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ENGINEERING FLIGHT TEST OF THE CH-47 (CHINOOK) HELICOPTER INTEGRAL WEIGHT AND BALANCE SYSTEMS (ENSURE)

FINAL REPORT

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MARCH 1968

This document will be downgraded to unclassified March 1971 .

US ARMY AVIATION TEST ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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ABSTRACT

An engineering research evaluation of two proposed integral weight and balance systems for the CH-47 Chinook Helicopter was conducted to determine the feasibility of such systems. The primary function of the systems is to accurately predict the aircraft gross weight and center of gravity location along with cargo hook load. The evaluation of these systems was conducted at Edwards Air Force Base, California, by the US Army Aviation Test Activity. The systems were tested throughout the entire envelope of allowable gross weight and center of gravity for the CH-47A aircraft. The testing consisted of determining the affects of rotor rpm, terrain, wind and control position, for various loading configurations, upon the indicated values of gross weight and center of gravity for the STAN (Fairchild-Hiller Control Company) and STOW (National Water Lift Company) weight and balance systems. Also evaluated were the problems of installation and calibration of the systems, repeatability, reliability, and compatibility with other systems. Both systems performed reasonably well with the helicopter in a static mode (rotors not turning), however, once the engines were started, the system repeatability and reliability degraded significantly. Results of the engineering evaluation indicate that the concept of such systems is feasible but that efforts must be directed toward the improvement of the systems' reliability with the helicopter operating in its various environments.

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INTRODUCTION

BACKGROUND

1. A letter from the 147th Aviation Company, Republic of Vietnam (RVN), dated 29 April 1966, to the US Army Combat Development Command (USACDC) recommended that a gross weight indicator system be incorporated as soon as practical in all CH-47 model helicopters. This recommendation (requirement) was based on the relative ease of overloading the cargo compartment due to the physical size of the CH-47 and its capability to be unintentionally operated outside of the gross weight envelope.

2. On 26 July 1966, the Chinook Project Manager, US Army Materiel Command (USAMC), informed the Chinook Field Office at the US Army Aviation Materiel Command (USAAVCOM) of Department of Army concurrence of the desirability for early installation of a gross weight indicator in the CH-47, that the requirement was designated "ENSURE", and that expeditious action be taken to obtain the desired system. On 29 July 1966, the Project Manager issued a plan by which USAAVCOM would take action to obtain the desired results. Two systems were developed and presented for testing as a result of that plan. Authority for the US Army Aviation Test Activity (USAAVNTA) to perform the test on the two systems was provided by Test Directive Number 67-04 (reference 1, appendix I), issued by USAAVCOM on 1 June 1967.

TEST OBJECTIVES

3. The objective of the integral weight and balance system test was to furnish the USAMC results derived from the USAAVNTA tests of a CH-47A Helicopter equipped with the Fairchild Controls system (STAN) and the National Water Lift system (STOW). Specific objectives included are:

a. Ease of installation and required modifications.

b. Initial calibration procedures.

c. Accuracy and recalibration requirements.

d. Repeatability.

e. Reliability.

f. Compatibility with aircraft systems.

Each system was evaluated with respect to the effects of:

a. Rotor speed.

b. Terrain variations.

c. Wind.

d. Loading configuration.

e. Hook load.

DESCRIPTION

4. The STAN integral weight and balance system consists basically of three types of components; an indicator panel, pressure transducers, and the hook load sensing assembly. The indicator panel, mounted in the cargo compartment, contains the necessary computing components, controls, and visual readouts for the gross weight and center of gravity (C.G.) determination. In addition, the panel contains a spirit level to account for variations in helicopter's attitude which provides an input to the computer. The four pressure transducers mounted on the oleo struts are provided with a pressure port for oleo pressure measurement and electrical connectors for transmission of the electrical signals over a cable network to the indicator panel. The hook load sensing assembly replaced the NAS 1314 machine bolt to measure external hook loads. This assembly is electrically connected to the indicator panel where the hook load is displayed. A further breakdown and detailed description of the STAN weight and balance system may be found in reference 2, appendix I. Photographs 1 through 4, appendix II, show the various components and installation of the STAN system.

5. The STOW integral weight and balance system consists of four basic components; a computer/indicator package, cargo hook instrumentation, forward landing gear instrumentation and aft landing gear instrumentation. The computer/indicator package contains all the necessary analog components, controls, and visual readout assemblies to indicate gross weight and C.G. values. Accompanying this package is a pendulum operated attitude compensator assembly, which automatically provide corrections for operation on sloped terrain. The cargo hook package includes calibrated strain gaged side plates to provide signals to sense external hook loads. The forward gear are equipped with four strain gaged axle assemblies to provide forward gear net supported weight. Aft gear loads are sensed by two strain gaged deflection cap sensors located on the uppermost section of the gear assemblies. All four strain gaged landing gear sensors are electrically connected by a cable network

to the computer/indicator package. A detailed breakdown and description of the STOW system may be found in reference 3, appendix I. Photographs 4 through 9, appendix II, picture the components and installation of the STOW system.

SCOPE OF TEST

6. The STAN and STOW integral weight and balance systems were evaluated in order to assess their potential for use in a CH-47 helicopter. The evaluation included a detailed analysis of their capabilities, deficiencies, and shortcomings in order to provide information as to which "off the shelf" system was most suitable and required the least modifications to be fully adaptable to the helicopter.

7. Testing was conducted at Edwards Air Force Base and Bishop, California, from 1 August 1967 through 12 January 1968. Sixteen test flights were conducted with a total of 30 productive flight hours. Testing was delayed prior to completion of the planned flights due to participation in rescue missions in Arizona. The effects of the exposure to severe cold encountered during these missions are presented in the Results and Discussion section of this report. Restrictions placed upon this evaluation were those dealing with the allowable gross weight-C.G. envelope and hook loads as presented in reference 4, appendix I, and illustrated in figure 1, appendix III. A summary of the tests performed during the study is presented in table 1. Detailed description of each test appears in the Results and Discussion section.

Table 1. PRESENTED ON PAGE 4 ▶

Table 1. Summary of Test

Operational Condition	Loading Range lb	C.G. Range in.	Rotor rpm	Wind kt	Control Position
Static	20,000 - 33,000	303 - 348	0	0	N/A
Dynamic	23,000 - 33,000	315 - 338	230	0-20	*
Slope	20,000 - 30,000	325 - 335	230	0-2	*
Parametric	23,000 - 30,000	322 - 348	0,90,230	0	**
Hook (sling and tethered)	0 - 12,000	N/A	N/A	0	***

* Control Position - longitudinal and lateral cyclic - neutral
directional - neutral
collective - 3^{o} detent

** Control Position - longitudinal cyclic - 1 in. forward to 1 in. aft of neutral in 1/4 in. increments
lateral cyclic - neutral
directional - neutral
collective - 3^{o} detent

*** Control Position - as required for stable hover

NOTE: Prior to recording data for the conditions in table 1, the system warm-up time was recorded and is summarized in tables 2 and 4.

METHODS OF TEST

8. Standard USAAVNTA test methods could not be used to acquire data for analyses and evaluation. Due to the unusual nature of this test program it was necessary to apply new test techniques in order to fully comply with each requirement as stated in the test directive (reference 1, appendix I). A detailed description of test methods is presented throughout the Results and Discussion section of this report.

CHRONOLOGY

9. The chronology is as follows:

Test directive issued	1 June	1967
Test aircraft received	17 June	1967
Test plan approved	30 June	1967
Test equipment received	11 July	1967
Test started	1 August	1967
Test discontinued	25 August	1967
Improved test equipment installed	16 November	1967
Test restarted	20 November	1967
Test completed (last flight)	12 January	1968
Draft report submitted	15 January	1968
Final report forwarded	March	1968

RESULTS AND DISCUSSION

GENERAL

10. Two "off-the-shelf" integral weight and balance systems were installed in one CH-47A helicopter to evaluate the feasibility of using an integral weight and balance system in the helicopter. The STAN and STOW systems were simultaneously tested to determine the effects of variations of rotor rpm, terrain, ramp position, wind, gross weight, and C.G. location. The accuracy, repeatability, and reliability of each system were noted at each test point. The results of the tests indicate that both systems lack accuracy and repeatability under various test conditions and that substantial improvement is mandatory before these systems could be considered as operationally suitable. It was determined that such a weight and balance system would be an advantageous device in informing the pilot of his loading condition provided that problem areas could be corrected. Correction of these problems would increase the flexibility of the system along with the reliability of determining the indicated gross weight and C.G. Table 2 summarizes the results of the engineering tests performed. Results of the evaluation indicate that the concept of such a system is feasible but that effort must be directed to the improvement of the system with the helicopter operating in its various environments.

STATIC OPERATING CONDITIONS

11. The effect of varying gross weight and C.G. with the helicopter in a static condition was investigated. The term "static" refers to the aircraft being physically indoors resting on level platform scales with the engine and auxiliary power unit (APU) shut down and power being supplied by an external power source. Ballasting to change the gross weight and C.G. was accomplished by physically driving previously weighed vehicles into the cargo compartment to selected compartment stations. True helicopter weight and C.G. were determined by physically weighing the helicopter at various loading configurations. Gross weight and C.G. were read directly from the STAN and STOW indicator systems for each loading condition. These readings were then compared directly with the helicopter's true weight and balance.

12. Figure 2, appendix III, shows the comparison of indicated to true gross weights for the helicopter in the static condition. Also shown are the lines of ideal gross weight (zero percent error) and the allowable ± 1 percent error. The STAN system deviation ranged from -1 to +3.5 percent. It is interesting to note that the STAN system indicated, in general, gross weights higher than actual, but

Table 2. Test Summary.

Operational Conditions	Guarantee G.W.	Guarantee C.G.	Results (degree of error) Stan G.W.	Stan C.G.	Stow G.W.	Stow C.G.
Static (1)(2)	1%	1%	-1 to +3.5%	-5 to +10%	-8 to +3%	±12%
Dynamic (1)(2)	1%	1%	-19 to +2%	-20 to +35%	-4 to 16%	-39 to +28%
Slope (1)(2)	N/A	N/A	0 to -1500 lb	-1.5 to +25 in.	-6500 to 6000 lb	-11 to +28 in.
Parametric (1)(2)	N/A	N/A	1000 lb	±15 in.	2000 lb	±15 in.
Hook (lb) (3)	1%		±2%		±2%	
Warm-up time (min)	N/A		5 min		40-45 min	

(1) For various gross weights (18,000 - 33,000 lb).

(2) For various C.G.s (301 - 349 in.).

(3) For various loads (2000 - 12,000 lb).

followed a proper trend. As real gross weight increased, the indicated gross weight increased in nearly a 1:1 proportion. The gross weight indicated by the STAN system tended to approach acceptable tolerances at higher gross weights. The higher than actual readings at low gross weights may be attributed to the friction effects of the hydraulic struts or to some other inherent system design feature. The STOW system generally indicated gross weights less than the actual helicopter weight and showed no improvement at high or low gross weights. The STOW system also showed proper trends in that a change of gross weight of the helicopter resulted in a proportional change of indicated gross weight.

13. Figure 3, appendix III, shows the comparison of indicated and true C.G. for the helicopter in the static condition. (Also shown are lines of ideal variation and acceptable tolerance from the ideal.) The ±1 percent tolerance was based on 1 percent of the total maximum C.G. travel (48 in. or 0.48 in.). Low reliability is explained by realizing that the center of gravity indication is based primarily upon moment summation of forward gear loads about the rear wheels. Inaccuracies in gear loading measurement tends to be magnified and directly contributes to the scatter (reliability) of the reading on the center of gravity scale of the system. Correction of the inaccuracies of the static center of gravity readouts of both the STAN and STOW system is mandatory for satisfactory operational use.

