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RDTE PROJECT NO.
AVSCOM PROJECT NO. 71-32
USAASTA PROJECT NO. 71-32

UTILITY TACTICAL TRANSPORT AIRCRAFT SYSTEM (UTTAS) MANEUVER CRITERIA

FINAL REPORT

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

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ABSTRACT

A maneuvering flying qualities evaluation was performed on the OH-6A, OH-58A, BO-105, and L-286 helicopters by the US Army Aviation Systems Test Activity, Edwards Air Force Base, California, between 9 August and 24 November 1971. The test objective was to evaluate the suitability of three types of rotor systems (articulated, teetering, and hingeless) to perform the proposed utility tactical transport aircraft system (UTTAS) pull-up and pushover maneuvers. The testing consisted of 41 flights for a total of 22 productive hours. The results obtained during this test established a data base to assess the applicability of the presently stated UTTAS maneuverability requirements. It was determined that present-day rotary-wing aircraft can be tested against the prescribed maneuver criteria with meaningful results. Three flying quality deficiencies were noted, correction of which is mandatory if procurement or envelope expansion is anticipated. The deficiencies were: loss of lateral control power below 0.5g in the OH-58A, mast bumping or spike knock in the OH-58A at load factors below 0.5, and excessive vibration during landing transition on the BO-105. There were two shortcomings, correction of which is desirable if procurement or envelope expansion is anticipated. The shortcomings were excessive cross-coupling during maneuvering tasks, apparent in all four test helicopters, and inadequate control margin at load factors less than 0.5 in the OH-58A.

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INTRODUCTION

BACKGROUND

1. Increasing attention has been focused on the operational maneuver capability of rotary-wing aircraft. Terrain-following flight was the object of early US Army Aviation studies. Initial advanced aerial fire support system (AAFSS) requirements included sustained 2.0g flight at 150 knots true airspeed (KTAS) as well as specific return-to-target times requiring improved maneuverability. In 1969, the US Army Aviation Systems Command (AVSCOM) directed the US Army Aviation Systems Test Activity (USAASTA) to expand the scope of Project No. 69-11, AH-1G maneuvering limitations tests, to include measurement of aircraft response in avoiding vertical obstacles (refs 1 and 2, app A).

2. As a result of these early US Army aviation operational maneuverability studies, a proposed maneuver criterion was drafted for inclusion in the utility tactical transport aircraft system (UTTAS) specification. The proposed specification was as follows:

> From a level unaccelerated flight condition at 150 knots equivalent airspeed (KEAS), it shall be possible to attain, within 1.0 second from the initial control input, a sustained load factor of 1.75 in a symmetrical pull-up. Following this load factor buildup, it shall be possible to maintain a minimum load factor of 1.75 for 3.0 seconds after the initial attainment of 1.75. Airspeed at the end of the 1.75g, 3.0-second duration segment of the maneuver shall not be less than 130 KEAS. At no time during this maneuver shall it be necessary to change the main rotor collective control from that required for the initial level unaccelerated flight condition. Also, from a level unaccelerated flight condition at 150 KEAS, it shall be possible to attain, within 1.0 second from the initial control input, a sustained load factor of 0.0 in a pushover. Following the attainment of this load factor, it shall be possible to maintain a load factor of 0.0 for 2.0 seconds. At no time during this maneuver shall it be necessary to change the main rotor collective control from that required for the initial level unaccelerated flight condition. At no time during either the pull-up or pushover maneuvers described above shall angular deviations in roll and yaw, greater than ±5 degrees from the initial unaccelerated level-flight conditions, be permitted.

As a result of USAASTA debriefings given during this evaluation, the UTTAS Request for Proposal (RFP) contains a revised maneuver criterion (ref 3, app A).

3. The US Army Aviation Systems Command directed USAASTA to evaluate the feasibility of the above maneuver criterion (ref 4, app A). The required

evaluation was to include qualitative and quantitative determinations of maneuver performance on four aircraft having three different types of rotor systems. Teetering (OH-58A), articulated (OH-6A), and hingeless (Lockheed L-286 and BoelKow BO-105) rotor systems were investigated. The rationale for testing three different types of rotor systems centers on the need to assess the capability of each system to perform the stated maneuver criteria. In that all the aircraft were tested under essentially the same blade loading (C_T/σ), the results of these tests were normalized and therefore provide a data base for rotor system assessment. A T-28B airplane was also used during the terrain-avoidance maneuver test (pull-up to pushover) to simulate and analyze the flight profile of an aircraft maneuvering at 150 KEAS.

TEST OBJECTIVE

4. The objective of this test was to conduct a helicopter maneuvering evaluation using the OH-58A, OH-6A, BO-105, and the L-286 to provide a data base that can be used to assess the applicability of presently stated UTTAS maneuverability requirements. Quantitative data were to be recorded to supplement pilot qualitative evaluations of the feasibility and operational suitability of the proposed maneuvers.

DESCRIPTION

5. The OH-58A light observation helicopter is a two-bladed, teetering, single-rotor aircraft which is described in the operator's manual (ref 5, app A). The OH-6A light observation helicopter has a four-bladed, articulated main rotor system, as described in the operator's manual (ref 6) The BoelKow BO-105 helicopter incorporates a hingeless, single main rotor system using four fiberglass blades and is powered by two Allison 250-C18 engines rated at 317 horsepower each. Additional data can be found in the BO-105 flight manual (ref 7). The Lockheed Model L-286 is a hingeless-rotor helicopter powered by a Canadian Pratt and Whitney PT6B-9 gas turbine engine. The single main rotor has four metal blades and is controlled through a four-armed control gyro. A more detailed description can be found in references 8 and 9. Table 1 lists salient geometric features of the four aircraft. Photographs are included in appendix B.

Table 1. Test Aircraft Geometry.

Aircraft	Main Rotor Type	Number of Blades	Rotor Diameter (ft)	Rotor Solidity
OH-58A	Teetering	2	35.33	0.0390
OH-6A	Articulated	4	26.33	0.0544
BO-105	Hingeless	4	32.16	0.0700
L-286	Hingeless	4	35.86	0.0788

SCOPE OF TEST

6. The test program consisted of pilot familiarization, simulation of the maneuver criteria, and a general evaluation of maneuvering handling qualities. The general evaluation included the following qualitative investigations: (1) assessment of maneuver control power, damping, and control sensitivity; (2) determination of stick force characteristics; and (3) evaluation of operational suitability, including assessment of the validity of the 1.0-second rise times, maneuver sustenance times, and adequacy of the uncommanded axis constraints. In addition, the specific UTTAS maneuvers were supplemented by a combined pull-up to pushover maneuver to assess the feasibility of this type maneuver to effect terrain avoidance. Testing was performed on the OH-58A, OH-6A, and the L-286 helicopters at Edwards Air Force Base, California. Testing of the BO-105 was performed at The Boeing Company, Vertol Division, Philadelphia, Pennsylvania. The UTTAS maneuver testing required 22 productive flight hours. An additional evaluation of the OH-58A was directed by AVSCOM (ref 10, app A) to evaluate the maneuver at load factors down to 0.0.

7. It was desired that the main rotor blade loading (C_T/σ) and advance ratio ($\mu = V_T/\Omega R$) should be held constant at a value approximating the UTTAS design condition ($C_T/\sigma = 0.0635$ at 1.0g) and at an airspeed such that the power required is equal to approximately one-half of the power available for the appropriate aircraft gross weight, pressure altitude, and ambient temperatures. This C_T/σ criterion could be used for the L-286; however, the other three test aircraft configurations and/or test conditions were not compatible with the above values, and it was necessary to vary the test conditions to ensure safety of flight and to yield acceptable test gross weights for each aircraft. To assure reasonable maneuvering performance, and to closely approximate the UTTAS design criteria, the following conditions were maintained for the OH-58A, OH-6A, and the BO-105: $C_T/\sigma = 0.0765$, and $\mu = 0.245$. Figures 1 through 4, appendix C, show the operating envelopes of the test aircraft at the chosen test conditions.

8. For all aircraft, only a single center of gravity (cg) was tested, and a minimum of aircraft instrumentation (app D) was provided to record aircraft performance during the maneuvers. At the completion of the maneuver criteria testing on the OH-6A, OH-58A, and the L-286, Askania cinetheodolite flight-path coverage was utilized to accurately assess the maximum terrain-avoidance capability of these aircraft utilizing the combination pull-up to pushover technique. Similar coverage was not obtained on the BO-105 because of the lack of facilities at Boeing-Vertol.

METHOD OF TEST

9. Prior to the actual test, a buildup period was used for familiarization with the individual flight characteristics of each helicopter. Maximum pitch attitude, cross-coupling, and any other parameters that might become critical during the maneuver or the recovery were noted. During the actual tests, normal acceleration, control positions, attitudes, and time were recorded by an oscillograph or a

cockpit-mounted movie camera. Special attention was paid to aircraft response time and characteristics following control inputs, maximum sustained maneuver capability, control cross-coupling, and general characteristics of maneuver response. Complete descriptions of the test maneuvers are shown in table 2. In addition, a series of combination pull-up to pushover maneuvers were flown by each pilot to qualitatively evaluate the handling qualities and suitability of each aircraft in reference to the proposed maneuver specifications and with regard to terrain avoidance. Qualitative ratings of handling qualities are based on the Handling Qualities Rating Scale (HQRS), presented as appendix E.

Table 2. Maneuvering Tasks.

Name	Description
Symmetrical pull-up from 1.0g	Starting from a specified C_T/σ and μ, input aft longitudinal cyclic control, holding the collective fixed, to obtain a symmetrical aircraft response. Develop and maintain normal acceleration as soon as possible (1.0 second desired) and sustain for not less than 3 additional seconds. Monitor and record aircraft response throughout. Repeat the sequence at increasing load factors to 1.75, or until another limit prevents continuation.
Symmetrical pushover from 1.0g	Starting from a specified C_T/σ and μ, input forward longitudinal control, holding the collective fixed, to obtain a symmetrical aircraft response. Develop and maintain normal acceleration as soon as possible (1.0 second desired), and sustain for not less than 2.0 additional seconds. Monitor and record aircraft response. Repeat the sequence at decreasing load factors to 0.0, or until another limit prevents continuation.
Symmetrical pushover from 1.75g	Starting from 1.75g or peak sustained load factor as established during symmetrical pull-up tests, input forward longitudinal cyclic control, collective fixed, to obtain a symmetrical aircraft response. Develop and maintain normal acceleration as soon as possible (1.0 second desired) and sustain for not less than 2.0 additional seconds. Monitor and record aircraft response. Repeat the sequence at decreasing load factors to 0.0, or until another limit prevents continuation.

CHRONOLOGY

10. The chronology of testing is as follows:

Test request received	22 July 1971
OH-6A test aircraft received	26 July 1971
OH-58A test aircraft received	9 August 1971
OH-6A test flying commenced	9 August 1971
OH-6A test flying completed	26 August 1971
OH-58A test flying commenced	27 August 1971
OH-58A test flying completed	2 September 1971
BO-105 test aircraft received	8 September 1971
BO-105 test flying commenced	8 September 1971
BO-105 test flying completed	10 September 1971
OH-58A retest commenced	20 September 1971
OH-58A retest completed	21 September 1971
Verbal debriefing completed	27 September 1971
BO-105 retest	26 October 1971
L-286 test aircraft received	22 November 1971
L-286 test flying commenced	22 November 1971
L-286 test flying completed	24 November 1971

RESULTS AND DISCUSSION

GENERAL

11. A maneuvering flying qualities evaluation was performed on the OH-6A, OH-58A, BO-105, and L-286 helicopters. The test objective was to evaluate the suitability of three types of rotor systems (articulated, teetering, and hingeless) to perform the proposed utility tactical transport aircraft system (UTTAS) pull-up and pushover maneuvers. The results obtained during this test established a data base to assess the applicability of the presently stated UTTAS maneuverability requirements. It was determined that present-day rotary-wing aircraft can be tested against the prescribed maneuver criteria with meaningful results. Three flying quality deficiencies were noted, correction of which is mandatory if procurement or envelope expansion is anticipated. The deficiencies were: loss of lateral control power below 0.5g in the OH-58A, mast bumping or spike knock in the OH-58A at load factors below 0.5, and excessive vibration during landing transition of the BO-105. There were two shortcomings, correction of which is desired if procurement or envelope expansion is anticipated. The shortcomings were: excessive cross-coupling during maneuvering tasks, apparent in all four test helicopters, and inadequate control margin at load factors less than 0.5 in the OH-58A.

12. The BO-105 was flown on two separate occasions. During the initial evaluation, the pilots were unable to establish and maintain a desired indicated load factor. This characteristic was unsatisfactory, although qualitatively the BO-105 appeared to have good control response characteristics. A later investigation by Boeing-Vertol revealed that the normal load factor indicator installed in the BO-105 was excessively damped, and the indicated load factor lagged the aircraft response. Since the pilot must use the cockpit indicator as a prime reference to perform pull-ups and pushovers, it was virtually impossible to accurately fly the prescribed maneuvers. Reevaluation of the BO-105 was performed with a properly calibrated electrical load factor indicator and with a backup mechanical-type indicator. The control response characteristics of the BO-105 were reevaluated as being greatly improved, although no modifications were performed on the aircraft or control system. The results of the reevaluation most adequately describe the maneuver response characteristics of the BO-105.

PULL-UP

13. Symmetrical pull-ups from 1.0g level flight to 1.75g accelerated flight were performed in the OH-6A, OH-58A, BO-105, and the L-286 under the conditions listed in table 3. Time histories of the complete pull-up to pushover maneuvers are presented as figures 1 through 4, appendix F. To obtain 1.75g in 1 second required a different control application technique for each aircraft. The OH-6A could be easily maneuvered into the 1.75g condition with minimum pilot effort, with only slight longitudinal control adjustments required as the airspeed decreased.

Table 3. Pull-up to Pushover Test Conditions.

Aircraft	Trim Calibrated Airspeed (ft)	Density Altitude (ft)	Outside Air Temperature (°C)	Gross Weight (lb)	Center of Gravity (in.)	Rotor Speed (rpm)	Advance Ratio	Thrust Coefficient[1]	Main Rotor Blade Loading[1]
OH-6A	89	6010	24.1	1950	97.9 (fwd)	477	0.293	0.00416	0.0765
OH-58A	90	3710	7.3	2650	106.9 (mid)	353	0.246	0.00297	0.0763
BO-105	89	6010	14.0	4250	125.1 (fwd)	425	0.234	0.00516	0.0737
L-286	94	5700	10.0	4170	150.6 (mid)	362	0.258	0.00491	0.0623

[1]Trim condition.

