NASA TECHNICAL NOTE

NASA TN D-5270

C. 1

NASA TN D-5270

A FLIGHT INVESTIGATION OF A LIGHTWEIGHT HELICOPTER TO STUDY THE FEASIBILITY OF FIXED-COLLECTIVE-PITCH AUTOROTATIONS

by Robert J. Pegg

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1969

A FLIGHT INVESTIGATION OF A LIGHTWEIGHT HELICOPTER TO STUDY THE FEASIBILITY OF FIXED-COLLECTIVE-PITCH AUTOROTATIONS

By Robert J. Pegg

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

A FLIGHT INVESTIGATION OF A LIGHTWEIGHT HELICOPTER TO STUDY THE FEASIBILITY OF FIXED-COLLECTIVE-PITCH AUTOROTATIONS

By Robert J. Pegg
Langley Research Center

SUMMARY

A flight investigation of a lightweight teetering-rotor helicopter was conducted to explore the limitations encountered in power-off flight with the collective pitch stick held in the trim level-flight position. The results indicate that with the collective pitch stick fixed in the trim level-flight position, autorotation is possible under selected conditions with attendant gains in helicopter performance. Aircraft vibrations limited successful use of this technique to airspeeds between 25 and 80 knots.

INTRODUCTION

The autorotation maneuver is generally considered to be an emergency flight maneuver for helicopters. Student pilots learning to fly helicopters are, therefore, instructed to be constantly aware of rotor speed and to reduce collective pitch immediately upon engine failure. It would appear, however, that some performance benefits could be obtained if the pilots were aware of the power-off capabilities of a particular helicopter and were trained to take advantage of these characteristics in an emergency situation. For example, theory indicates that additional time and gliding range can be obtained from an autorotating helicopter by holding the collective pitch stick in the level-flight position. Little documented evidence of this procedure is found in the literature; for example, reference 1 appears to contain the only reported instance of such trials. The purpose of this investigation was to obtain further information on the increased power-off performance benefits and limitations associated with the application of this flight technique.

EQUIPMENT AND PROCEDURES

Test Helicopter

The test helicopter was a turbine-powered vehicle that is representative of the current lightweight observation-class helicopter. Its physical characteristics are listed in table I, and a photograph of the aircraft is shown as figure 1. The helicopter has a two-bladed teetering main rotor system with a stabilizer bar. The normal operating weight during these tests was approximately 2500 pounds (11 121 newtons), which corresponds to a rotor-blade mean lift coefficient of 0.37 at sea level and 100-percent rotor speed. The helicopter is powered by a 274-shaft-horsepower (204.4-kW) free-turbine engine. Because of the engine-fuel-governor characteristics, the engine was provided with a pilot-actuated valve that bypassed the normal engine governor and quickly reduced the gas-generator speed to the idle setting. This valve provided the capability of rapidly reducing the engine torque during the test maneuver. Cockpit controls included the conventional cyclic pitch stick, rudder pedals, and collective pitch stick, all of which were powered by an irreversible hydraulic boost system. Pilot-adjustable friction devices provided the only control-system feel forces. A low-authority rate-damping augmentation system is installed in the helicopter but was not used during this investigation.

Instrumentation

In general, the instrumentation consisted of standard NASA sensing and recording equipment. Recorded parameters that were pertinent to this investigation were engine torque, airspeed, control positions, normal acceleration, rotor speed, and pressure altitude. The airborne instrumentation is shown in figure 2. The rotor and engine speeds were displayed to the pilot in terms of percent of design operating speeds. For this investigation, 100-percent design operating speed was used as the speed at which the maneuvers were initiated.

Description of Test Maneuver

The standard prescribed maneuver used by a pilot to enter a practice autorotation is to set up the desired cruise condition and then to lower the collective pitch stick to its minimum position while simultaneously closing the throttle to the idle power setting; throughout the maneuver, the pilot maintains the desired flight path and airspeed with the cyclic pitch stick and rudder pedals for steady-state autorotation. The test maneuver used in this investigation differed from the standard procedure in that the collective pitch stick was not lowered to its minimum position. It was maintained in its original level-flight position. However, at termination of the test maneuver, the collective pitch stick was lowered in order to regain proper rotor speed for landing.

Initially, the pilot entered autorotation at various airspeeds by using the standard procedure and then increased collective pitch to investigate the effects of reduced rotor speed in steady-state autorotation. As the pilot gained confidence, autorotations were performed by reducing engine speed to idle and holding the collective pitch stick fixed in the trim level-flight position. Forward speed was held constant throughout the maneuver. Dynamic effects after rapid power reduction and rapid changes in collective pitch were also sampled in a gradual manner.

All tests were performed at approximately sea-level conditions and were initiated from level flight with the helicopter operating at a moderate mean lift coefficient. At airspeeds above 80 knots and below 25 knots, limiting flight conditions prevented the pilot from attaining steady-state autorotation at reduced rotor speeds.

