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SPECIAL STUDY
OF
AUTOROTATIONAL PROCEDURES

FINAL REPORT

KENNETH R. FERRELL
CHIEF, ADVANCED METHODOLOGY
AND ANALYSIS DIVISION

JOHN J. SHAPLEY, JR.
PROJECT PILOT

APRIL 1968

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

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ABSTRACT

A limited investigation was conducted to evaluate the effects of maneuvering flight during autorotation and the flight characteristics during power recovery from autorotation. The investigation was conducted at Edwards Air Force Base, California at the request of the Directorate of Rotary Wing Training, US Army Aviation School, Fort Rucker, Alabama. The testing consisted of 6.5 flight hours and was conducted from 11 December 1967 through 24 January 1968. The tests indicated that the existing method of presenting autorotation rate of descent information in the operator's manual is not representative of the operational requirement. A maximum glide technique which utilizes low rotor speeds can be misleading, especially at high gross weights, in that rate of descent may increase, glide distance may decrease, and rotor energy will be less than optimum. The rapid increase in descent angle and rate of descent at speeds below 50 KIAS can be very deceptive. Altitude above the ground is probably the most important compensating factor during practice autorotations. Power recovery techniques are not particularly demanding at light weights but become extremely important at the limit gross weights. A quantitative investigation of the autorotational procedures, including landings, is to be accomplished during a scheduled near term project.

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INTRODUCTION

BACKGROUND

1. Preliminary discussions with the Department of Rotary Wing Training, US Army Aviation School, Fort Rucker, Alabama, indicated a necessity for investigating the performance and flight characteristics of the UH-1 aircraft during autorotational descent, maneuvering, and landing. Direction to proceed with this effort is contained in reference 1, appendix I. The training procedures and techniques used at the school were observed by the US Army Aviation Test Activity (USAAVNTA) personnel prior to starting the test program. Procedures as used at the aviation school and other pertinent information were also provided to the test team.

STUDY OBJECTIVES

2. The study objectives were of both an immediate and a long range nature. The immediate objective was to obtain autorotative flight information which would provide an insight relative to possible contributing factors and/or solutions at the earliest date. In addition, it was desired to determine the advisability and nature of any future in these areas. The long range objective was to gather data that would define the requirements for specific programs or the necessary modifications of current testing and training programs.

DESCRIPTION

3. The flight investigation was conducted with a standard UH-1B aircraft, which has a single main lifting rotor and an antitorque tail rotor configuration. Power is supplied by a Lycoming T-53-11 free turbine engine. The normal operating gross weight of the helicopter varies from 6600 pounds to a maximum of weight of 8500 pounds. A skid type landing gear is provided. The dual control system consists of cyclic and collective sticks and directional control pedals. The control system is fully boosted and irreversible. A detailed description of the aircraft and associated systems can be obtained from reference 2, appendix I.

SCOPE OF STUDY

4. The scope of the program was limited to those tests that could be accomplished without installing test instrumentation. The investigation was limited to a density altitude of 5000 feet and a mid center of gravity location. The test gross weights were 6600

and 8500 pounds. In the interest of timeliness and safety, the tests and maneuvers were accomplished at approximately 2000 feet above ground level. The conditions selected for the evaluation were those which would yield data pertinent to the items specified in reference 1, appendix I.

METHODS OF TEST

5. The methods utilized during these tests were essentially of a static type. The steady state descent test was accomplished by stabilizing at the desired airspeed, rotor speed, and attitude prior to recording the data. Bank angle and sideslip angle were determined from the standard cockpit instruments. Altitude and time data were obtained from a standard altimeter and a manually operated stop watch.

CHRONOLOGY

6. The chronology of events pertinent to the flight test evaluation is:

Test directive received	8	December	1967
Test aircraft assigned	11	December	1967
Tests started	11	December	1967
All tests completed	24	January	1968
Draft report submitted	4	March	1968
Final report forwarded		April	1968

RESULTS AND DISCUSSION

GENERAL

7. Individual items discussed in this report are generally well known; however, it is interesting to note as to which are the most important for a given situation and what the cummulative effects may be. A limited study involving an actual flight test was conducted to evaluate the complex variables of the autorotative descent, approach and landing. The effects of maneuvering flight during the autorotation and the flight characteristics during power recovery from an autorotation were also evaluated. The tests indicated that the existing method of presenting the autorotation rate of descent information in the operator's manual is not representative of the operational requirements. A maximum glide technique that utilizes low rotor rpm, especially at high gross weights can be misleading in that the rate of descent may increase, glide distance may decrease and rotor energy will be less than that required to control the rate of descent at termination of this autorotation. The study indicated that height above the ground is probably the most important factor to be considered during practice autorotations. Power recovery techniques were determined to become extremely important at the high gross weights. A "key position" to be established at a particular point during the autorotational approach should serve to make the pilot's tasks from that point to touchdown less complicated. The results of the study will be used in the formulation of a more comprehensive program which is to be accomplished in the near future.

GENERAL CONSIDERATIONS

8. A power-off approach to a landing area generally is considered an emergency situation. The helicopter is in a controllable condition and, within the limits of the external environment, pilot capabilities and aircraft capabilities, a safe landing can be accomplished. It should be recognized that the pilot is in an emergency situation and cannot possibly be provided data from all influencing parameters. The pilot may not be able to assimilate and respond to all the cockpit information that is being provided. Thus it would appear that a better selection of information for the pilot, rather than more information, would provide greater benefits.

9. Prior to discussing the human factors it is useful to examine the physical relationships of the aircraft and its environment.