The OH-58A had a slower response, as shown in figure 2, and thus did not meet the criteron of attaining 1.75g in 1 second. Other than the slower response, the aircraft handled similar to the OH-6A, with only minor longitudinal control adjustments required during the maneuver. The BO-105 and the L-286 required a completely different technique, in that a large aft input was required initially followed by a rapid forward input of approximately the same magnitude once the 1.75g condition was reached (essentially a pulse input), as shown in figures 3 and 4, appendix F. Although the control input technique varied somewhat, the OH-6A, BO-105, and the L-286 exhibited control response characteristics that allowed the pilot to perform the pull-up maneuver in the prescribed time.

14. Cross-coupling was apparent in all four aircraft, and required lateral and/or directional control movement to prevent angular deviations greater than ±5 degrees from the initial roll and yaw trim condition. Figures 1 through 4, appendix F, show that lateral and directional control inputs were required by the pilots to arrest roll and yaw attitude changes induced from the longitudinal cyclic motion. Control inputs were applied in response to motion cues that the pilot felt during the maneuver sequence. The nature of the test program maneuvers required that the pilots "fly" the g-meter, and it was very difficult to cross-check other instruments or the horizon and make control inputs to retain a single-axis response. Little or no directional control movement is indicated on any of the time histories because of the difficulty in detecting yaw excursions. Figure 2 shows yaw excursions which were typical for all four aircraft. Figure 5 illustrates an extreme example of roll and yaw excursions that occurred when a pull-up and pushover were performed with no lateral cyclic or pedal inputs. The control force required to obtain 1.75g was approximately 5 pounds for all four aircraft. Nose-up pitch attitudes for all four aircraft were approximately 40 to 50 degrees. These high pitch attitudes were distracting initially; however, after a short period of time, the pilots adapted to the unusual attitudes associated with the maneuver and were relatively at ease. The cross-coupling exhibited by the test helicopters was considered excessive, and correction of this shortcoming would provide for improved maneuvering operations. The ±5-degree angular deviation restriction stated in the criteria is considered to be too severe and should be relaxed to ±10 degrees.

PUSHOVER

15. Symmetrical pushovers, from 1.0g during level balanced flight to low fractional or 0.0g accelerated flight, were performed in all four aircraft under the conditions listed in table 4. Time histories of these maneuvers are presented as figures 6 through 10, appendix F. The response of the BO-105, L-286, and the OH-6A was very quick which made it relatively easy to obtain zero or near zero g sustained flight in 1 second. Published limits precluded testing the OH-58A below 0.5g; however, at this condition, the results of the pushover were similar to the other aircraft, except for a slower response. During the testing of the OH-6A, L-286, and the BO-105, no unusual shock or vibration was encountered, and loss of apparent control power was not critical at or near 0.0g. The control force required to obtain the minimal load factor was approximately 5 pounds for all four aircraft.

Table 4. Pushover Test Conditions.

Aircraft	Trim Calibrated Airspeed (kt)	Density Altitude (ft)	Outside Air Temperature (°C)	Gross Weight (lb)	Center of Gravity (in.)	Rotor Speed (rpm)	Advance Ratio	Thrust Coefficient[1]	Main Rotor Blade Loading[1]
OH-6A	91	6020	25.0	1950	97.9 (fwd)	475	0.300	0.00420	0.0772
OH-58A	89	8800	11.7	2620	106.9 (mid)	351	0.244	0.00298	0.0765
OH-58A	87	5300	7.1	2520	106.9 (mid)	352	0.246	0.00298	0.0765
BO-105	90	5820	14.0	4250	125.1 (fwd)	421	0.238	0.00522	0.0746
L-286	92	5510	10.0	4070	150.6 (mid)	362	0.251	0.00477	0.0605

[1]Trim condition.

16. Reference 10, appendix A, directed that the published 0.5g restriction of the OH-58A be lifted and the maneuver be reflown at 0.0g. Attempts to reach 0.0g resulted in forward control stop contact while entering the pushover maneuver (fig. 11, app F). The inadequate longitudinal control margin is a shortcoming, correction of which is desired if the flight envelope of the OH-58A is to be expanded.

17. During a 1.75g pull-up to a 0.1g pushover in the OH-58A, a significant mast bump or spike knock was felt during the recovery. Figure 11, appendix F, also shows numerous trace interruptions that occurred coincident with the mast bump or spike knock. In addition, the aircraft appeared to lose most of the lateral control power. Figure 11 shows an uncommanded roll rate during the maneuver which required essentially full lateral control displacement to arrest (HQRS 8).

18. Cross-coupling was apparent in the pushover maneuver in all four aircraft. Lateral and/or directional control movements were required to prevent angular deviations greater than ±5 degrees from the initial roll and yaw trim condition. Figures 6 through 10, appendix F, show that lateral and directional control inputs were used to arrest roll and yaw attitude changes induced from the longitudinal cyclic motion. Like the pull-up maneuvers, these inputs were applied in response to motion cues that the pilot felt while "flying the g-meter," and were not, in most cases, sufficient to result in an absolute symmetrical maneuver. The nose-low pitch attitudes were approximately 40 degrees, and like the pull-up maneuver, were initially very distracting and uncomfortable; however, within very little time, the pilots adapted to the unusual attitudes and were relatively at ease. Correction of the excessive cross-coupling exhibited by the test helicopters is desired for improved maneuvering operation. The ±5-degree angular deviation restriction stated in the UTTAS maneuver criteria is considered to be too severe and should be relaxed to ±10 degrees.

TERRAIN-AVOIDANCE MANEUVER

19. A qualitative and quantitative evaluation was made of all four aircraft with respect to the suitability of the maneuver criteria to effect terrain avoidance. The primary technique used was to combine the pull-up and pushover maneuvers to simulate the avoidance of an obstacle while conducting nap-of-the-earth flight. To augment the qualitative findings, actual flight-path profiles were obtained using Askania cinetheodolite coverage of the OH-6A, OH-58A, and the L-286 helicopters. Similar coverage was not obtained on the BO-105 because of the lack of facilities at the test site. The Askania cinetheodolite coverage was also used for the fixed-wing T-28B airplane because none of the test helicopters could obtain 150 KEAS. Although the T-28B is an airplane, its profile closely approximates the profile that a helicopter (UTTAS or otherwise) flying at 150 KEAS would exhibit, presuming it could establish and sustain the same load factors during the same time frames. The Askania results are presented as figures 12 and 13, appendix F. These results illustrate the suitability of the OH-6A, OH-58A, L-286, and the T-28B to effect vertical terrain clearance using the combined maneuver. It should be emphasized

that the pull-up portion of the maneuver, for all four aircraft, consisted of a sustained 3-second pull-up at 1.75g. However, the pushover portion varied, in that the sustained 2-second load factor was approximately 0.2, 0.2, 0.5, and 0.0 for the OH-6A, L-286, OH-58A, and the T-28B, respectively. Both maneuvers, pull-up to pushover, and the pushover alone, indicate that both the OH-6A and the L-286 have a better terrain avoidance capability than the OH-58A. This is apparently due to those aircrafts' better response characteristics and quickness in establishing a desired load factor. Qualitatively, the BO-105 exhibited similar terrain avoidance characteristics to the L-286. The T-28B results illustrate the added height and gained horizontal distance required when an aircraft performs the maneuver at the 150-knot UTTAS cruise speed. To provide a more compact maneuver profile at this higher speed, it is recommended that the UTTAS maneuver criteria be changed to reflect a requirement to establish 2.0g in 1 second and sustain this load factor for 3 additional seconds.

20. The method of effecting the pull-up and pushover maneuver was varied in order to optimize the technique. Control variations consisted of a pure cyclic-only maneuver, a combination of cyclic and collective, and essentially a collective-only maneuver. It was readily determined that the best technique, for all four helicopters, was a combination of cyclic and collective. Combined application of cyclic and collective resulted in essentially no change in the flight profile (fig. 14, app F). When compared with a cyclic-only maneuver, the following improved characteristics were observed: (1) the maneuver was less abrupt; (2) there were smaller attitude changes, and therefore less loss of airspeed; (3) the pilot was afforded a better field of view; and (4) the maneuver felt more natural to the pilot. Using the pure cyclic technique, during simulated nap-of-the-earth flight, pitch attitudes were on the order of +50 to -50 degrees, whereas the combination technique resulted in smaller attitude changes (+30 to -30 degrees). Within the scope of this test, the technique of combined application of longitudinal cyclic and collective to accomplish the terrain avoidance maneuver was found to be the preferable technique and should be considered during the preparation of future helicopter maneuver criteria.

AIRSPEED VARIATION

21. Both pull-up and pushover maneuvers were also performed at higher than the target (μ = 0.245) airspeeds in all four aircraft for comparative purposes. Since none of the test aircraft were capable of 150 KEAS, the UTTAS maneuver speed, the T-28B airplane was used to approximate the flight path of an aircraft performing the UTTAS criteria maneuvers, and the combination pull-up and pushover at the predicted UTTAS airspeed. A 15-knot higher airspeed produced what felt like blade stall onset or buffet in the OH-58A, and a less optimum control response in the OH-6A, resulting in degraded maneuver capability. For the BO-105 and the L-286, a like increase of airspeed (90 to 105 KIAS) enhanced the maneuver, in that the response was quicker, the pitch attitudes were not as great, and it was easier to tailor a desired load factor. Flying the T-28B at the predicted UTTAS cruise speed showed that the expected pitch attitudes of a UTTAS aircraft performing the

maneuver criteria at 150 KIAS will be on the order of +30 and -30 degrees. These attitude changes were satisfactory and would not be objectionable to an experienced operational pilot. The OH-6A, L-286, and OH-58A helicopters experienced an approximate 30- to 40-knot loss of airspeed during the pull-up maneuver, hence the subsequent pushover was initiated at approximately 50 KIAS. Based on quantitative (instrument panel) results and qualitative observations, it appears that the BO-105 experienced a larger loss of airspeed during the pull-up maneuver.

SUMMARY EVALUATION

22. Throughout the conduct of this test, attention was directed to the general handling quality characteristics of the four aircrat.. Tables 5, 6, and 7 summarize the qualitative ratings of the four test aircraft with respect to the maneuver criteria and to their general handling and flight characteristics. Where task-oriented requirements are implied, the scale is based on the same criteria described in the Handling Qualities Rating Scale (app E); otherwise, the 1-to-10 scale is arbitrary where the number 1 equates to the highest rating, with 10 being the lowest. Because of the very low rating assigned to the severe transition vibration characteristics of the BO-105, a more detailed discussion of this phenomenon is warranted. The vibration intensity was not strictly a function of airspeed but appeared to be closely coupled to the aircraft attitude assumed in the region of 20 KIAS. During normal and maximum performance takeoffs, there was only a slight increase in vibration intensity through transition. During all landing transitions, there was a rapid build of vibration intensity at or near 20 KIAS that was judged to be severe by the evaluation pilots. This vibration characteristic would be considered a deficiency during a procurement evaluation, in that the intensity caused considerable pilot distraction from the prime task of landing the aircraft (HQRS 7).

WEIGHT AND BALANCE

23. Weighing of the BO-105 and the L-286 was accomplished by the contractors. Weighing of the OH-6A and the OH-58A and computation of longitudinal cg's for all four aircraft were accomplished by USAASTA personnel. The results are shown in appendix G.

Table 5. Qualitative Evaluation of OH-6A, OH-58A; BO-105, L-286.

Symbols: OH-6A - ○
OH-58A - △
BO-105 - □
L-286 - X

UTTAS MANEUVERING FLIGHT	GOOD			IMPROVEMENT DESIRED			IMPROVEMENT REQUIRED			UNSATISFACTORY
	1	2	3	4	5	6	7	8	9	10
General maneuverability		X ○	△	□						
Control response		○ □ X	△							
Ability to tailor an accurate load factor		○ △	□ X							
Cross-coupling				X	△	○ □				
Control harmony			○ △ X	□						
Terrain avoidance suitability		○	□ △ X							
Pull-up		○	△ □ X							
Pushover			○ □ X	△						
Pull-up to pushover			○ □ X	△						
Vibration characteristics			○ X	△	□					
Power management			□ ○ △ X							

Table 6. Qualitative Evaluation of OH-6A, OH-58A; BO-105, L-286.

Symbols: OH-6A - ○
OH-58A - △
BO-105 - □
L-286 - ×

LEVEL FLIGHT TASK	GOOD			IMPROVEMENT DESIRED			IMPROVEMENT REQUIRED			UNSATISFACTORY
	1	2	3	4	5	6	7	8	9	10
Flight attitude		△ ×	○		□					
Vibration level			○ △ □ ×							
Noise		□ ×		○ △						
Power management		□	○ ×	△						
Gust disturbance characteristics		×			△	○ △				
Trimmability		×	△	○ □						
Control force feel			△ ×	○ □						
Turns		○	□ △ ×							

Table 7. Qualitative Evaluation of OH-6A, OH-58A; BO-105, L-286.

Symbols: OH-6A - ○
OH-58A - △
BO-105 - □
L-286 - X

HOVER TAKEOFF AND LANDING TASK	GOOD			IMPROVEMENT DESIRED			IMPROVEMENT REQUIRED			UNSATISFACTORY
	1	2	3	4	5	6	7	8	9	10
Transition vibration			○ △ X				□			
Hover vibration			○ △ □ X							
Cross-coupling			○ △ X	□						
Touchdown level		○ □	X	△						
Touchdown slope		○		X	△ □					
Aircraft attitude			⊙ △ □ X							
Rearward flight				○ △ □						
Sideward flight			X	○	△ □					

CONCLUSIONS

GENERAL

24. The following conclusions were reached upon the completion of the test program:

a. Present-day rotary aircraft can be tested against new rotorcraft criteria with meaningful results.

b. The ±5-degree angular deviation restriction stated in the maneuver criteria is too severe (paras 14 and 18).

c. During the maneuvering testing of the OH-6A, L-286, and BO-105, no unusual shock or vibration was encountered, and loss of control power was not critical (para 15).

d. The OH-58A cannot meet the proposed pushover criteria (para 16).

e. The OH-6A, the L-286, and the BO-105 exhibited a better terrain-avoidance capability than the OH-58A (para 19).

f. Combined application of longitudinal cyclic and collective is the preferable technique to effect terrain avoidance (para 20).

DEFICIENCIES AND SHORTCOMINGS AFFECTING MISSION ACCOMPLISHMENT

25. Correction of the following deficiencies is mandatory for satisfactory operation if procurement or envelope expansion is anticipated:

a. Loss of lateral control power below 0.5g in the OH-58A (HQRS 8) (para 17).

b. Mast bumping or spike knock in the OH-58A at load factors below 0.5 (para 17).

c. Excessive vibration during landing transition on the BO-105 (HQRS 7) (para 22).

26. Correction of the following shortcomings is desirable for improved operation and mission capabilities if procurement or envelope expansion is anticipated:

a. Excessive cross-coupling during maneuvering tasks, apparent in all four test helicopters (paras 14 and 18).

b. Inadequate longitudinal control margin at load factors less than 0.5 in the OH-58A (para 16).

