RESEARCH MEMORANDUM

for the
Office of Naval Research, Department of the Navy

HIGH-SPEED DRAG AND OPENING CHARACTERISTICS

OF A KAMAN ROTOCHUTE MODEL

By Vernard E. Lockwood

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
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SUMMARY

An experimental investigation has been made in the Langley high-speed 7- by 10-foot tunnel in the Mach number range from 0.40 to 0.80 to determine the drag and opening characteristics of a model of a Kaman Aircraft Corporation Rotochute. The Rotochute, which is basically a two-bladed flapping rotor with governor-controlled blades designed for lowering cargo containers from high-speed aircraft, was tested at various Mach numbers simulating constant rates of descent. In these tests, the drag, rotational speed, and coning angle of the blades were determined. In some additional tests, in which the Rotochute was allowed to open at various airspeeds, time histories of the drag and rotational-speed variation from opening to equilibrium rotational speed were obtained. The tests were made at an angle of attack of 0°. Two sets of blades were tested: one having an NACA 0015 airfoil section and the other an NACA 0008 airfoil section. In order to expedite publishing of the data, no analysis is presented.

INTRODUCTION

At the request of the Office of Naval Research, Department of the Navy, a wind-tunnel investigation was made to determine the high-speed drag and opening characteristics of a model of the Kaman Aircraft Corporation Rotochute. The Rotochute (figs. 1 and 2) is an aerial vehicle designed for the delivery of M-2 cargo containers from aircraft in low-altitude high-speed ground-supply missions. The history and development of various models of the Rotochute are presented in reference 1. The results of an experimental investigation of one of these designs to determine the low-speed static aerodynamic and operational characteristics are presented in reference 2.
The present paper contains the results of tests at several Mach numbers to determine the drag and rotational speed of the Rotochute for steady-state conditions. This paper also includes time histories of the drag and rotor revolutions from opening of the Rotochute until a constant rotational speed was obtained. (This operation takes place in what amounts to a transient tunnel Mach number condition resulting from dynamic-pressure reductions of about 10 percent which occur when the Rotochute blades open.) A 16-mm-film record, from which the coning angles of the rotor were determined, was made of the rotor operations. The tests were made at an angle of attack of 0° through a Mach number range from 0.40 to 0.80.

**SYMBOLS**

The symbols used herein are standard NACA symbols. The drag was measured parallel to the wind axes.

- **S** disk area of rotor blades operating at zero cone angle, sq ft
- **D** drag, lb

\[ \Delta D = (D)_{\text{rotor attached}} - (D)_{\text{suspension system, including Rotochute body}} \]

- **V** tunnel airspeed, ft/sec
- **V_t** rotor-blade tip speed, RΩ, ft/sec
- **R** rotor radius, ft
- **Ω** rotor speed, radians/sec
- **a_0** cone angle, deg (see fig. 3)

\[ \Delta C_D \] incremental drag coefficient, \( \Delta D / qS \)

- **t** time after release of rotor, sec
- **M** Mach number

- **q** dynamic pressure, \( \rho V^2 / 2 \), lb/sq ft
- **ρ** mass density of the air, slugs/cu ft
- **N** revolutions
A brief description of the use and the operation of the Rotochute is given herein. The purpose of the Rotochute is the delivery of M-2 supply containers in low-altitude high-speed ground-supply missions. This will involve decelerating missiles weighing up to 650 pounds from forward velocities of approximately 1,000 feet per second ($M = 0.90$) to descent velocities at touchdown of about 25 feet per second in less than 500 feet vertical distance. This operation is accomplished by a two-bladed flapping rotor synchronized in coning by means of suitable linkages. The blade pitch angle is regulated by a governor to prevent the rotor overspeeding.

In practice, the Rotochute is carried aboard an aircraft either internally or externally with the blades folded back for compactness. A static line attached to the Rotochute releases a mechanism which allows the blades to pivot about the blade-sweep hinge with the tips moving in the direction of rotation. The relative angle of the blades to the airstreams sets up aerodynamic forces which start rotation. The centrifugal forces on the blades force the tips away from the axis of rotation. An equilibrium rotational speed and coning angle which depend largely upon the aerodynamic drag and the centrifugal forces are quickly obtained.

MODEL AND APPARATUS

The Rotochute model which was supplied by the Kaman Aircraft Corporation consisted of a rotor and body as shown in figure 1. The blades of the rotor are mounted on the hub at the blade pitch hinge. The blade pitch-control spring holds the blades against a stop in the static condition of about $10^0$ nose down, when referred to a normal attitude. A means of adjusting the spring tension and the stop are provided. The blades are also attached at the blade coning hinge, allowing the blades to fold back in a plane parallel to the airstream (fig. 1(b)). The blades are held in a fully extended position when inoperative by the blade support arm and the tendency of the blade sweep spring to rotate the rear-bearing housing. A mechanism is also provided for changing the blade sweep angle which consists of a blade sweep spring, sliding collar, blade sweep-control arm, and the blade sweep hinge. For the rotor release tests (opening), a block was placed between the hub plate and sliding collar for compressing the sweep spring. When operation was desired, the sweep mechanism and rotor lock, which was provided for the rotor as an assurance against turning prematurely, were released from outside of the tunnel through cables attached to the block and locking pin. (It should be noted here that when the blades are rotated forward about their coning hinge
axis, the 10° sweep results in an angle-of-attack change of approximately 10° when the blades are fully extended.)