At any given time the helicopter is in an energy state which is the sum of all the potential and kinetic energies. In unpowered flight, this may be described in terms of the helicopter gross weight, airspeed, height above the ground, and the rotational energy of the dynamic components. The resultant energy at touchdown must be no greater than the absorbing capability of the landing gear. The energy relationships during the descent are controlled by utilizing the lifting capability of the rotor to arrest the rate of descent. There are energy level changes that are beyond the maximum performance of the rotor over a finite time and from these conditions a safe landing is not possible. The air density, wind speed and relative wind direction are increasingly significant factors as the ground is approached. Wind shear and direction changes near the ground may suddenly reduce an apparent safe condition to an unsafe condition. The terrain on which the landing is to be made is a factor and must be compatible with the forward speed and type of landing gear. During power recoveries engine and rotor response characteristics are added variables. The recovery must be started at a sufficient height to allow the engine to provide torque and for the rotor to develop sufficient lift to control the rate of descent.

10. The descent, approach, and landing can be considered as separate entities. The descent is essentially a steady state condition with small airspeed changes and gentle turns. There is usually sufficient altitude to compensate for any maneuvering effects. During the approach, there are often requirements for rather abrupt maneuvers. These are usually turns to align the aircraft with the most favorable terrain and speed changes to attain the desired airspeed. The landing is a rapidly changing dynamic condition from initiation of flare to touchdown. Prior to the flare, the aircraft must be within the safe energy envelope, which is rotor speed, rate of descent, airspeed, and height above the ground.

PILOT CONSIDERATIONS

11. The pilot considerations are considerably different for the descent, approach, and landing phases. During the steady state descent the pilot is most concerned with maintaining minimum rate of descent or best glide conditions and general maneuvering to the landing area. The height above the ground will determine the nature of the maneuvering and the division of the pilot's attention to internal and external information. As the approach is made the pilot must make several critical decisions in a short period of time.

The pilot's attention is directed more to the external environment as the ground is approached and greater selectivity must be used relative to monitoring cockpit instruments. The landing is the most critical portion with many pilot tasks and very little time available in which to accomplish them. It is here that the penalty is exacted for any adverse conditions or actions that have transpired during the descent or approach phase.

STEADY STATE AUTOROTATION PERFORMANCE

12. The rate of descent performance of certain UH-1 helicopters has been established and documented in references 2 through 8, appendix I. The parameters tested were airspeed, rotor speed, gross weight, and altitude. The rate of descent variation with airspeed obtained during these tests is shown in figure 1, appendix II. The curve shape is classical and shows the minimum rate of descent to occur at an indicated airspeed of approximately 45 knots. It should be noted that both the indicated airspeed and rate of descent systems are strongly influenced by response and lag factors and the values are suspect at low speed-high rate of descent conditions. The result is that the pilot may unknowingly be in a hazardous situation when the approach and landing phase is reached. The airspeed position error during autorotation is presented in reference 2, appendix I. This information is presented in the operator's manual. Rate of descent is relatively insensitive to airspeed when operating within 5 knots of the speed for minimum rate of descent. However, as the high and low airspeed extremes are approached, the variation becomes increasingly greater. The airspeed for maximum glide distance is approximately 15 to 20 knots above that for minimum rate of descent. The rate of descent at this condition is approximately 200 feet per minute greater than minimum. The pilot should realize that caution must be exercised when using airspeed to "stretch" the glide to reach the landing area. Rate of descent increases rapidly as the helicopter is slowed to a speed below that for minimum rate of descent. This may become a factor when the pilot is concerned with "overshooting" the intended landing area and has his attention focused on the external sight picture which became increasingly less accurate as airspeed was further decreased. Most UH-1 standard airspeed systems are unreliable at less than 30 KIAS.

13. The rate of descent is decreased and glide distance is greater at lower rotor speeds. This characteristic is illustrated in figure 1, appendix II. Maintaining a low rotor speed near the ground or to "stretch" the glide may introduce some undesirable

conditions. There is a minimum effective rotor speed below which further benefits cannot be achieved and a performance degradation will result. Care must be used to prevent this particularly when near the ground and the pilots attention is directed outside the cockpit. An additional factor is that the lower rotor speeds provide less rotor energy with which to cushion the landing. This can best be demonstrated by performing autorotation landings from a hover at various rotor speeds.

14. Extensive tests have established that the steady state rate of descent does not change to any extent with altitude variations for a given rotor speed. During the approach and landing phase at high altitude, the collective control requirement will be greater and the blade angle of attack will be higher. Flaring the aircraft and applying additional collective will further increase the blade angle of attack. An accelerated stall may develop with large losses in lift. High forward speed, abrupt flares, low rotor speeds, and high rates of descent are all factors which aggravate the altitude influences during landing.

GROSS WEIGHT EFFECTS

15. Rate of descent may increase somewhat with added weight, particularly at high density altitudes, and low rotor speeds where high blade angles are required. This effect is illustrated in figure 1, appendix II. For a given airspeed and rate of descent the energy level that must be arrested is higher and the allowable landing gear limit touchdown speed is lower at the higher weights. Because of the higher energy level, the cyclic flare will not be as effective in reducing forward speed as at lighter weight and more collective pitch will be necessary to stop the rate of descent.

MANEUVERING AUTOROTATION PERFORMANCE

16. The influence of bank angle is shown in figures 2 through 4, appendix II. An indicated 30-degree bank increased the rate of descent approximately 200 fpm with the magnitude of the increase appearing to be independent of airspeed or gross weight. It is interesting to note the rapid increase in descent angle that occurs as airspeed becomes less than 50 KIAS. Bank angle will result in higher rates of descent for any airspeed. This is of particular interest when the pilot's attention is directed outside of the cockpit and he may not be closely monitoring airspeed. Although not quantitatively documented, pitch attitude would seem to be a poor indicator of the airspeed since the attitude change is relatively small from 0 to 50 KIAS during autorotation.

