A New Rotating Parachute Design Having High Performance

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A new concept of rotating parachute has been designed primarily for recovery of high-performance re-entry vehicles. Design and development/testing results are presented from low-speed wind tunnel testing, free-flight deployments at transonic speeds, and tests in a supersonic wind tunnel at Mach 2.0. Drag coefficients of 1.25 based on the disk area of the 2-ft-diam rotor have been measured in the wind tunnel. The stability of the rotor is excellent, with oscillation of its centerline being less than 3 deg. Good agreement between theoretical and measured performance parameters is shown.

Nomenclature

C_D = drag coefficient based on constructed canopy diameter
d = constructed diameter of rotor disk, ft
D = rotor drag, lb
J = advance ratio
n = revolutions per second
q = dynamic air pressure, $= \frac{1}{2}\rho_0 V^2$
s = rotor disk area, $= \pi/4\ d^2(\mathrm{ft}^2)$
T = thrust, lb
t = time, s
V = vehicle velocity, ft/s
W = vehicle plus rotor weight, lb
ρ_0 = air density, slugs/ft^3
Δ = increment

Subscripts

d = deployment of parachute
f = fill time of parachute

Introduction

THE Rotating Flexible Decelerator (RFD) was designed in November 1979. The purpose of the design was to take advantage of autorotation developed by the relative air motion. Autorotation provides gyroscopic stability, much like a spinning top, and maximum projected area due to centrifugal force, which should provide high drag coefficient and drag efficiency. A stable decelerator, both static and dynamic, is very desirable and necessary on most retardation system designs. The canopy structure was designed to be efficient in transferring loading to the lines.

First testing results from low-speed and supersonic wind tunnel tests are presented. Data from free flight deployments of rocket and sled launched test vehicles are also presented.

Rotor Design

The basic rotor design is shown in Fig. 1. It is 2 ft in diameter with 12 gores and 12 suspension lines 2-ft long made of 2000 lb braided Kevlar-29. The skirt band is 4000 lb by 1-in. wide Kevlar. The blades, which are shown crosshatched, are made of 3.0 oz/yd^2 Kevlar cloth as well as the circular vent cap. This cap was found necessary to insure inflation in free-flight deployments. Since the blades cover only about two-thirds of the gore width, they assume an angle of attack relative to the rotational velocity vector as a result of interradial bulge from air loads. This results in a force vector tilted relative to the plane of rotation and, thereby, gives a rotational force. The completed rotor made entirely of Kevlar weighed 0.43 lb.†

Wind Tunnel Tests

The first test of the new rotor was conducted late in July 1982 at the Vought Corporation 7 × 10-ft Low Speed Wind Tunnel. The 2-ft-diam rotor was very stable as shown in Figs. 2 and 3, since any oscillation of the rotor centerline would result in this Polaroid photo being blurred. Note the flat profile of the canopy caused by centrifugal force of rotation. The side view of the suspension line profile resembles an egg beater due to the centrifugal force which tends to stretch the rotor flat.

In February 1983, the same rotor was tested at a Mach number of 2 in the 10 × 10-ft Supersonic Wind Tunnel at NASA, Cleveland, Ohio.

Rocket-Boosted Free-Flight Tests

A small, cylindrical 50-lb vehicle with four fins was boosted by one Zuni rocket to reach transonic speeds for initial deployment tests of the 2-ft rotor. Six tests using the 2-ft rotor were