RECOMMENDATIONS

27. The deficiencies, correction of which is mandatory, should be corrected prior to procurement or envelope expansion.

28. The shortcomings, correction of which is desirable, should be corrected prior to procurement or envelope expansion.

29. The stated maneuver criteria angular deviation restriction of ±5 degrees should be changed to ±10 degrees (paras 14 and 18).

30. The technique of using combined application of longitudinal cyclic and collective to effect terrain avoidance should be considered during the preparation of future helicopter maneuver criteria (para 20).

31. The identified deficiencies and shortcomings of this report should be avoided in future design.

APPENDIX A. REFERENCES

1. Letter, USAASTA, SAVTE-T, 19 March 1971, subject: AH-1G Maneuvering Characteristics.

2. Final Report, USAASTA, Project No. 69-11, *Engineering Flight Test, AH-1G Helicopter (HueyCobra) Maneuvering Limitations,* March 1971.

3. Request for Proposal, DAAJ01-72-R-0254 (P40), *Utility Tactical Transport Aircraft System*, 30 December 1971.

4. Letter, AVSCOM, AMSAV-EFT, 23 July 1971, subject: UTTAS Maneuverability Program.

5. Technical Manual, TM 55-1520-228-10, *Operator's Manual, Army Model OH-58A Helicopter,* 13 October 1971, with Change 3, 15 April 1971.

6. Technical Manual, TM 55-1520-214-10, *Operator's Manual, Helicopter, Observation OH-6A (Hughes),* July 1969, with Change 6, 5 February 1971.

7. Flight Manual, The Boeing Company, Vertol Division, *BO-105 Flight Manual*, 26 July 1971.

8. Flight Manual, Lockheed-California Company, *Model L-286 Flight Manual,* 30 July 1966.

9. Certification Report, *FAA Certification of the Model L-286 Helicopter,* 29 July 1966.

10. Message, AVSCOM, AMSAV-EFT, 121845Z, 7 September 1971, Unclas, subject: UTTAS Maneuverability Program.

APPENDIX B. PHOTOGRAPHS

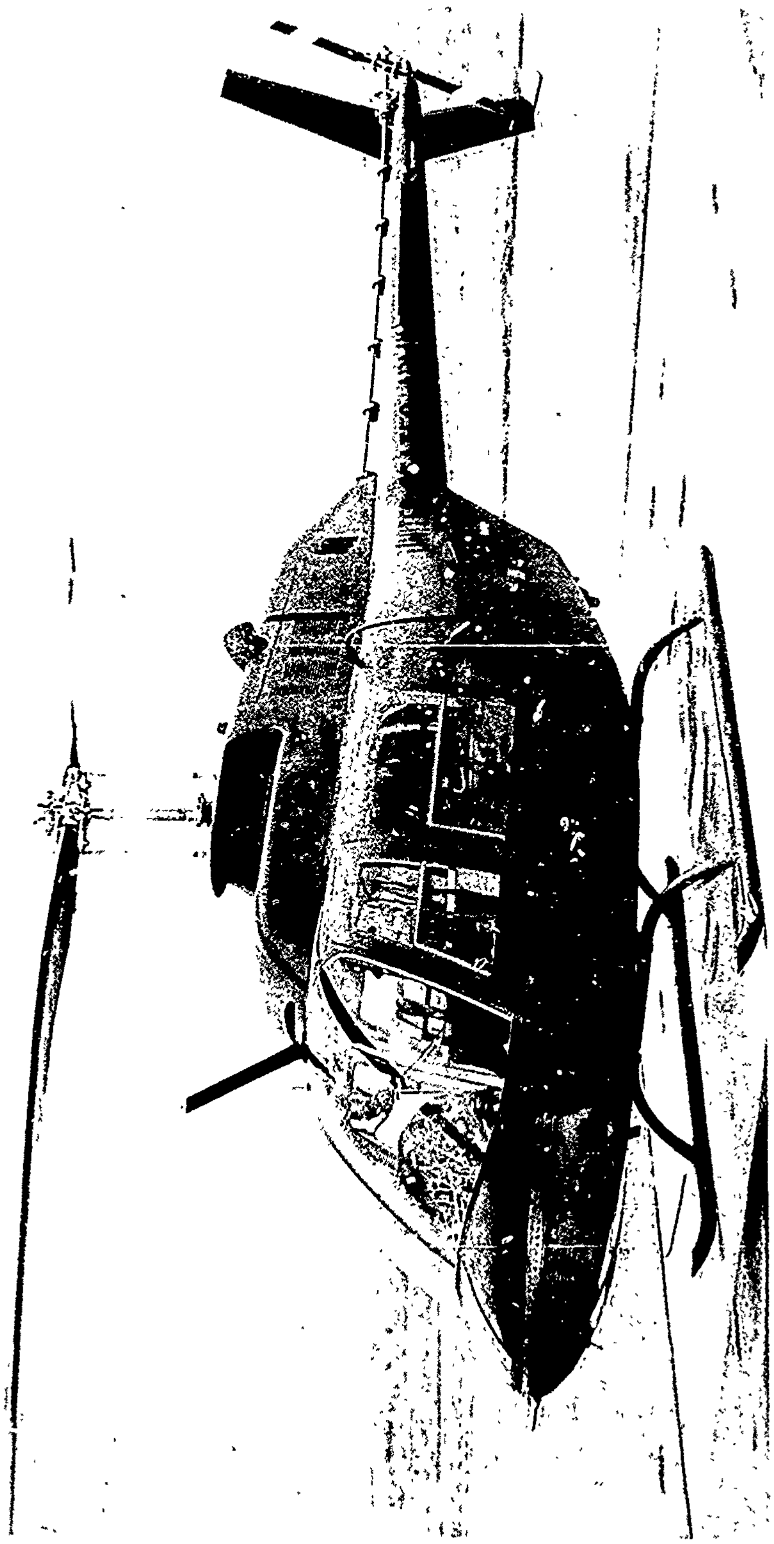


Photo 1. OH-58A.

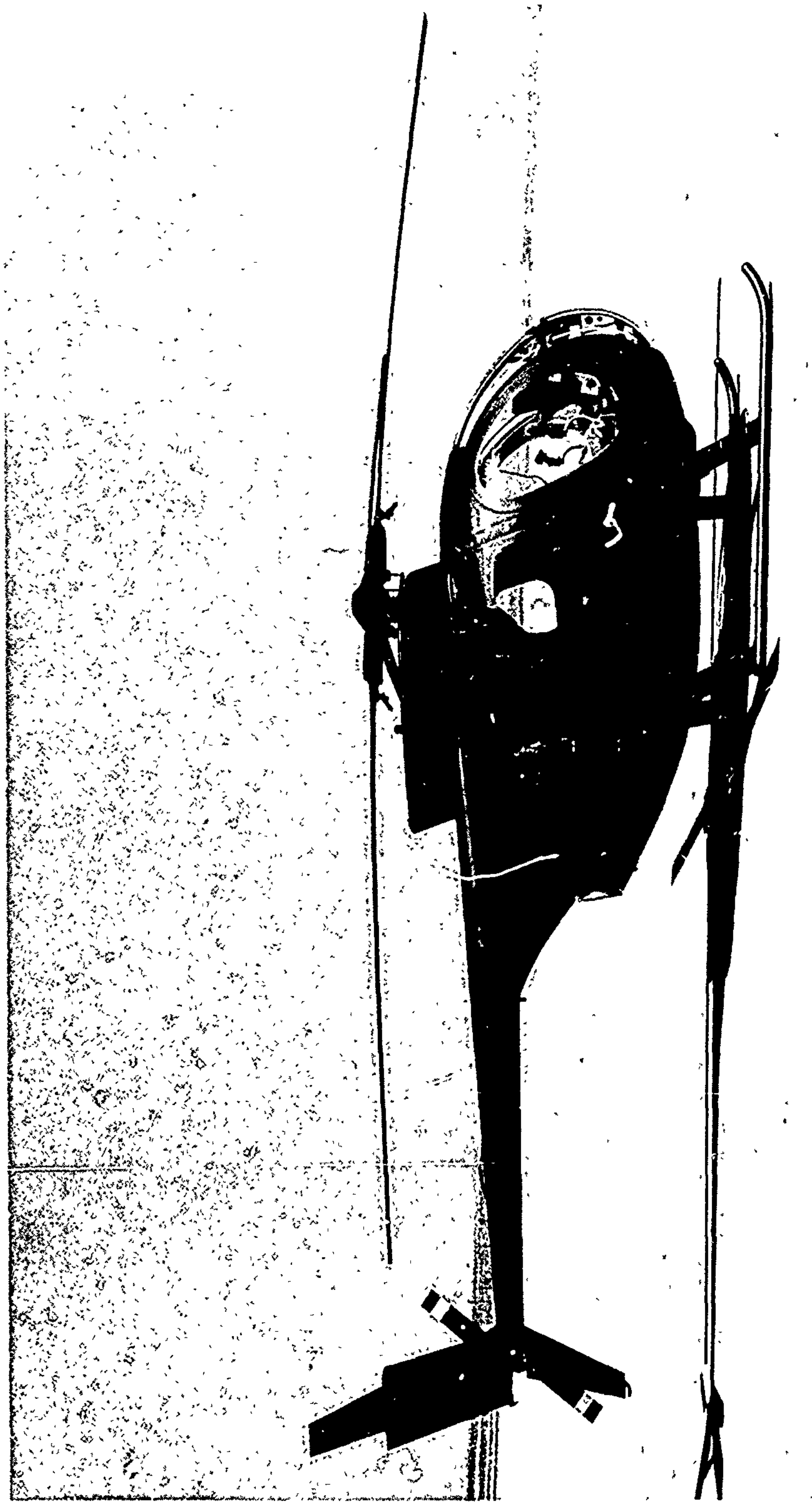


Photo 2. OH-6A.

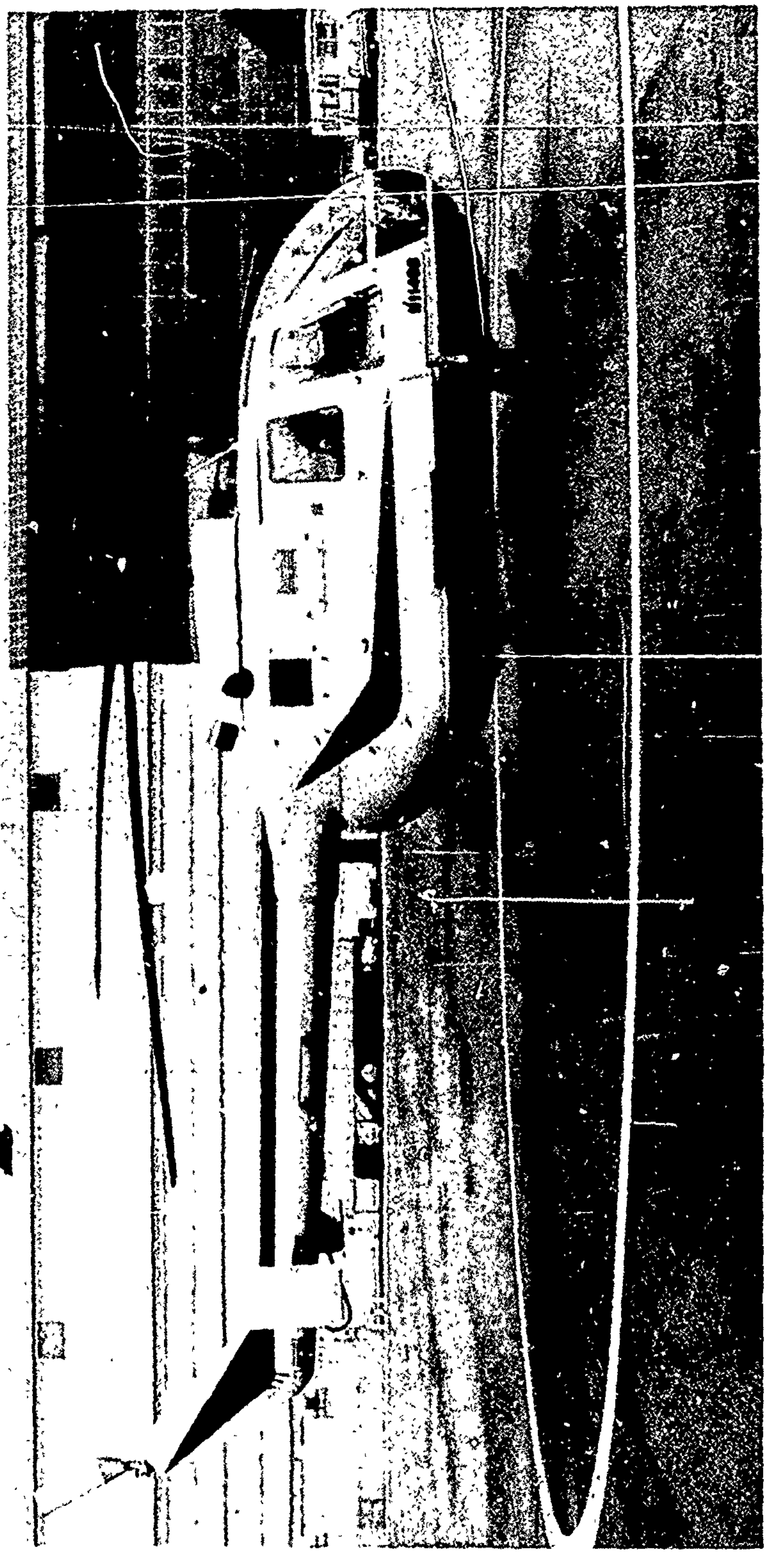


Photo 3. BoelKow BO-105.

Photo 4. Lockheed Model L-286.