The results of this investigation cannot be applied in a general way to other helicopters or test conditions. For example, operation at higher rotor-blade mean lift coefficients or lower rotor inertia, operation in turbulent weather conditions, and the effect of unexpected, abrupt, and complete power failure on the initial behavior of the aircraft and pilot could completely change the results.

RESULTS AND DISCUSSION

Effects of Collective-Pitch Setting on Rotor Speed

During steady-state autorotations performed with the collective pitch stick held in the trim level-flight position, the rotor speed attained stabilized values that are shown in figure 3. Below approximately 25 knots and above approximately 80 knots, stabilized rotor speeds necessary to obtain constant rates of descent are below about 65-percent rotor speed and result in unacceptable aircraft vibration. These limiting conditions are reviewed in more detail in a subsequent section of this report.

A typical time history of a fixed-collective-pitch autorotation is shown in figure 4. This figure shows the variation of rotor speed, rate of descent, engine power, normal acceleration, and control positions during an autorotation maneuver with the indicated airspeed held constant at approximately 45 knots. The figure shows that no excessive control motions were required to perform the maneuver from entry to recovery. Realistic entries into the maneuver, however, could not be fully evaluated because of the gradual reduction of engine torque.

Effects of Reduced Rotor Speed on Power-Off Performance

The primary performance advantage noted when the helicopter was autorotated at reduced rotor speeds with the collective pitch stick fixed in the trim level-flight position was a substantial increase in aircraft lift-drag ratio (L/D) over the cruise speed range of 30 to 65 knots as shown in figure 5. The percentage increase in L/D indicated by the measured autorotative performance at the higher collective pitch values corresponds to that predicted by available rotor theory. The increase in aircraft L/D is attributed to the reduced blade profile power required at the low rotor speeds and resulted in lower rates of descent as shown in figure 6 and longer glide ranges as shown by the example in figure 7. The data in figure 7 were obtained at an airspeed of 45 knots. The initial altitude was 2500 feet (762.0 meters). Figure 7 shows that an additional 2300 feet

(701.04 meters) of glide range (an increase of about 35 percent) and approximately 30 seconds additional airborne time can be gained by autorotating at the reduced rotor speed.

Effects of Reduced Rotor Speed on Autorotation Maneuvering

In this investigation, aircraft motions after rapid power reduction were small and easily controlled. The piloting task was no more demanding during the test maneuver than during a standard autorotation. Pilot attention, however, was necessary to reduce the collective pitch in sufficient time to regain proper landing rotor speed. Throughout the test airspeed range, the helicopter required approximately 500 feet (152.4 meters) in which to regain adequate rotor speed (at least 95 percent) for initiating a landing. At all airspeeds, rotor-speed recovery for this aircraft followed approximately the same pattern; 4 seconds were required to attain 80-percent rotor speed and 9 seconds to achieve the additional rotor speed. During this time, the descent rate increased, and the pilot had to be aware of this increase during the flare while landing.

Several additional maneuvers were attempted while the helicopter was autorotating at low rotor speeds. At an airspeed of 60 knots, cyclic-pitch-stick step inputs of approximately 1 inch (2.54 cm) both forward and to the left slowed the rotor speed about 3 percent. Step inputs of approximately 1 inch (2.54 cm) both rearward and to the right increased rotor speed about 3 percent. The inputs were held for about 2 seconds, and no adverse flying qualities were noted during the maneuvers. Large changes in yaw attitude were not attempted during autorotation at these low rotor speeds.

Decelerating and accelerating forward-speed maneuvers (at approximately 1 ft/sec^2 or 0.3 m/sec^2) were made from 92 to 60 knots and from 30 to 60 knots, respectively. There was no difficulty in either decelerating or accelerating the aircraft at low rotor speeds. When decelerating the helicopter from 92 knots, very heavy vibration was encountered below 85-percent rotor speed but disappeared as airspeed was reduced to 60 knots and rotor speed stabilized at 74 percent.

Directional-control effectiveness remained adequate throughout all flight maneuvers during autorotation at low rotor speeds.

Because of the particular engine-governing system used in this helicopter, abrupt torque reductions could not be obtained except by actually shutting off the engine. For safety reasons, this technique was not used; however, complete engine-out autorotation was made from a low hover to check the engine-torque decay characteristics. When the engine was stopped, the torque decreased to zero within 2 seconds. It should be noted that if power failure occurred in level flight, the torque would decrease to zero in approximately the same amount of time. For the test maneuver of this investigation, approximately 10 seconds were required to obtain zero torque. Although entry into autorotation with the collective pitch fixed presented no problem, a detailed assessment of conditions after abrupt power failure could not be made with this test helicopter.