17. Figures 5 and 6, appendix II, show that rate of descent also increases with angle of sideslip. The increase was approximately 140 fpm for each "ball width" out of trim at the airspeed for minimum rate of descent. There was no definable difference with gross weight. The increase in rate of descent with sideslip angle characteristically became greater as airspeed became higher. Rates of descent in excess of 2500 feet per minute can be achieved during a 30-degree banked turn, left sideslip at the minimum rate of descent airspeed (fig 3, app II).

18. During an autorotational descent to a landing, the significant physical parameters are to be airspeed, rotor speed, gross weight, density altitude, bank angle, and sideslip angle. In addition there are a multitude of pilot factors, the details of which are beyond the scope of this report. The individual or combined effects of these variables are not particularly adverse at high heights above the ground. The margin that is available under ideal conditions and with optimum technique will determine what latitude can be tolerated in the flight variables. The repeatability with which a given maneuver can be accomplished will also be influenced by the margin. To illustrate, consider an arbitrary set of circumstances. Assume a power loss, a 180-degree autorotational turn, and a landing at a given site. The aircraft configuration is fixed, the technique was near optimum, and there was a reasonable margin. Now suppose that at some later time the same maneuver is attempted. The pilot's recognition of power failure may be different, the turn radius may not be the same, the density altitude and gross weight have not remained constant. As a result, the altitude loss, airspeed, rotor speed, and rate of descent relationships will be changed accordingly at the end of the turn. The pilot must now make an autorotation landing from a different flight condition than existed on the previous maneuver. The conditions may be such that the requirements are beyond the capabilities of the aircraft and/or pilot. In view of these considerations, it appears that altitude above the ground is the most important single compensating factor. Since conditions are continually changing and the pilot cannot be assumed to be consistently perfect, the altitude at which a given maneuver is started should provide a margin that can reasonably be expected to compensate for the effects previously discussed. The necessary altitude margin will depend to a large extent upon the pilot skill and experience level as well as the aircraft performance and terrain.

19. It might be advisable to consider a "key position" during practice autorotational landings such as 200 feet altitude, 55

KIAS at 320 rotor rpm. At that "key position" the helicopter should be in a level attitude and all maneuvering completed so that the pilot can devote full attention to the landing portion of the autorotation.

POWER RECOVERY

20. A limited amount of observed quantitative power recovery data was obtained during this evaluation. The autorotation factors previously discussed show that the height required for a power recovery can vary significantly with the events prior to initiating the recovery. The power recovery capability is essentially determined by ambient conditions, rotor characteristics, engine characteristics, and pilot technique. Applying power will accelerate the engine and then accelerate the rotor unless the demand is too great. At a constant or decreasing airspeed, the rate of descent must be arrested by:

a. Engine power over a finite time period.

b. Rotor energy through rpm bleed.

c. Kinetic energy through cyclic flare.

21. Considering each of the above:

a. When operating on the "back side" of the autorotation curve, the rate of descent is high. At the same conditions, engine power required for level flight may be high. Only the engine power in excess of that required for level flight is available to arrest the descent. This excess power available to arrest the rate of descent may be very small or negative when above the OGE hover ceiling capability. For this situation settling with power may occur and the rate of descent cannot be entirely arrested with engine power alone over <u>any</u> time period.

b. If the rotor energy is dissipated early, not only is the effect largely lost at a height where the resulting rotor thrust is not augmented by ground effect, but the rotor speed is reduced so that the rotor is no longer aerodynamically efficient and the engine power available is reduced.

c. At low airspeed, a cyclic flare becomes virtually useless. The engine response time will be influenced by ambient air temperature, pressure altitude, and individual engine characteristics. The thrust capability generated by the power application will depend upon the rotor speed and collective pitch techniques. A brief investigation was conducted during flights 1 and 2 (tables 1 and 2). The following observed data were recorded during power recovery from autorotation:

Table 1. Engine Acceleration and Altitude Loss.

Condition	Method	Time to [illegible] (seconds)	[illegible]
[illegible] kt, 320 rotor rpm	Normal ([illegible] throttle slowly followed by gradual increase of collective)	[illegible]	[illegible]
[illegible] kt, 320 rotor rpm	Increased collective, dropped rpm to 300, added throttle.	5.0	[illegible]
[illegible] kt, 300 rotor rpm	Rapid collective increase followed by throttle increase.	5.8	80
60 kt, 300 rotor rpm	Rapid collective increase followed by *throttle increase.	4.0	Less than 100

*During the power recovery a gradual cyclic flare was initiated to control the rate of descent through kinetic energy.

Table 2. Engine Acceleration and Altitude Loss.

[illegible]	Method	(AVG N_2 (seconds)	Indicated alt. loss(ft)
[illegible]	Normal (Add throttle slowly followed by gradual increase of collective).	4.6	160
[illegible]	Collective application followed by throttle application.	3.3	150
[illegible]	Simultaneous throttle and collective application.	5.0	100 - 120
[illegible]	[illegible] collective and [illegible] application.	[illegible]	[illegible]
[illegible]	[illegible] application [illegible] by throttle [illegible]	[illegible]	[illegible]

*During the power recovery a gradual cyclic flare was initiated to control the rate of descent through kinetic energy.