14. During the testing phase the helicopter was exposed to an environment of sub-freezing temperatures for a period of ten days. After this exposure, a series of static tests were performed on the aircraft. These data for both the STAN and STOW systems are illustrated by the flagged points in figures 2 and 3. Exposure to cold had no noticeable effect on the STAN system. Data taken for this system fell within the tolerances shown for gross weight. The C.G. location, however, was determined to be within the same scatter band exhibited by the system in previous tests. The STOW system gross weight indications were affected by exposure to a cold environment. Indicated gross weight varied approximately 2000 pounds below the ideal for all ranges of true gross weight. This behavior presents itself as a calibration shift of the STOW system due to environmental effects which is undesirable for field use. Correction of this deficiency of the STOW system is mandatory for satisfactory Army use.

DYNAMIC OPERATING CONDITIONS

15. The effects of varying gross weight and C.G. with the helicopter operating in a dynamic condition were investigated. The term "dynamic" refers to the helicopter being outdoors on a hard level unobstructed surface, engines running, and rotors turning at 230

rpm. Control positions were set as follows: Collective at 3-degree detent, neutral position for directional, lateral and longitudinal controls. Neutral position was defined as the position assumed by the cyclic and directional controls when the rigging pins were installed in the aircraft. The helicopter was then loaded with one or more vehicles of known weight and C.G. at onboard locations determined from the static tests. Fuel was accurately accounted for during each run. Therefore, the actual gross weight and C.G. were computed for each loading configuration throughout this series of tests. After the loading was complete and the helicopter true gross weight and C.G. were determined, the helicopter was allowed to roll forward a short distance, and then braked to a stop. The braking allowed the helicopter to rock slightly thus relieving static strut friction and allowing the full load of the helicopter to be supported by the fluid column in the strut. Indicated gross weight and C.G. were recorded for both the STAN and STOW systems for each loading condition. Wind velocity and wind direction were also recorded for each test condition.

16. Figure 4, appendix III, presents indicated gross weight readings plotted against helicopter true gross weights for various relative wind speeds and directions. Testing conditions were similar for all test days with temperatures ranging from 34 to 37-degrees Centigrade (C) except for one test condition of 18 to 20 knot winds when the temperature was 10 degrees C. It is interesting to note that with zero wind, the indicated data for both the STAN and STOW systems fell within the allowable tolerance of 1 percent (±1 percent). However, as the wind speed increased, the percent deviation for both systems increased up to 19 percent for the STAN system and 16 percent for the STOW system. The inaccuracies of the systems are not suitable for operational use. Correction of inaccurate and unrepeatable gross weight indications of both the STAN and STOW systems with regard to wind effects is mandatory for satisfactory Army use.

17. Figure 5 presents indicated C.G. readings plotted against true C.G. for the conditions discussed in paragraph 16. Also presented is a line of ideal C.G. (indicated equals actual value of C.G.) and the allowable tolerance of 1 percent defined as 1 percent of the maximum C.G. travel, 48 in. (or 0.48 in.). This figure clearly illustrates the need for a more accurate means of determining the indicated C.G. for both the STAN and STOW systems. Deviations for the STAN system were as high as 35 percent while the STOW system deviated as much as 39 percent from the ideal. The inaccuracies in C.G. determination are not suitable for operational use. Correction of inaccurate and unrepeatable C.G. indications of both the STAN and STOW systems with regard to wind effects is mandatory for satisfactory Army use.

SLOPE OPERATIONS

18. The effects of varying the physical attitude of the helicopter upon the indicated values of gross weight and C.G. for the STAN and STOW weight and balance systems were determined. In this series of tests the helicopter was landed on varying sloped surfaces. After a level-ground static reading was taken the engines were started and rotor speed was set at 230 rpm. Collective was held in the 3-degree detent position while cyclic and directional controls were in a neutral position. These positions are explained in paragraph 15. Indicated values of gross weight and C.G. were recorded. Both up-slope and down-slope attitudes were investigated up to ±10-degree slope. This test was performed at gross weight conditions of 22,620 and 29,775 pounds with C.G.s of 334.2 and 324.6 inches respectively. Figure 6 illustrates the variation of indicated gross weight and C.G. with the helicopter's attitude for both the STAN and STOW systems for a light weight and aft C.G. This figure shows that indicated gross weight for the STAN system for a limited range of slope (±6 degrees) was relatively independent of position and was affected mainly by system accuracy. The STOW system illustrates that indicated gross weight varied proportionately with the helicopter's attitude. The indicated C.G. showed a tendency to vary in a semi-exponential form with slope for both the STAN and STOW systems. It should be pointed out that the STAN system indicated C.G. showed a tendency to deviate less with nose down slopes than the STOW system. Figure 7 presents the same information discussed above for the high gross weight forward C.G. case. Variation in both indicated C.G. and gross weight for both systems behaved in a similar manner. It should be noted that for the high gross weight conditions a more accurate prediction of gross weight and C.G. were obtained from both systems. The inaccuracies in gross weight and C.G. determination caused by slope effects are not suitable for operational use. Correction of the STAN and STOW gross weight and C.G. indications as affected by slope is mandatory for Army use.

PARAMETRIC STUDIES

19. A series of tests were performed to determine the effects of variations in stick position, rotor rpm, loading ramp position, and loading upon the indicated values of gross weight and C.G. location. A need for the results of such a test was determined by the fact that for a tandem rotor helicopter such as the CH-47, longitudinal stick movement produces a differential collective pitch in the rotor system.

20. The first series of tests investigated the effects of longitudinal stick position for one rotor speed and one loading config-

uration. In this test the rotor speed was set at 230 rpm with the collective in the 3-degree detent position. Lateral and directional controls were in neutral positions. During the test the helicopter was operated on level, hard terrain into zero to three-knot winds. Indicated gross weight and C.G. for both conditions with the lift correction device OFF and ON were taken for longitudinal stick positions of one inch aft of neutral to one inch forward of neutral position in 1/4-inch increments. Results of this test are presented in figure 8, appendix III. This test was not designed to determine system accuracy but to develop trends to be used in the final analysis of the systems.

21. Both the STAN and STOW systems registered that the indicated gross weight for both lift correction device ON and OFF modes were essentially independent of longitudinal stick position. As shown in figure 8, the true gross weight lies between those values predicted by both systems with lift correction ON. These series of tests were performed after the helicopter's exposure to extreme cold and the resultant calibration shift of the STOW system. It is interesting to note that both systems registered a nearly constant indicated gross weight (for both lift correction ON and OFF) for the longitudinal stick in a neutral and aft position. It is concluded that the two rotors at this rpm, directional and collective control settings, support a constant gross load and that the rotor load is essentially independent of cyclic stick position.

22. Indicated C.G. developed a completely different trend. Longitudinal displacement of the cyclic control produces differential collective pitch in the forward and aft rotor. As longitudinal control is moved forward, the aft collective pitch increases while the forward rotor collective pitch decreases. This phenomenon reverses itself for aft cyclic motion. As the longitudinal control is moved, blade angle of attack varies along with the vertical component of thrust for each rotor system. This variation in individual disk loading with longitudinal cyclic displacement (at a constant rotor rpm) showed only a slight affect upon indicated gross weight but a significant influence upon the indicated C.G. As the stick moved the total load supported by both rotor systems remained essentially constant while the individual vertical component of rotor thrust varies with stick position. The net load supported by the forward and aft gear shifted the indicated C.G. Figure 8, appendix III, presents the indicated C.G. for both lift correction device ON and OFF modes for both the STAN and STOW systems. Variations in indicated C.G. of over 30 inches occurred during these tests. This variation is not suitable for operational use. Correction of the systems' inaccurate C.G. indications with variations in cyclic stick position is mandatory for satisfactory Army use.

23. The results of these tests are questionable as to the exact magnitude of change of ground bearing characteristics of the CH-47A helicopter with rotor rpm and control position. This is due to the inherent inaccuracies of both systems tested. A study should be conducted to determine these characteristics before a new or modified weight and balance system is presented for evaluation. A study of this nature would provide manufacturers with the knowledge needed to satisfactorily design a system of this type.

24. An additional series of tests were conducted to determine the effects of rotor rpm upon the indicated C.G. and gross weights for both systems under consideration. Testing conditions for these tests were the same as for the previous tests however, the wind speed range was zero to two knots. Indicated values of gross weight and C.G. were recorded (lift correction off) for both systems and compared with the true helicopter's weight and balance condition. Figures 9 through 12 present the differences between true and indicated gross weights and centers of gravity for various loading conditions and longitudinal cyclic stick position. For all loading conditions, the gross weight increment increased with increased rotor rpm as was expected. The test data presented in appendix III illustrate the possible effects of negative angle of attack due to blade twist, rigging differences, reverse flow, rotor efficiencies, relative wind, and blade centrifugal forces along with rotor rpm upon the total rotor systems lift (indicated gross weight). Also presented are the variations in C.G. for forward, neutral, and aft stick positions for the entire available range of rotor rpm. It is interesting to note that with a forward stick position, the correction to be added to the indicated value of C.G. tends to move the C.G. forward. This forward movement increases with rotor speed. The reverse phenomenon is indicated for an aft stick position and, as expected, the neutral stick position varies between the forward and aft C.G. limits with rotor rpm. Table 3 summarizes the conditions investigated for this series of tests.

Table 3. Summary of Parametric Test Conditions.

Figure No.	Gross Weight lb	Center of Gravity in.	Rotor rpm
9	23,766	333.2	90-230
10	26,860	318.15	90-230
11	26,360	329.24	90-230
12	30,137	324.12	90-230

25. The reduction in gross weight error by operating at a rotor speed of 90 rpm (approximately ground idle rpm) was 11 percent over the 230 rpm readings and in error from static readings by 1.8 percent. This indicates the possibility of improving the overall accuracies of both the STAN and STOW systems by restricting operational readouts to static and ground idle conditions. The requirement to operate at ground idle would not hamper combat operational requirements due to the rapid acceleration characteristics of the rotor-engine system of the CH-47 helicopter if the need for rapid deployment occurred. Longitudinal stick position was important in determining the C.G. reading in both systems. It is recommended that a stick position light be installed so that the pilot could properly position the stick each time a reading is taken.

HOOK LOADING TESTS

26. Tests were performed to determine the ability of the installed weight and balance systems to predict variations in hook load for both a free and tethered hover loading condition. During the free hover tests a series of known weights were attached to the sling cargo hook and the helicopter was hovered both in-ground-effect (IGE) and out-of-ground-effect (OGE). Loadings used for this test ranged from approximately 2000 to 10,000 pounds. Each loading configuration was investigated many times to ascertain the degree of repeatability. Indicated hook loads were recorded simultaneously for each system. Results of this test are presented in figure 13, appendix III. Tethered loadings were determined by hovering the helicopter directly over a calibrated load cell. Loadings investigated during this test varied from 2000 to approximately 12,000 pounds. Results of this test are also presented in figure 13 which illustrates the indicated hook load variations with true hook load. The ideal line and lines of allowable tolerance are also presented. The STAN system indicated hook loads tended to be higher than allowable at low hook loads and then tended to be lower than allowable at high hook loads. The STOW system indicated loads varied just the opposite being low at low hook loads and above specification requirements at higher loadings. Even so, the total variation from the ideal ranged between ± 2 percent for both systems. This was considered reasonable however, the specification required ± 1 percent agreement. Improvement in the accuracy of hook load indications is desirable for operational use.

MISCELLANEOUS

System Warm-up Time

27. Before data was taken on any day, the time for system warm-up was noted. Selector switches for both systems were placed in the

TEST position to determine whether they were fully warmed. The STAN system would be stabilized when the gross weight indicated 32,000 pounds and the C.G. indicated 12 inches aft of Station 331. The STOW system would read 25,000 pounds gross weight and 331 inches C.G. at system warm-up. Results of this test are presented in table 4. It is recommended that the warm-up time for the STOW system be decreased from the present 40-45 minutes required.