At airspeeds below 25 knots, a light-to-moderate one-per-revolution vertical vibration of increasing severity was noted as the rotor speed was allowed to decrease through a range from 85 to 65 percent. At airspeeds above 80 knots, it was necessary to reduce the collective pitch within 4 seconds after power reductions because heavy vibrations, similar to those encountered in blade stall, were experienced at rotor speeds below about 80 percent. When engine power was reduced while hovering at altitudes of approximately 4000 feet (1219.2 meters), violent rotor motions were experienced at approximately 85-percent rotor speed as behavior similar to that caused by vortex-ring flow conditions or rotor weaving was encountered.

During all these vibrational conditions, smooth flight could be immediately restored by rapidly reducing the collective pitch of the rotor. The rotor speed immediately increased, and standard autorotation at 95- to 100-percent rotor speed could be established. Figure 3 shows these vibrational limitations.

CONCLUSIONS

A flight investigation of a lightweight turbine-powered teetering-rotor helicopter has been conducted to provide information on the operational characteristics during autorotations with the collective pitch stick held in the trim level-flight position. The results cannot be applied in a general way to other helicopters or test conditions. For example, operation at higher rotor-blade mean lift coefficients or lower rotor inertia, operation in turbulent weather conditions, and the effect of unexpected, abrupt, and complete power failure on the initial behavior of the aircraft and pilot could completely change the results. In spite of this lack of generality, the following results are considered to be of special interest:

1. When the engine power was abruptly cut to the idle setting, it was possible to enter safely into autorotation from level flight at moderate airspeeds without moving the collective pitch stick from the level-flight position.

2. Maintaining the collective pitch control in the level-flight position during steady-state autorotation from an initial altitude of 2500 feet (762.0 meters) and at an airspeed of 45 knots resulted in an increase in glide range of approximately 2300 feet (701.04 meters) or an increase of about 35 percent over the glide range for standard autorotation. This increase in glide range represented an increase in descent time of about 30 seconds.

3. The collective pitch stick had to be lowered from the level-flight position before landing to provide sufficient stored energy to flare the aircraft. This procedure required approximately 13 seconds and an altitude of 500 feet (152.4 meters).

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 18, 1969,
721-06-00-06-23.

REFERENCE

1. Harriman, T. J.: Miscellaneous Flight Characteristics of the Model 47 Helicopter. Proceedings of the Fifth Annual Forum, Amer. Helicopter Soc., Inc., May 1949.

TABLE I.- PHYSICAL CHARACTERISTICS OF TEST HELICOPTER

Main rotor:	
Diameter, ft (m)	33.33 (10.16)
Number of blades	2
Blade chord, in. (cm)	13 (33.02)
Airfoil section	Modified NACA 0011 (drooped leading edge)
Twist, deg	-10
Flapping angle, deg	±4.5
Blade taper ratio	1
Blade area, ft^2 (m^2)	36.1 (3.354)
Disk area, ft^2 (m^2)	873 (81.10)
Solidity	0.0414
Tip speed, ft/sec (m/sec)	689 (210.01)
Design operating speed, rpm	394
Tail rotor:	
Diameter, ft (m)	5.16 (1.58)
Number of blades	2
Blade chord, in. (cm)	5.25 (13.34)
Airfoil section	BHC-TAD-S_2
Twist, deg	0
Blade taper ratio	1
Blade area, ft^2 (m^2)	2.26 (0.210)
Disk area, ft^2 (m^2)	21.0 (1.951)
Solidity	0.108
Design operating speed, rpm	2553
General:	
Normal weight, lb (N)	2500 (11 121)
Empty weight, lb (N)	1500 (6672)
Overload gross weight, lb (N)	2900 (12 000)
Overall length, ft (m)	30.08 (9.17)
Landing-gear tread, ft (m)	6.58 (2.01)
Power (Allison T63-A-5), hp (kW)	274 (204.4)
Maximum level-flight airspeed, knots	115
Gear ratios:	
Power turbine to engine output shaft	5.833/1
Engine output shaft to main rotor	15.23/1
Engine output shaft to tail rotor	2.35/1
Inertias:	
Aircraft moment of inertia about longitudinal axis, slug-ft^2 (kg-m^2)	340 (461)
Aircraft moment of inertia about lateral axis, slug-ft^2 (kg-m^2)	1550 (2101)
Aircraft moment of inertia about vertical axis, slug-ft^2 (kg-m^2)	1300 (1763)
Rotor polar moment of inertia, slug-ft^2 (kg-m^2)	510 (691)
Total distance control travels from grip center:	
Lateral control stick, in. (cm) –	
Right	4.24 (10.77)
Left	5.07 (12.88)
Longitudinal control stick, in. (cm) –	
Rearward	5.2 (13.21)
Forward	5.8 (14.73)
Rudder pedals, in. (cm) –	
Right	2.70 (6.86)
Left	2.35 (5.97)
Collective pitch stick, in. (cm) –	
Up	10.7 (27.18)