APPENDIX C. OPERATING ENVELOPES

FIGURE 1 OH-6A TEST ENVELOPE

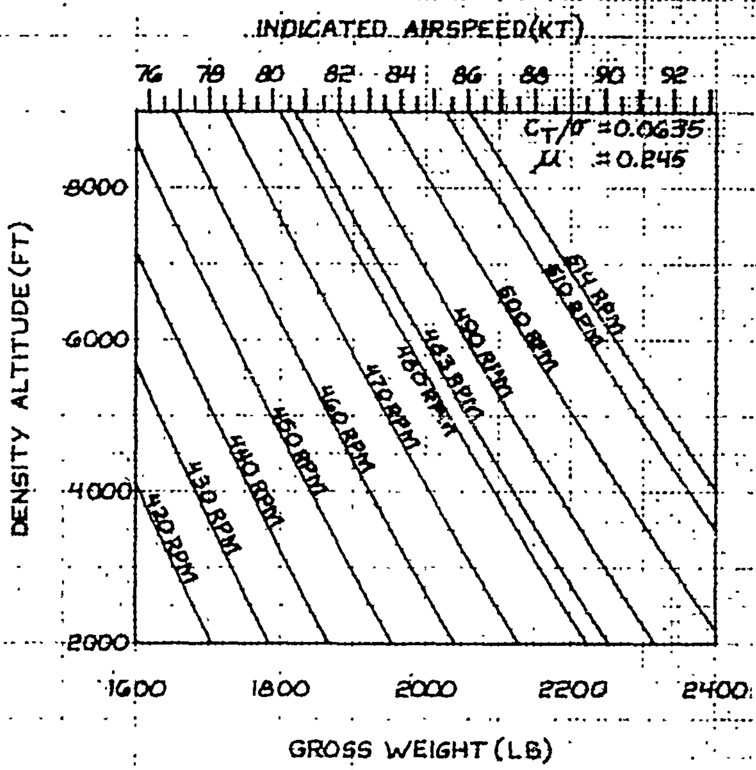


FIGURE 2 OH-58A TEST ENVELOPE

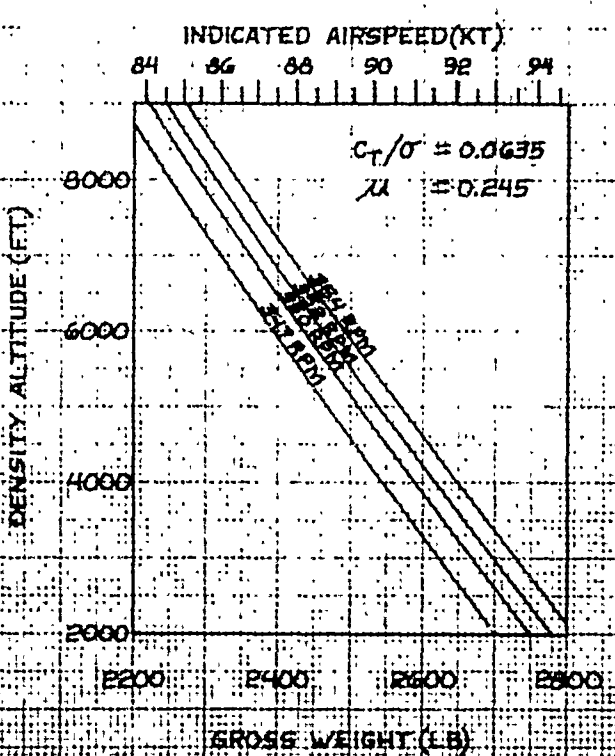


FIGURE 3 BO-105 TEST ENVELOPE

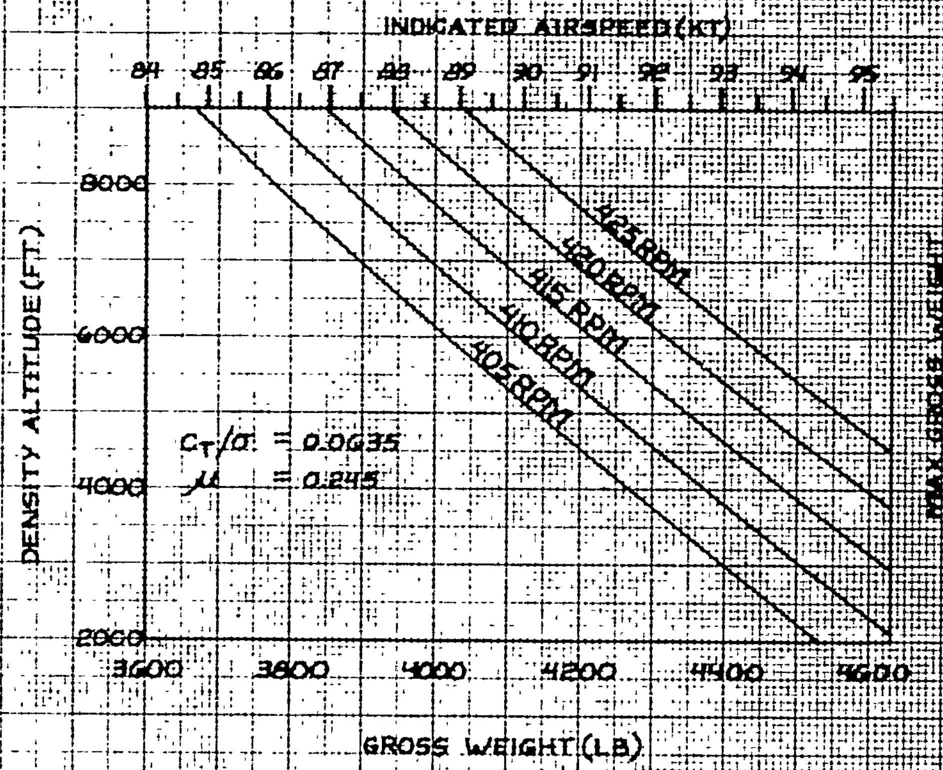
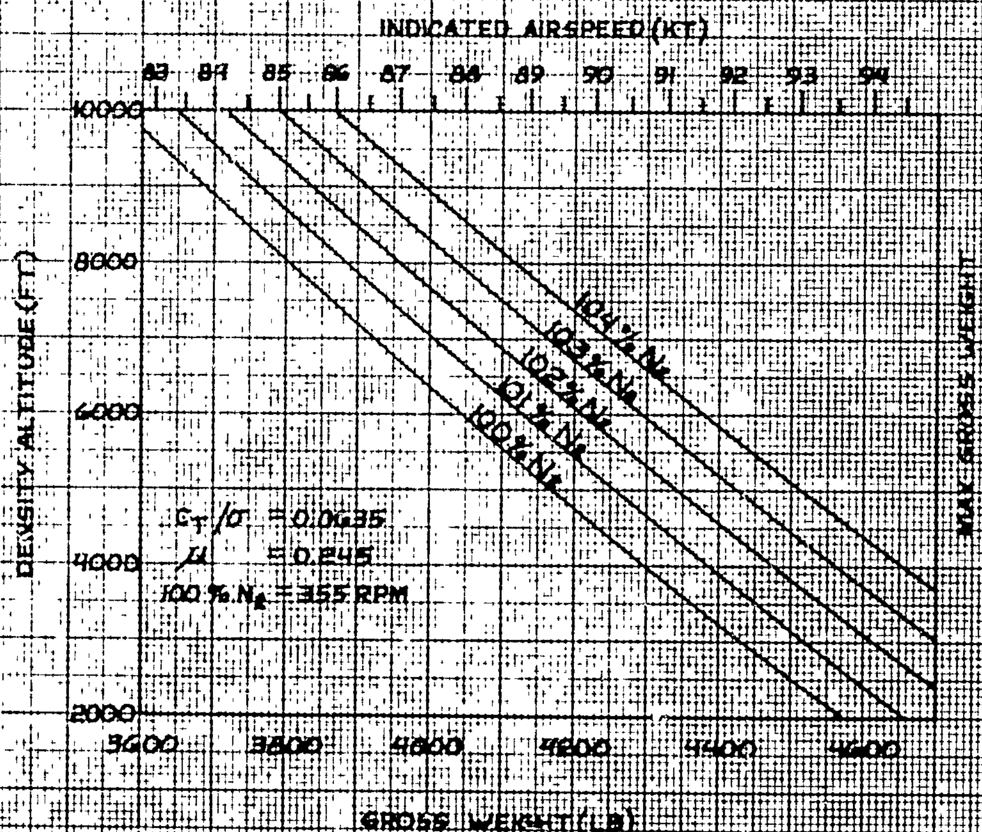


FIGURE 4 L-286 TEST ENVELOPE



APPENDIX D. TEST INSTRUMENTATION

1. Each aircraft was equipped with the following instrumentation. USAASTA personnel performed installation, calibration, and maintenance of the instrumentation for the OH-6A and OH-58A helicopters. Boeing-Vertol was responsible for the BO-105 helicopter instrumentation.

<u>OH-6A Cockpit Panel</u>

Airspeed
Altitude
Free air temperature
Main rotor rpm
Longitudinal control position
Lateral control position
Directional control position
Collective control position
Center-of-gravity normal acceleration
Clock (Hayden timer)
High-speed movie camera

<u>OH-58A Cockpit Panel</u>

Airspeed
Altitude
Free air temperature
Main rotor rpm
Longitudinal control position
Lateral control position
Directional control position
Collective control position
Fuel-used totalizer
Torque pressure
Center-of-gravity normal acceleration

<u>OH-58A Oscillograph</u>

Roll attitude
Pitch attitude
Yaw attitude
Roll rate
Pitch rate
Yaw rate
Longitudinal control position
Lateral control position
Directional control position

Collective control position
Throttle position
Torque pressure
Main rotor rpm
Airspeed
Altitude
Center-of-gravity normal acceleration

BO-105 Cockpit Panel

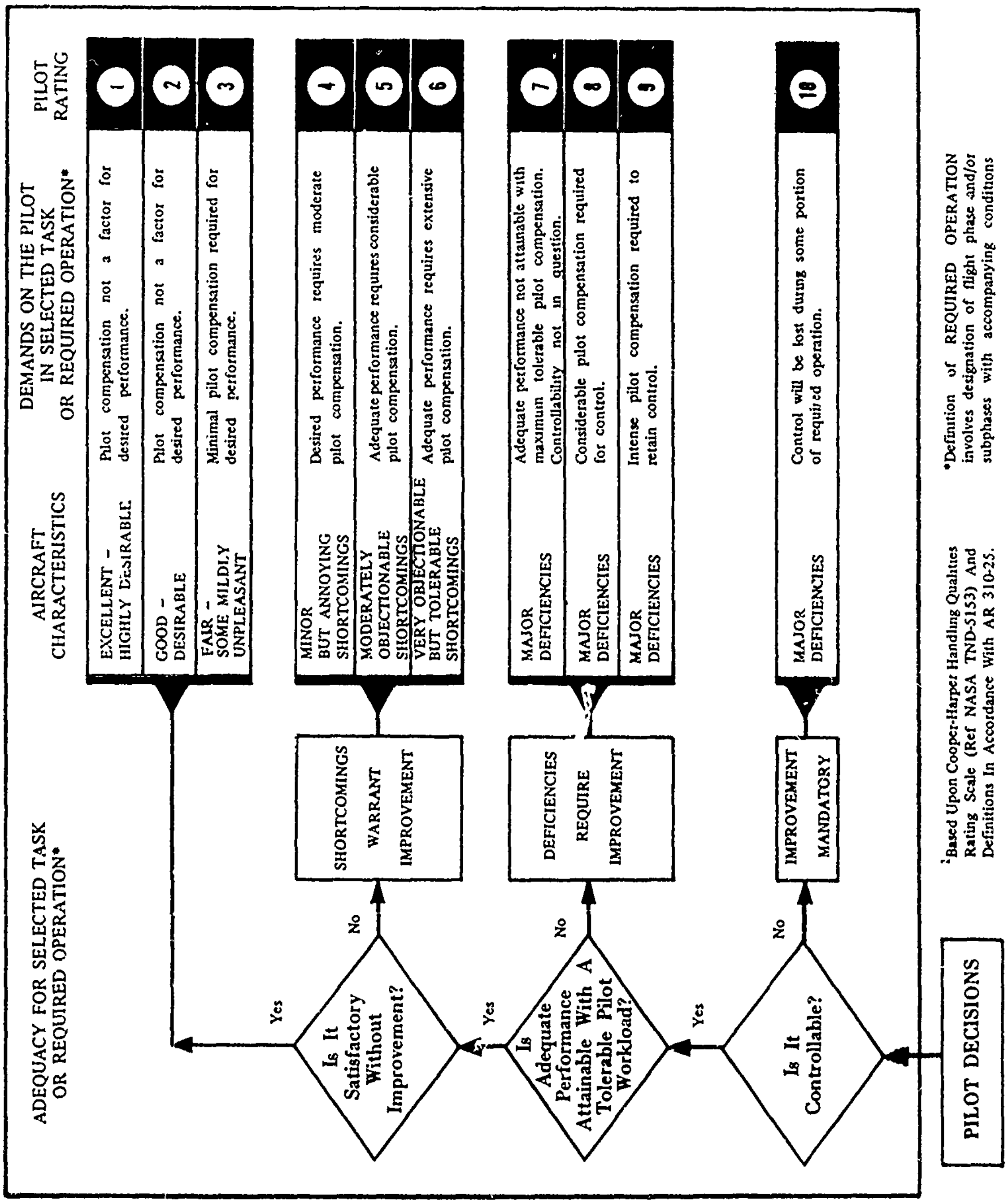
Airspeed
Altitude
Free air temperature
Main rotor rpm
Longitudinal control position
Lateral control position
Center-of-gravity normal acceleration
High-speed movie camera

L-286 Cockpit Panel

Airspeed
Altitude
Free air temperature
Main rotor rpm
Longitudinal control position
Lateral control position
Directional control position
Collective control position
Center-of-gravity normal acceleration
Clock
High-speed movie camera

2. For the OH-6A, L-286, and the BO-105, data were displayed on panel instruments which were photographed at a rate of 24 frames per second.

APPENDIX E. HANDLING QUALITIES RATING SCALE

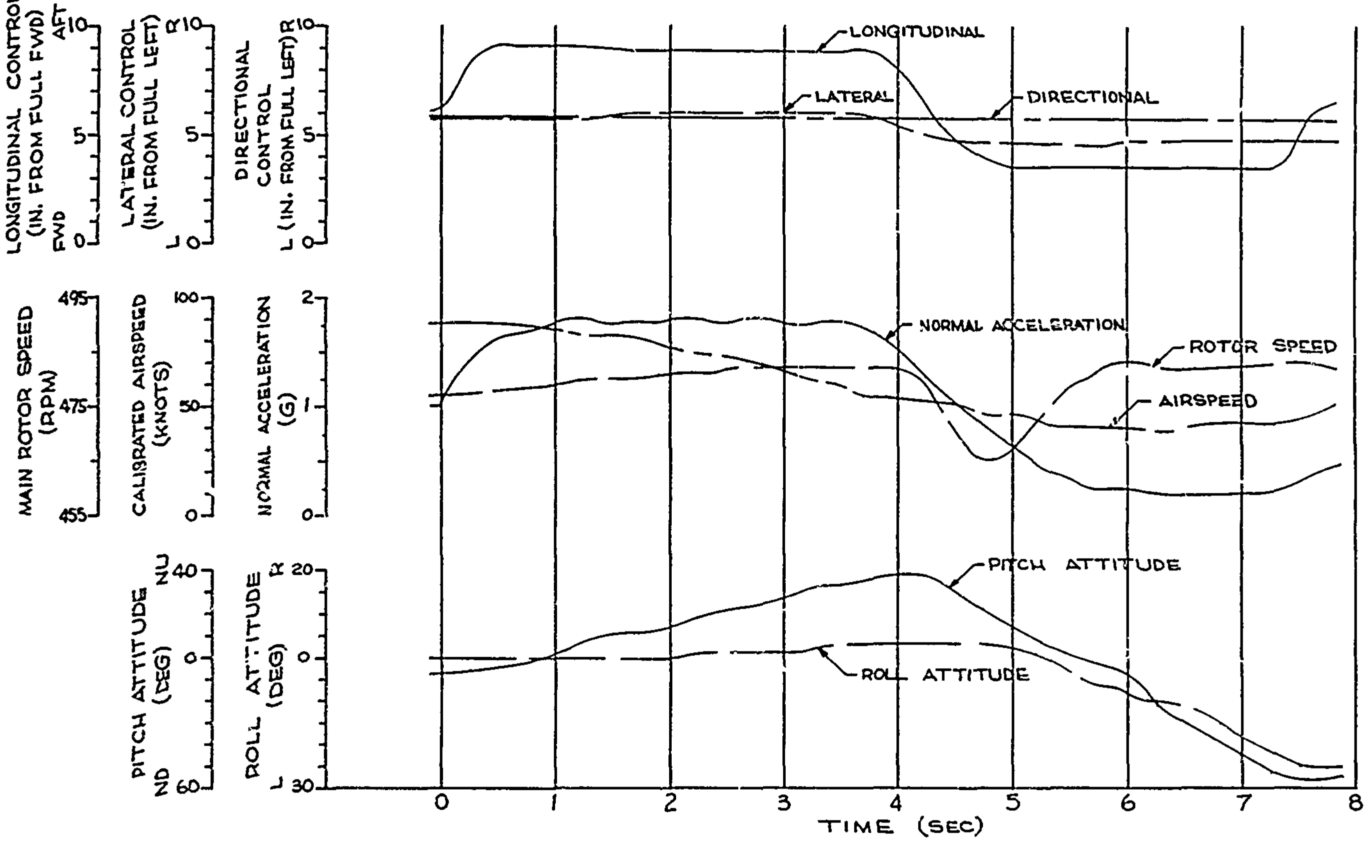


APPENDIX F. TEST DATA

FIGURE 1 .PULL UP TO PUSHOVER.