Table 4. Results of Warm-up Tests.

System	Time to Warm-up min	Outside Air Temperature Degrees C
STAN	5 - 6	30 - 37
	7	10
STOW	40 - 45	30 - 37
	40 - 45	10

Ease of Installation

28. Drilling of the forward strut boss for installation of the National Water Lift sensors required special carbide tip drills along with other special equipment such as a pneumatic drill motor and a hydraulic ram with controlled feed. The drilling was performed by the field maintenance machine shop and required 9.5 hours to drill and finish. The right hand end cap and aft landing gear shock strut had insufficient clearance at the forward bulkhead in the wheel well. In order to install the system the wire bundle fitting was cut off and the forward bulkhead extrusion ground down 3/16-inch to allow proper clearance. The STOW system required 176 manhours for the initial installation. This system was installed in the cargo compartment for ease of location and speed.

29. The STAN system required 48 manhours for the initial installation. No problems were encountered. This system was installed in the cargo compartment for ease of location and speed. It must be pointed out that the pressure transducer connection to the oleo strut is made directly with a length of tubing. In the event of a transducer failure, excessive maintenance manhours would have to be expended in bleeding the oleo strut to reduce the pressure and allow removal of the transducer. This loss of hydraulic fluid could be eliminated by the addition of a shut-off

valve upstream of the transducer near the oleo strut tap. This would enable rapid replacement of the transducer, minimal fluid loss and minimal maintenance time consumed in the process. It is suggested that the display be installed in the cockpit to provide a ready reference to the pilot once a suitable display is made available.

Initial Calibration Procedures

30. The STAN system was calibrated at the factory and required no field or post-installation calibration. The STOW system was calibrated by placing the helicopter on the platform scales and performing the following operations:

a. Forward Landing Gear: One wheel was raised an incremental amount by raising the platform scale under that particular wheel and the scale reading of the platform recorded. The axle sensor output was then adjusted. This was performed on all 4 axles of the 2 forward gear many times to check for repeatability.

b. Aft Landing Gear: The two aft landing gear wheels were raised incrementally one at a time by the scale platform and the weight recorded. The landing gear shock strut end cap sensor output was then adjusted. This was also performed many times to check for repeatability.

This initial procedure required 98 manhours.

Accuracy and Recalibration Requirements

31. Neither system attained the required plus or minus one percent accuracy for gross weight or C.G. determination with the initial calibration. The STAN system was removed and the calibration was rechecked at the factory with no change from the initial calibration being determined.

32. The National Water Lift Company replaced the forward gear axles and sensors with a newly designed axle and sensor attaching technique. A recalibration of this system was performed using a Cox and Stevens electronic weighing kit and steel plate. This recalibration required 264 manhours to complete. The tests presented in this report were performed with the new axles installed in the helicopter. No data are presented with the original axle configuration.

Compatibility with Aircraft Systems

33. Both systems are compatible with aircraft systems. No major modification was required with respect to compatibility with the helicopter upon installation or operation of these systems.

CONCLUSIONS

GENERAL

34. The following conclusions were reached upon completion of the evaluation of both the STAN and STOW integral weight and balance systems:

a. Both systems possess too many unsatisfactory performance characteristics to permit effective operational use (para 10).

b. The feasibility of the systems is good provided that the reliability and accuracy of the data readouts are improved to fall within reasonable tolerances for all operational conditions (para 10).

SPECIFIC DEFICIENCIES AND SHORTCOMINGS AFFECTING MISSION ACCOMPLISHMENT

35. Correction of the following systems deficiencies are mandatory for Army use:

a. The inaccuracies of the static readouts for both systems (para 14).

b. Inaccurate and unrepeatable gross weight and C.G. indicated values with regard to wind effects for both systems (para 20 and 21).

c. The inaccuracies caused by slope (helicopter's attitude) (para 18).

d. The systems indicated gross weight and C.G. values as effected by control position and differential rotor lift (para 21 through 25).

36. Correction of the following shortcomings are desirable for improved operation and mission capabilities:

a. The accuracy of the systems in predicting hook loads (para 26).

b. The required warm-up time (time to reach stabilized test model values) for the STOW was excessive (para 27).

RECOMMENDATIONS

37. The equipment evaluated should not be accepted for Army use because of inaccurate performance and lack of reliability.

38. The deficiencies, correction of which is mandatory, should be corrected prior to acceptance for operational use.

39. The shortcomings, correction of which is desirable, should be corrected as soon as practicable after acceptance of a system possessing suitable characteristics.

40. Further study should be made to determine accurately, the effects of rotor rpm and control position upon the ground bearing load of the CH-47 helicopter to provide information to successfully design a system for use in this type of helicopter (para 23).

41. The ground operational restriction for the CH-47 helicopter should be limited to ground idle rotor speed or to a static condition to reduce the error caused by control position and rotor rpm (para 25).

42. Excessive maintenance manhours would be expended on the STAN system in the event of a pressure transducer failure. It is recommended that a shut-off valve should be installed to prevent loss of oleo strut hydraulic fluid during a pressure transducer change (para 29).

43. A flight control light display should be installed to inform the pilot that the flight controls (longitudinal cyclic and collective) are in the proper position for accurate weight and balance indicated values (para 25).

44. Gross weight and C.G. indicators should be installed in the cockpit of the helicopter on the pilot's instrument panel (para 29).

45. A method of calibration should be devised for the STOW system to reduce the excessive time required (para 30).

APPENDIX I REFERENCES

1. Letter, Hq, USAAVCOM, AMSAV-ER, 1 June 1967, subject: "Test Directive, Engineering Test CH-47 Integral Weight and Balance System (ENSURE)."

2. Project Document, Fairchild Controls, PDS 968-6016, December 1965.

3. Project Document, National Water Lift Company, Proposal No. 5761, October 1966.

4. TM 55-1520-209-10, "Operator's Manual, Army Model CH-47A Helicopter," 10 February 1966.

5. TM 55-1520-209-20, "Organizational Maintenance Manual, Army Model CH-47A," 18 April 1966.

6. US Air Force Technical Order 1-1B-40, "Weight and Balance Data, CH-47A 64-13106."

APPENDIX II PHOTOGRAPHS

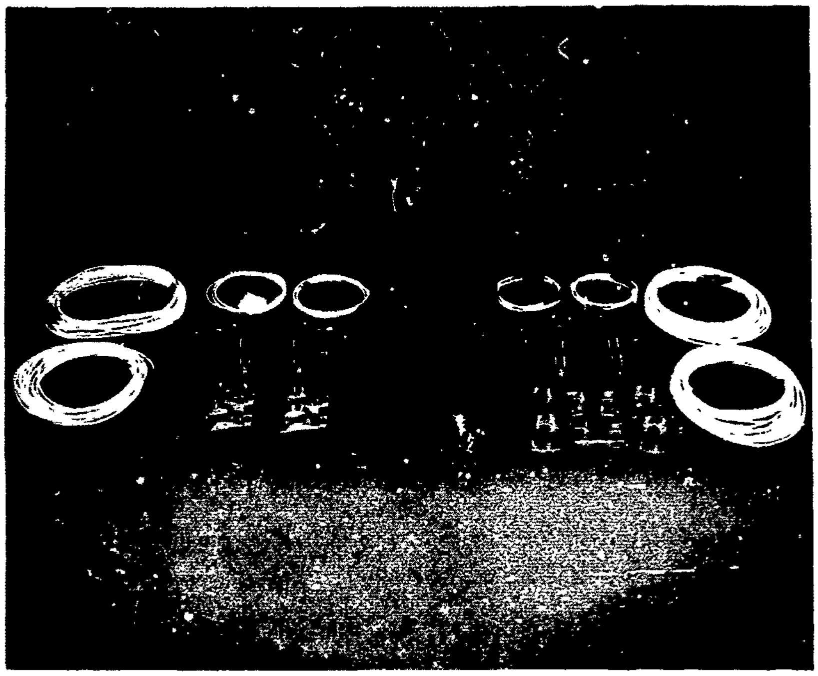


PHOTO 1 LAYOUT OF COMPONENTS OF STAN SYSTEM SHOWING TRANSDUCERS, HYDRAULIC AND ELECTRICAL CONNECTORS AND DISPLAY ASSEMBLY.

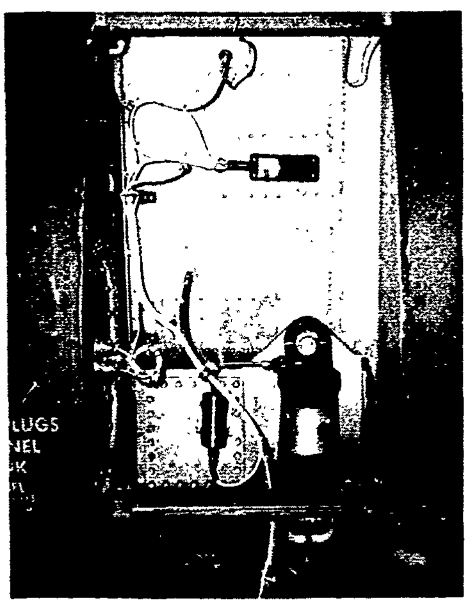


PHOTO 2 INSTALLATION OF STAN SYSTEM ON FORWARD STRUT.

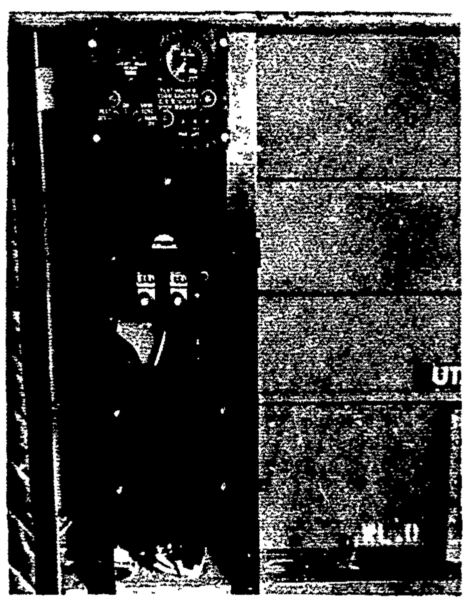


PHOTO 3 DISPLAY PANEL AND CONTROLS OF STAN WEIGHT AND BALANCE SYSTEM.

PHOTO 5
STOW INSTALLATION INCLUDING DISPLAY ASSEMBLY, ATTITUDE COMPENSATOR AND COMPUTING PACKAGE

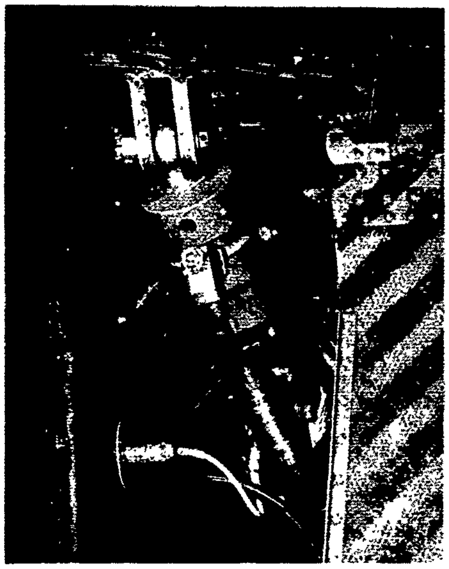


PHOTO 4 AFT STRUT ASSEMBLY OF STAN AND STOW WEIGHT AND BALANCE SYSTEMS.