Figure 1.- Test helicopter. L-68-2633

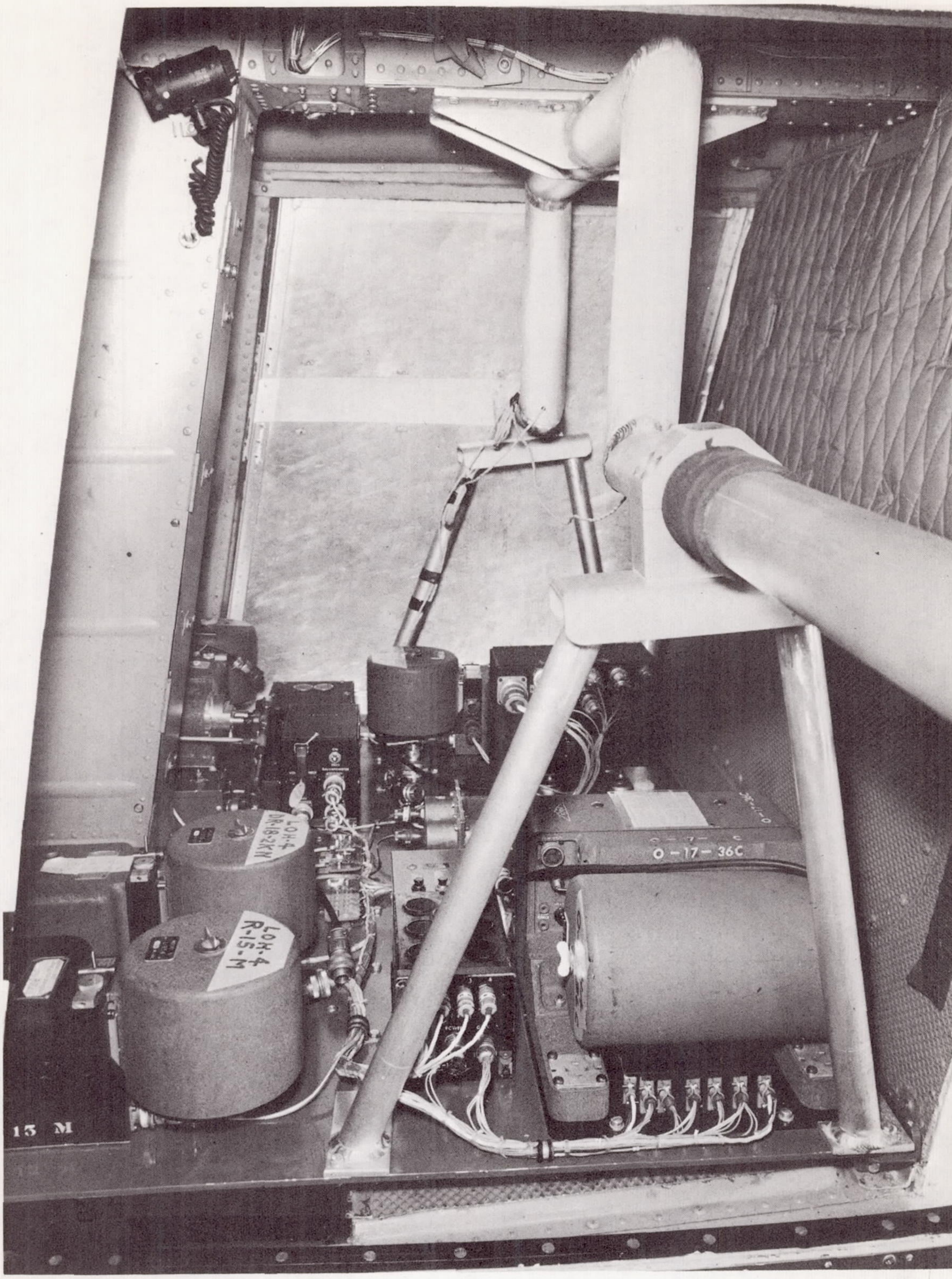

Figure 2.- Airborne instrumentation. L-66-4845

