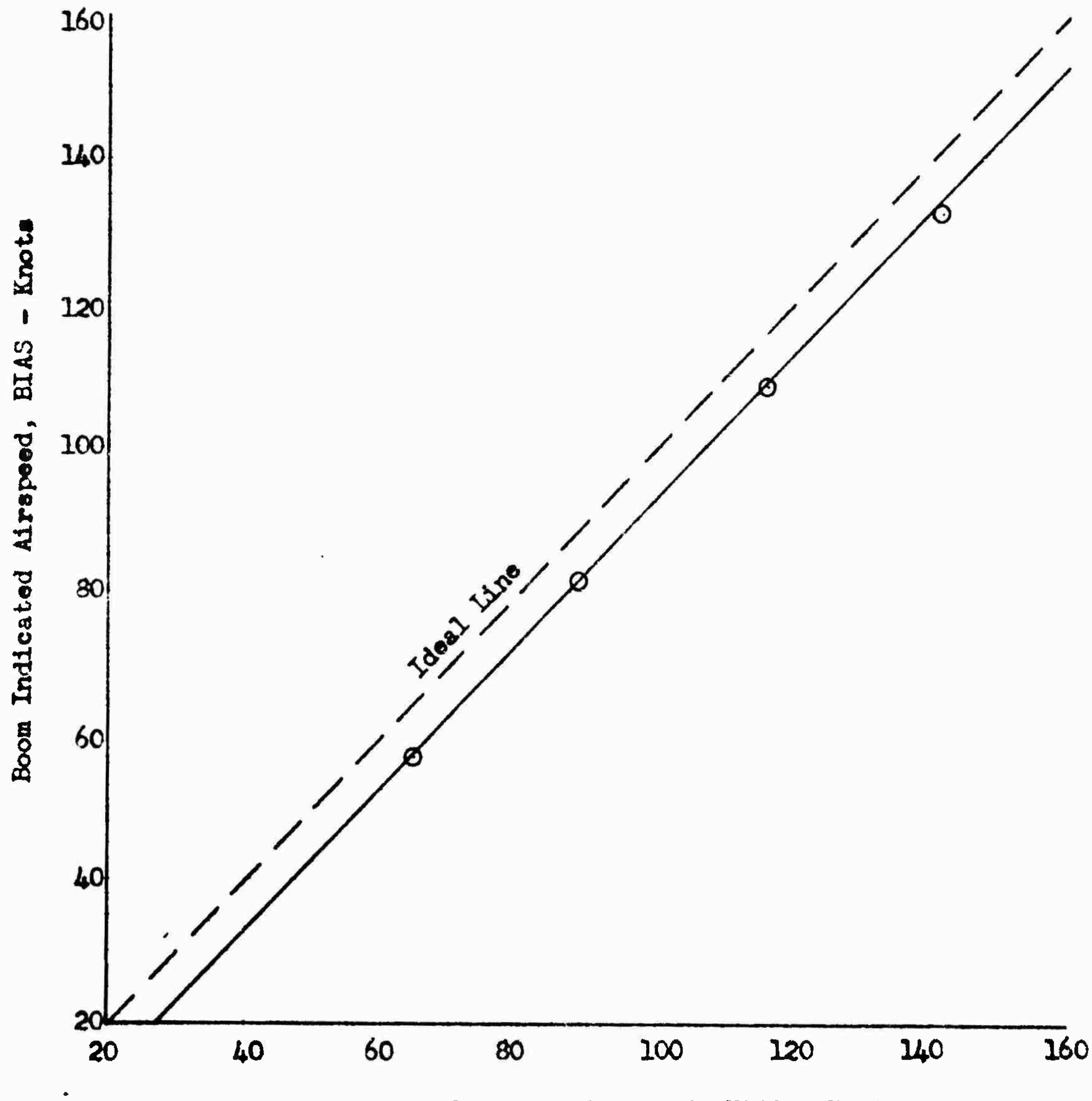
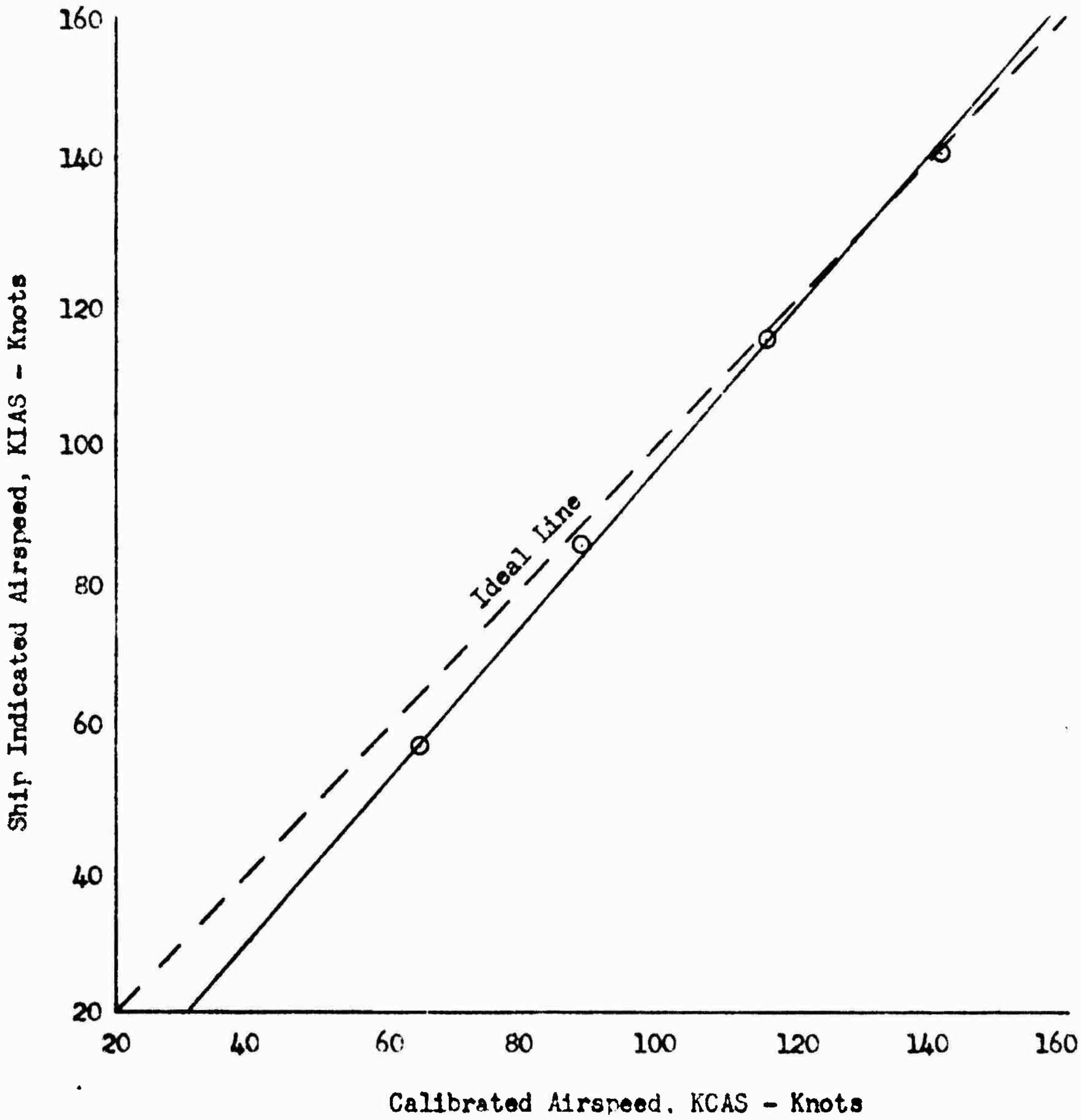