**During power recovery condition a value of 8.2 seconds was recorded. The N_2 rpm decreased to approximately 5400 and heavy rotor blade stall was encountered at which time the collective was lowered to alleviate the blade stall condition. This also allowed the rotor system to be unloaded sufficiently to enable the power recovery to be effective. If the collective had not been lowered, it is doubtful if the N_2 speed would increase regardless of the time available.

22. It would appear from the observed data that a practice forced landing with a power recovery from a low altitude under conditions similar to last condition in table 2, would result in an accident. It is not beyond the realm of possibility that the chances for a successful power off landing might be better than a power recovery under such conditions, providing an adequate landing area is available. As previously mentioned, these tests were conducted at safe heights above the ground. Division of pilot attention near the ground would make the landing task much more difficult.

CONCLUSIONS

23. The following conclusions were reached upon completion of the study.

a. In addition to the rate of descent performance presented in engineering flight test reports and operator's manuals, the effects of maneuvering flight should be defined and presented (para 12).

b. Rate of descent increases with bank angle and sideslip angle (para 16 and 17).

c. Operators should use caution when utilizing maximum glide techniques with low rotor rpm at low heights above the ground, especially at high gross weights (para 13).

d. Glide angle and rate of descent increases rapidly at airspeeds below 50 KIAS (para 12 and 16).

e. Height above the ground is probably the most important safety factor during practice autorotations (para 18).

f. Power recovery techniques are not particularly demanding at the lower gross weights and the altitude required for a power recovery was 100 feet or less under the conditions tested (para 21).

g. Power recovery techniques are of extreme importance at high gross weights. Under certain conditions a power recovery is doubtful if not impossible (para 21).

h. Consider a "key position" during practice autorotational landings, such as 200 feet altitude, 55 KIAS at 320 rpm (para 19).

i. The complexity of the approach, landing, and power recovery phases was beyond the magnitude of this study (para 22).

RECOMMENDATIONS

24. Maneuvering rate of descent information should be gathered during current engineering flight test and be included in the operator's manual (para 12).

25. Operator should exercise caution when using low rotor rpm techniques during the autorotational landings phase, especially under high gross weight operating conditions (para 13).

26. Autorotation descent angle and rates versus airspeed information should be included in the operator's manual (para 16).

27. Consideration should be given to establishing a "key position" during practice autorotations. This "key position" should be defined in terms of steady state altitude airspeed and rpm (para 19).

28. The critical nature of the power recovery techniques at high gross weight conditions should be demonstrated at the US Army Aviation School (para 21).

29. Quantitative definition of the approach, landing, and power recovery phases should be accomplished (para 21 and 22).

APPENDIX I. REFERENCES

1. Test Directive, Letter, AMSAV-ER, "Request for Special Study, Autorotational Procedures," 13 December 1967.

2. Operator's Manual, TM 5-1520-211-10, "Army Models UH-1A and UH-1B Helicopters," June 1967.

3. Final Report, USAAVNTA, "Engineering Flight Test of the UH-1B Helicopter Equipped with the Model 540 Rotor System, Phase D," USATECOM Project No. 4-4-0108-03, December 1966.

4. Final Report, AFFTC, AFFTC-TR-59-33, "ARDC YH-40 Performance Evaluation," January 1960.

5. Technical Report No. 65-5, AFFTC, "UH-1F Category II Performance," July 1965.

6. Addendum 1 to AFFTC-54-59-33, "ARDC HU-1 (H-40) Performance Evaluation," September 1960.

7. Final Report, USAAVNTA, "Engineering Evaluation of UH-1B Helicopter Equipped with Model 540 Rotor System, Phase B," USATECOM Project No. 4-4-0108-03, June 1966.