The model suspension system is shown in figure 2 and schematically in figure 3. In these tests, the body, which served as a part of the suspension system, was mounted on a 2-inch-diameter pipe which in turn was supported from the tunnel walls by two sets of diagonally opposed cables. The system was restrained in drag by a diagonal cable. From the geometry of the system (fig. 3), it can be seen that the load in the vertical load cable was approximately equal to the drag of the system, and this was determined from the load cell which had been calibrated as mounted by applying a force in the drag direction. The drag data from the Rotochute opening tests were measured on a recording oscillograph while that of the steady-state tests were measured by use of a potentiometer. The rotational speed of the rotor was measured on a recording oscillograph from an electrical tachometer made up of a magnet and coil mounted on the rotor and body, respectively.

Two sets of blades were tested in this investigation: one having an NACA 0015 section and the other an NACA 0008 section. The blades had a constant chord with circular tips. Other physical characteristics of the blade are given in the following table:

<table>
<thead>
<tr>
<th>NACA blade section</th>
<th>Chord, ft</th>
<th>Diameter, ft</th>
<th>Blade length including root, ft</th>
<th>Disk area, sq ft</th>
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<td>12.15</td>
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</table>

No attempt was made to measure the preload on the governor springs. The preload was less for the NACA 0008 blades than for the NACA 0015 blades. However, the governing spring constant was the same for both sets of blades.

TESTS

Three types of tests were made to determine the high-speed drag and opening characteristics of the Rotochute. The first tests were made to determine the drag of the support system (tare drag) inasmuch as the drag measured in the steady-state and opening tests which followed was a combination of the drag of the rotor and the support system. The steady-state tests were made with the rotor autorotating at constant
Mach numbers during which the drag and rotational speed were recorded. The opening tests of the Rotochute were made at preset tunnel Mach number to determine the rotor drag and rotational-speed variation with time from a point just prior to release until an equilibrium rotational speed was obtained. (In these tests, the rotor blades assumed an attitude prior to release similar to that shown in fig. 1(b)). Motion pictures were taken at approximately 60 frames per second of all tests with the rotor operating except the steady-state tests of the NACA 0008 blades.

PRESENTATION OF DATA

Figure 4 is a typical oscillograph record of the operation of the rotor following release at a preset tunnel Mach number. Figures 5 and 6 show the variation of the incremental drag and revolutions of the rotor from time of release until a steady-state condition was obtained. The incremental drag, in pounds, is presented in lieu of incremental drag coefficient because of the change in dynamic pressure occurring during the opening operation. The results of tests to determine drag, rotor tip velocity, and coning angle for the steady-state conditions are given in figure 7. The Mach numbers at which the coning angles are given for NACA 0008 blades were not measured for equilibrium conditions as motion pictures were not available for this configuration. They were measured, however, from motion pictures of the openings at a time when the drag values were at their maximum as shown in figure 6(a). Inasmuch as the maximum values of the drag at this time are approximately equal to the steady-state values (table I), it is thought that the error in Mach number may be relatively small.

Langley Aeronautical Laboratory, National Advisory Committee for Aeronautics, Langley Field, Va., May 28, 1954.

Vernard E. Lockwood
Aeronautical Research Scientist

Approved: Thomas A. Harris
Chief of Stability Research Division

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REFERENCES


TABLE I
AERODYNAMIC CHARACTERISTICS OF KAMAN ROTOCHUTE MODEL
TESTED IN LANGLEY HIGH-SPEED 7- BY 10-FOOT TUNNEL

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<thead>
<tr>
<th>Type of test</th>
<th>NACA blade section</th>
<th>M</th>
<th>Q, lb/sq ft</th>
<th>V, ft/sec</th>
<th>D, lb</th>
<th>( \Delta C_D )</th>
<th>Rotational speed, rpm</th>
<th>( V_b, ) ft/sec</th>
<th>( \phi, ) deg</th>
<th>(q) after opening, lb/sq ft</th>
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(q) after opening, lb/sq ft
Figure 1 - Details of the Kamus Rotorcraft tested in the Langley high-speed 7' by 10-foot tunnel.
Figure 1 - Concluded.

(b) Blades folded back.

- Blade sweep hinge
- Blade pitch hinge
- Blade cone-angle hinge
- Spindle
- Sliding collar
- Magnetic
- Blade leading edge
- Rotor lock
- Coil
Figure 2.- Model of a Kaman Rotochute mounted in the Langley high-speed 7- by 10-foot tunnel.
Figure 3 - Sketch of tunnel mounting system.
Figure 4. - Typical record taken on release of the Rotochute with the NACA 0008 blades.
Figure 5.- Effect of the Mach number on the opening characteristics of the rotor with NACA 0015 blade sections.
(b) $N$ against $t$.

Figure 5. - Concluded.

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Figure 6.- Effect of Mach number on the opening characteristics of the rotor with the NACA 0008 blade sections.
Time, $t$, sec

(b) $N$ against $t$.

Figure 6.- Concluded.
(a) $\Delta C_D$ against $M$.

Figure 7. - Comparison of the governing characteristics of different rotor blades on a model of the Kaman Rotochute.
Figure 7. - Continued.

(b) $V_t$ against $M$.

Rotor tip velocity, $V_t$, ft/sec

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