Figure No. 41
Ship System Airspeed Calibration
YCH-47C U.S.A. S/N 66-19121
Level Flight
Mid C.G.

Note:
1. Solid line is Vertol data
2. Test points are APE verification
3. Ground speed course method
4. Average gross weight = 29000 lb
5. Average Density Altitude = Sea Level
6. Average rotor speed = 235 R.P.M.



APPENDIX III
TEST METHODS

1. AIRSPEED CALIBRATION:

a. A level flight airspeed calibration was accomplished over a surveyed ground course to verify the contractor's boom pitot-static calibration and determine the standard airspeed system position error.

b. Reciprocal headings were flown OGE at the same BIAS, and the average lapsed time was used to correct for wind velocity and direction. The calibration was conducted at a normal operating rotor speed. Variations with ground proximity, gross weight and C.G. location were not determined.

c. Photopanel and magnetic tape data were recorded continuously during the calibration.

2. HOVER PERFORMANCE:

a. Hover performance data were obtained using the free-flight hover method at a 10-foot aft gear height (bottom of wheel) for IGE and 150-foot radar height for OGE. A weighted cord attached to the right aft gear was used to determine IGE hover height. Radio communication with a ground station was maintained to establish the correct IGE hover height.

b. The gross weight of the helicopter was varied by using two external sling loads of approximately 8000 pounds and 13,000 pounds while maintaining a mid C.G. location. Actual rotor speed was varied from 225 to 245 rpm at each hover height and weight condition tested.

c. Each test point was stabilized for 30 seconds prior to recording data on the photopanel and magnetic tape. Three 10-second recordings were made at 20-second intervals. OAT and H_p were recorded from a calibrated self-contained unit located at least 600 feet from the helicopter. Wind direction and velocity were recorded from a hand held anemometer in conjunction with OAT and H_p for each test point.

3. CLIMB PERFORMANCE:

a. The best climb airspeed was determined from level flight performance and contractor data for various G.W.'s rotor speeds, power and altitudes. Dual engine climbs were accomplished from approximately

S.L. to the flight envelope release altitude at NP. Single engine climbs were accomplished from S.L. to service ceiling at MP. Dual engine climbs were started at the Mission I and III G.W.'s while single engine climbs were accomplished to reach service ceiling at the Mission I G.W.

b. Photopanel and magnetic tape recordings were made every 30 seconds for dual engine climbs and every 60 seconds for single engine climbs.

4. AUTOROTATIONAL DESCENTS:

a. Autorotational descents were conducted at constant airspeed and varied rotor speeds to determine the rpm for the minimum R/D. Additional tests were conducted to determine R/D's at constant rotor speeds and various airspeeds for Mission I and II G.W.'s at a mid C.G. The engine condition levers were retarded to the GROUND position for the autorotations so that engine power would not be applied to the rotor system.

b. Photopanel and magnetic tape recordings were made continuously during descents.

