AEDC-TDR-62-79

WIND TUNNEL INVESTIGATION OF CAPSULE EJECTIONS FROM THE SIDE AND BASE OF A CARRIER VEHICLE AT MACH NUMBERS 2, 4, 5, AND 8

By

L. A. Morgan

von Kármán Gas Dynamics Facility

ARO, Inc.

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NOTICES

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a subsidiary of Sverdrup and Parcel, Inc.

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ABSTRACT

Tests were conducted in the 40-Inch Supersonic and 50-Inch Mach 8 Tunnels of the von Kármán Gas Dynamics Facility to determine the separation characteristics of ejected capsules while in the influence of the flow field of the carrier vehicle. High-speed movies were obtained of cylindrical and cone-cylinder flared capsules ejected at Mach numbers 2, 4, 5, and 8 with a constant free-stream Reynolds number of 3.4×10^6 per ft. The capsule orientations along their trajectories are presented to illustrate the results obtained.

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NOMENCLATURE

A	Reference area, $in.^2$
C_D	Drag coefficient, drag force/qA
I	Mass moment of inertia about the capsule cg, slug-$in.^2$
$\bar{M}$	Local Mach number
M_∞	Free-stream Mach number
p_o	Stilling chamber pressure, psia
$\bar{q}$	Local dynamic pressure, psia
q_∞	Free-stream dynamic pressure, psia
T_o	Stilling chamber temperature, °F
v_e	Capsule ejection velocity, fps

1.0 INTRODUCTION

Simulation of the separation of a data capsule from a vehicle traveling on a high-speed trajectory was investigated by ejecting capsules from the side and base of a carrier vehicle in the 40-In. Supersonic and the 50-In. Mach 8 Tunnels of the von Kármán Gas Dynamics Facility, Arnold Engineering Development Center (VKF-AEDC), Air Force Systems Command (AFSC). Tests were conducted at Mach numbers 2, 4, 5, and 8 with a constant free-stream Reynolds number of 3.4×10^6 per ft on December 28-30, 1961 and January 11-16, 1962.

The Air Force Office of Scientific Research (AFOSR), Office of Aerospace Research (OAR), is sponsoring a research program being conducted by the Cook Research Laboratories on the dynamics of separating bodies. In the first phase of testing (Ref. 1), static force data on a capsule at various positions in the interference field of a carrier vehicle were obtained at Mach numbers 2, 4, and 5 in the VKF 40-In. Supersonic Tunnel. With these data and results from a theoretical study of the flow fields around the carrier vehicle, the separation behavior of the capsule can be predicted (Refs. 2 and 3). The dynamic tests reported herein will be used to help evaluate this method of prediction.

2.0 APPARATUS

2.1 WIND TUNNELS

The 40-In. Supersonic and 50-In. Mach 8 Tunnels are continuous, closed-circuit, variable-density wind tunnels.

The 40 by 40-In. Supersonic Tunnel (Fig. 1a) has a flexible-plate-type nozzle which is automatically driven to produce Mach numbers from 1.5 to 6. The tunnel operates at maximum stagnation pressures from 29 to 200 psia at M_∞ = 1.5 to 6, respectively, and at stagnation temperatures up to 300°F (M_∞ = 6). Minimum operating pressures are about one-tenth of the maximum.

The 50-In. Mach 8 Tunnel (Fig. 1b) has a contoured axisymmetric nozzle and operates at stagnation pressures from 100 to 800 psia and stagnation temperatures up to about 900°F.

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A complete description of the tunnels and airflow calibration information may be found in Ref. 4.

2.2 MODELS AND SUPPORT SYSTEM

The dimensions of the carrier vehicle and installation photographs of it installed in the 40-In. Supersonic Tunnel are presented in Fig. 2. The carrier was sting-mounted for the side ejection phase and strut-mounted for the base ejection phase of testing. The strut was mounted vertically from the diffuser plate in the supersonic tunnel. In the Mach 8 tunnel the strut was at an angle (Fig. 4c), mounted from one of the off-center observation ports. This enabled the use of the top centerline port for camera coverage of the capsule in the yaw plane.