8. Final Report, AFFTC-TR-61-39, "YHU-1B Category I Performance, Stability and Control Tests," July 1961.

APPENDIX II. TEST DATA

FIGURE NO. 1
DESCENT PERFORMANCE VARIATION WITH AIRSPEED
UH-1B S/N 03546

SYM	GROSS WT-LB	ROTOR SPEED-RPM
○	6068	320
□	8605	320
△	8600	300

AVG. DENSITY ALT = 5000 FT
SIDESLIP ANGLE = 0
BANK ANGLE = 0

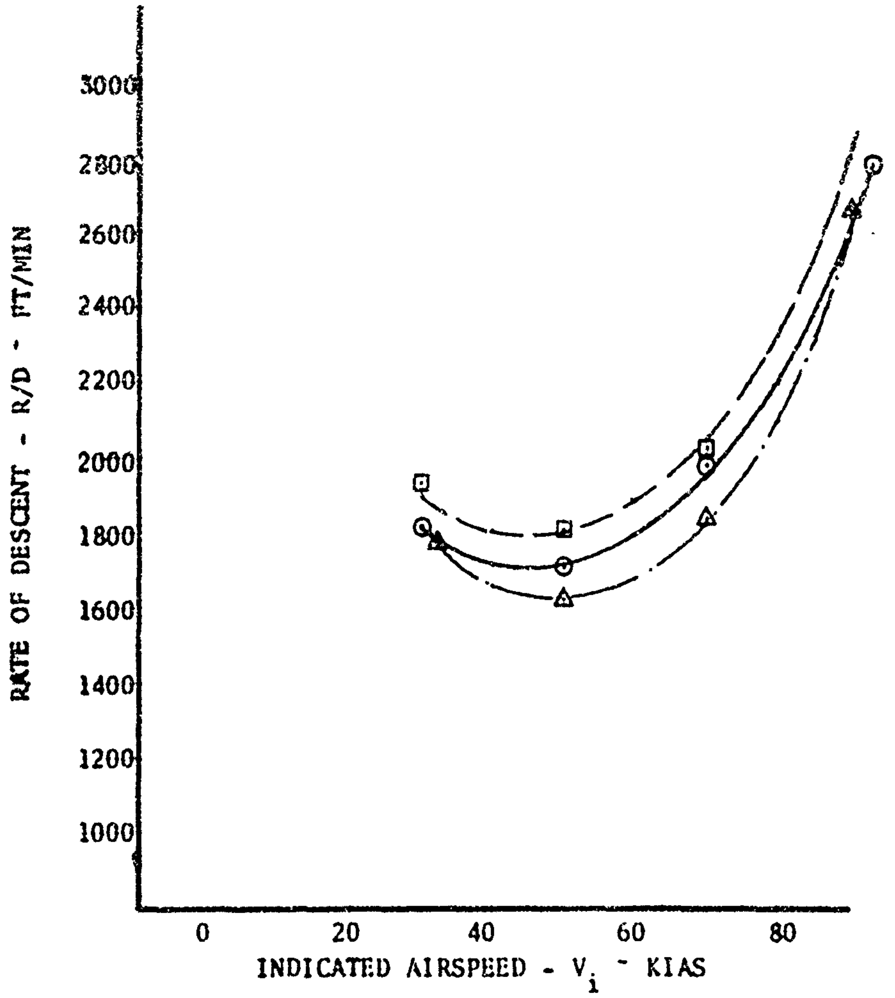


FIGURE No. 2
DESCENT PERFORMANCE VARIATION WITH AIRSPEED
UH-1B S/N 03546

SYM	BANK ANGLE -DEGREES
○	0
□	15 RT
△	30 RT

GROSS WT = 6068 LB.
ROTOR SPEED = 324 RPM
SIDESLIP ANGLE = 0 DEG.
AVG DENSITY ALT = 5000 FT.