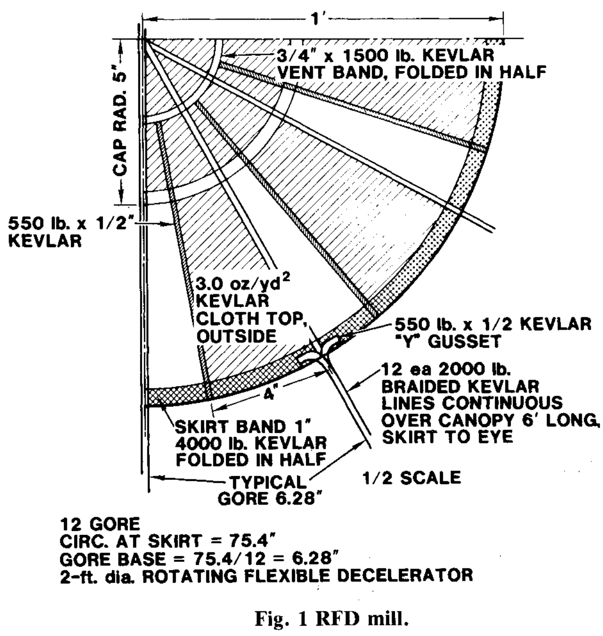

Fig. 1 RFD mill.

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†As a comparison, a 19-in.-diam ribbon-type parachute[1] weighed 0.52 lb and had half the drag coefficient.

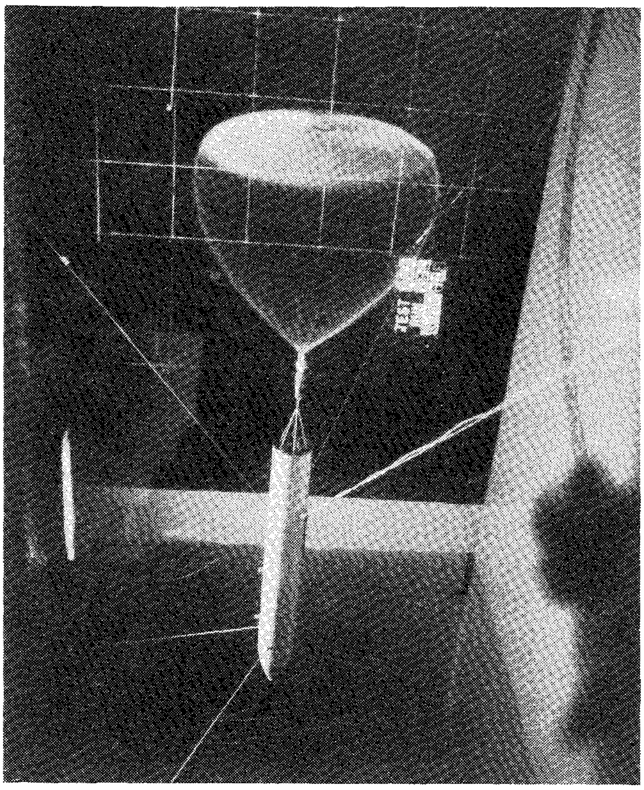

Fig. 2 2-ft-diam rotor in Vought Corporation 7×10-ft low-speed wind tunnel.

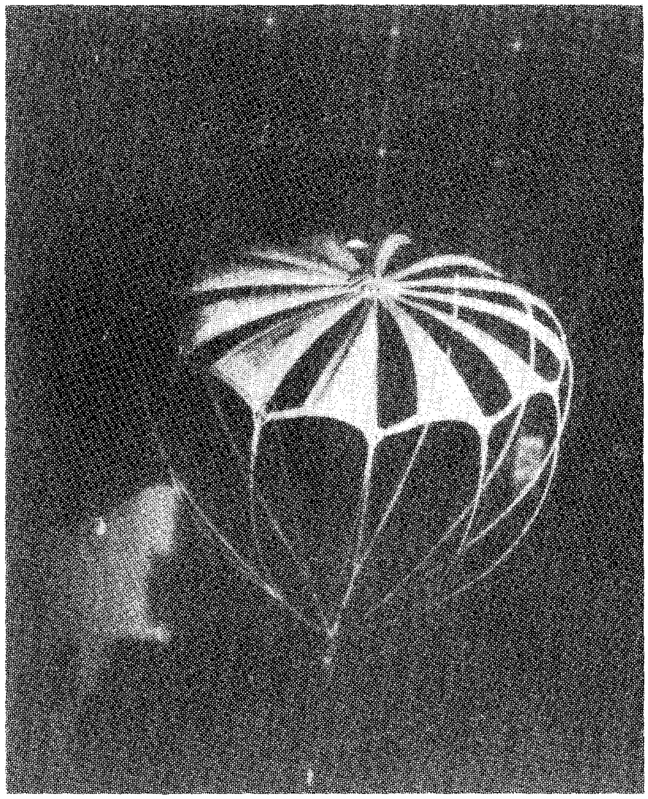

Fig. 3 2-ft rotor photo by strobe light.