A total of 55 capsules, consisting of a cylindrical capsule and a flared capsule with two different frequencies, were ejected. The dimensions and weight of these capsules and their mass moment of inertia about the capsule center of gravity are presented in Fig. 3.

The carrier vehicle, capsules, and ejection mechanism were supplied by the Cook Research Laboratories. The ejection mechanisms (Fig. 4) were such that a series of capsules could be ejected on command before reloading was required. Four capsules could be ejected from the side and three capsules from the base. Figure 4b shows the base ejection mechanism with its load of three capsules. The ejection velocity (v_e) of the capsules could be varied by the control of the air pressure applied to an ejection piston. In the base ejection mode, different capsule holders and piston positions were used to eject capsules at either +10 or -20 deg.

The mechanisms were water-cooled for operation at the high temperatures encountered in the Mach 8 tunnel.

3.0 TEST PROCEDURE

The conditions at which these tests were conducted correspond to a constant Reynolds number of 3.4×10^6 per ft and are summarized in the table on the following page.

Mach Number	p_o, psia	T_o, °F	q_∞, psia
2.0	14	100	5.02
4.0	39	100	2.88
5.0	72	145	2.38
8.1	800	875	3.47

Records of the behavior of the ejected capsules were obtained with two high-speed movie cameras operating within the range of 1500 to 2500 frames per second with a timing mark of 100 cps. In the supersonic tunnel tests, the cameras recorded the relative trajectory motion of the capsule to the carrier vehicle, and one camera was installed in the schlieren system to photograph the local flow field of the ejected capsules. In the Mach 8 tunnel, one camera photographed the vertical trajectory and another camera, mounted in the top port, photographed the yaw plane characteristics of the ejected capsules. At Mach 8, a conventional, short range, divergent ray, spark shadowgraph system was used to record the flow pattern about the carrier vehicle.

To obtain a quick determination of the capsule's separation characteristics, an auxiliary Polaroid camera equipped with a rotating disc shutter was used. The films from this camera were viewed immediately after the capsule ejection; some typical pictures are presented in Fig. 5.

4.0 DISCUSSION OF RESULTS

Typical results from each mode of ejection are presented in the form of schematic diagrams in Figs. 6 and 7. The ejection velocities (v_e) were obtained from the trajectory plots for the first 0.01 sec of capsule travel. The initial positions are believed to be accurate to within a tenth of an inch, which corresponds to a possible ejection velocity variation of ±1.7 fps.

4.1 SIDE EJECTION

The three capsule configurations tested are shown ejected at Mach number 2 from the side of the carrier vehicle in Fig. 6a. The models were dynamically stable, and little variation was observed in their trajectories for the same ejection velocity although the configurations are different and in the case of the flare configuration have different moment of inertias.

The effect of Mach number variations on the behavior of a cylindrical capsule is presented in Fig. 6b. No dynamic instability was present at M_∞ = 2, 5, and 8. The capsule traveled slower at M_∞ = 5, which is understandable when the variations of axial force with Mach number and dynamic pressure are considered. A simplified analysis of the flow field and forces acting on the capsule can be obtained by limiting the discussion to the last 0.03-sec period of the trajectories shown. It should be noted that the capsule is traveling in an expanding flow field at M_∞ = 5 and 8. Using an estimated local Mach number ($\tilde{M}$) and accounting for the total pressure loss through the carrier bow shock, the local dynamic pressure ($\tilde{q}$) and the drag coefficient on a cylinder (Ref. 5) were obtained to provide a comparison of the axial force per unit area ($C_D\tilde{q}$) with free-stream Mach number. The results of this simplified analysis, presented in Fig. 6b, show that the axial force acting on the capsule at M_∞ = 5 is less than at M_∞ = 2 and 8, and thus the trends shown in the trajectory diagrams are to be expected.