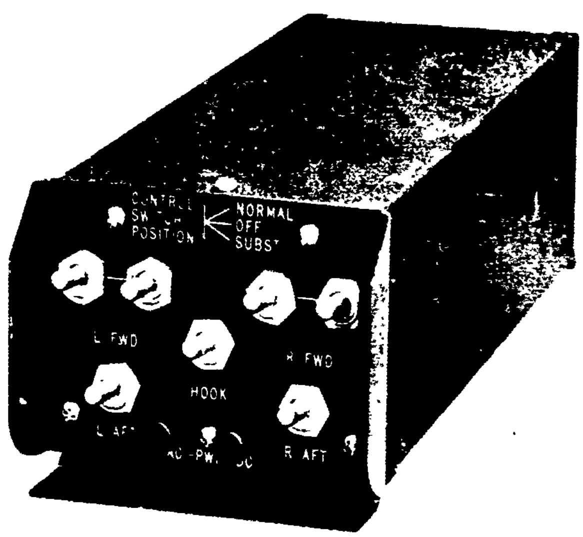


PHOTO 6 STOW CALIBRATION COMPUTER PACKAGE.

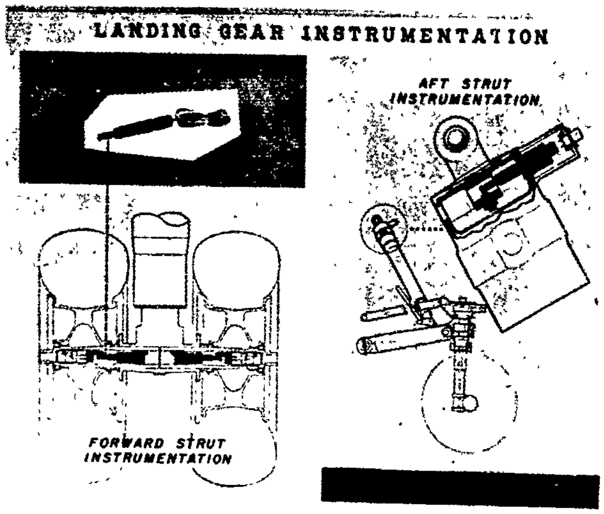


PHOTO 7 SCHEMATIC VIEW OF STOW SYSTEM INSTALLATION ON FORWARD AND AFT LANDING GEAR.

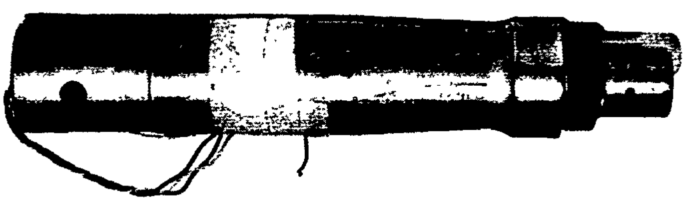


PHOTO 8
FORWARD INSTRUMENTED AXLE ASSEMBLY - STOW SYSTEM SIDE VIEW.

PHOTO 9
FORWARD INSTRUMENTED AXLE ASSEMBLY - STOW SYSTEM - END VIEW SHOWING PLACEMENT OF STRAIN GAGES.

APPENDIX III TEST DATA

FIGURE No. 1

GROSS WEIGHT AND CENTER OF GRAVITY MAP

CH-47A S/N 463106

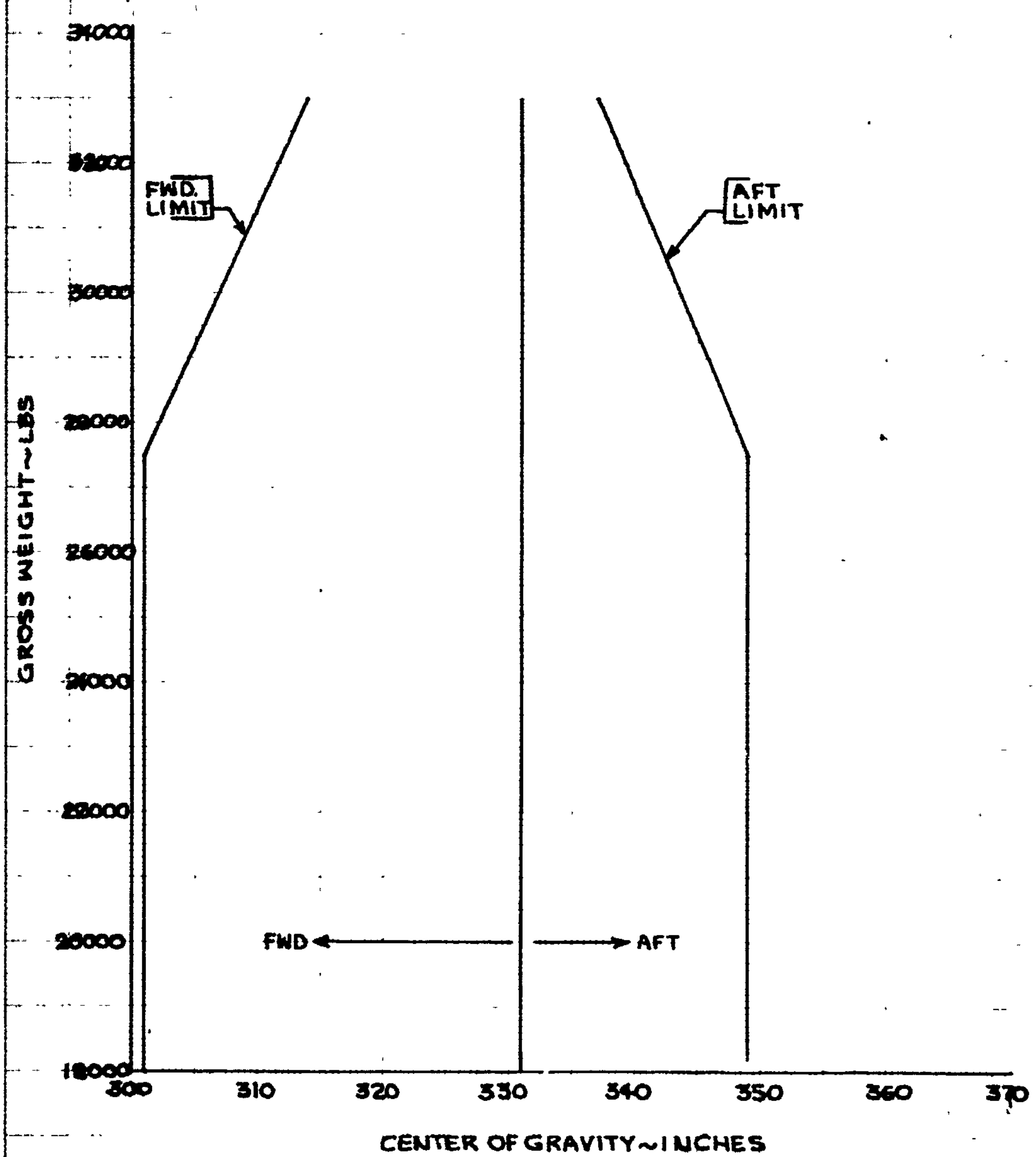
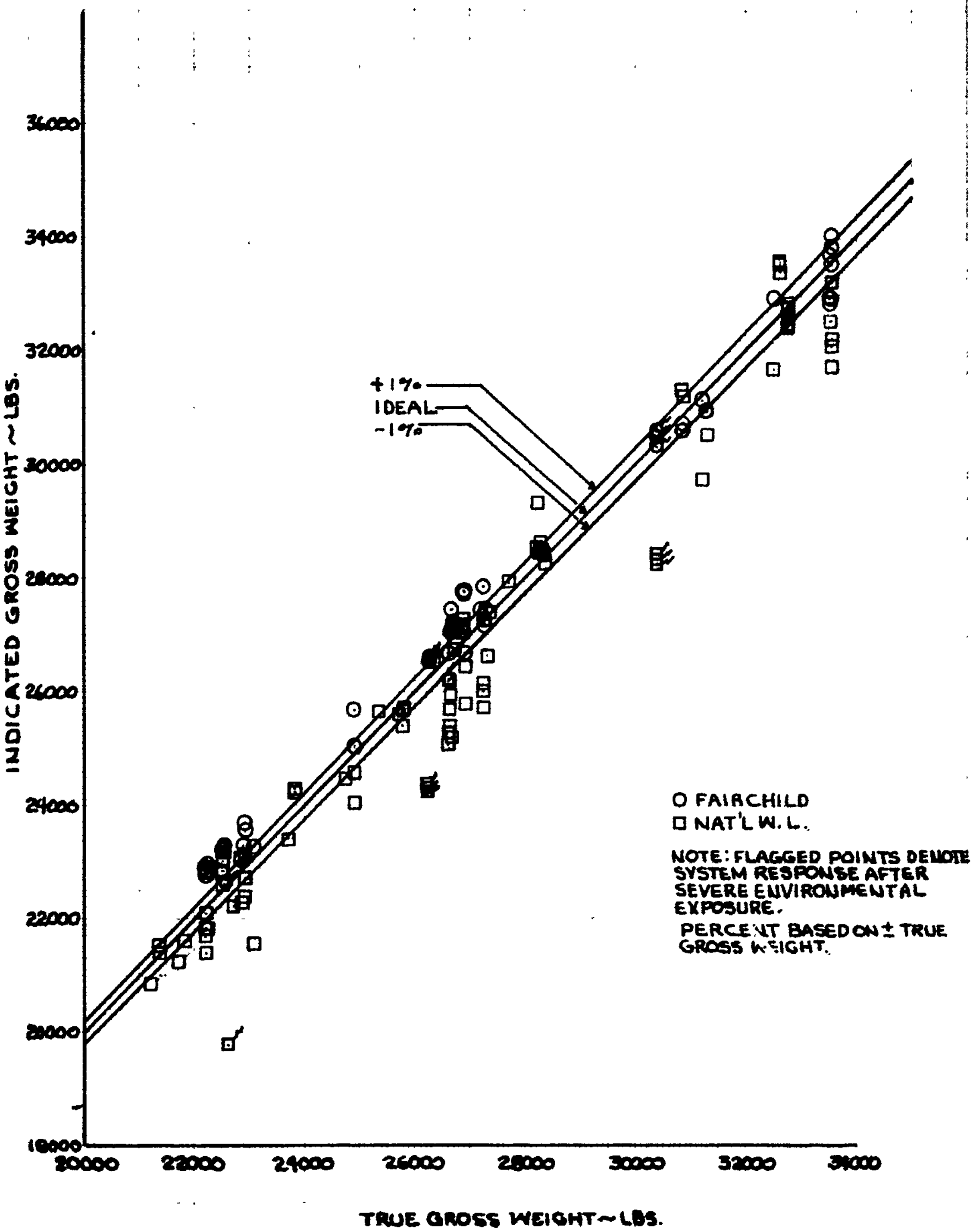