Table 1 6 ft Rotating Flexible Deceleration Tests (1983)

No.	Date	6 ft rotor D_0, line strength	Weight, lb	P_0 slugs/ft^3	V_d, fps	q_d, psf	Δt_d, s	Δt_f, s	rps	g max, g	Results
1	5/18	2000/RFD-6-1	72.00	0.00193	500	240	0.22	0.09	30	42	Successful
2	6/3	4000	74.75	0.001897	780	577	0.12	–	–	40	Blade panel stitching 1.5 failed, low rpm
3	8/26	2000/RFD-6-1	73.50	0.00187	820	629	–	–	–	–	Stitching of blades failed
4	10/14	2000/RFD-6-2	73.50	0.00192	850	720	0.13	–	–	–	Cutter did not fire, no disreef, no damage
5	10/26	2000/RFD-6-2	73.50	0.00197	830	690	0.14	0.18	33	95	Successful, no damage

conducted. It was found necessary to add a Kevlar cloth central disk to the rotor to insure initial inflation. On some tests the lid collided with the inflating rotor, so reefing for 0.5 s was used to avoid this problem. It was found that new swivels should be used for each test to avoid swivel failure at the high speeds of up to 130 rps. A larger 73.5-lb vehicle was ejected upwards from a sled on the 1-mile long track to deploy the 6-ft-diam rotor. Five tests were conducted using this vehicle as listed in Table 1. Some stitching problems were found on the second two tests that were easily corrected. The first and last tests were successful at deployment velocities of 500 and 830 ft/s.

Velocity decay with time is shown in Fig. 4. The deceleration pulse from a typical deployment is shown in Fig. 5 from an onboard telemetry system.

Analysis of Rotor Data

Drag

The variation of drag coefficient with Mach number is shown in Fig. 6. The drag coefficient is based on the constructed area of a solid disk (3.14 ft^2 for a 2-ft-diam rotor). The drag coefficient is very high (1.25) at low subsonic Mach number and decreases to 0.65 at $M=2$. As comparison values, 0.5 for a ribbon parachute and 0.7 for a solid canopy are shown in Fig. 6. The wind tunnel data (square symbols) for a 2-ft rotor agree with free-flight (circles) for the same rotor and also a larger 6-ft-diam rotor (diamonds).

Rotational Speed

The variation of rotational speed with Mach number is shown in Fig. 7.

Theory of Rotor

Conventional propeller theory can be used to analyze rotor performance where the advance ratio is

$$J=\frac{V}{nd}=2.5 \text{ (empirical constant)}$$

For a 6-ft-diam rotor operating at 500 ft/s forward velocity, the rotational speed is

$$n=\frac{V}{Jd}=\frac{500}{2.5d}=\frac{200}{d}=\frac{200}{6}=33 \text{ rps}$$

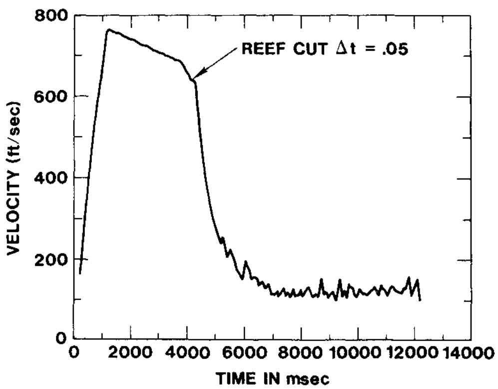

Fig. 4 Variation of test vehicle velocity with time from laser tracker for deployment during free-flight of 2-ft-diam rotor test R802831.