Figure 6c shows the effect of changing the ejection velocity on a low frequency flared capsule at M_∞ = 5. With the greater ejection velocity (v_e = 10 fps) the capsule interacts with the carrier bow shock, and a large amplitude of oscillation is produced which ultimately is damped.

4.2 BASE EJECTION

The capsules could be ejected from the base of the carrier at an attitude of +10 or -20 deg. The +10-deg attitude was used to offset the effect of gravity on the ejected capsule so that its flight path would be down the base wake core of the carrier (Fig. 7a). The attitude of -20 deg was used so that the capsule would penetrate the base wake (Fig. 7b). The resultant effect of a changing wake on the capsule with Mach number is shown clearly in Fig. 7. The approximate shape of the wake is presented for M_∞ = 2 but was not clearly defined at the other Mach numbers. Also shown are estimates of the wake shape assuming the wake is turbulent (Ref. 6). In the case of the wake core penetration tests, the wake flow had the most pronounced effect at M_∞ = 2 where the capsule began tumbling, beginning at about the location of the trailing shock. At Mach numbers 4 and 8 the capsules were observed to separate more uniformly.

During the wake penetration tests at M_∞ = 2 and 4 an ejection velocity of 7 fps was used, whereas at M_∞ = 8 it was increased to 9 fps. The tests at each Mach number showed that large amplitude oscillations were induced as the capsule passed through the wake boundary (see Fig. 7b).

5.0 SUMMARY OF RESULTS

Based on tests conducted to determine the separation characteristics of capsules ejected from the side and base of a carrier vehicle at M_∞ = 2, 4, 5, and 8 with a constant Reynolds number of 3.4×10^6 per ft, the following results were obtained:

1. Capsule configuration and moment of inertia had little effect on the trajectory at M_∞ = 2.
2. The cylindrical and cone-cylinder flare capsules were dynamically stable when ejected from the side of the carrier and had more uniform trajectories when the bow shock was avoided.
3. More uniform trajectories were obtained by ejecting through the base wake core rather than at an angle through the wake boundary.

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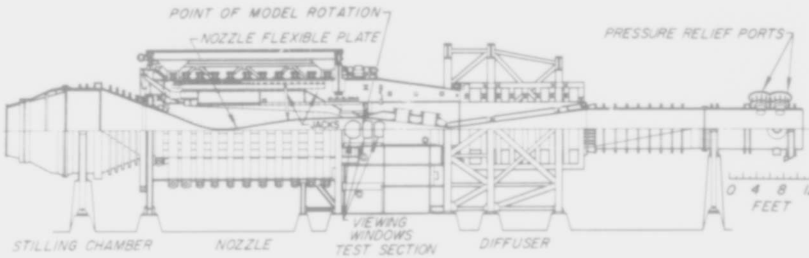
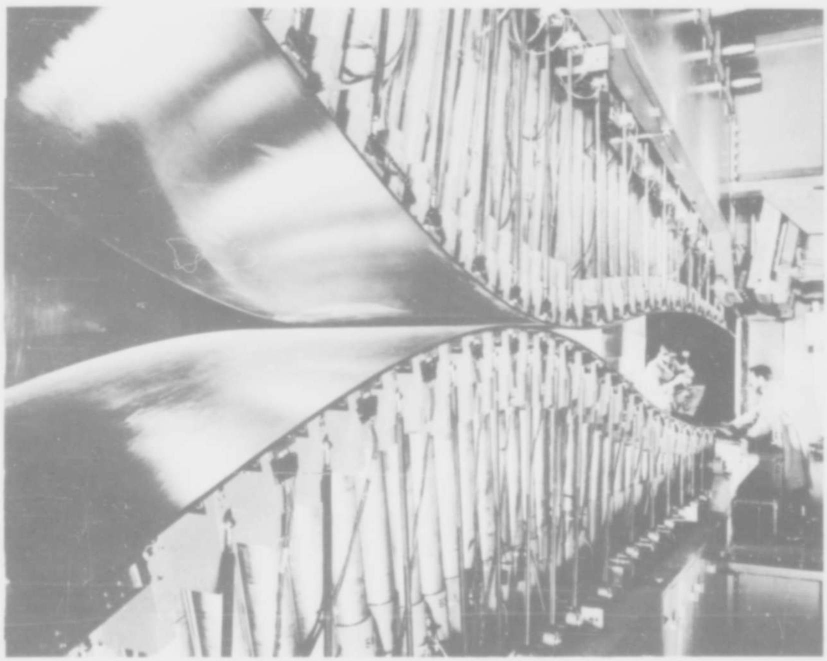