5. K_P AND K_W:

a. Climbs and descents were conducted at approximately Mission I G.W. to determine K_P. K_W was derived from level flight performance data.

b. Data were recorded on the photopanel and magnetic tape for a 60 second period for K_P and as specified under level flight performance for K_W.

6. LEVEL FLIGHT PERFORMANCE:

a. Level flight tests were conducted at various W/δ's and $N/\sqrt{\theta}$'s to determine power required and engine characteristics. All tests were conducted at a mid C.G. During each test W/δ was maintained constant by increasing altitude as fuel was consumed. The $N/\sqrt{\theta}$ was maintained constant by varying rotor speed at OAT changed to minimize compressibility effects.

b. Each test point was stabilized for 30 seconds prior to recording data on the photopanel and magnetic tape. Four 10 second recordings were made at 30 second intervals for each test point.

APPENDIX IV
DESCRIPTION OF TEST HELICOPTER

1. The test helicopter was basically configured as a production CH-47C as stated in the Detail Specification except for the nonstandard items:

a. Slip ring assemblies (pineapples) mounted on top of the forward and aft rotor heads. Assemblies were 28.25 inches in length and 4.5 inches in diameter. Both assemblies had an f_e of 1.90 ft^2. A full swiveling yaw vane was mounted on the forward assembly.

b. Two installed YT55-L-11 calibrated engines.

c. Swivel head pitot-static boom 148 inches long from the nose of the helicopter to the tip of the pitot tube and a nominal 3.75 inches in diameter. The boom had an f_e of .32 ft^2.

d. Photopanel installed from stations 160 to 182, BL 30 L/H, at a mid WL of plus 23.

e. Ampex tape recorder (Model AR200) installed from stations 102 to 127, BL 34L/H, at a mid WL of minus 10.

f. Internally mounted water ballast tanks are as follows:

(1) 4087 lb capacity installed from stations 225 to 345, BL 35 L/H, mounted on isolated flooring.

(2) 3990 lb capacity installed from stations 225 to 345, BL 35 R/H, mounted on isolated flooring.

(3) 1052 lb capacity installed from stations 160 to 195, BL 35 L/H, mounted on isolated flooring.

(4) 1083 lb capacity installed from stations 195 to 230, BL 35 L/H, mounted on isolated flooring.

g. Internally mounted wooden ballast boxes installed as follows:

(1) Two approximately 1175 pound lead capacity boxes on centerline of helicopter at mid stations 160 and 390 on the isolated floor.

(2) Two approximately 1175 pound lead capacity boxes on centerline of helicopter at a mid station between boxes of 525 on the ramp.

(3) One approximately 1175 pound lead capacity box at a mid station of 390, BL 35 L/H on the isolated flooring.

(4) Three approximately 1175 pound lead capacity boxes on BL 35 R/H at mid stations of 160, 390 and 450 on the isolated flooring.

h. One rosemont temperature probe at station 250, BL 30 R/H, fuselage underside.

2. The following installed development ECP's were incorporated on the test helicopter during the evaluation:

ECP	Title	Effectivity
402	Aft rotor shaft	B-464(S/N 67-18494)
434R2	Aft pylon absorber (tuned to 243 rpm)	B-356(S/N 66-19098)
435	Fwd transmission	B-434(S/N 67-18464)
436	Aft transmission	B-434
446	Engine transmission	B-464
447	Combining transmission	B-464
448	Drive shafting	B-464
451	Lag dampers	B-464
454	Install automatically tuned vibration absorbers	B-464
553R(1)	Increased fuel capacity with fuel cell vibration isolation	B-464

(1) The test helicopter had increased fuel capacity with full fuel isolation per ECP 450 and 553, no revision. ECP 553R was the "Override System." Inasmuch as fuel system tests were not conducted during the evaluation, test data was not affected.

3. The following associated (not part of the development contract) ECP's were incorporated on the test helicopter during the evaluation:

ECP	Title	Effectivity
411R3	-7C engine installation with provisions for -11 engine	B-464(S/N 67-18494)
418	Pop out ind. on fwd transmission	B-401(S/N 67-18431)
419	Pop out ind. on aft transmission	B-430(S/N 67-18460)

ECP	Title	Effectivity
420	Jets for forward transmission lubricators	B-445(S/N 67-18475)
421	Jets for aft transmission lubricators	B-445
441	Drain slots in BRG-Fwd transmission	B-445
442	Drain slots in BRG-Fwd transmission	B-445
478	10 ply tires and improved wheel braking	B-464
571	Revise aft rotor longitudinal cyclic trim schedule	B-464
440	Add attachments to installation of pinion, eng. transmission	B-440(S/N 67-18462)
551	Delete provisions and installation of the ARA-56 homing antenna	B-432(S/N 67-18462)
522	Incorporate improved lubrication of engine transmission quill shaft	
521	Carburization and grinding of engine transmission pinion gear spline	

4. The following associated changes were not incorporated on the test helicopter during the evaluation:

ECP(1)	Title	Effectivity
45R1	Installation of SAS failure light	B-464(S/N 67-18494)
383	Add material to casting-aft transmission housing	B-464
541	Increase fatigue life of driv collar scissors and bolts	B-464
562	Improve water sealing of droop snoot blade	B-464
508	Add a metal retainer to the windshield installation	B-425(S/N 67-18455)
527(2)	Replace mag brake switch in thrust grip	B-437(S/N 67-18467)
548(2)	Incorporate pressure relief provisions in thrust stick boost actuator	B-433(S/N 67-18463)

(1) These ECP's will not affect the performance results obtained during the evaluation.