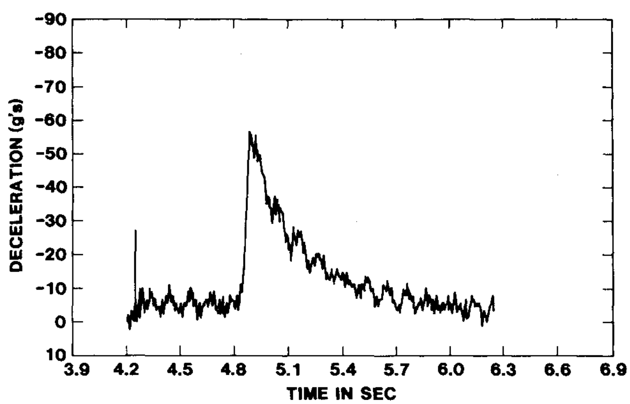

Fig. 5 Variation of deceleration with time for rocket boosted test 5 of 2-ft rotor on 1/7/83.

For a 2-ft-diam rotor the speed would be 100 rps. This agrees with data in Fig. 7.

The drag values were analyzed using thrust coefficient

$$C_T = \frac{T}{\rho v^2 d^4}$$

For test 5 of Table 1 the peak deceleration was 95 *g*.

$$T = D = 95(73.5) = 6982.5 \text{ lb}$$

$$q = \tfrac{1}{2}\rho_0 V^2 = \tfrac{1}{2}(0.00197)500^2 = 246 \text{ lb/ft}^2$$

$$C_D = \frac{D}{qS} = \frac{6982.5}{246\pi 6^2/4} = 1$$

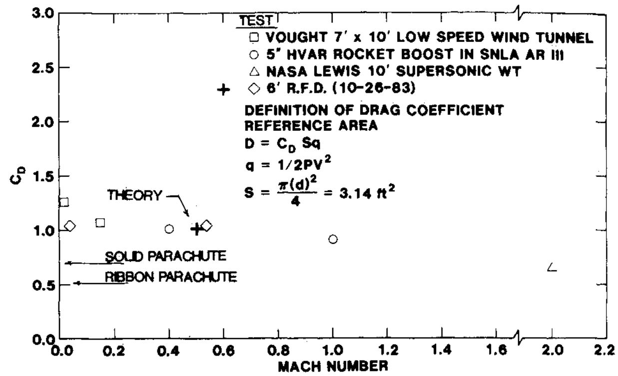

Fig. 6 RFD Mill drag coefficient variation with Mach number.

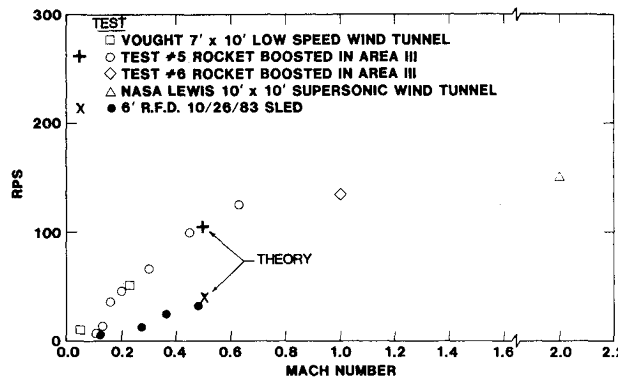

Fig. 7 Rotational speed vs Mach number for RFD.

This agrees with experimental values as shown in Fig. 6.

Conclusions

Initial wind tunnel and free-flight testing of a new rotating parachute design has led to the following conclusions. 1) High drag coefficients of 1.0 to 1.25 were measured. 2) The design has high static and dynamic stability (oscillations of less than 3 deg). 3) A theory for analyzing rotor performance parameters is shown to agree well with test results.

Acknowledgment

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References

[1] Pepper, W.B., "Preliminary Report on Development of an Interim Parachute Recovery System for a Reentry Vehicle," *Journal of Aircraft*, Vol. 17, March 1980, pp. 218-224.