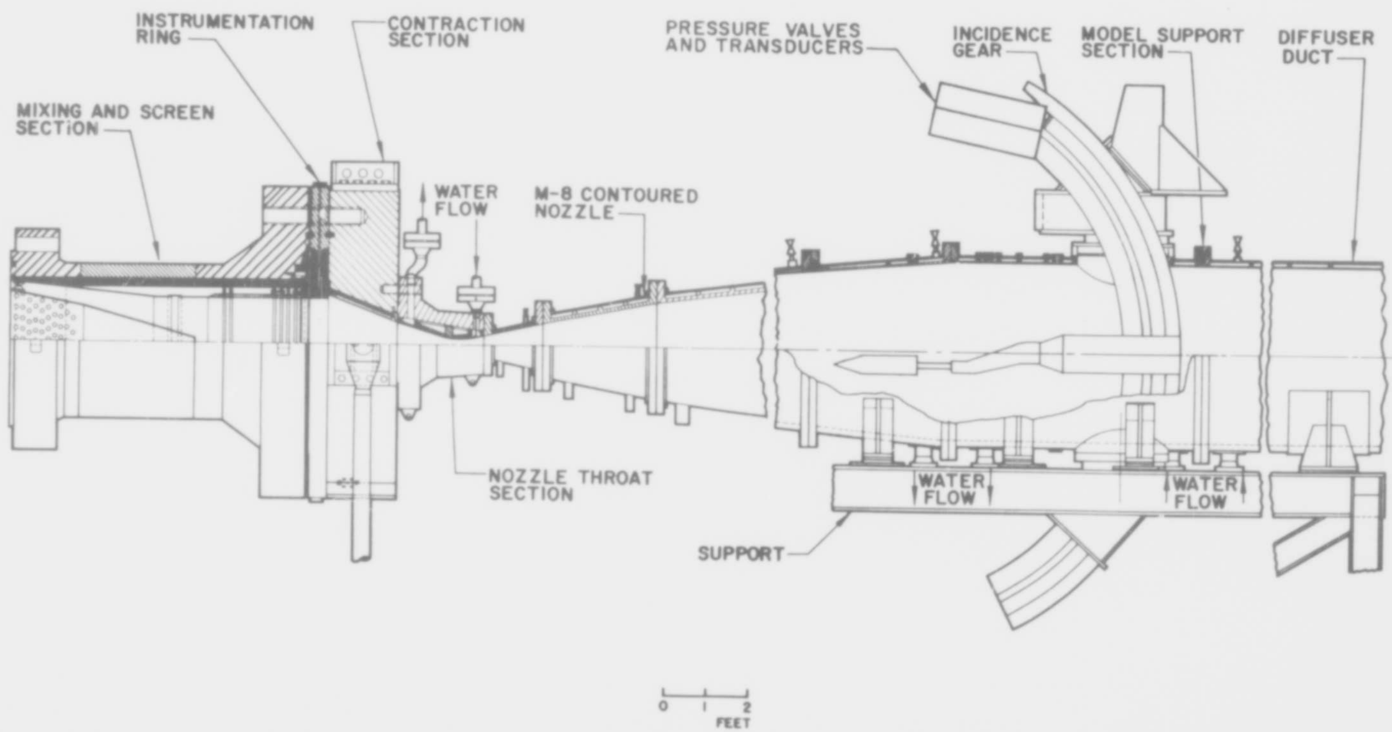
Assembly



Nozzle and Test Section

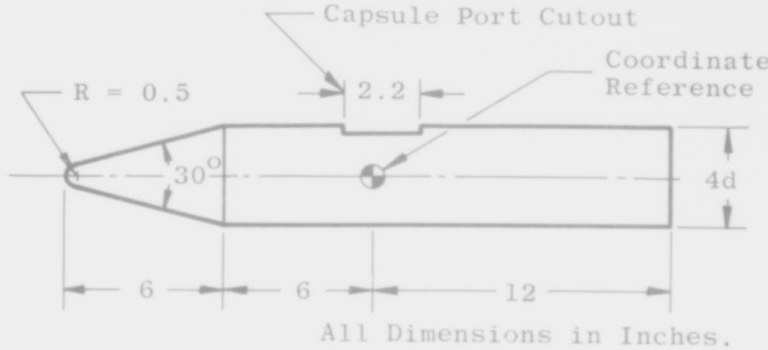
a. The 40-Inch Supersonic Tunnel

Fig. 1 Wind Tunnels

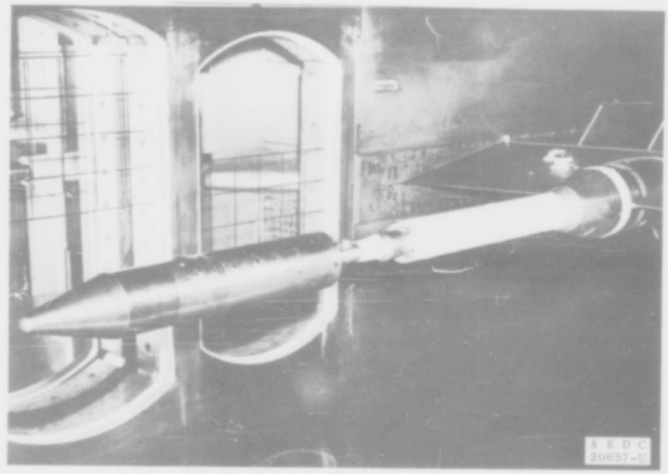


b. The 50-Inch Mach 8 Tunnel

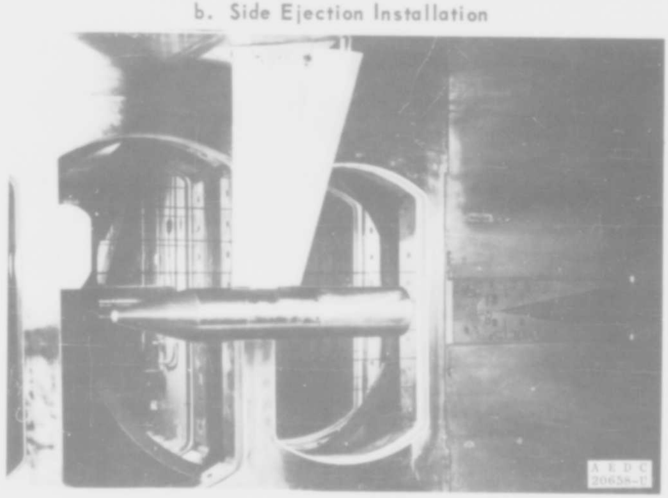
Fig. 1 Concluded



a. Carrier Vehicle Geometry



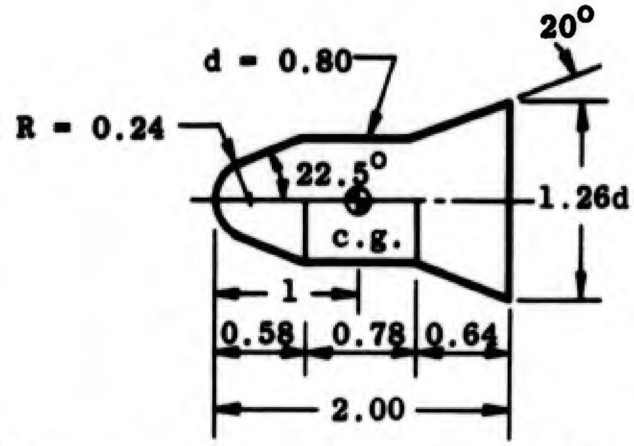
b. Side Ejection Installation



c. Base Ejection Installation

Fig. 2 Carrier Vehicle Geometry and Installation Photographs, 40-In. Supersonic Tunnel

All Dimensions in Inches.