(2) These ECP's incorporated during the evaluation. Data was not affected by their incorporation.

APPENDIX V
TEST INSTRUMENTATION

Item	Photopanel	Cockpit	Magnetic Tape
Airspeed-boom	s	s	s
Airspeed-ship's	c	c	s
Altitude-boom	c	c	s
Altitude-ship's	c	c	s
Radar altimeter		s	s
OAT	s	c	s
TIME	s	s/s	s
Angle of sideslip	s	s	s
Rotor rpm	c	s	s
1/REV magnetic pickup			s
#1 Eng fuel flow rate			s
#2 Eng fuel flow rate			s
#1 Eng fuel temp	s		s
#2 Eng fuel temp	s		s
#1 Eng fuel counter	s		s
#2 Eng fuel counter	s		s
#1 Eng N_1	c	c	s
#2 Eng N_1	c	c	s
#1 Eng T.I.T.	s	s	
#2 Eng T.I.T.	s	s	
#1 Eng ENG. torque	c	c	
#2 Eng ENG. torque	c	c	
Fwd rotor torque			s
Fwd rotor torque			s
Fwd rotor torque			s
Aft rotor torque			s
Aft rotor torque			s
Aft rotor torque			s
Fwd cyclic trim pos.	s	s	s
Aft cyclic trim pos.	s	s	s
Record counter	c	c	
Fuel quantity indicator		s/s	
MA-1 compass		s/s	
Sideslip indicator		s/s	
Long. stick position		s	s
Lateral stick position		s	s
Dir. pedal position		s	s

Item	Photopanel	Cockpit	Magnetic Tape
Collective stick position		s	s
Attitude indicator		s/s	
Pitch attitude			s
Roll attitude			s
Yaw attitude			s
Vertical speed indicator	c	s/s	

Additional instrumentation used:

Hand held:

20 lb force gage - c
40 lb force gage - c
10 second chronometer

Legend:

c - Production unit, calibrated.
s - Sensitive unit, calibrated.
s/s - Production unit, not calibrated.

APPENDIX VI
GLOSSARY OF TERMS

Symbol	Definition	Unit
BIAS	Boom system indicated airspeed	Knots
BL	Buttline	Inches
C.G.	Center of gravity	Inches
^{o}C	Degrees centigrade	
C_P	Power coefficient	
C_T	Thrust coefficient	
DCP	Differential collective pitch	
ECP	Engineering change proposal	
^{o}F	Degrees Fahrenheit	
f_e	Effective flat plate area	Square feet
fpm	Feet per minute	
G.W.	Gross weight	Pounds
GW/δ	Generalized gross weight	
H_D	Density altitude	Feet
H_P	Pressure altitude	Feet
IGE	In ground effect	
K_P	Rate of climb power correction factor	
KTAS	Knots true airspeed	
K_W	Rate of climb weight correction factor	

Symbol	Definition	Unit
LCST	Longitudinal cyclic speed trim	
L/H	Left hand	
MP	Military power	
MRP	Military rated power	
N	Rotor speed	Revolutions per minute
NAMPP	Nautical air miles per pound of fuel	
NAMT	Nautical air miles traveled	
NM	Nautical mile	
NP	Normal power	
NRP	Normal rated power	
N_Z	Limit load factor	
N_1	Gas producer	
N_2	Power turbine	
$N/\sqrt{\theta}$	Referred rotor speed	
OAT	Outside air temperature	
OGE	Out of ground effect	
R/C	Rate of climb	Feet per minute
R/D	Rate of descent	Feet per minute
R/H	Right hand	

Symbol	Definition	Unit
SAS	Stability augmentation system	
shp	Shaft horsepower	
$SHP/\delta\sqrt{\theta}$	Generalized shaft horsepower	
S.L.	Sea level	
SL/STD	Sea level standard	
T.I.T.	Turbine inlet temperature	Degrees centigrade
TOCG	Takeoff center of gravity	
TOGW	Takeoff gross weight	
V_{NE}	Never exceed airspeed	Knots
$\frac{V}{\sqrt{\theta}}$	Referred airspeed	
W.L.	Water line	Inches
δ	Ratio of ambient pressure to standard pressure (S.L.)	
θ	Ratio of ambient temperature to standard temperature (S.L.)	