OH 6A — USA S/N 65-12927

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG C.G (IN.)	AVG THRUST COEFF ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN. FROM FULL DN)	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
89	1950	4050	4100	24.1	97.9 (FWD)	41.62	3.2	39	34

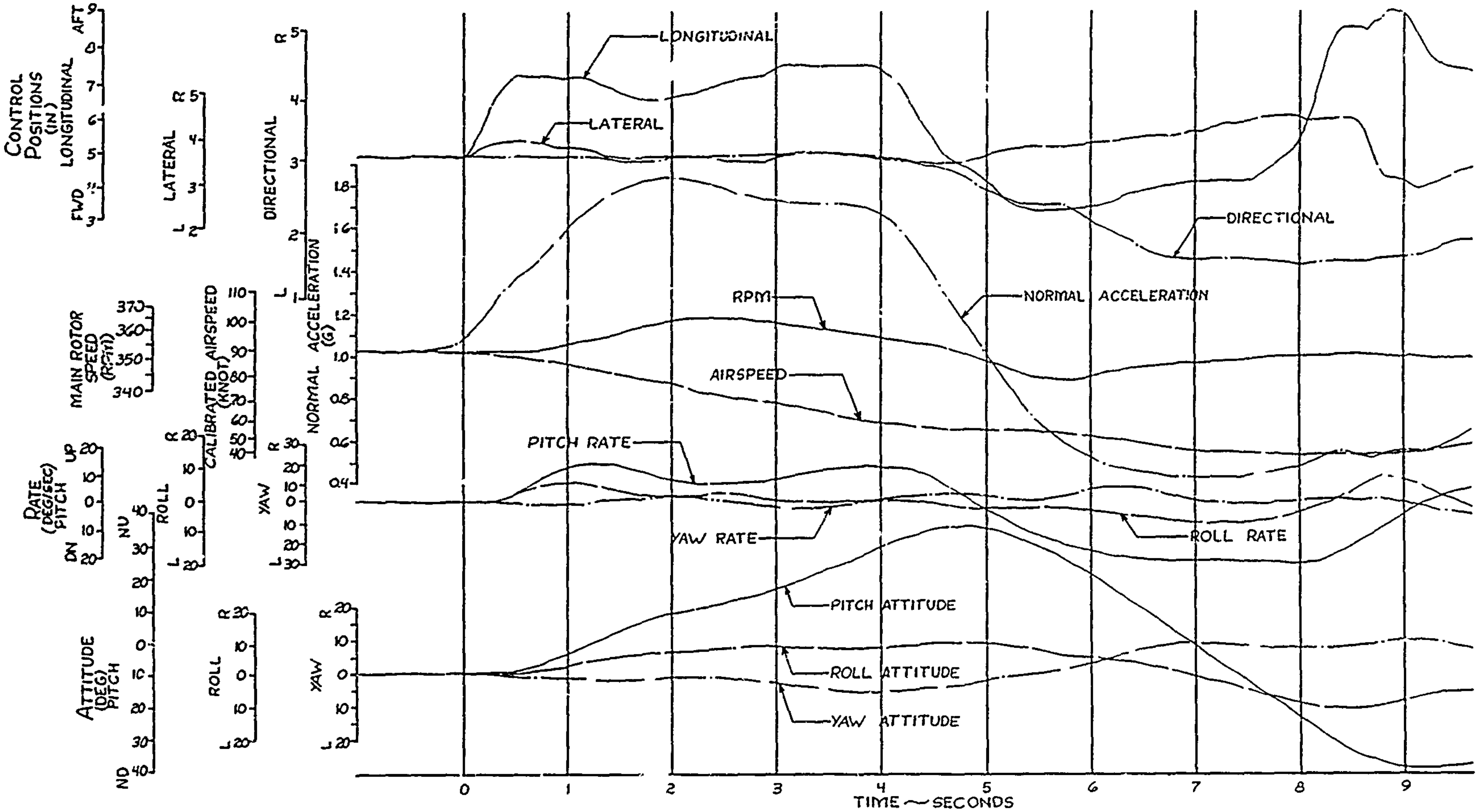


FULL CONTROL TRAVEL:
LONGITUDINAL = 12.4 IN.
LATERAL = 12.5 IN.
DIRECTIONAL = 7.5 IN.

FIGURE 2 PULL-UP TO PUSHOVER

OH-58A USA S/N 68-16706

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG. C.G. (IN)	AVG THRUST COEFFICIENT ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN)	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
90	2650	3740	3980	7.3	106.9(MID)	29.74	5.3	52.5	59.7



FULL CONTROL TRAVEL:
LONGITUDINAL = 12.0 IN.
LATERAL = 10.3 IN.
DIRECTIONAL = 6.9 IN.

FIGURE 3. PULL UP TO PUSHOVER.

BO105 S/N 1149B

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG CG (IN.)	AVG THRUST COEFF ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
89	4250	4980	5280	14	125.1(FWD)	51.56	NOT AVAILABLE	60	70

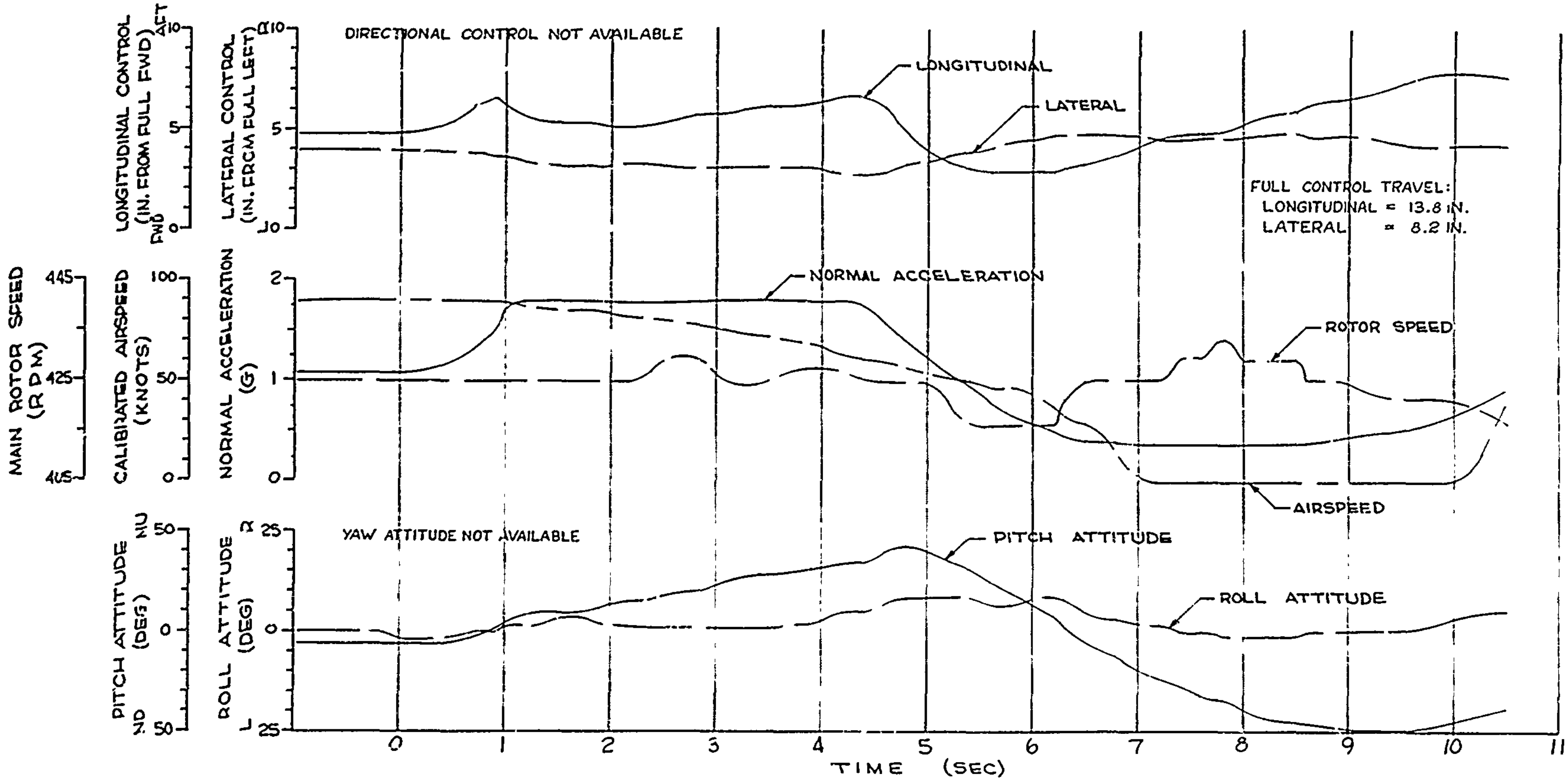


FIGURE 4 PULL UP TO PUSHOVER
L-286 S/N 265LC

TRIM AIRSPEED (KCAS)	GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	C.G (IN)	THRUST COEFFICIENT ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN)	INITIAL SHAFT HORSEPOWER	FINAL SHAFT HORSEPOWER
94	4170	5100	5400	10.0	150.6(MID)	4994	4.7	255	320

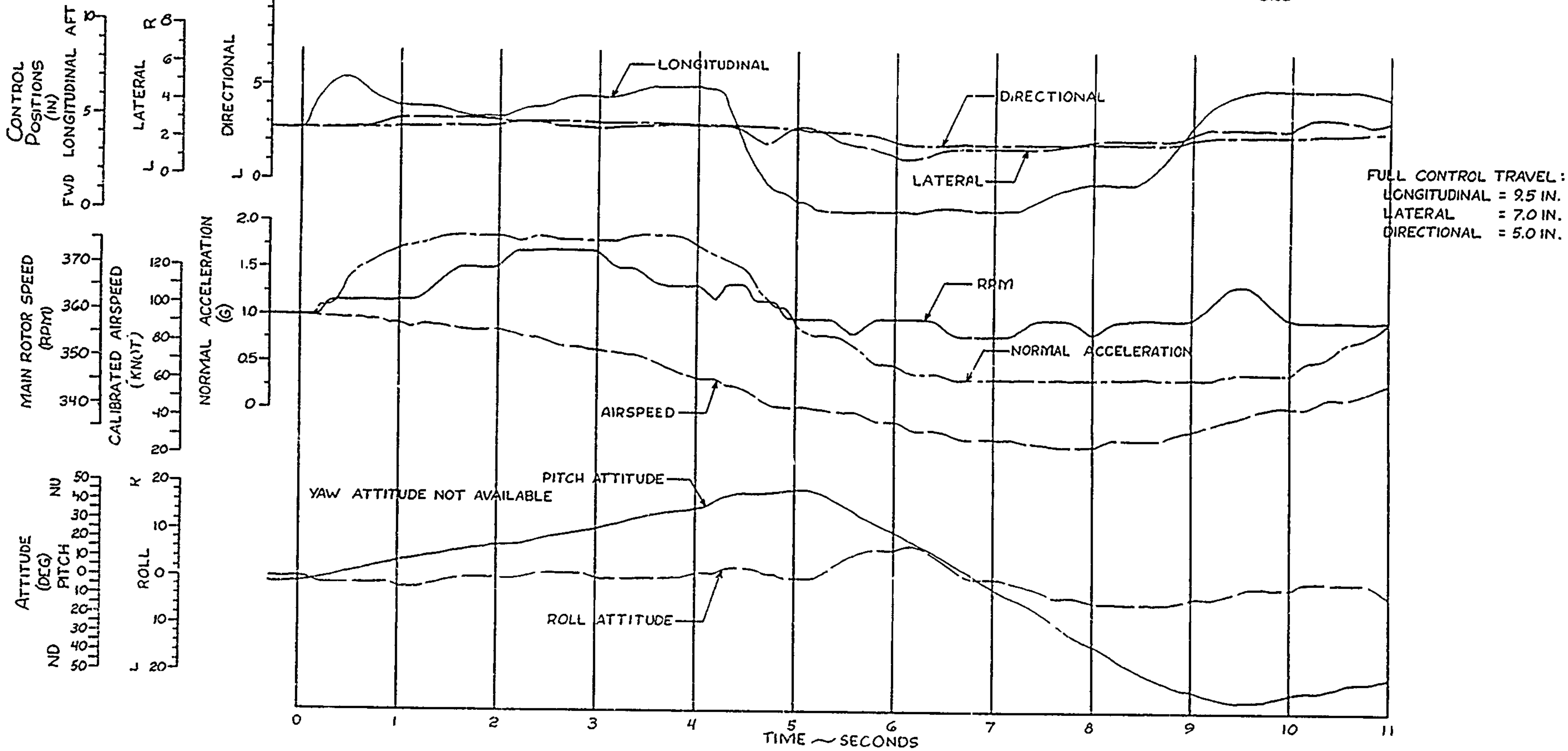


FIGURE 5 PULL-UP TO PUSHOVER

OH-58A USA S/N 68-16706

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG CG (IN)	AVG THRUST COEFFICIENT ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN)	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
89	2630	3600	3880	12.6	106.9(MID)	29.91	5.4	53.9	57.5