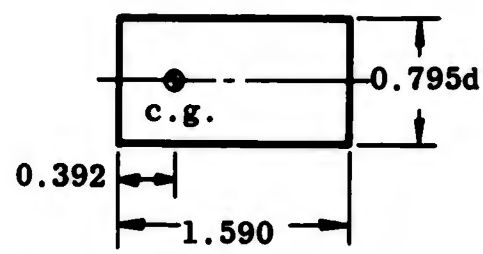
High Frequency

Wt = 0.188 lb
I = 0.000718 Slug-in.^{2}

Low Frequency

Wt = 0.162 lb
I = 0.001893 Slug-in.^{2}

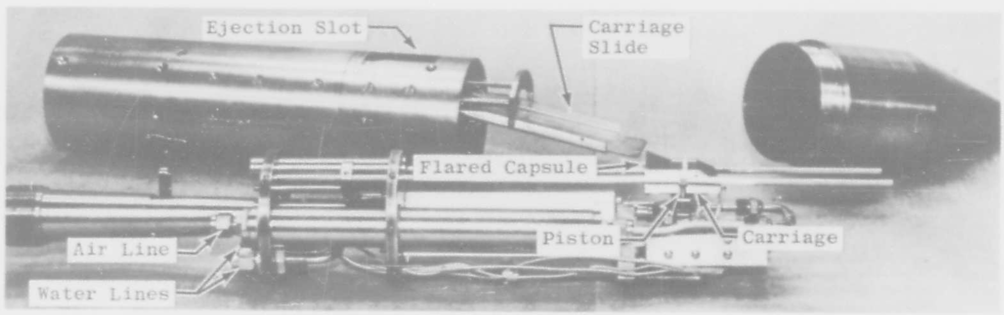
a. Flared Capsule



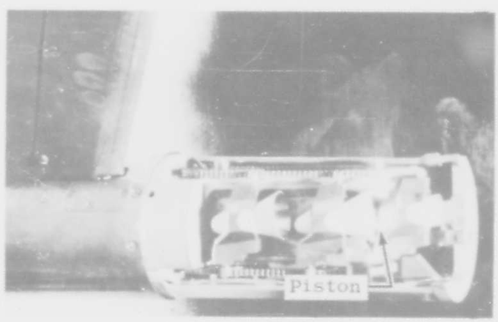
Wt = 0.158 lb
I = 0.000459 Slug-in.^{2}

b. Cylindrical Capsule