FIGURE No. 2
VARIATION OF INDICATED GROSS WEIGHT
CH-47A S/N 46106
STATIC CONDITION



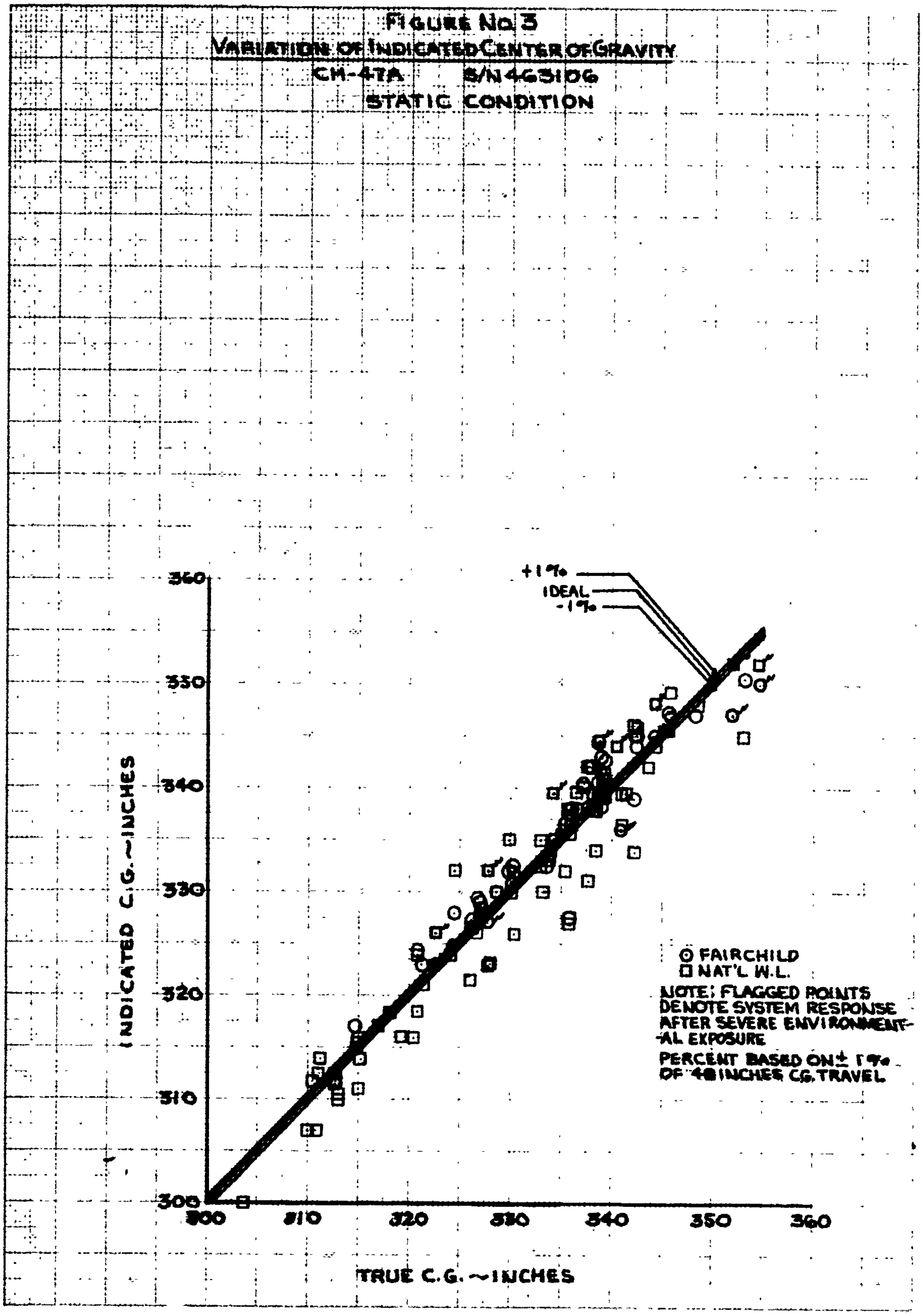


FIGURE No. 3
VARIATION OF INDICATED CENTER OF GRAVITY
CH-47A S/N 463106
STATIC CONDITION
+1%
IDEAL
-1%
INDICATED C.G. ~ INCHES
300
310
320
330
340
350
360
TRUE C.G. ~ INCHES
FAIRCHILD
NAT'L W.L.
NOTE: FLAGGED POINTS DENOTE SYSTEM RESPONSE AFTER SEVERE ENVIRONMENTAL EXPOSURE
PERCENT BASED ON ± 1% OF 48 INCHES C.G. TRAVEL

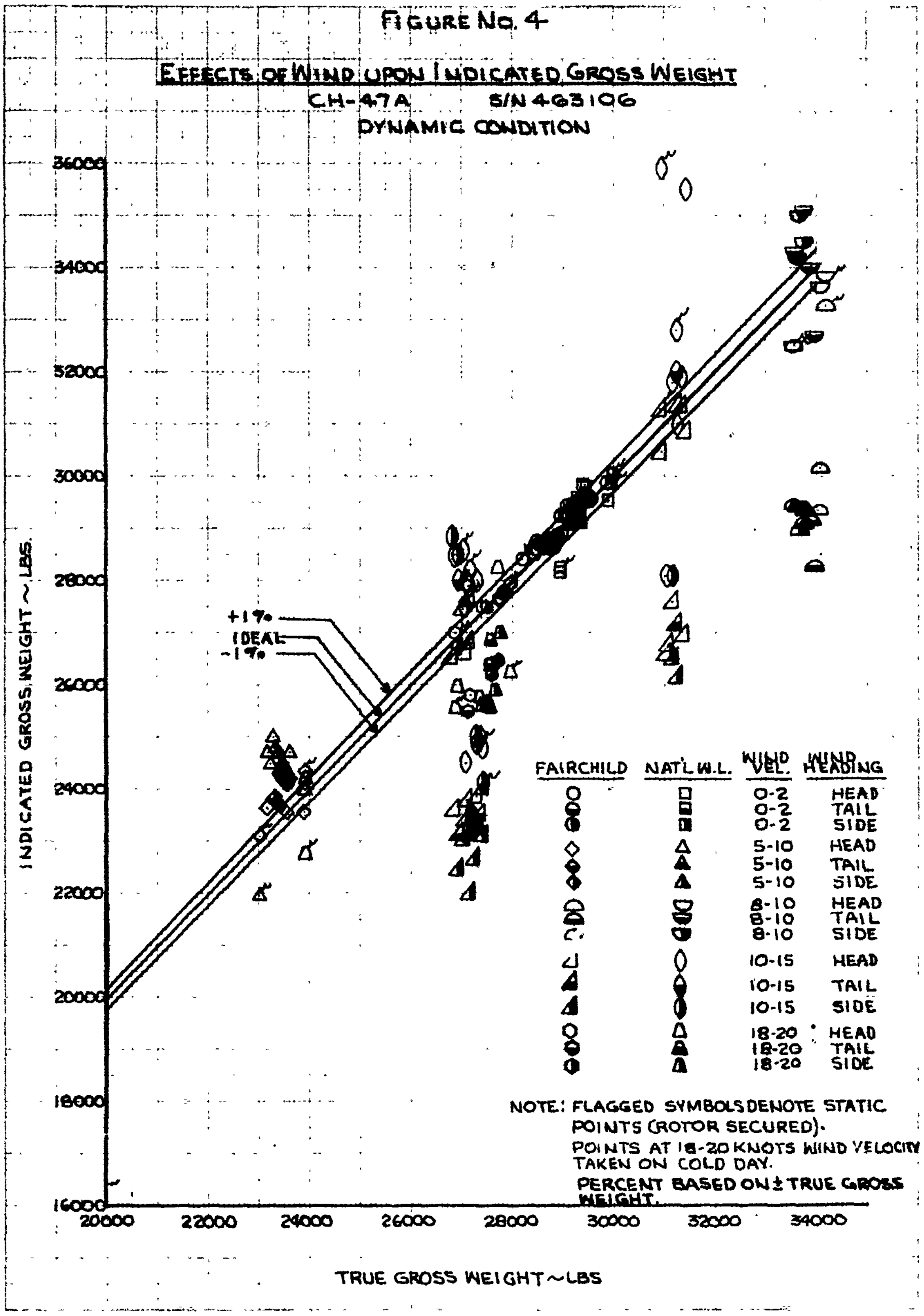


FIGURE No. 4
EFFECTS OF WIND UPON INDICATED GROSS WEIGHT
CH-47A S/N 463106
DYNAMIC CONDITION
INDICATED GROSS WEIGHT ~ LBS.
TRUE GROSS WEIGHT ~ LBS
16000
18000
20000
22000
24000
26000
28000
30000
32000
34000
36000
20000
22000
24000
26000
28000
30000
32000
34000
+1%
IDEAL
-1%
FAIRCHILD
NAT'L W.L.
WIND VEL.
WIND HEADING
0-2 HEAD
0-2 TAIL
0-2 SIDE
5-10 HEAD
5-10 TAIL
5-10 SIDE
8-10 HEAD
8-10 TAIL
8-10 SIDE
10-15 HEAD
10-15 TAIL
10-15 SIDE
18-20 HEAD
18-20 TAIL
18-20 SIDE
NOTE: FLAGGED SYMBOLS DENOTE STATIC POINTS (ROTOR SECURED).
POINTS AT 18-20 KNOTS WIND VELOCITY TAKEN ON COLD DAY.
PERCENT BASED ON ± TRUE GROSS WEIGHT.