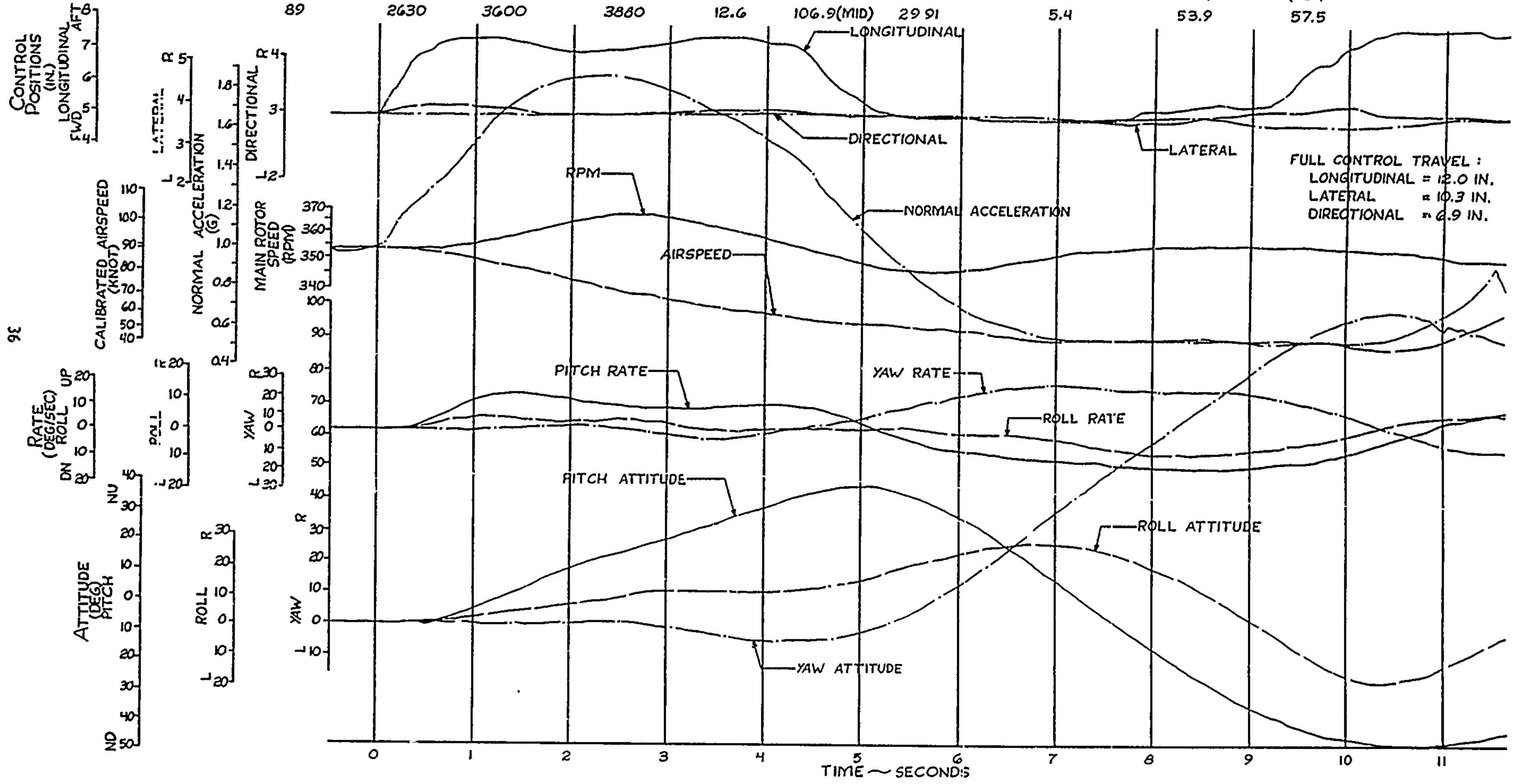


FIGURE 6 .PUSHOVER.

BO 105 S/N 1149B

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG CG (IN.)	AVG THRUST COEFF ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
90	4250	4820	4580	14.0	125.1(FWD)	52.24	NOT AVAILABLE	62	28

FULL CONTROL TRAVEL:
LONGITUDINAL = 13.8 IN.
LATERAL = 8.2 IN.

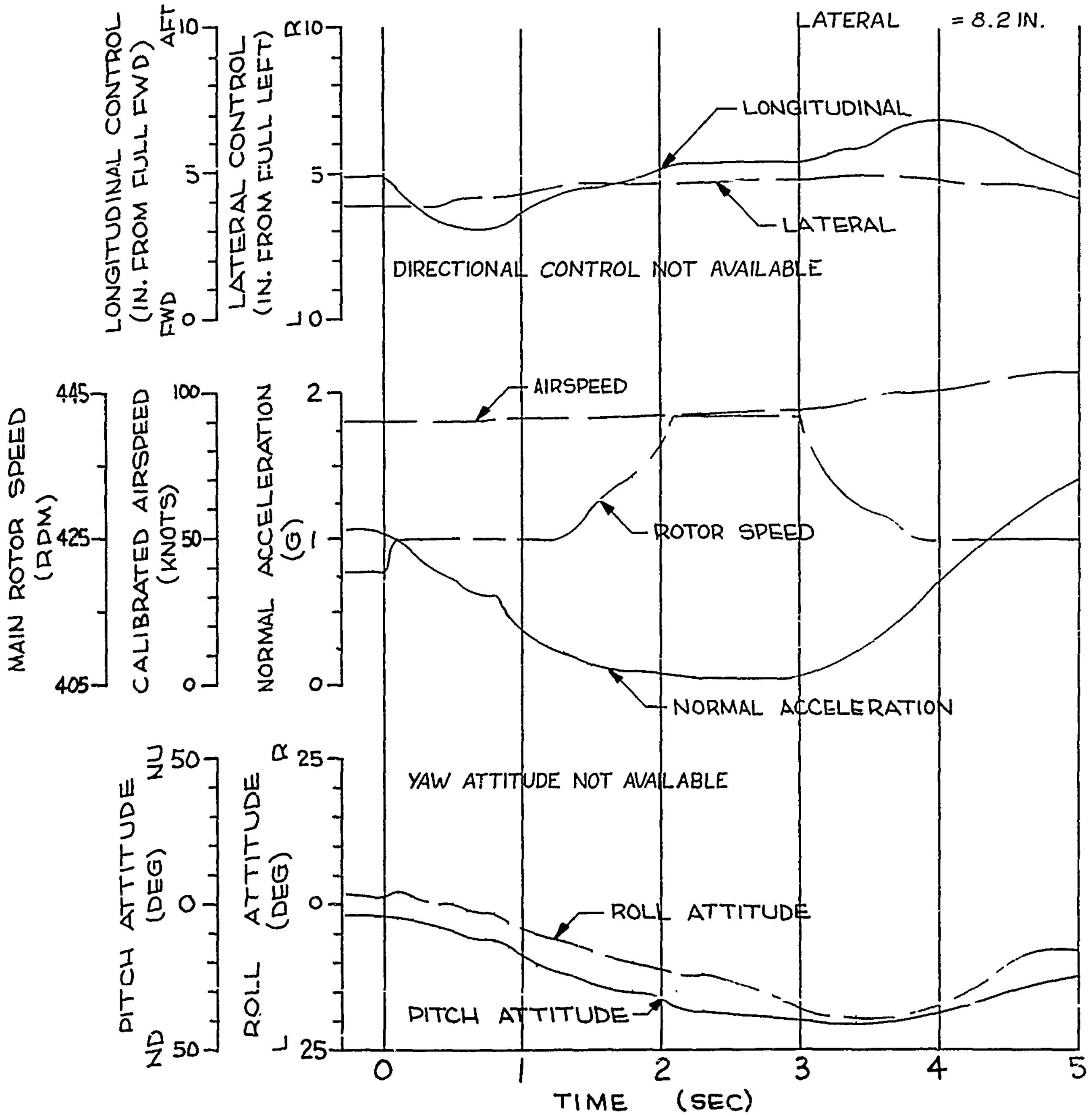


FIGURE 7 PUSHOVER

L-286 S/N 265LC

TRIM AIRSPEED (KCAS)	GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	C.G. (IN)	THRUST COEFFICIENT ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN)	INITIAL SHAFT HORSEPOWER	FINAL SHAFT HORSEPOWER
92	4070	4950	4890	10.0	150.6(MID)	47.66	4.9	300	150

FULL CONTROL TRAVEL:
LONGITUDINAL = 9.5 IN.
LATERAL = 7.0 IN.
DIRECTIONAL = 5.0 IN.

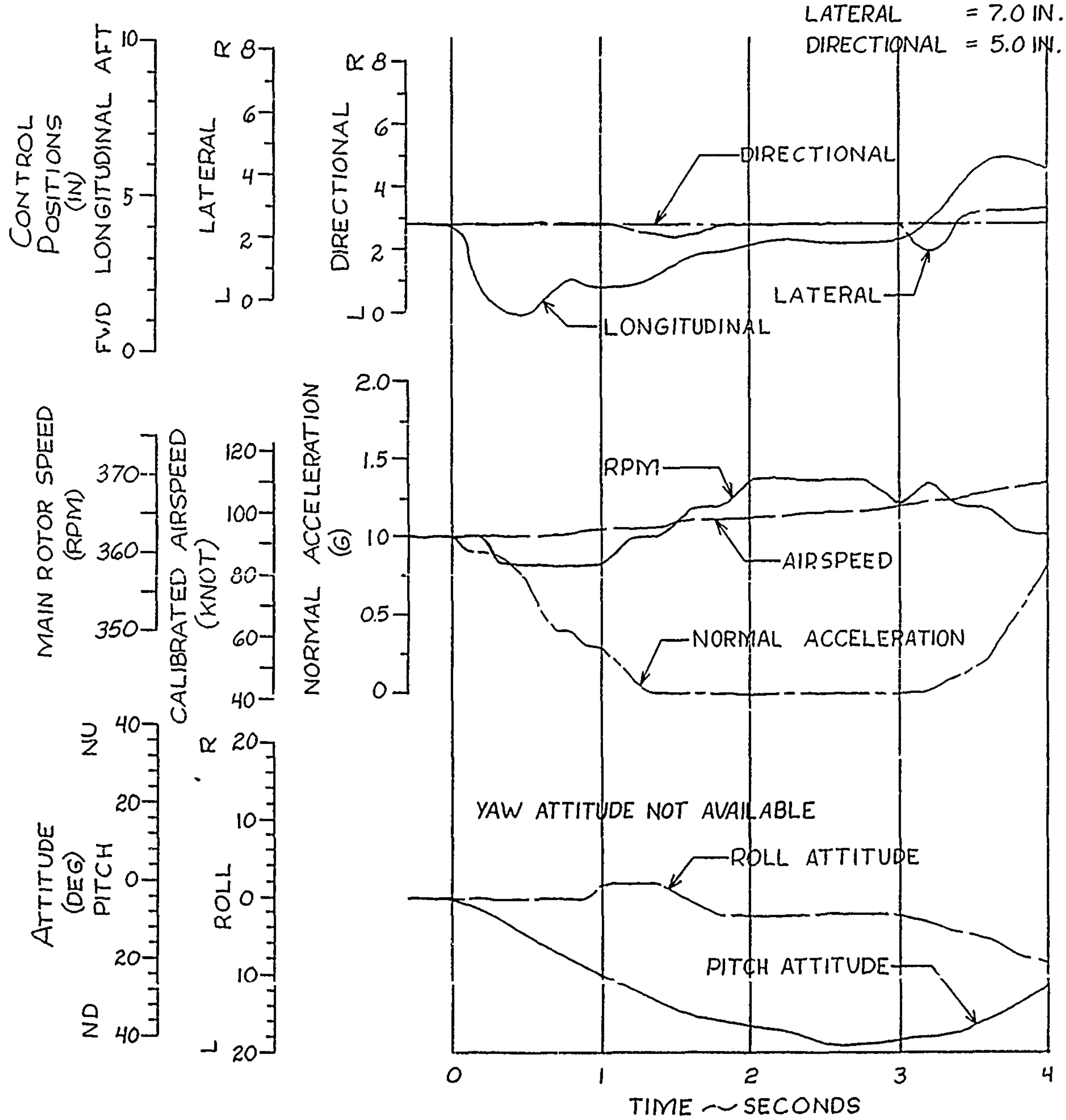


FIGURE 8 . PUSHOVER.

OH 6A USA S/N 65-12927

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG C G (IN.)	AVG THRUST COEFF ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN. FROM DN)	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
91	1950	3980	3920	25.0	97.9(FWD)	42.01	3.22	42	40

FULL CONTROL TRAVEL:
LONGITUDINAL = 12.41 IN.
LATERAL = 12.5 IN.
DIRECTIONAL = 7.5 IN.