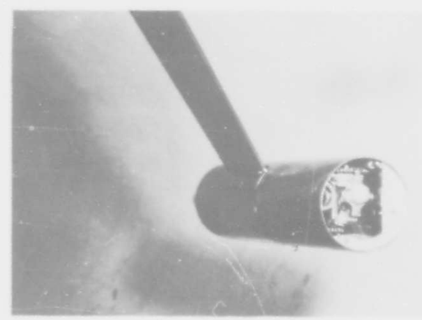
Fig. 3 Capsule Details



a. Side Ejection



b. Base Ejection



c. Base Ejection Installation Looking Upstream in the 50-In. Mach 8 Tunnel

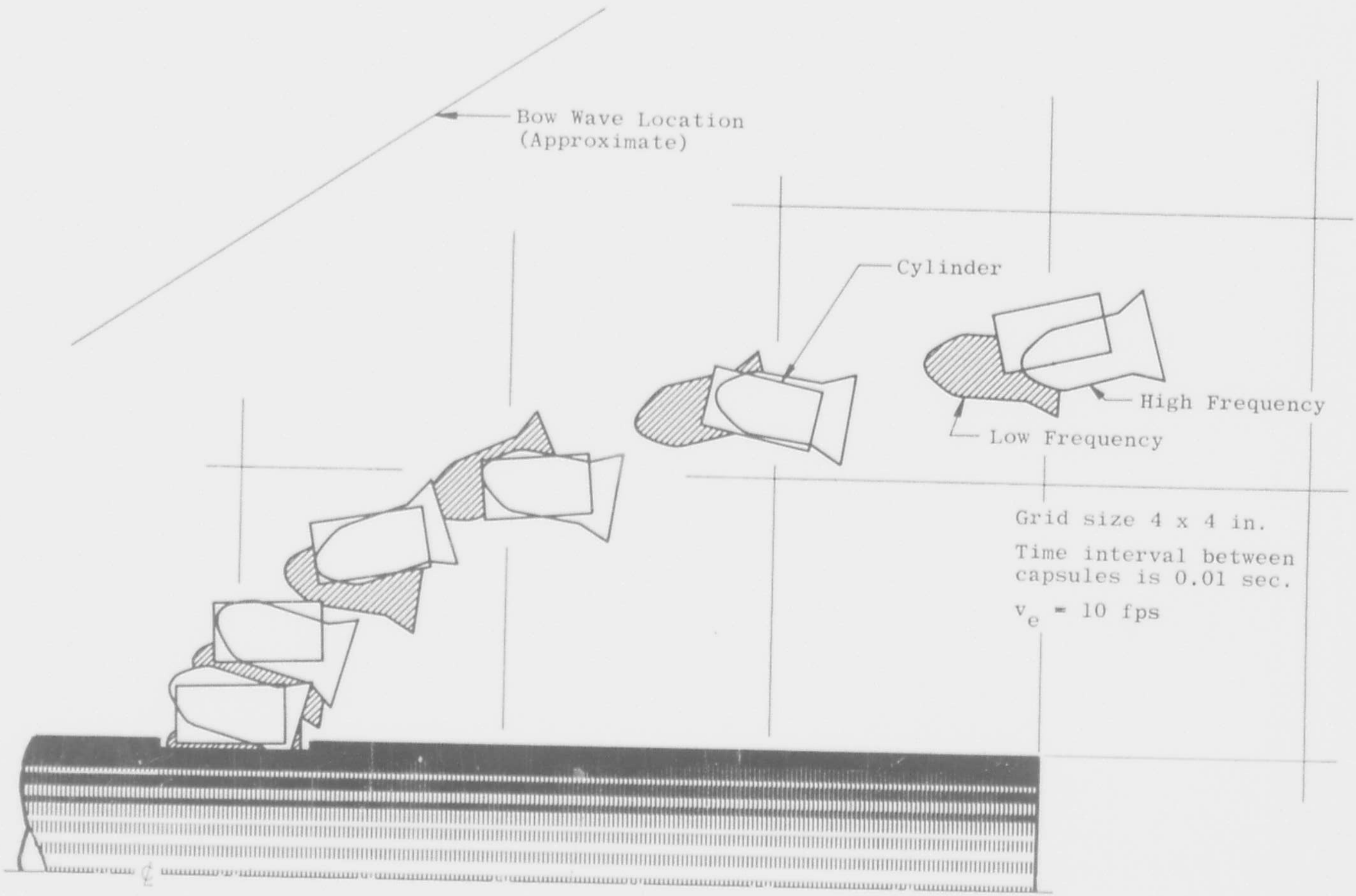
Fig. 4 Ejection Mechanisms

a. Side Ejection of a Flared Capsule in the 40-In. Supersonic Tunnel