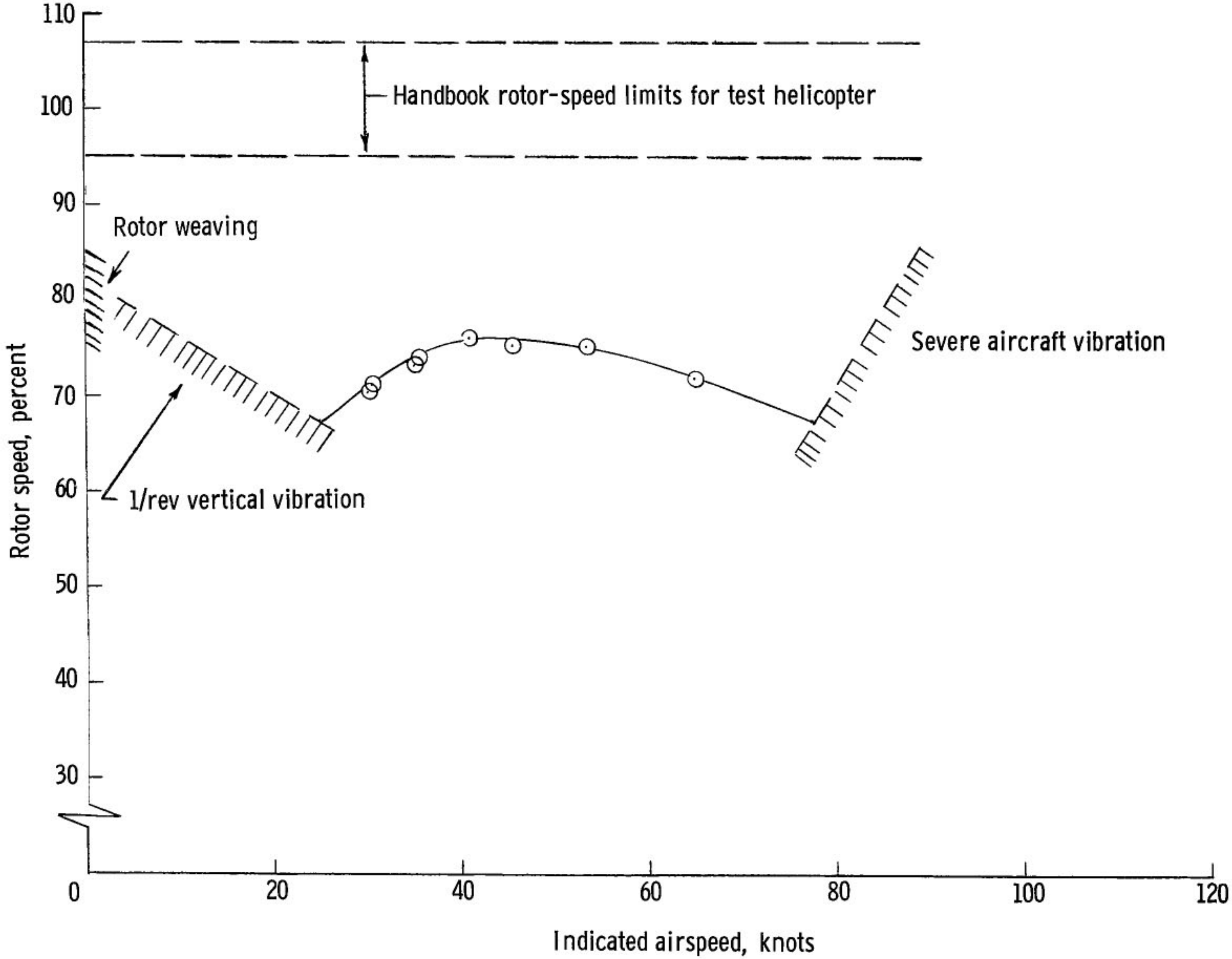

Figure 3.- Stabilized rotor speeds for steady-state autorotation with collective pitch stick in level-flight position.