APPENDIX VII
CH-47C FLIGHT ENVELOPE OF APE 1

1. Operating Weights:

Maximum takeoff weight (for test purposes only)	47,000 lb
Maximum landing weight (for test purposes only)	47,000 lb
Maximum test gross weight	46,000 lb

2. Gross weight - longitudinal C.G. envelope[1]

Gross Weight (lb)	C.G. Range (in)
20,000 - 28,500	30.0 fwd - 18.0 aft
33,000	21.3 fwd - 7.0 aft
44,800	12.0 fwd - 5.0 aft

3. Load factor - gross weight envelope

Gross Weight (lb)	Load Factor (N_z)
20,000 - 44,800	1.5

4. Airspeed - Altitude - Gross Weight Envelope - 235-245 rpm Rotor Speed — Figure A

5. Airspeed - Altitude - Gross Weight Envelope - 245 rpm Rotor Speed — Figure B

6. Airspeed - Sideslip Envelope[2]

Airspeed (KTAS)	Sideslip Angle (degrees)
0 - 38	90
38	45
165	11

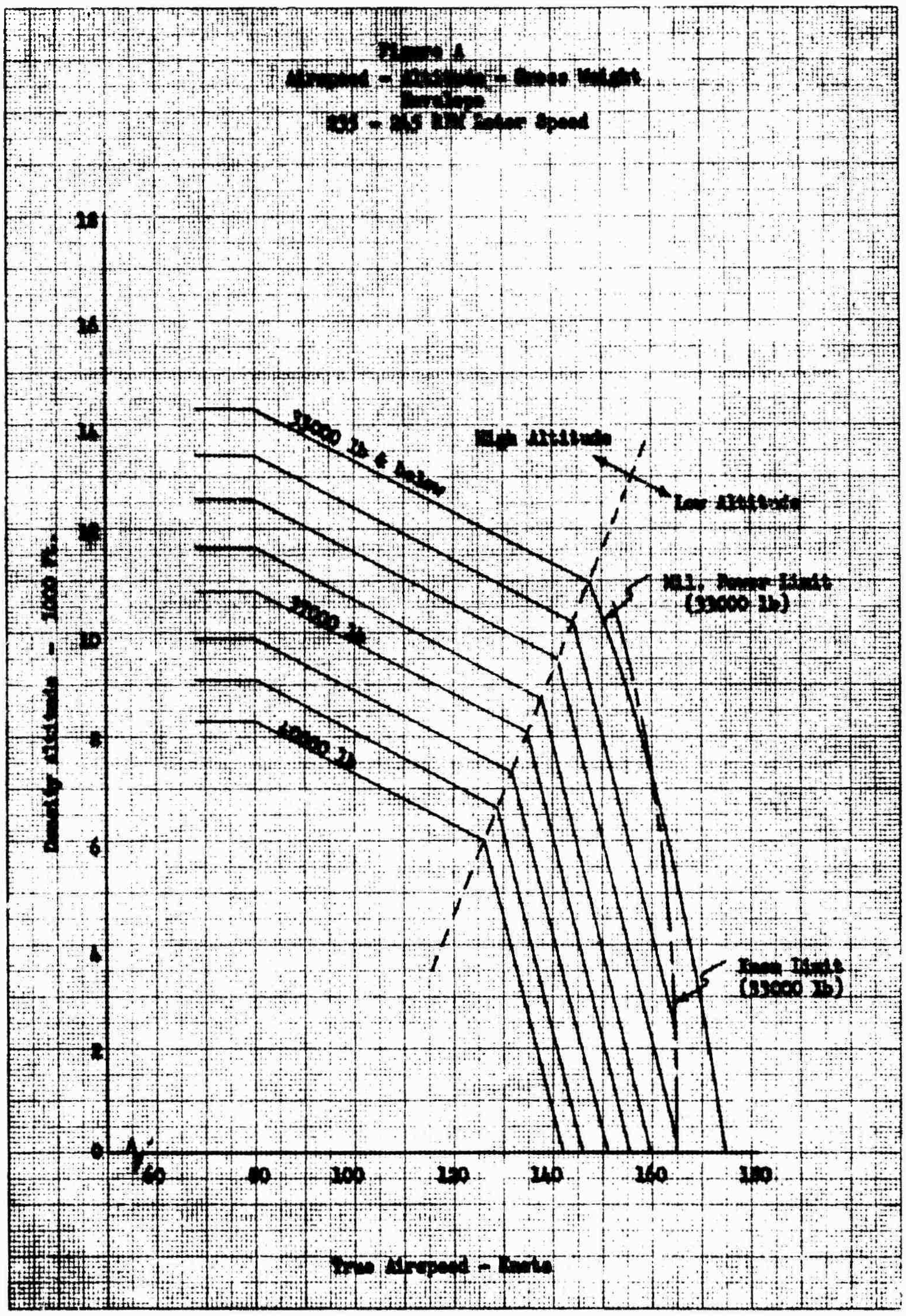
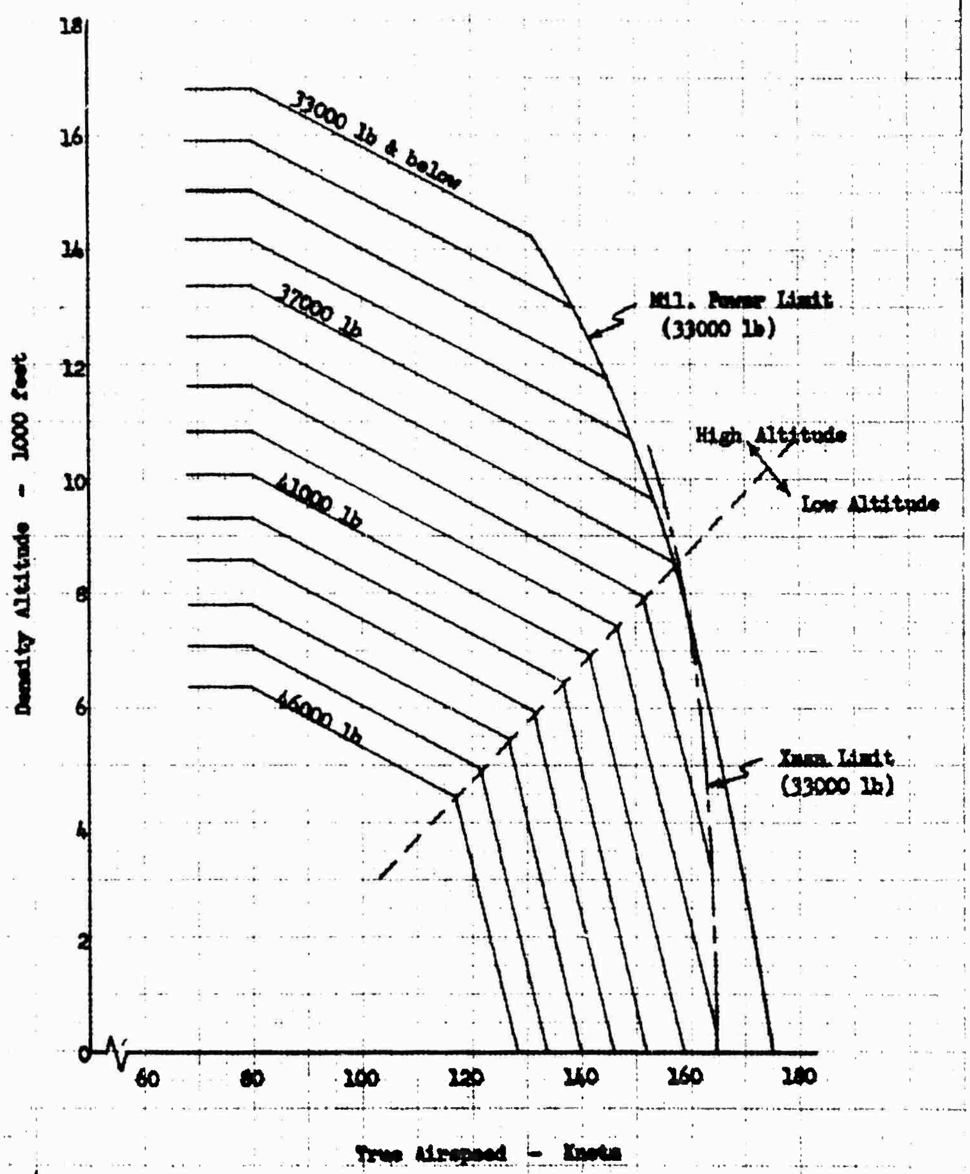