FIGURE No. 5

EFFECTS OF WIND UPON INDICATED CENTER OF GRAVITY

CH-47A S/N 463106

DYNAMIC CONDITION

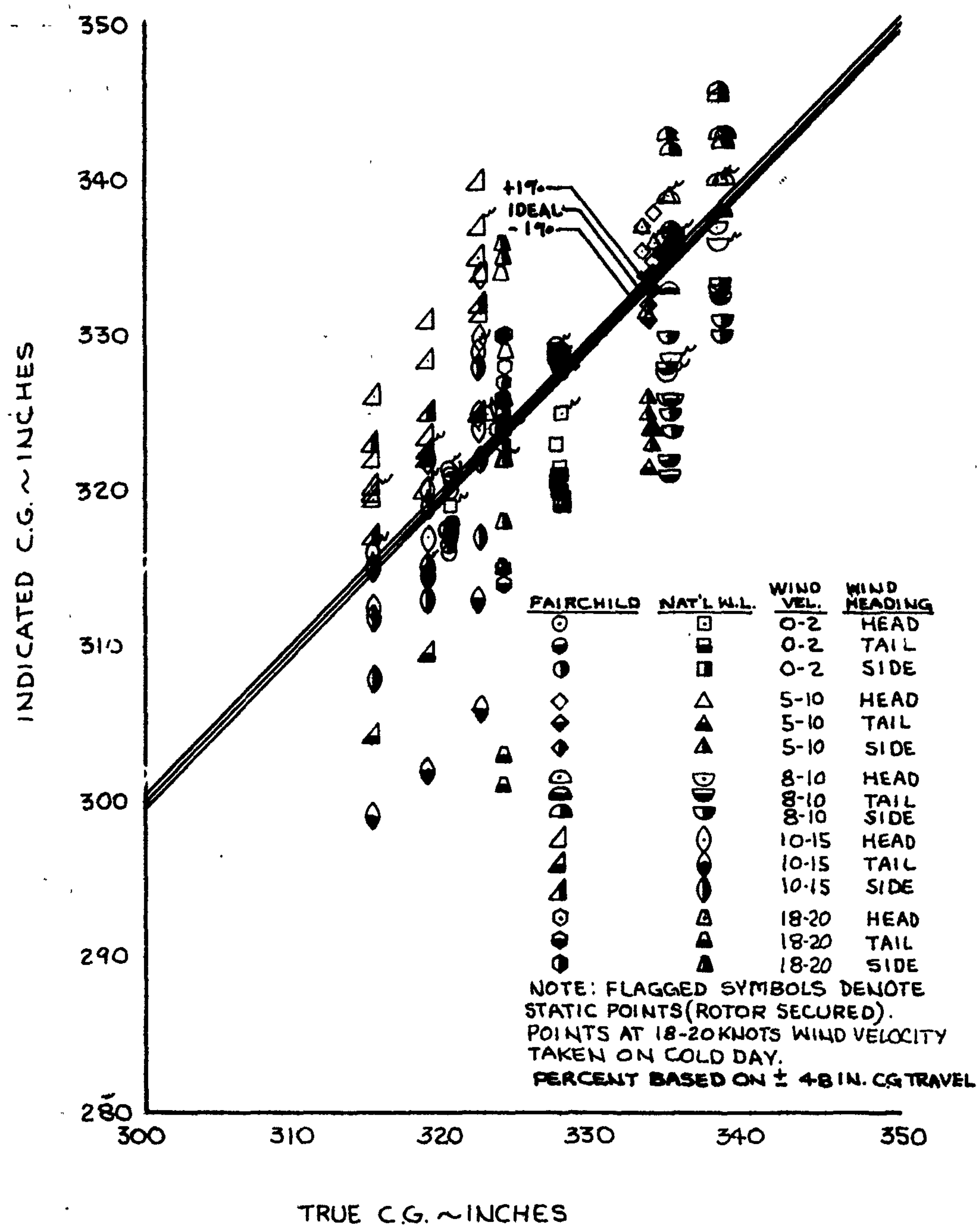


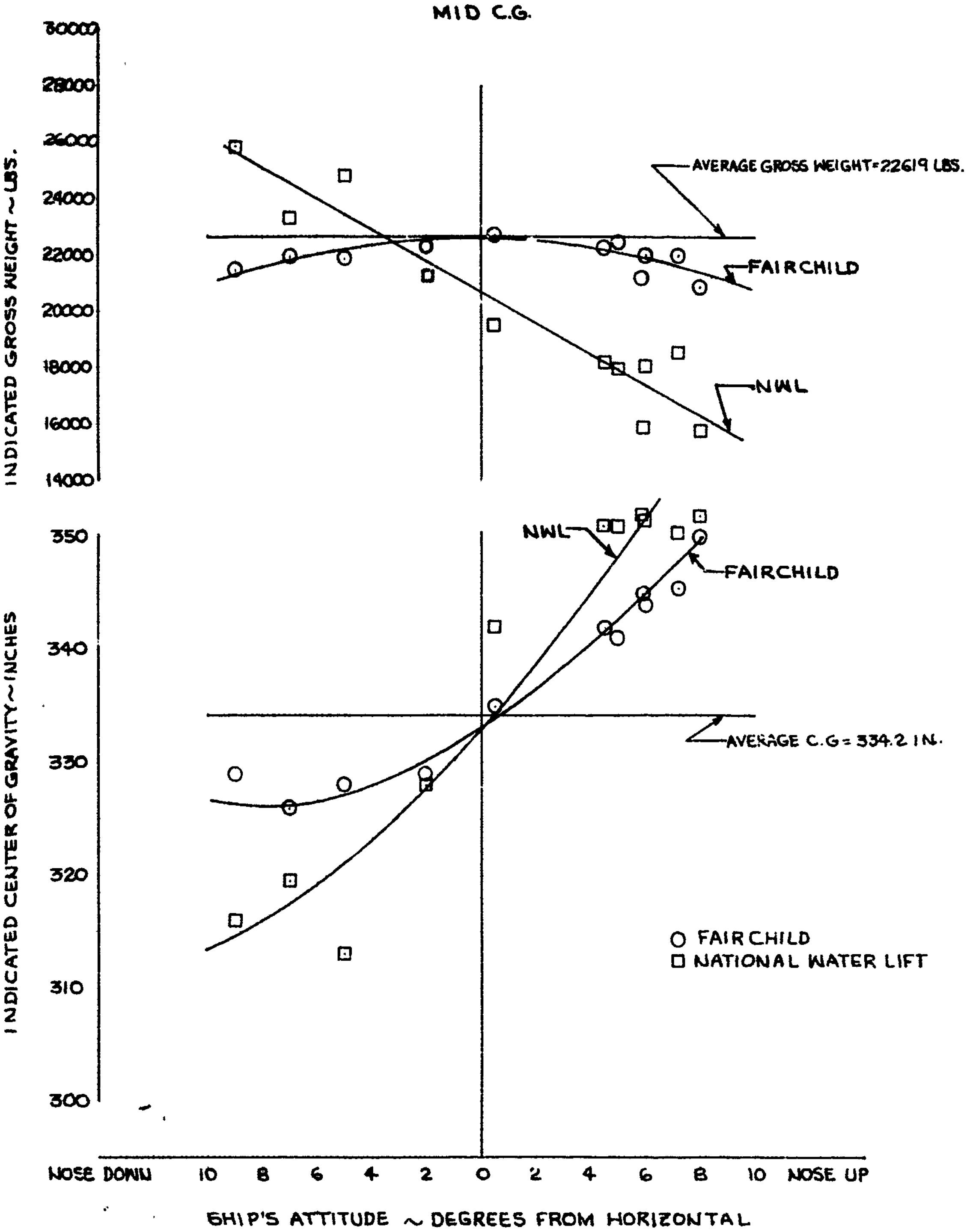
FIGURE NO. 6

EFFECT OF SLOPE UPON INDICATED GROSS WEIGHT AND CENTER OF GRAVITY

CH-47A S/N 463103

LIGHT WEIGHT

MID C.G.



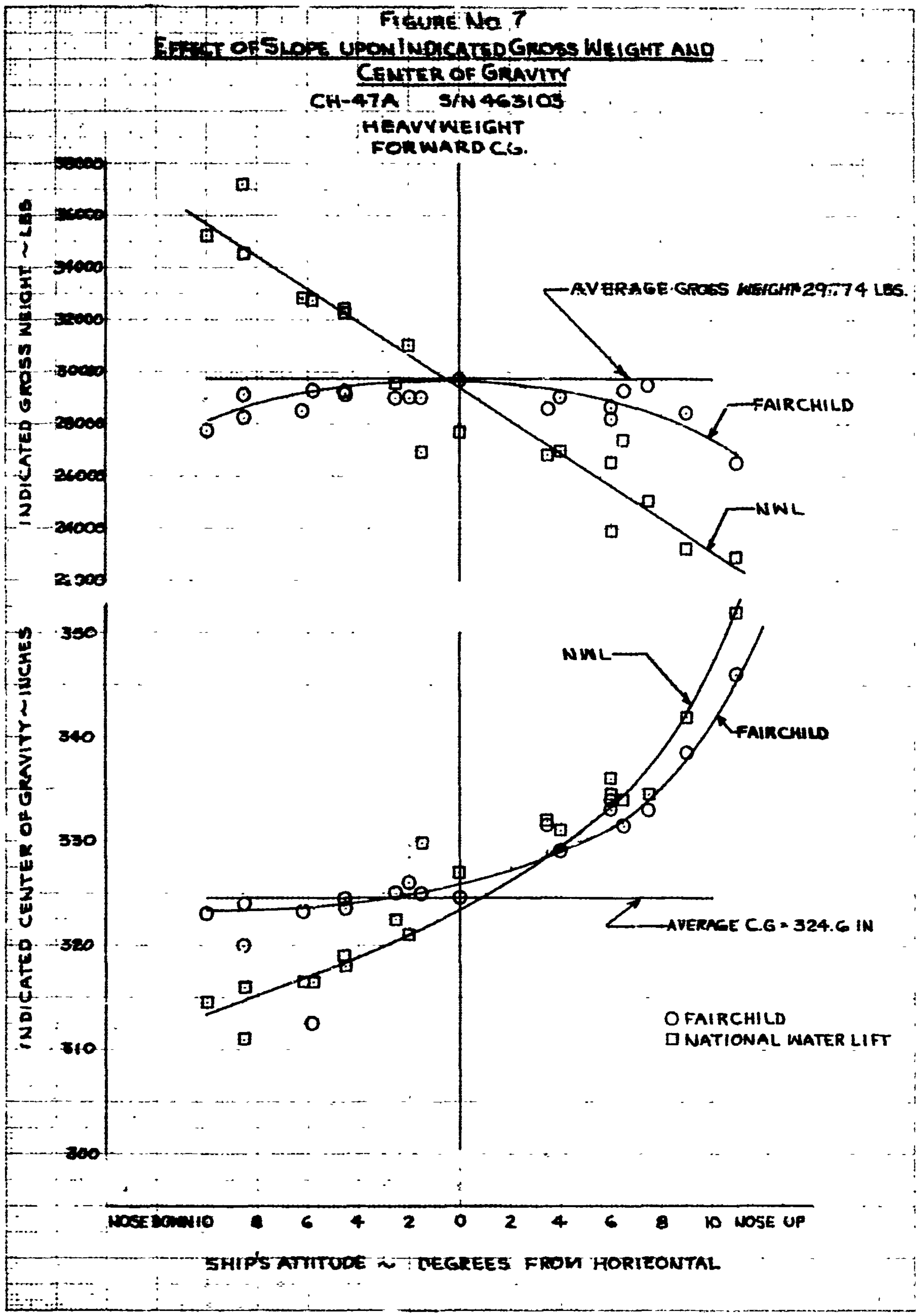


FIGURE NO. 7
EFFECT OF SLOPE UPON INDICATED GROSS WEIGHT AND CENTER OF GRAVITY
CH-47A S/N 463103
HEAVYWEIGHT
FORWARD C.G.
INDICATED GROSS WEIGHT ~ LBS.
AVERAGE GROSS WEIGHT 29,774 LBS.
FAIRCHILD
NWL
INDICATED CENTER OF GRAVITY ~ INCHES
NWL
FAIRCHILD
AVERAGE C.G = 324.6 IN
O FAIRCHILD
□ NATIONAL WATER LIFT
NOSE DOWN 10 8 6 4 2 0 2 4 6 8 10 NOSE UP
SHIP'S ATTITUDE ~ DEGREES FROM HORIZONTAL

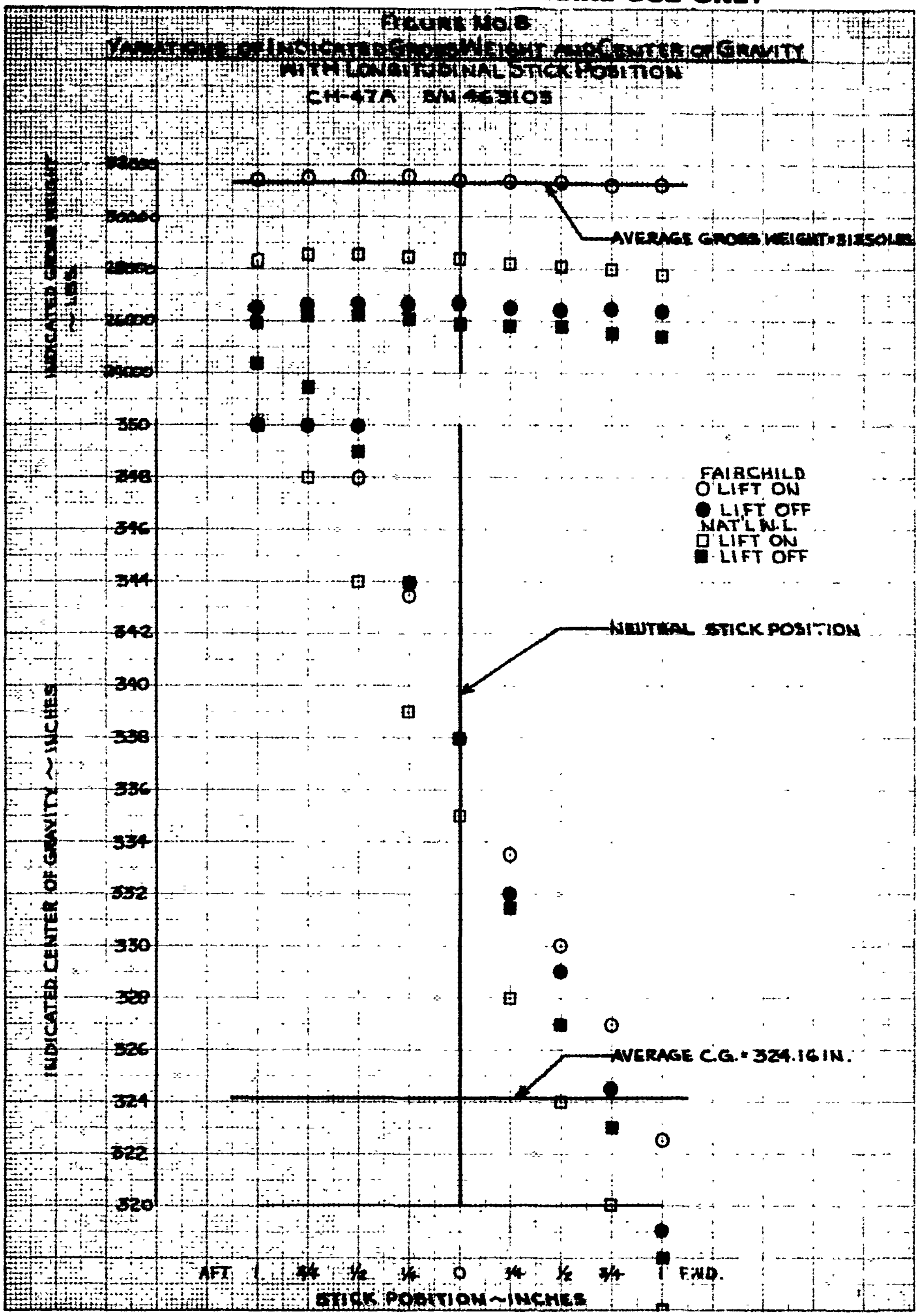


FIGURE NO. 8
VARIATIONS OF INDICATED GROSS WEIGHT AND CENTER OF GRAVITY WITH LONGITUDINAL STICK POSITION
CH-47A S/N 463105
INDICATED GROSS WEIGHT ~ LBS.
INDICATED CENTER OF GRAVITY ~ INCHES
AVERAGE GROSS WEIGHT = 31250 LBS.
FAIRCHILD
LIFT ON
LIFT OFF
NAT'L W.L.
LIFT ON
LIFT OFF
NEUTRAL STICK POSITION
AVERAGE C.G. = 324.16 IN.
AFT
FWD.
STICK POSITION ~ INCHES