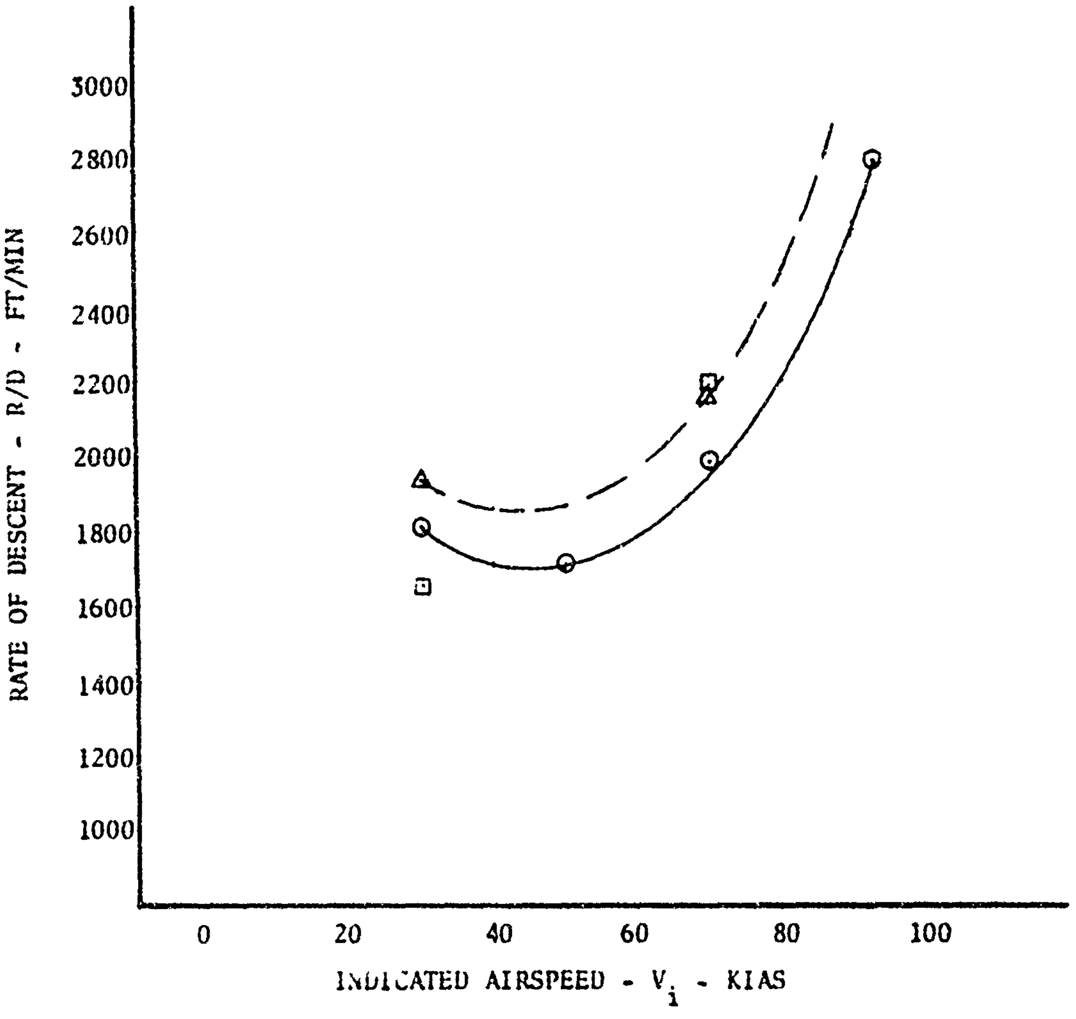


FIGURE NO. 4
DESCENT ANGLE VARIATION WITH AIRSPEED
UH-1B S/N 03546

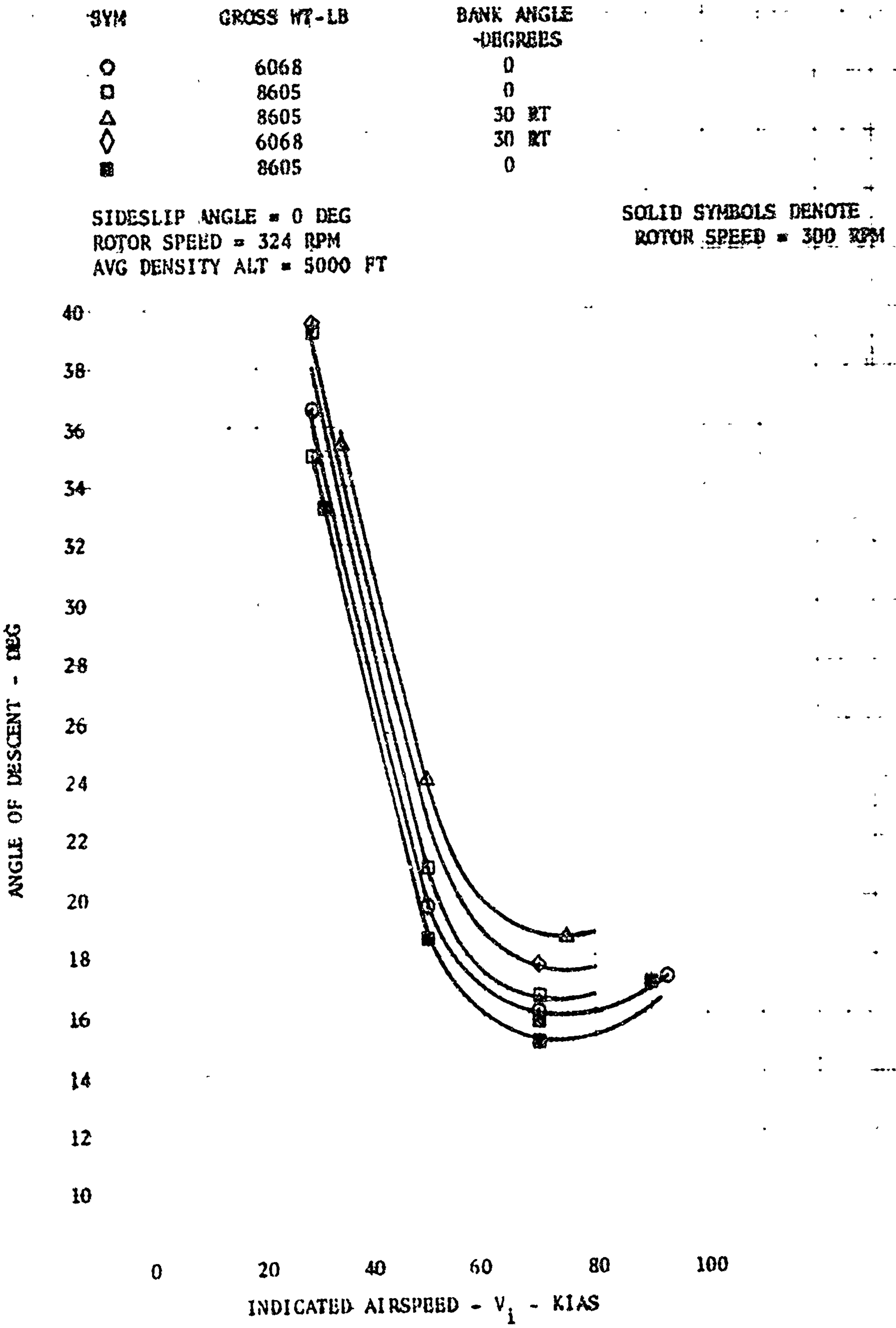


FIGURE NO. 3
RATE OF DESCENT VARIATION WITH AIRSPEED
UH-1B S/N 03546

SYM	BANK ANGLE - DEGREES	SIDESLIP ANGLE - DEGREES
○	0	0
□	30 RT	0
△	30 RT	One Ball Left

AVG DENSITY ALT = 5000 FT
ROTOR SPEED = 324 RPM
GROSS WT = 8605 LB

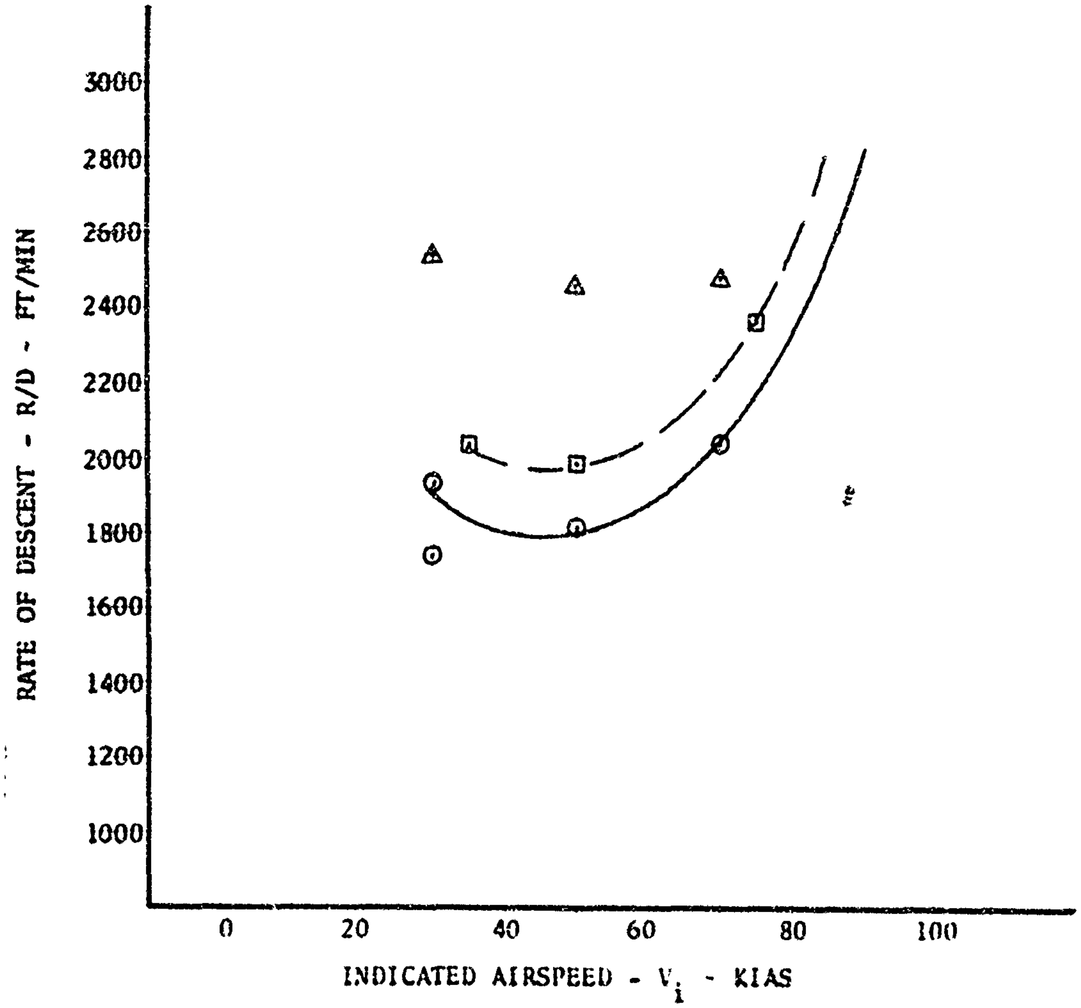


FIGURE NO. 5
RATE OF DESCENT VARIATION WITH AIRSPEED
UH-1B S/N 03546

SYM	SIDESLIP ANGLE - DEGREES
○	0
□	1 BALL LT
△	1 1/2 BALL LT

AVG DENSITY ALT = 5000 FT
BANK ANGLE = 0 DEG
ROTOR SPEED = 324 RPM
GROSS WT = 6068 LB

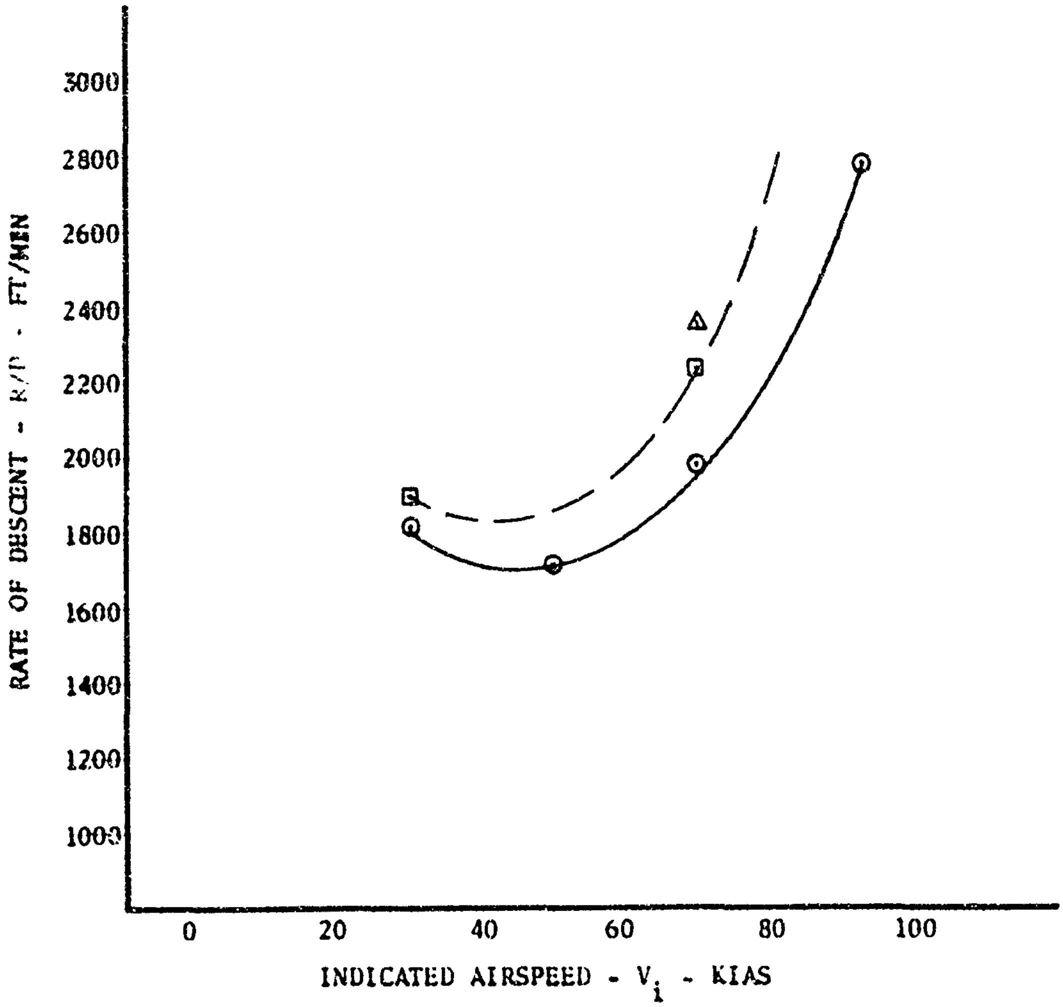
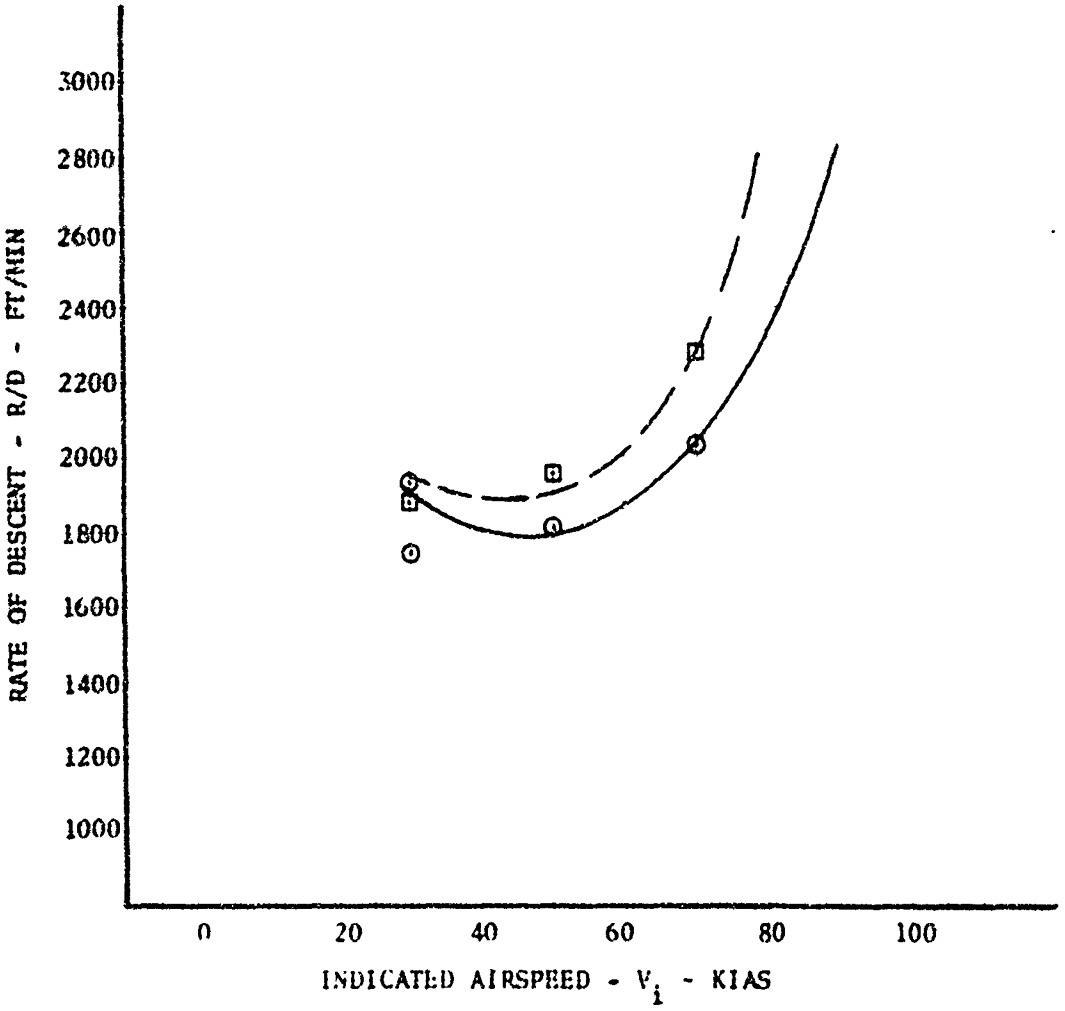


FIGURE NO. 6
RATE OF DESCENT VARIATION WITH AIRSPEED
UH-1B S/N 63546