High Altitude
Low Altitude
True Airspeed - Knots
0
2
4
6
8
10
12
14
16
18
60
80
100
120
140
160
180

Figure B
Airspeed - Altitude - Gross Weight
Envelope
245 RPM Rotor Speed



7. Airspeed - bank angle envelope[3]:

Gross Weight (lb)	Airspeed (kt)	Bank Angle (degrees)
40,000 and below	V_{NE}	25
	V_{NE}-15	40
	Below V_{NE}-15	40
Above 40,000	V_{NE}	20
	V_{NE}-12.5	32
	Below V_{NE}-12.5	32

8. Rotor speed limitations:

Power-on (Hover)	223 to 250 rpm
Power-on (Except Hover)	223 to 247 rpm
Power-off	223 to 261 rpm

9. Engine operating limitations:

YT55-L-11

Ratings	shp	Output Shaft Speed rpm	Measured Gas Temperature T.I.T. °C
Maximum (10 min)	3750	16,000	896
Military (30 min)	3400	16,000	849
Normal	3000	15,950	804

Installed engine N_1 limits per Engine Run Sheets.

Measured gas temperatures during starting and acceleration is 940°C and 910°C respectively.

Maximum torque is 1300 ft-lb.

Engine Oil Data:

	Pressure psi	TEMP °F
NRP	70 ± 20	190
G.I.	20 (MIN)	190

NOTE: Transmission ratio = output shaft speed/rotor speed = 16,000/250 = 64:1

10. Transmission operation limitations:

    Input torque limits/engine
    Dual engine 1015 ft-lb continuous (78 percent)
    Single engine 1330 ft-lb (100 percent)

For transmission oil system operating limits see TM 55-1520-209-10, Chapter 7, Section II. During hover performance testing only, the dual engine torque limitation shall be 1100 ft-lb (85%) at 243 rotor rpm. Total time above 1015 ft-lb (78%) shall not exceed 3 hours.

11. Prohibited maneuver:

Aerobatics are prohibited with this helicopter as well as the following additional maneuvers until such time as the structural demonstration is completed:

a. Severe pull-ups.
b. Rolling pull-outs.
c. Quick stops.

12. For all areas of operation not covered in this flying envelope, operation of the aircraft should be in accordance with TM 55-1520-209-10, "Operators Manual, Army Models CH-47A and CH-47B Helicopter." Where limitations are given for each model, utilize the CH-47B limitations.

13. Use 235 rotor rpm for vibration specification compliance and Mission I guarantee compliance. Use 245 rotor rpm for Mission II guarantee compliance. Single engine service ceiling guarantee compliance will be demonstrated at 230 rotor rpm.