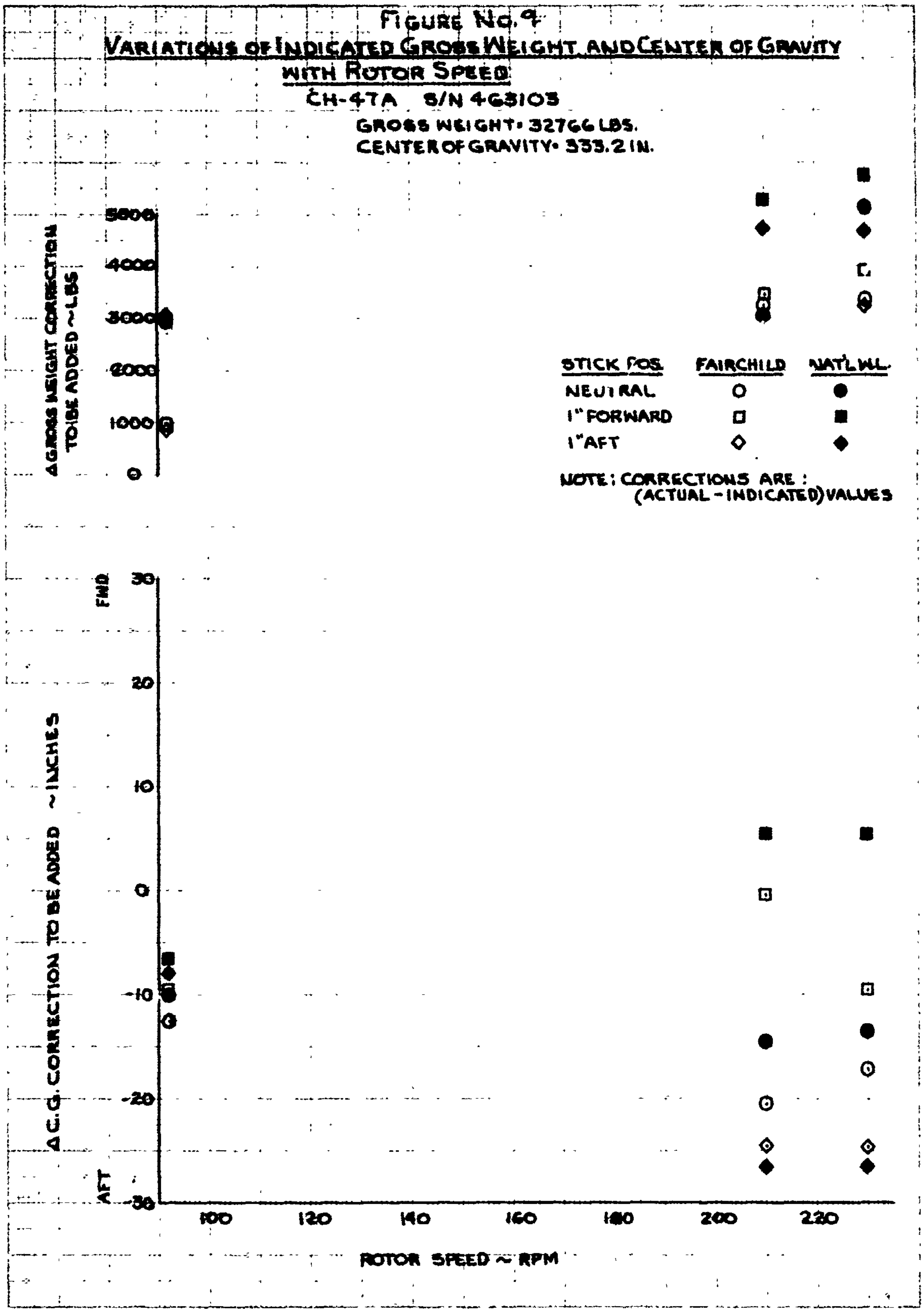


Figure No. 9
Variations of Indicated Gross Weight and Center of Gravity with Rotor Speed
CH-47A S/N 463105
GROSS WEIGHT = 32766 LBS.
CENTER OF GRAVITY = 333.2 IN.
Δ GROSS WEIGHT CORRECTION TO BE ADDED ~ LBS
5000
4000
3000
2000
1000
0
STICK POS.
FAIRCHILD
NAT'L W.L.
NEUTRAL
1" FORWARD
1" AFT
NOTE: CORRECTIONS ARE: (ACTUAL - INDICATED) VALUES
FWD
AFT
Δ C.G. CORRECTION TO BE ADDED ~ INCHES
30
20
10
0
-10
-20
-30
100
120
140
160
180
200
220
ROTOR SPEED ~ RPM

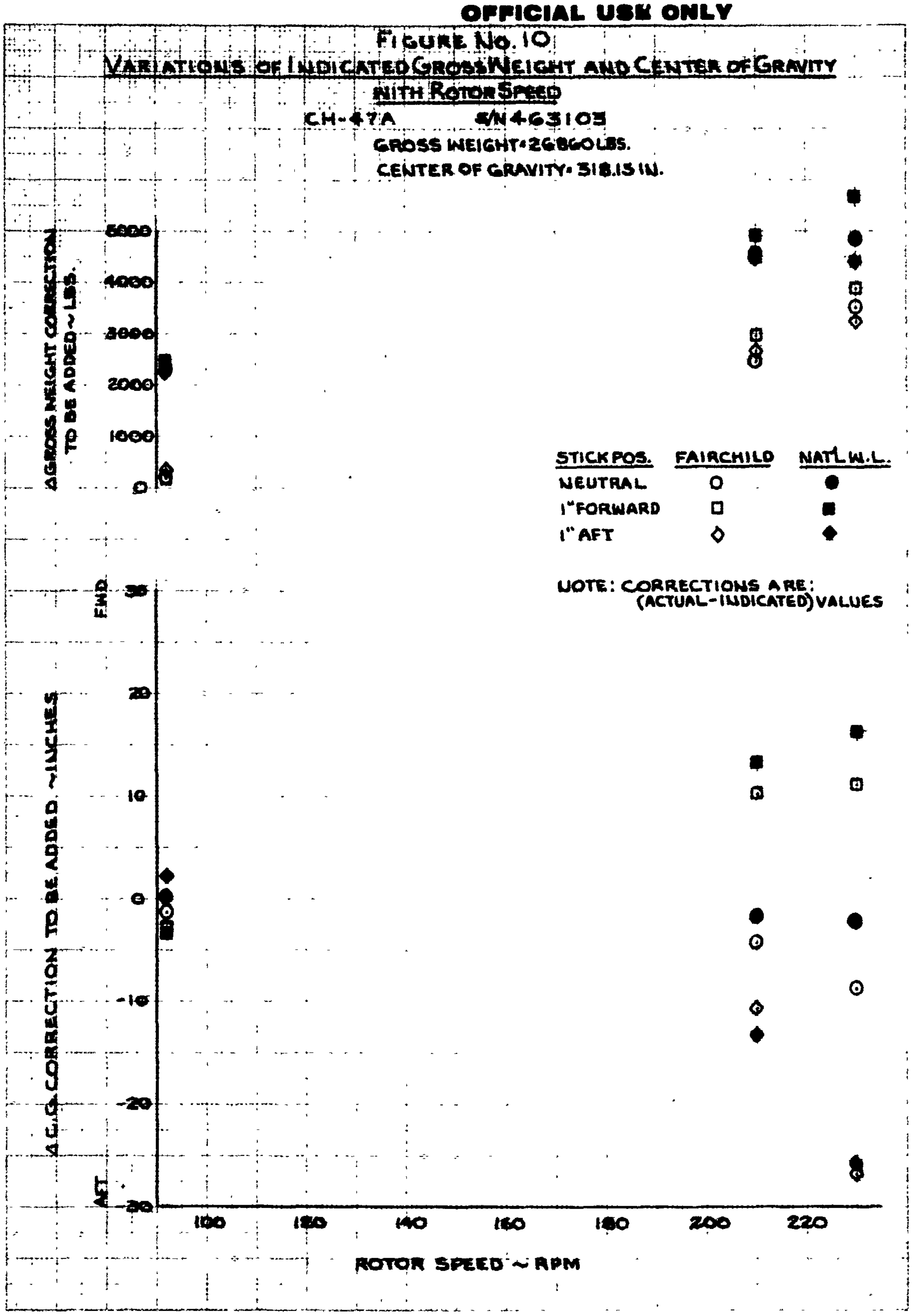


FIGURE No. 10
VARIATIONS OF INDICATED GROSS WEIGHT AND CENTER OF GRAVITY WITH ROTOR SPEED
CH-47A S/N 463105
GROSS WEIGHT: 26860 LBS.
CENTER OF GRAVITY: 318.15 IN.
ΔGROSS WEIGHT CORRECTION TO BE ADDED ~ LBS.
5000
4000
3000
2000
1000
0
STICK POS.
FAIRCHILD
NAT'L W.L.
NEUTRAL
1" FORWARD
1" AFT
NOTE: CORRECTIONS ARE: (ACTUAL - INDICATED) VALUES
Δ C.G. CORRECTION TO BE ADDED ~ INCHES
FWD
AFT
30
20
10
0
-10
-20
-30
100
120
140
160
180
200
220
ROTOR SPEED ~ RPM

FIGURE No. 11

VARIATIONS OF INDICATED GROSS WEIGHT AND CENTER OF GRAVITY WITH ROTOR SPEED

CH-47A S/N 4-63103

GROSS WEIGHT = 26360 LBS.
CENTER OF GRAVITY = 329.24 IN.