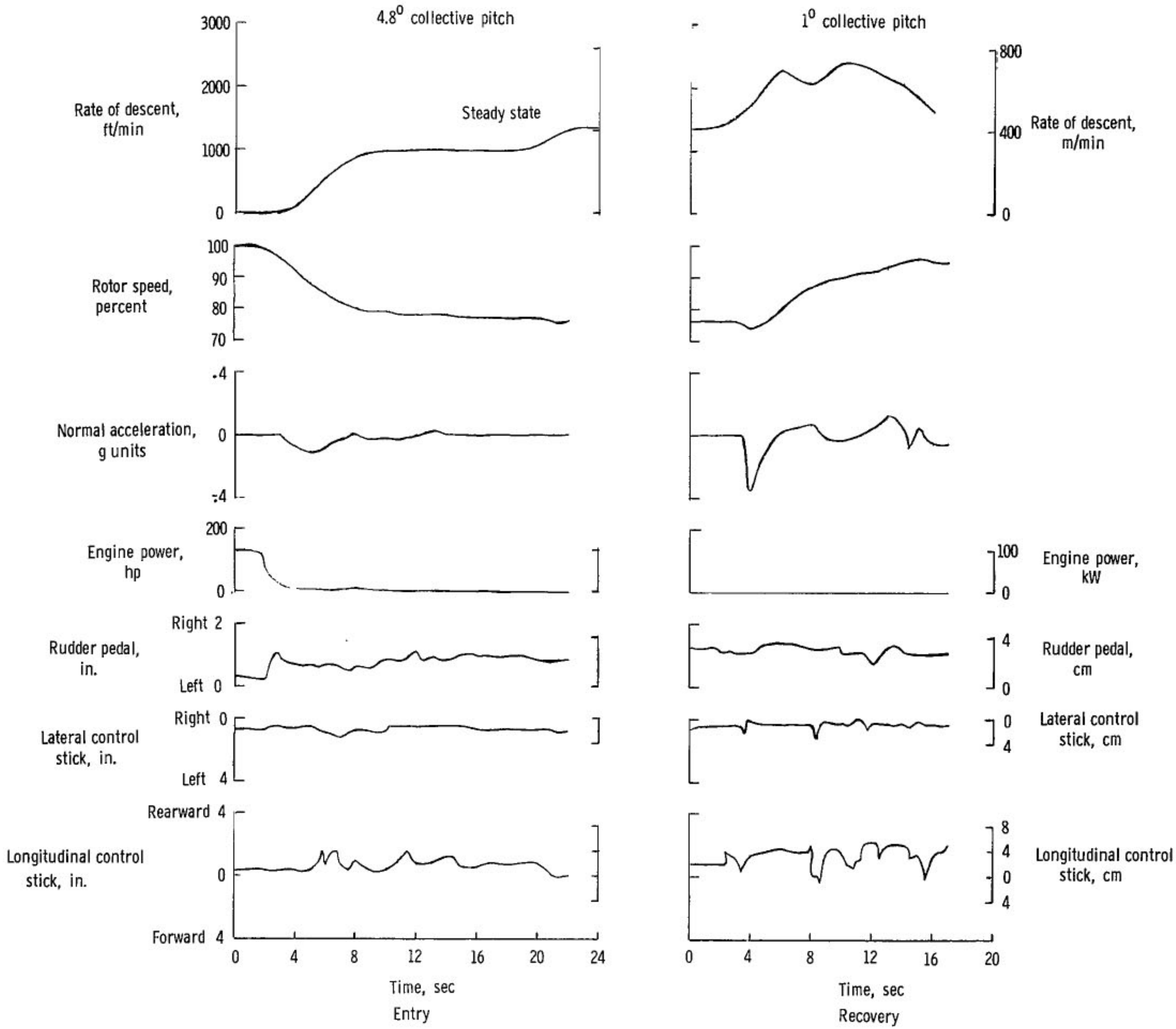

Figure 4.- Time history of entry into and recovery from test maneuver. Indicated airspeed of 45 knots and steady-state rate of descent of 1350 ft/min (411.48 m/min).