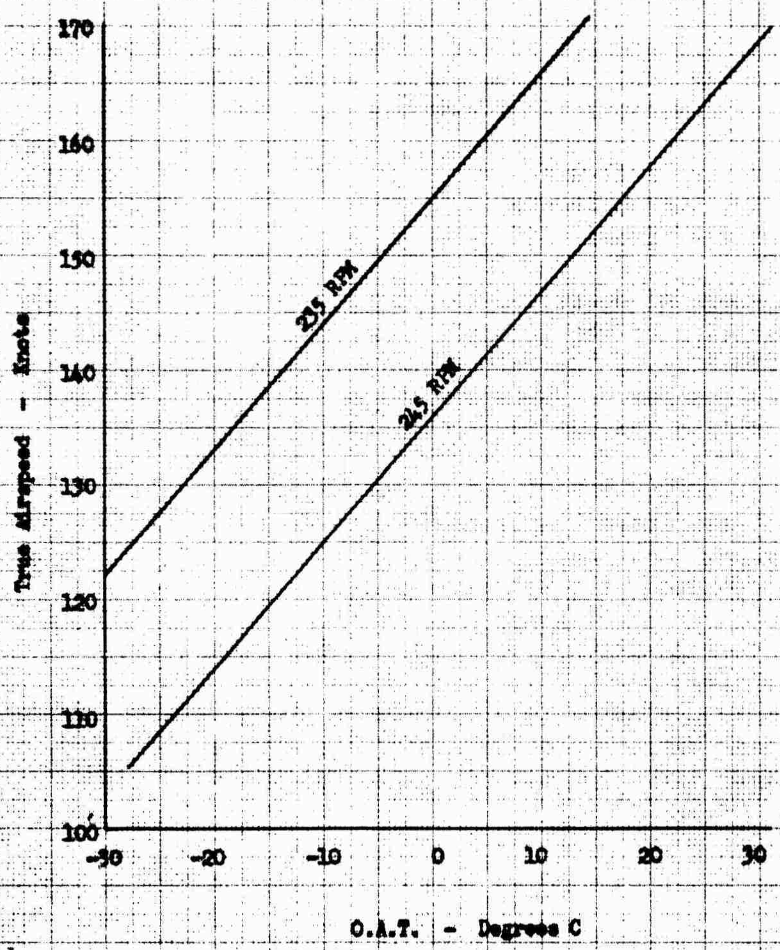
14. Limited Test Zone: See Figure C.

(1) Linear variation in C.G. between gross weights indicated.
(2) Linear variation between sideslip angles indicated.
(3) Linear variation between bank angles indicated.

Figure C
Structural Restriction
Aft Drive Collar Fatigue Limit

Record for flight in excess of TAS shown

1. IAS
2. Hp
3. OAT
4. N_R
5. Elapsed time



APPENDIX VIII
GUARANTEED PERFORMANCE

The following values are guaranteed, except where specifically designated, and are based upon given mission gross weights where applicable. All performance is based on Sea Level/Standard, KTAS and normal power between 225 and 250 rpm rotor speed at any longitudinal C.G. within the design envelope. Performance guarantees are quoted for an aircraft configured for an internal cargo mission (no outside mirror or troop seats). Guarantee compliance will be demonstrated as defined in Boeing-Vertol Report 114-TN-601, Revision A, as approved by the Procuring Activity.

	MISSIONS (1)				
	I (2)	II	III (3)	IV	V
Estimated gross weight (lb) Payload, outbound (lb) Payload, inbound (lb)	37,700 12,000 6,000	33,000	44,800	44,800	44,800
Maximum cruise speed at SL/STD, normal power (KTAS)		155			
Service ceiling, single engine at MP	4,000				
Radius of action (NP)	100				

(1) Missions are defined in the Detail Specification.

(2) For Mission I the helicopter shall be capable of hovering at 6,000 ft for ten minutes at 95°F, OGE at the gross weight required for accomplishment of Mission I (guaranteed). The Mission I gross weight includes an outbound payload of 12,000 ft, return payload of 6,000 ft, and fuel for a radius of 100 NM.

(3) During Mission III the helicopter shall be capable of hovering OGE at Sea Level/Standard day, maximum power and at a gross weight of 43,000 lb (guaranteed).