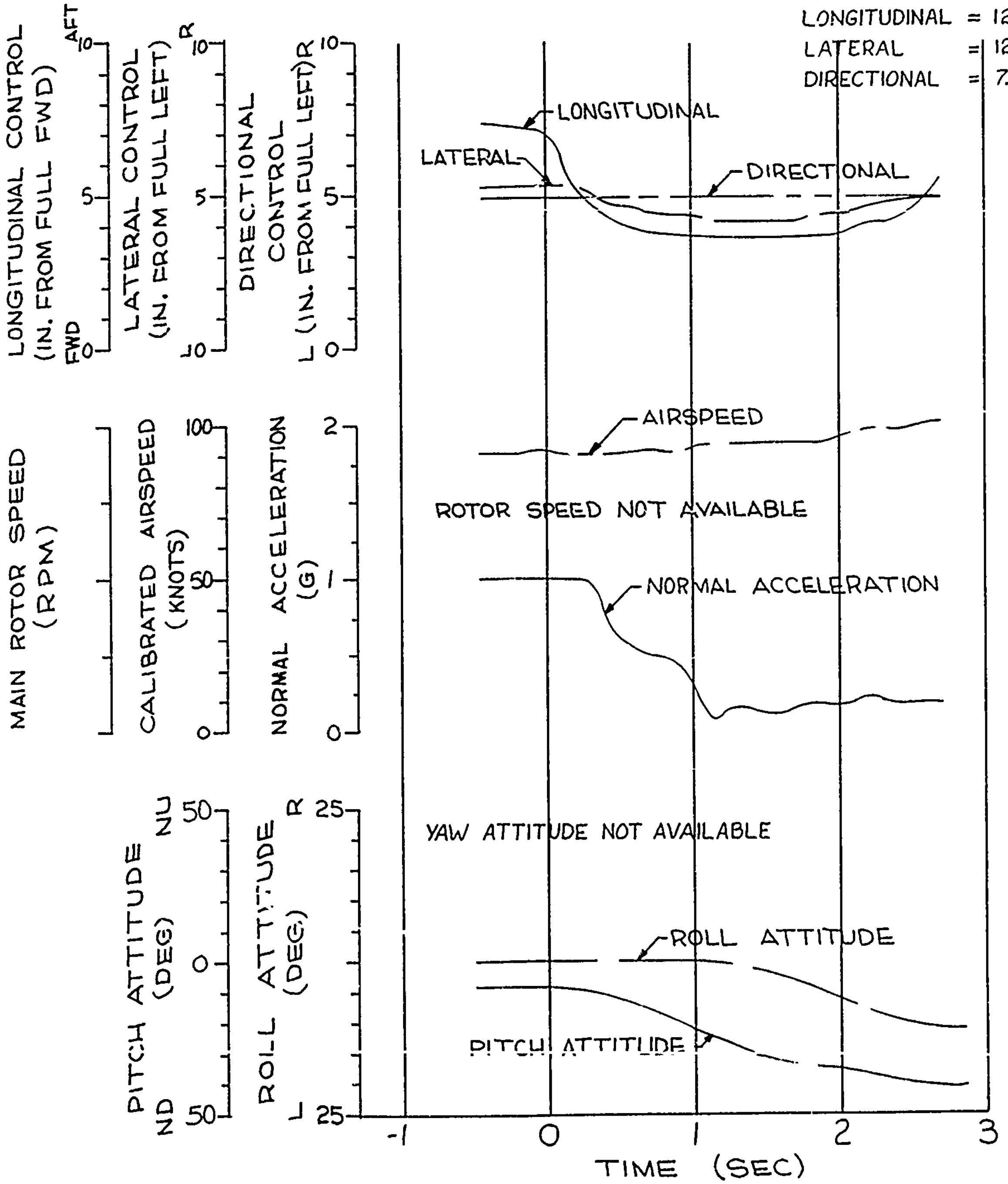


Figure 9 Pushover

OH-58A USA S/N 68-16706

Trim Airspeed (KCAS)	Avg Gross Weight (LB)	Initial Pressure Altitude (FT)	Final Pressure Altitude (FT)	Initial OAT (°C)	Avg CG (IN)	Avg Thrust Coefficient ($C_T \times 10^4$)	Collective Control Position (IN)	Initial Torque Reading (PSI)	Final Torque Reading (PSI)
89	2620	3400	3270	11.7	106.5(MID)	29.82	5.5	53.9	52 3

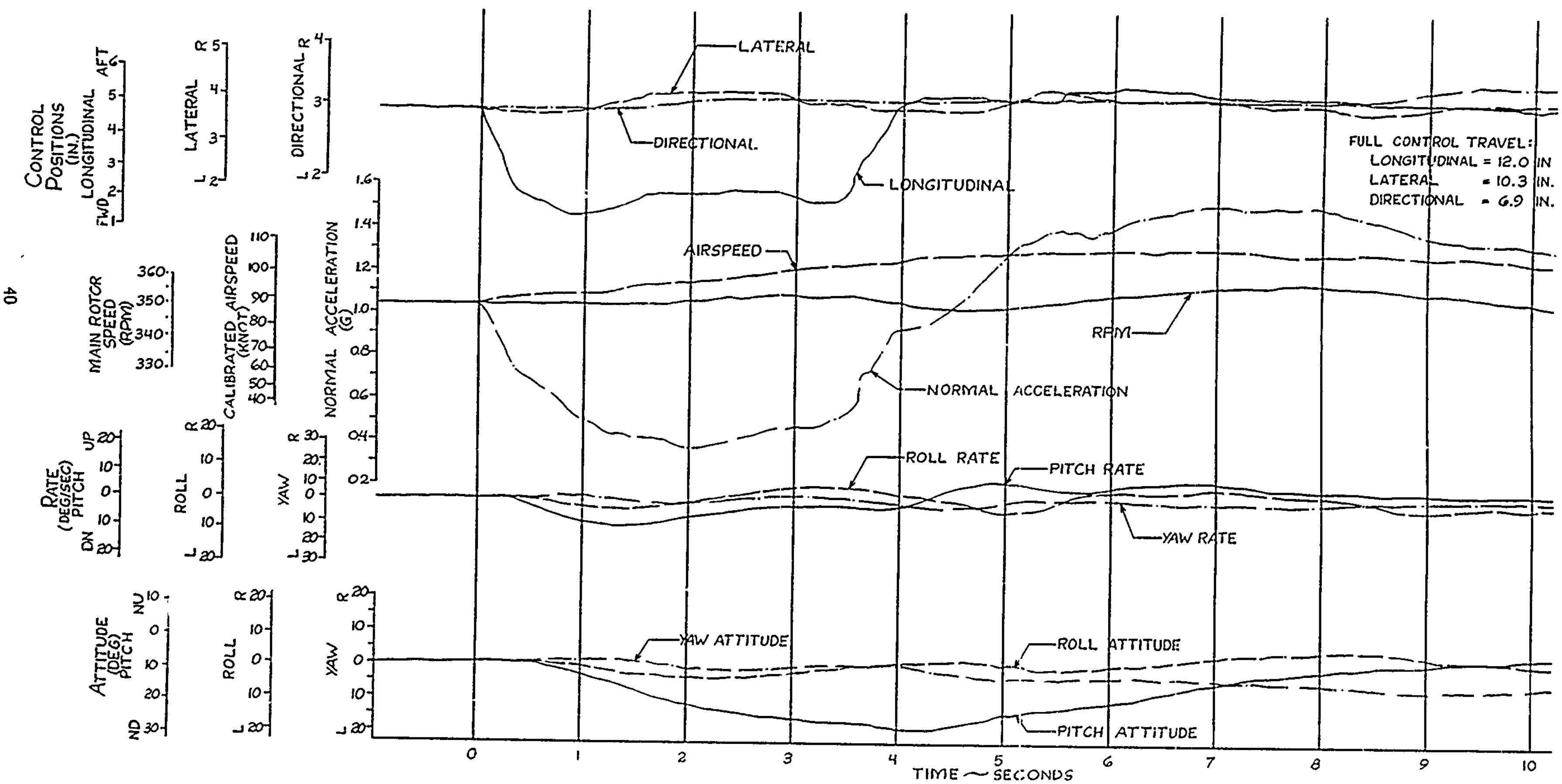


Figure 10 Pushover

OH-58A USA S/N 68-16706

Trim Airspeed (KCAS)	Avg Gross Weight (LB)	Initial Pressure Altitude (FT)	Final Pressure Altitude (FT)	Initial OAT (°C)	Avg CG (IN)	Avg Thrust Coefficient ($C_T \times 10^4$)	Collective Control Position (IN)	Initial Torque Reading (PSI)	Final Torque Reading (PSI)
87	2520	5050	4910	7.1	106.9(MID)	29.84	5.5	45.7	40.0

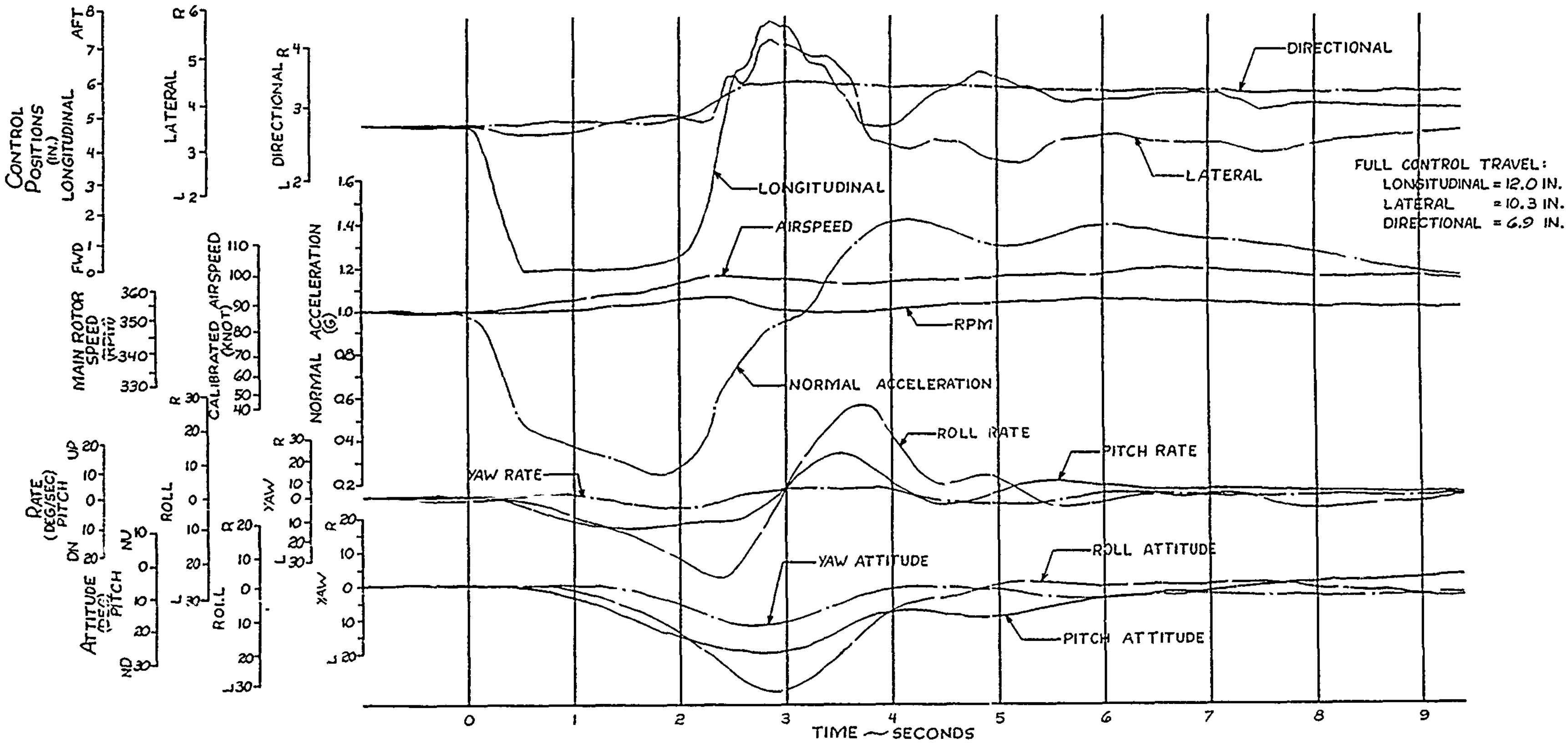


FIGURE 11 PULL-UP TO PUSHOVER
OH-58A USA S/N 68-16706

TRIM AIRSPEED (KCAS)	AVG GROSS WEIGHT (LB)	INITIAL PRESSURE ALTITUDE (FT)	FINAL PRESSURE ALTITUDE (FT)	INITIAL OAT (°C)	AVG CG (IN)	AVG THRUST COEFFICIENT ($C_T \times 10^4$)	COLLECTIVE CONTROL POSITION (IN)	INITIAL TORQUE READING (PSI)	FINAL TORQUE READING (PSI)
87	2520	5050	5290	7.1	106.9(MID)	29.8	5.5	44.7	47.4

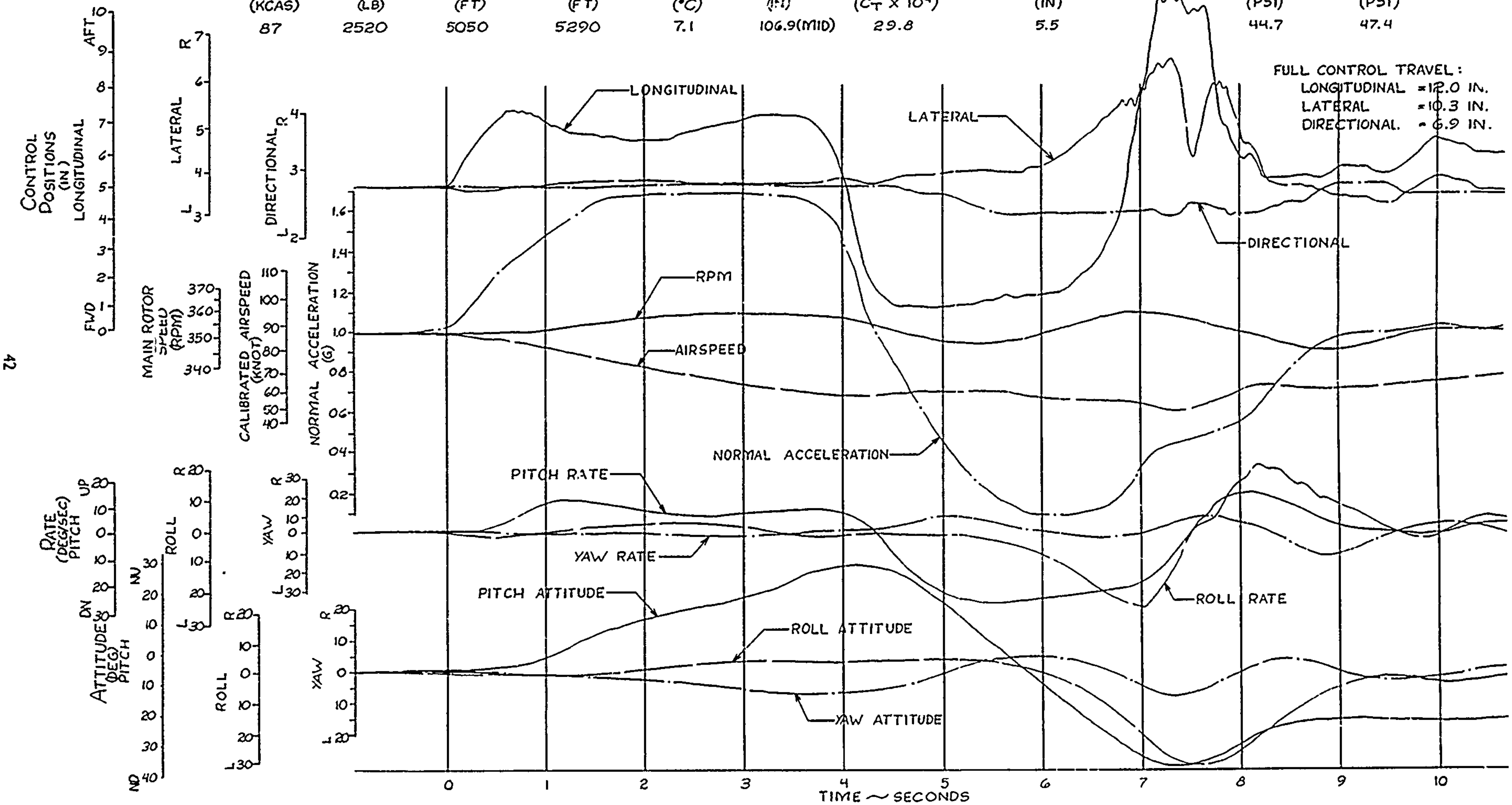


FIGURE 12 PROFILE COMPARISON IN PULL-UP TO PUSHOVER

	Trim Calibrated Airspeed (KT)	Pressure Altitude (FT)	OAT (°C)	Minimum Load Factor (g)	Maximum Load Factor (g)
——— OH-58A	90	3960	7.1	0.5	1.75
– – – OH-6A	89	3660	7.7	0.2	1.75
— - — T-28B	157	3970	7.1	0.0	1.75
- - - - L-28G	94	5100	10.0	0.2	1.75

NOTE: DATA NOT AVAILABLE FOR BO-105.