SYM	SIDESLIP ANGLE - DEGREES
○	0
□	1 BALL LT

AVG DENSITY ALT = 5000 FT
GROSS WT = 8605 LB
BANK ANGLE = 0 DEG
ROTOR SPEED = 324 RPM



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13 ABSTRACT

A limited investigation was conducted to evaluate the effects of maneuvering flight during autorotation and the flight characteristics during power recovery from autorotation. The investigation was conducted at Edwards Air Force Base, California at the request of the Directorate of Rotary Wing Training, US Army Aviation School, Fort Rucker, Alabama. The testing consisted of 6.5 flight hours and was conducted from 11 December 1967 through 24 January 1968. The tests indicated that the existing method of presenting autorotation rate of descent information in the operator's manual is not representative of the operational requirement. A maximum glide technique which utilizes low rotor speeds can be misleading, especially at high gross weights, in that rate of descent may increase, glide distance may decrease, and rotor energy will be less than optimum. The rapid increase in descent angle and rate of descent at speeds below 50 KIAS can be very deceptive. Altitude above the ground is probably the most important compensating factor during practice autorotations. Power recovery techniques are not particularly demanding at light weights but become extremely important at the limit gross weights. A quantitative investigation of the autorotational procedures, including landings, is to be accomplished during a scheduled near term project.

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