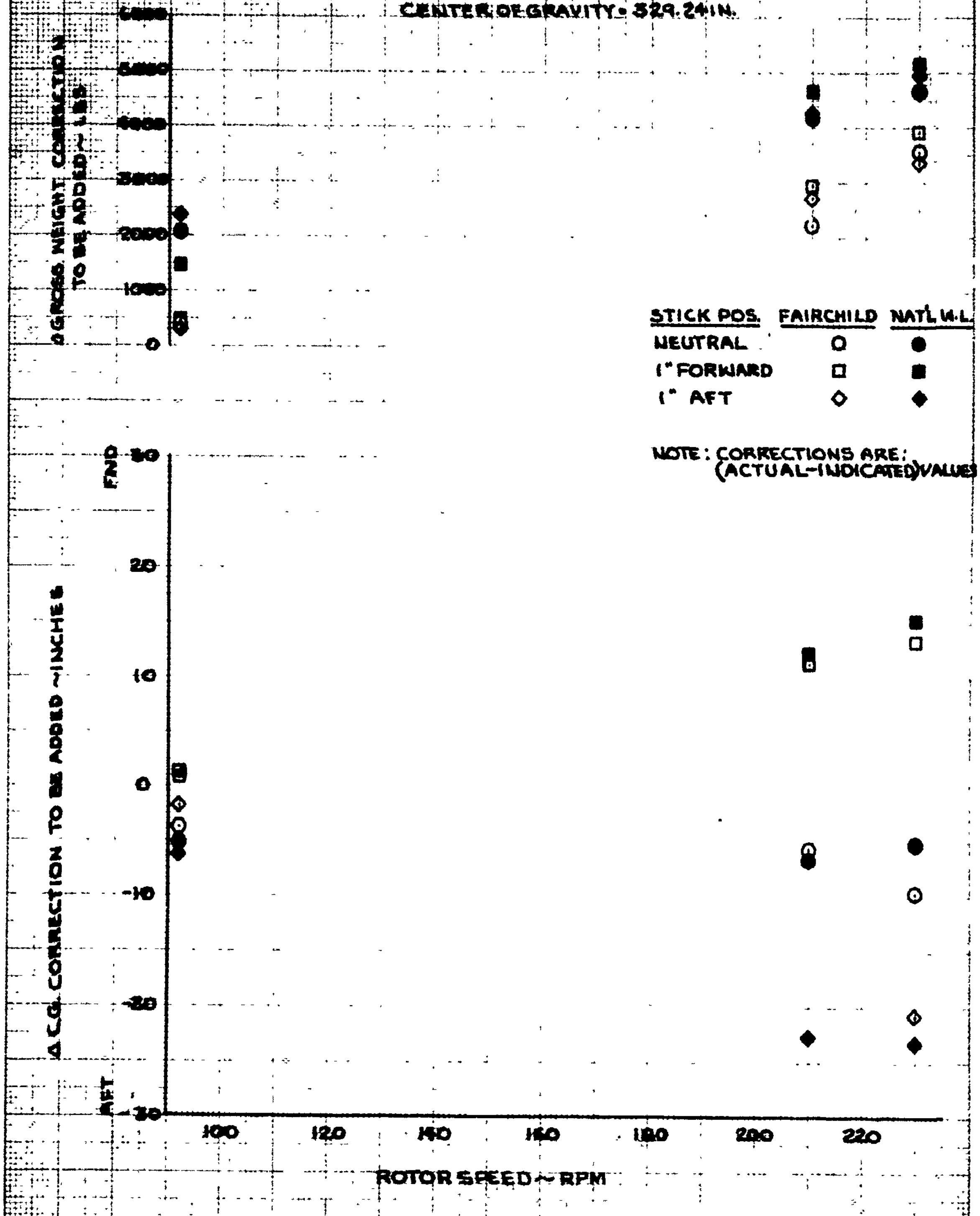


FIGURE No. 12

VARIATIONS OF INDICATED GROSS WEIGHT AND CENTER OF GRAVITY WITH ROTOR SPEED

CH-47A S/N 463103

GROSS WEIGHT: 30137 LBS.

CENTER OF GRAVITY: 324.12 IN.

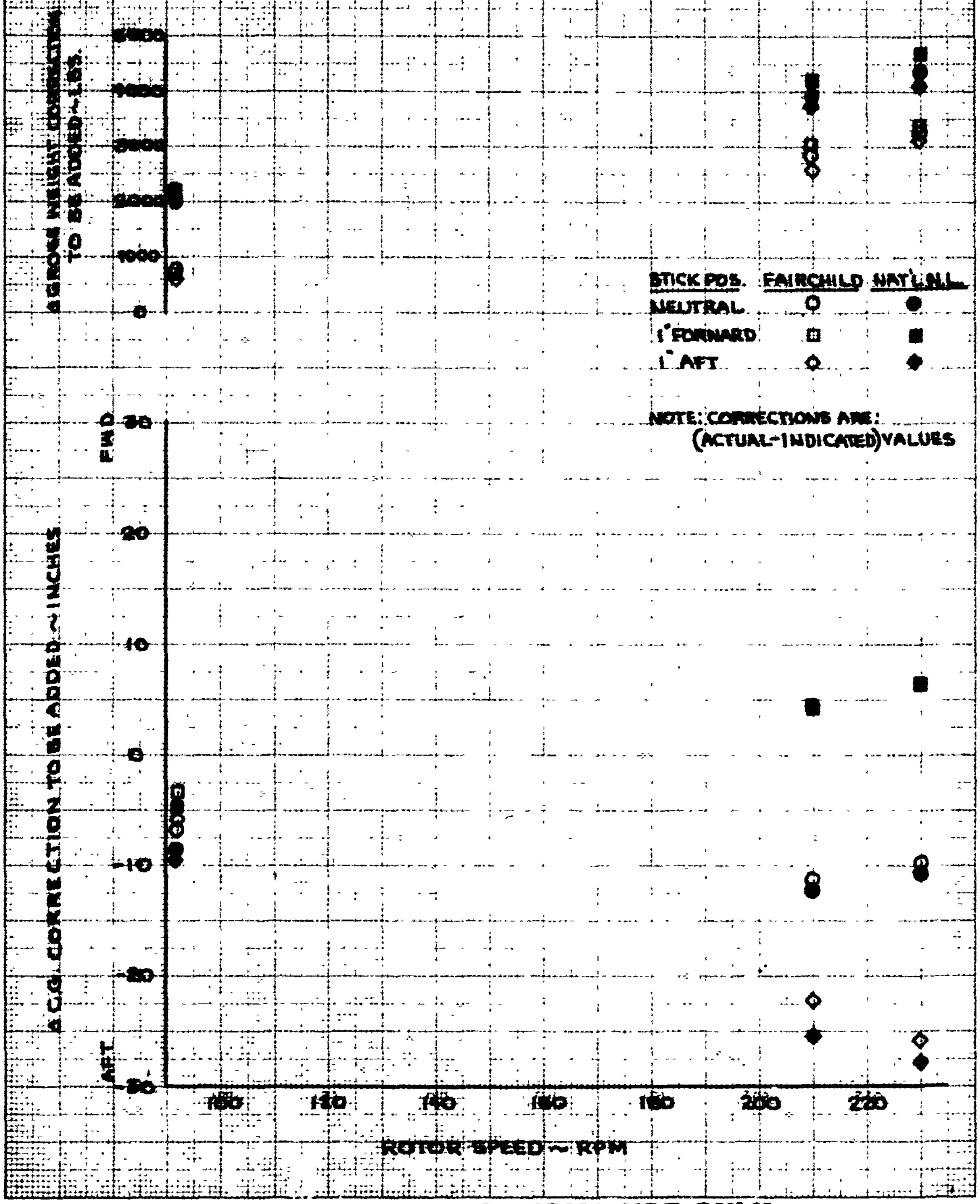
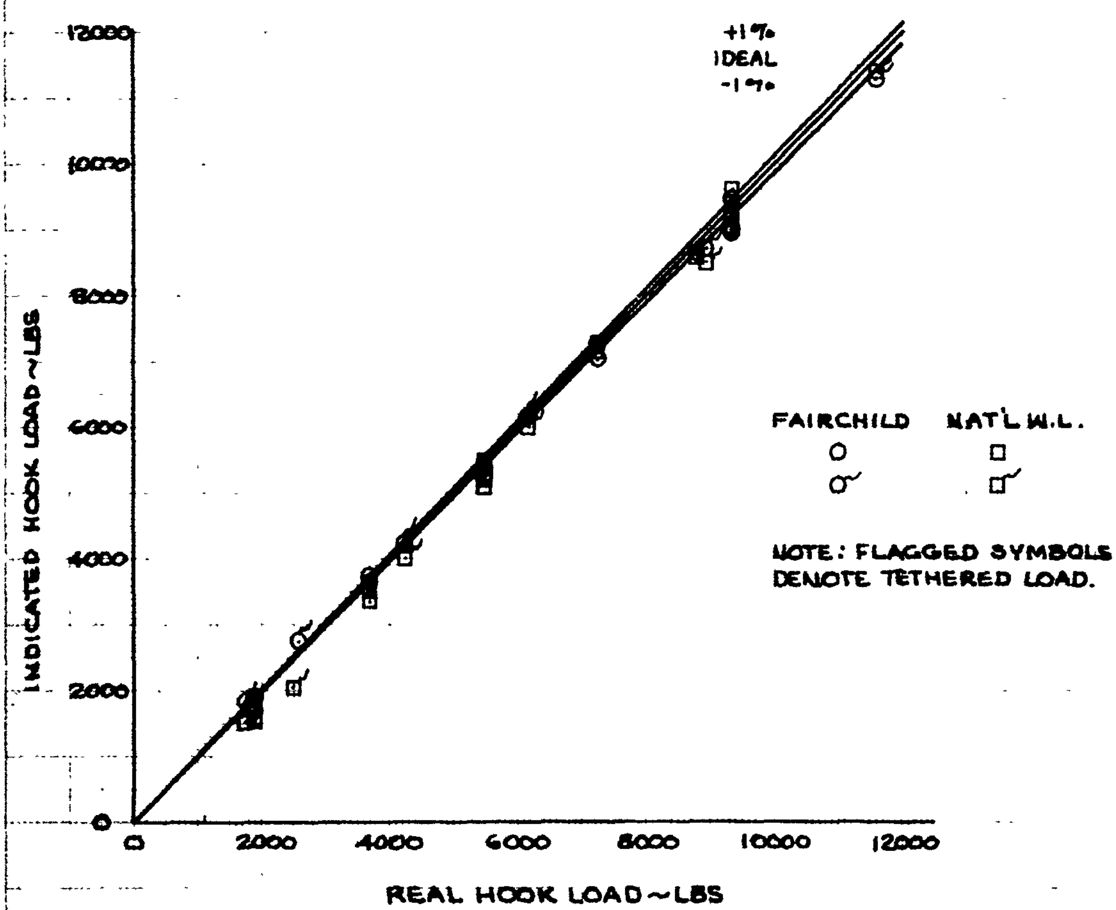


FIGURE No. 13
INDICATED HOOK LOADS VS. ACTUAL HOOK LOADS
CH-47A S/N 463103



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13. ABSTRACT

An engineering research evaluation of two proposed integral weight and balance systems for the CH-47 Chinook Helicopter was conducted to determine the feasibility of such systems. The primary function of the systems is to accurately predict the aircraft gross weight and center of gravity location along with cargo hook load. The evaluation of these systems was conducted at Edwards Air Force Base, California, by the US Army Aviation Test Activity. The systems were tested throughout the entire envelope of allowable gross weight and center of gravity for the CH-47A aircraft. The testing consisted of determining the affects of rotor rpm, terrain, wind and control position, for various loading configurations, upon the indicated values of gross weight and center of gravity for the STAN (Fairchild-Hiller Control Company) and STOW (National Water Lift Company) weight and balance systems. Also, evaluated were the problems of installation and calibration of the systems, repeatability, reliability, and compatibility with other systems. Both systems performed reasonably well with the helicopter in a static mode (rotors not turning), however, once the engines were started, the system repeatability and reliability degraded significantly. Results of the engineering evaluation indicate that the concept of such systems is feasible but that efforts must be directed toward the improvement of the systems' reliability with the helicopter operating in its various environments.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Integral weight and balance systems						
CH-47 helicopter						
STOW system						
STAN system						
Rotor rpm						
Environment						
Control position						
Terrain						
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Compatibility						

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