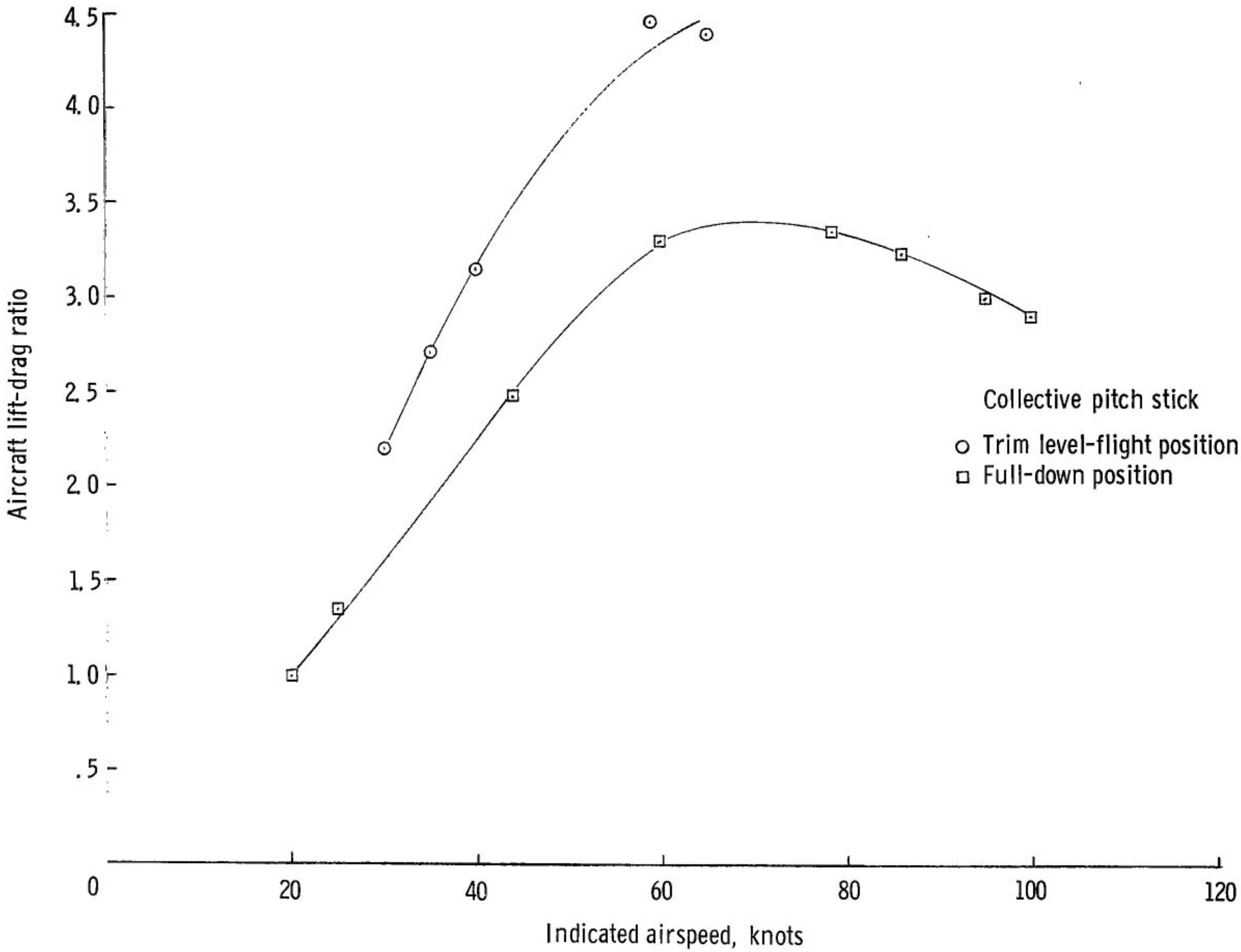

Figure 5.- Variation of aircraft lift-drag ratio with airspeed.

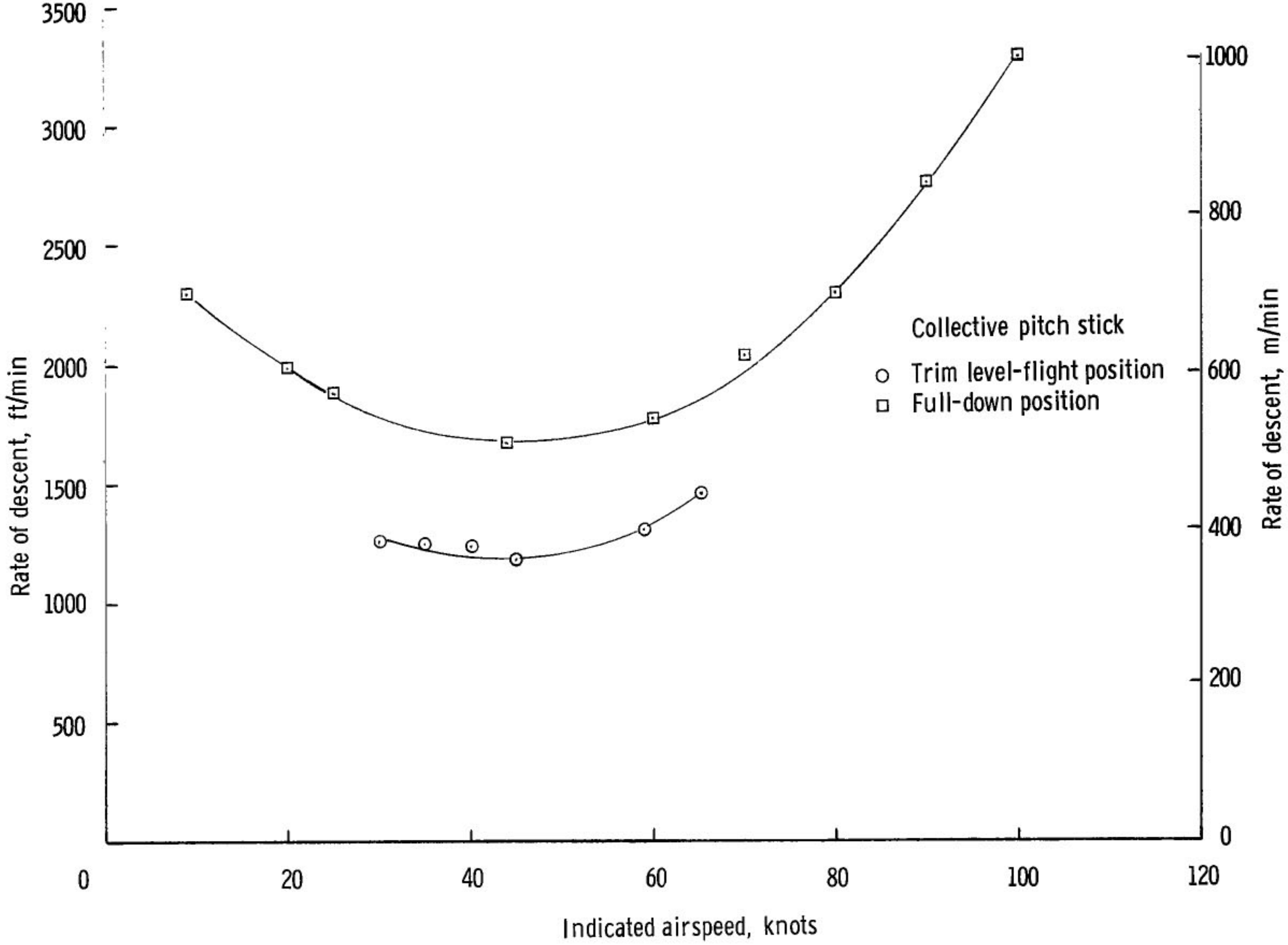

Figure 6.- Variation of descent rate with airspeed.