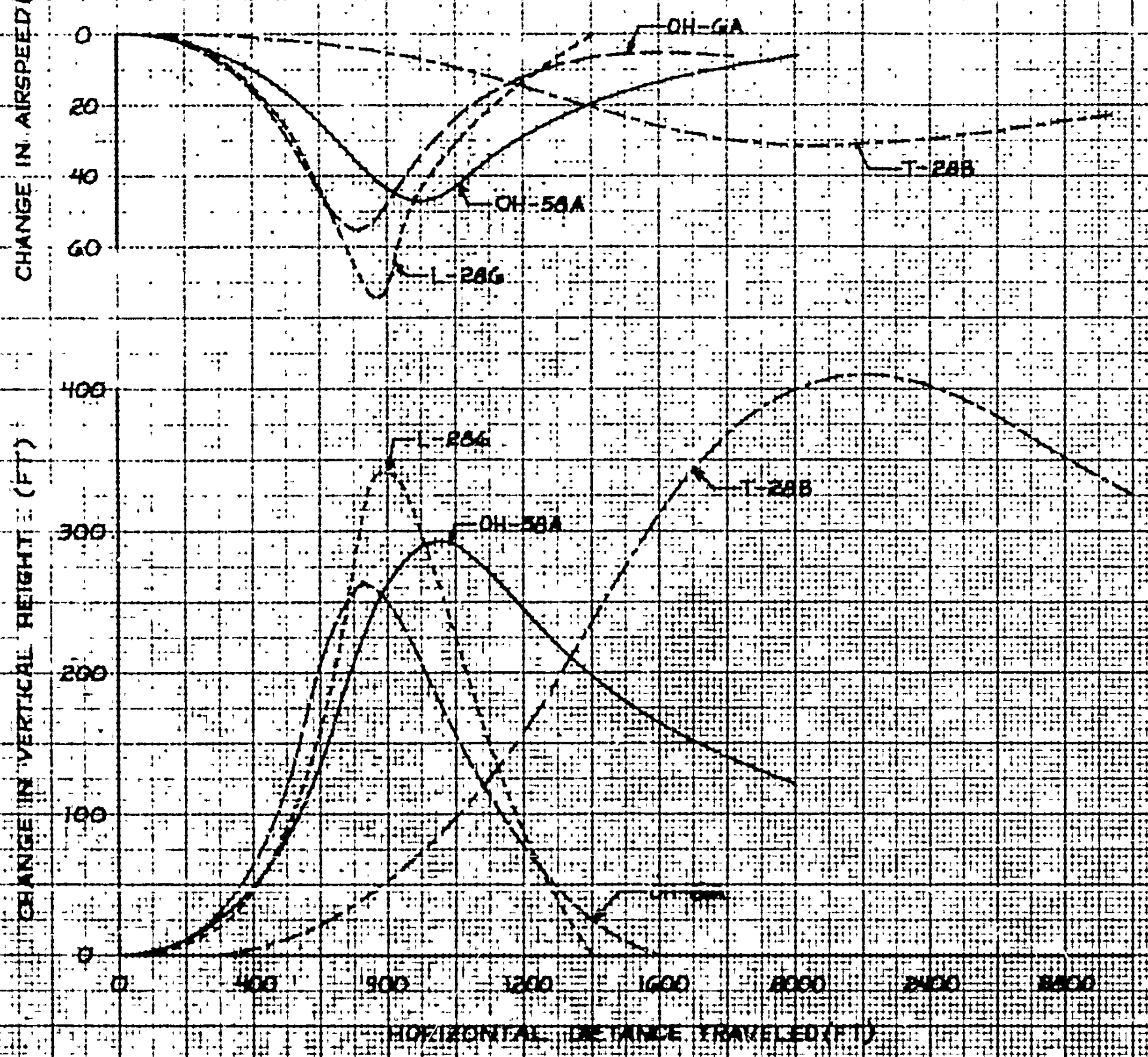


FIGURE 13 PROFILE COMPARISON IN PUSHOVER

	TRIM CALIBRATED AIRSPEED (KT)	PRESSURE ALTITUDE (FT)	OAT (°C)	MINIMUM LOAD FACTOR (g)
OH-58A	90	[illegible]	7.3	0.5
OH-6A	92	3580	7.9	0.0
T-28B	155	[illegible]	7.3	0.0
L-286	92	4950	10.0	0.0

NOTE: DATA NOT AVAILABLE FOR BO-105.

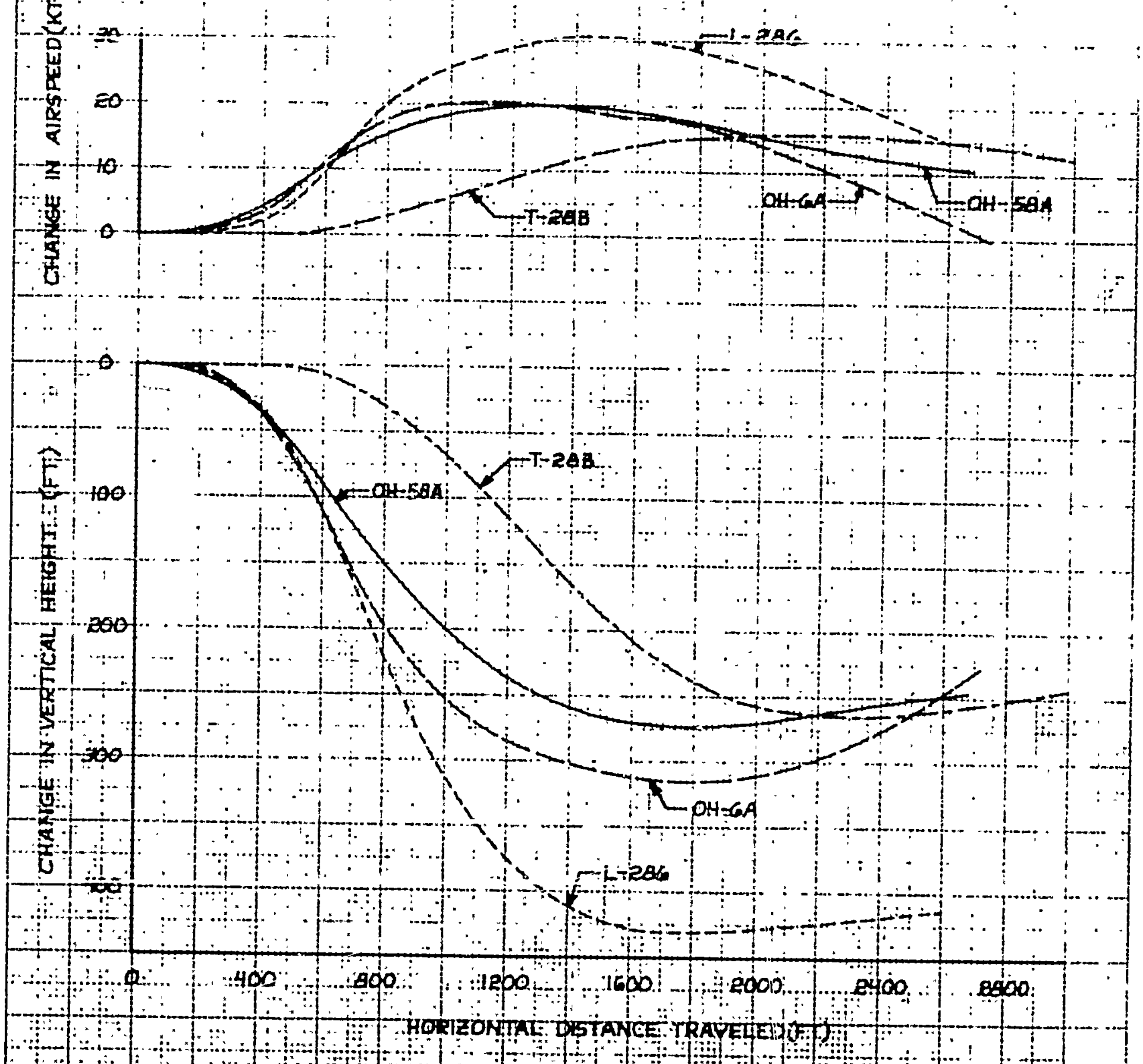
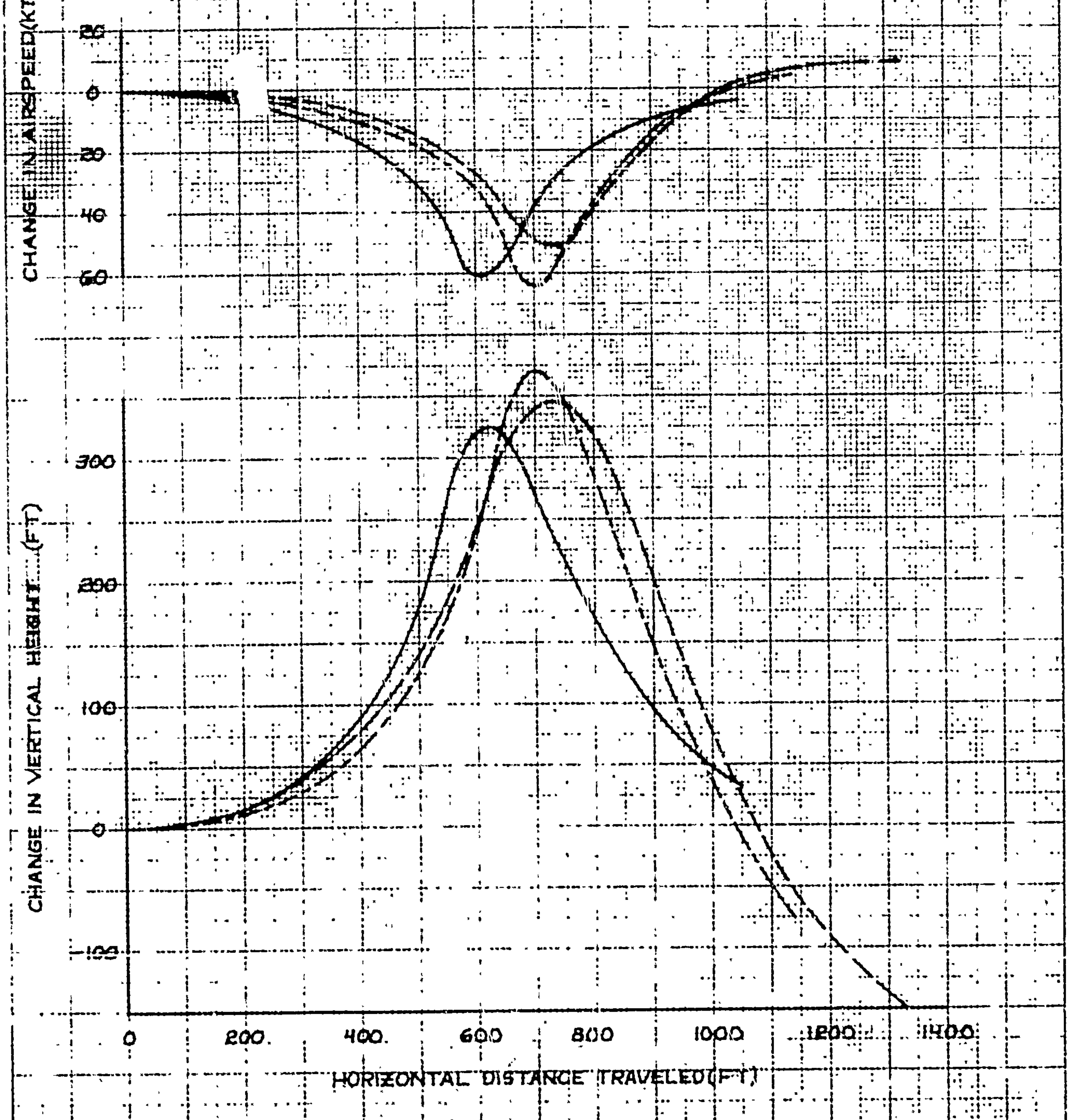


FIGURE 14 OH-6A TECHNIQUE COMPARISON IN PULL-UP TO PUSHOVER

Line	Technique	Trim Calibrated Airspeed (KT)	Pressure Altitude (FT)	OAT (°C)	Min. Load Fact. (g)	Max. Load Fact. (g)
————	LONGITUDINAL CONTROL ONLY	94	4610	5.9	0.2	1.75
— — —	LONGITUDINAL COLLECTIVE CONTROL (LARGER INPUT)	94	4310	6.5	0.2	1.75
– – – –	LONGITUDINAL COLLECTIVE CONTROL (SMALLER INPUT)	94	4630	5.8	0.2	1.75



APPENDIX G. WEIGHT AND BALANCE

AIRCRAFT	BASIC WEIGHT[1]	LONGITUDINAL CENTER OF GRAVITY
OH-6A	1192 pounds	106.1 inches
OH-58A	1884 pounds	115.6 inches
BO-105	2705 pounds	132.5 inches
L-286	3125 pounds	157.5 inches

[1]Includes instrumentation, unusable fuel, and oil.

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US ARMY AVIATION SYSTEMS COMMAND
ATTN: AMSAV-EF
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13. ABSTRACT

The test objective of the

A maneuvering flying qualities evaluation ~~was performed~~ on the OH-6A, OH-58A, BO-105, and L-286 helicopters, by the US Army Aviation Systems Test Activity, Edwards Air Force Base, California, between 9 August and 24 November 1971. The test objectives was to evaluate the suitability of three types of rotor systems (articulated, teetering, and hingeless) to perform the proposed utility tactical transport aircraft system (UTTAS) pull-up and pushover maneuvers. The testing consisted of 41 flights for a total of 22 productive hours. The results obtained during this test established a data base to assess the applicability of the presently stated UTTAS maneuverability requirements. It was determined that present-day rotary-wing aircraft can be tested against the prescribed maneuver criteria with meaningful results. Three flying quality deficiencies were noted, correction of which is mandatory if procurement or envelope expansion is anticipated. The deficiencies were: loss of lateral control power below 0.5g in the OH-58A, mast bumping or spike knock in the OH-58A at load factors below 0.5, and excessive vibration during landing transition on the BO-105. There were two shortcomings, correction of which is desirable if procurement or envelope expansion is anticipated. The shortcomings were excessive cross-coupling during maneuvering tasks, apparent in all four test helicopters, and inadequate control margin at load factors less than 0.5 in the OH-58A.

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