APPENDIX IX PILOT'S RATING SCALE

CONTROLLABLE CAPABLE OF BEING CONTROLLED OR MANAGED IN CONTEXT OF MISSION, WITH AVAILABLE PILOT ATTENTION	ACCEPTABLE MAY HAVE DEFICIENCIES WHICH WARRANT IMPROVEMENT, BUT ADEQUATE FOR MISSION. PILOT COMPENSATION, IF REQUIRED TO ACHIEVE ACCEPTABLE PERFORMANCE, IS FEASIBLE.	SATISFACTORY MEETS ALL REQUIREMENTS AND EXPECTATIONS, GOOD ENOUGH WITHOUT IMPROVEMENT CLEARLY ADEQUATE FOR MISSION.	EXCELLENT, HIGHLY DESIRABLE	A1
			GOOD, PLEASANT, WELL BEHAVED	A2
			FAIR. SOME MILDLY UNPLEASANT CHARACTERISTICS. GOOD ENOUGH FOR MISSION WITHOUT IMPROVEMENT.	A3
		UNSATISFACTORY RELUCTANTLY ACCEPTABLE. DEFICIENCIES WHICH WARRANT IMPROVEMENT. PERFORMANCE ADEQUATE FOR MISSION WITH FEASIBLE PILOT COMPENSATION.	SOME MINOR BUT ANNOYING DEFICIENCIES. IMPROVEMENT IS REQUESTED. EFFECT ON PERFORMANCE IS EASILY COMPENSATED FOR BY PILOT.	A4
			MODERATELY OBJECTIONABLE DEFICIENCIES. IMPROVEMENT IS NEEDED. REASONABLE PERFORMANCE REQUIRES CONSIDERABLE PILOT COMPENSATION.	A5
			VERY OBJECTIONABLE DEFICIENCIES. MAJOR IMPROVEMENTS ARE NEEDED. REQUIRES BEST AVAILABLE PILOT COMPENSATION TO ACHIEVE ACCEPTABLE PERFORMANCE.	A6
	UNACCEPTABLE DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT. INADEQUATE PERFORMANCE FOR MISSION EVEN WITH MAXIMUM FEASIBLE PILOT COMPENSATION.		MAJOR DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT FOR ACCEPTANCE. CONTROLLABLE. PERFORMANCE INADEQUATE FOR MISSION, OR PILOT COMPENSATION REQUIRED FOR MINIMUM ACCEPTABLE PERFORMANCE IN MISSION IS TOO HIGH.	U7
			CONTROLLABLE WITH DIFFICULTY. REQUIRES SUBSTANTIAL PILOT SKILL AND ATTENTION TO RETAIN CONTROL AND CONTINUE MISSION.	U8
			MARGINALLY CONTROLLABLE IN MISSION. REQUIRES MAXIMUM AVAILABLE PILOT SKILL AND ATTENTION TO RETAIN CONTROL.	U9
UNCONTROLLABLE CONTROL WILL BE LOST DURING SOME PORTION OF MISSION.			UNCONTROLLABLE IN MISSION.	10

Revised Pilot Rating Scale

APPENDIX X
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Commander Naval Air Test Center (FT23) Patuxent River Maryland 20670	1	-	-	1
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Final Report, June 1966 through June 1968

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Commanding General US Army Materiel Command ATTN: AMCPM-CH P.O. Box 209, St Louis, Missouri 63166

13. ABSTRACT

Army Preliminary Evaluation I was conducted to verify the performance guarantees, obtain limited handbook data and evaluate the mission effectiveness of the YCH-47C helicopter. The performance testing was conducted in the vicinity of Philadelphia International Airport, Pa. and Millville Airport, N. J. by the US Army Aviation Test Activity. The testing consisted of nineteen productive flights and 22.1 productive flight hours and was conducted from 19 February through 14 March 1968. Within the scope of this evaluation all performance guarantees were met. The maximum cruise speed capability was 155 KTAS and limited by heavy cockpit vibration. The outstanding 95 degree Fahrenheit day in ground effect and out of ground effect hover capability enhances the mission effectiveness of the aircraft. The flight envelope release V_{NE} for all gross weights tested at 245 rpm rotor speed and low and high altitudes was not attained. The airspeed was limited by as much as 15 KTAS due to heavy cockpit vibration, but not to the extent that the mission effectiveness of the helicopter would be seriously degraded. The V_{NE} was easily exceeded for all gross weights tested at 235 rpm rotor speed-high altitudes with no vibration limitations encountered. There were eleven shortcomings for which correction is desirable for improved Army use. There were no deficiencies noted for which correction would be mandatory for acceptable helicopter operation and/or capabilities as per mission requirements.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Army Preliminary Evaluation I						
Performance guarantees						
Limited handbook data						
Evaluate mission effectiveness						
YCH-47C helicopter						
Performance guarantees were met						
Maximum cruise speed						
Heavy cockpit vibration						
Hover capability						
V_{NE} was exceeded						
235 rpm rotor speed						
Eleven shortcomings						

US ARMY AVIATION SYSTEMS TEST ACTIVITY
Errata Number 1, 3 December 1968
USAAVNTA Project Number 66-28

Following changes should be made to Final Report for Engineering Flight Test of the YCH-47, Medium Transport Helicopter, Army Preliminary Evaluation, USAAVNTA Project Number 66-28:

a. Replace first two sentences, Para 15 with the following:

"15. All generalized performance data presented are based on the generalized parameters, generalized gross weight (GW/δ), generalized shaft horsepower ($SHP/\delta\sqrt{\theta}$), referred airspeed ($V/\sqrt{\theta}$) and referred rotor speed ($N/\sqrt{\theta}$) as specified in reference 7, appendix I. Where the actual $N/\sqrt{\theta}$'s flown varied from the $N/\sqrt{\theta}$'s presented in the generalized performance plots, the compressibility corrections shown in figure I, appendix II, for hover and figures 2 and 3 for level flight were used.

b. Change the word "at" to "as" in line 12 of para 20.

c. Change line 13, para 20 to read: "number decreases. Above 130 KTAS and below 80 KTAS considerable".

d. Add the word "to" after the word "attention" in line 15 of Para 25.

e. Add the word "level" after the word "moderate" in line 4 of para 26.