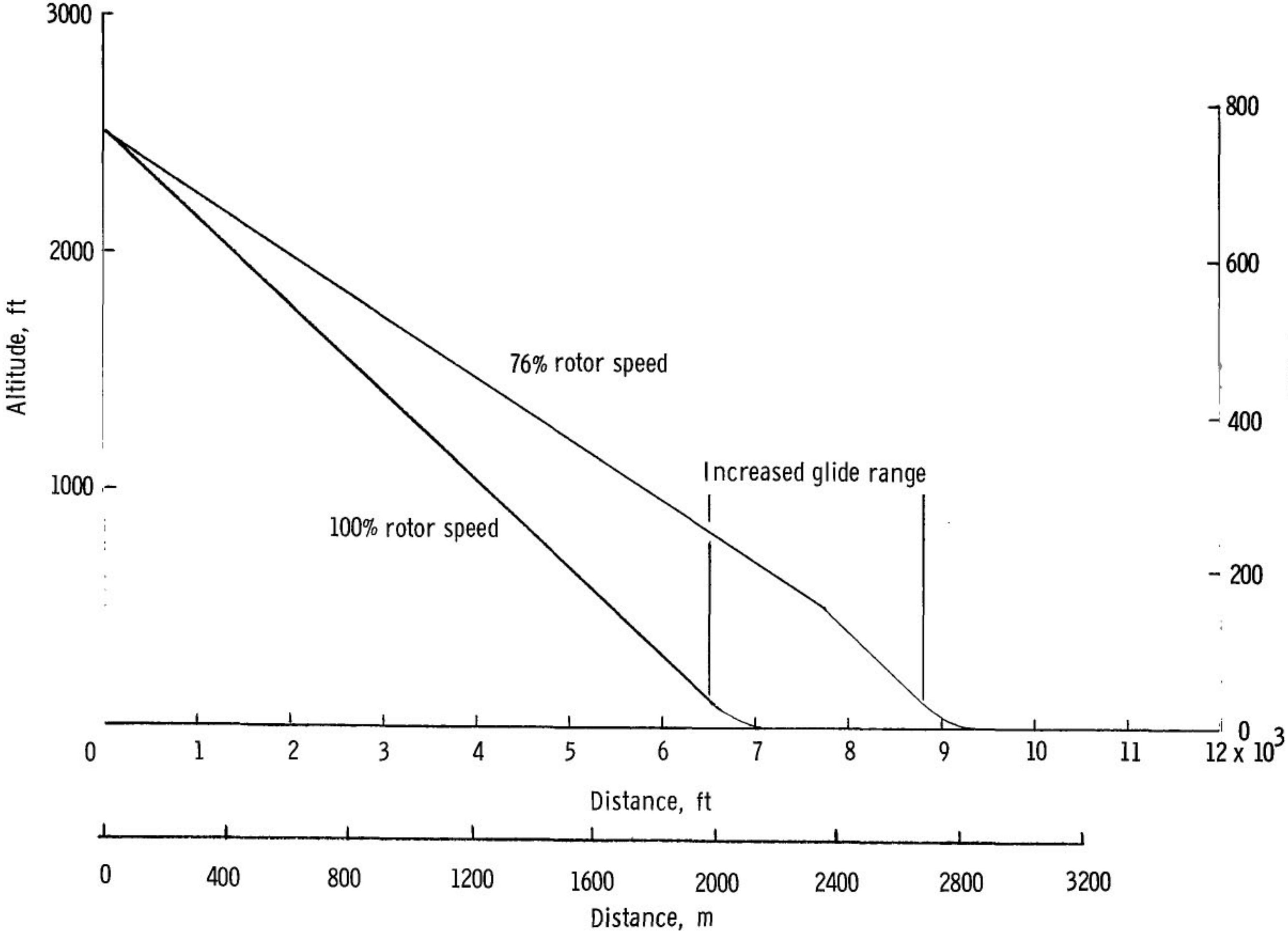

Figure 7.- Flight trajectories at a constant airspeed of 45 knots and an aircraft weight of 2500 pounds (11 121 newtons).

NASA-Langley, 1969 — 2 L-6534

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546