b. Side Ejection of Cylindrical Capsule in the 40-In. Supersonic Tunnel

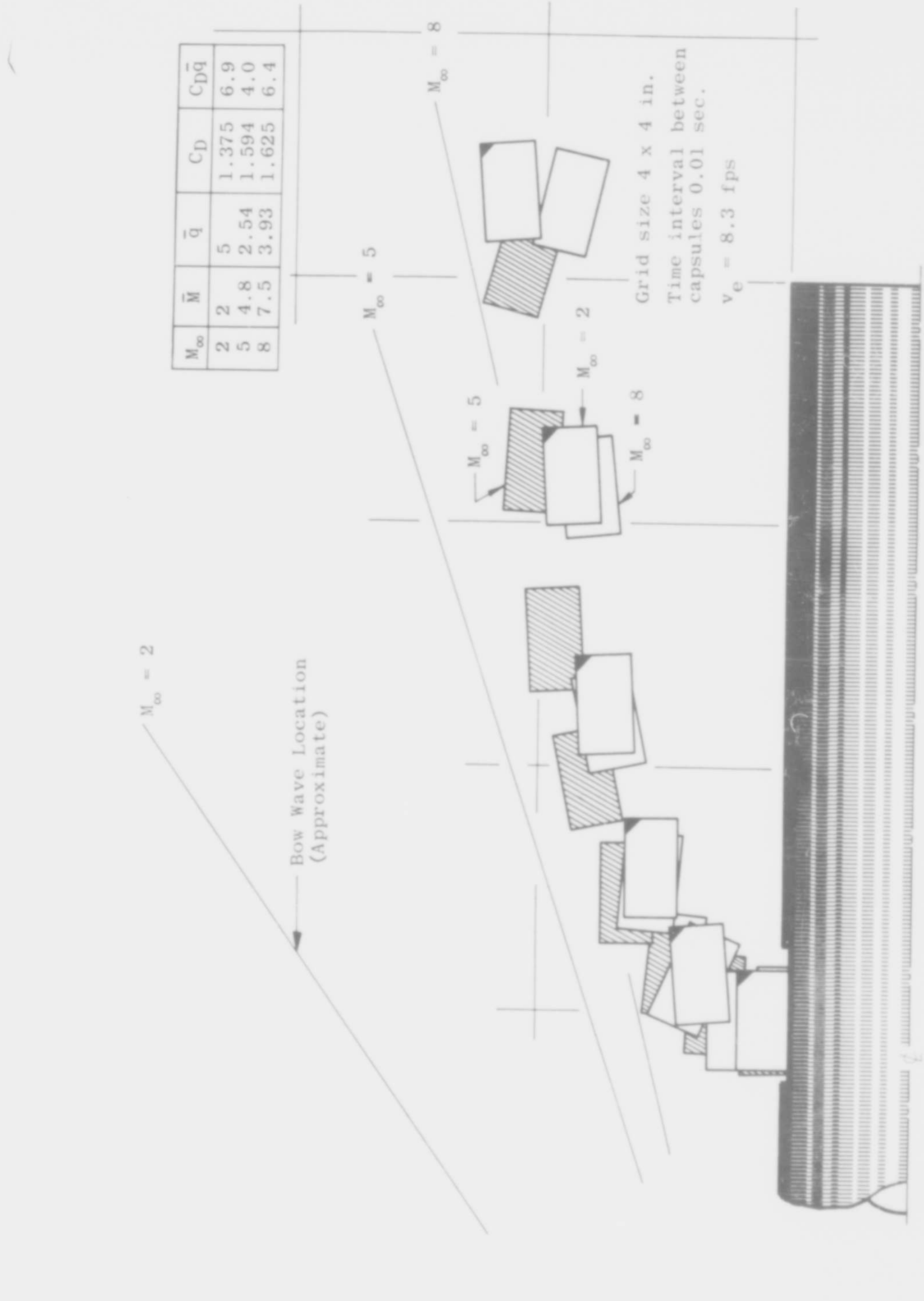
c. Base Ejection (–20 deg) of Cylindrical Capsule in the 50-In. Mach 8 Tunnel

Fig. 5 Typical Trajectories from a Rotating Shutter Polaroid Camera



a. Comparison of Capsule Configurations Ejected at $M_\infty = 2$

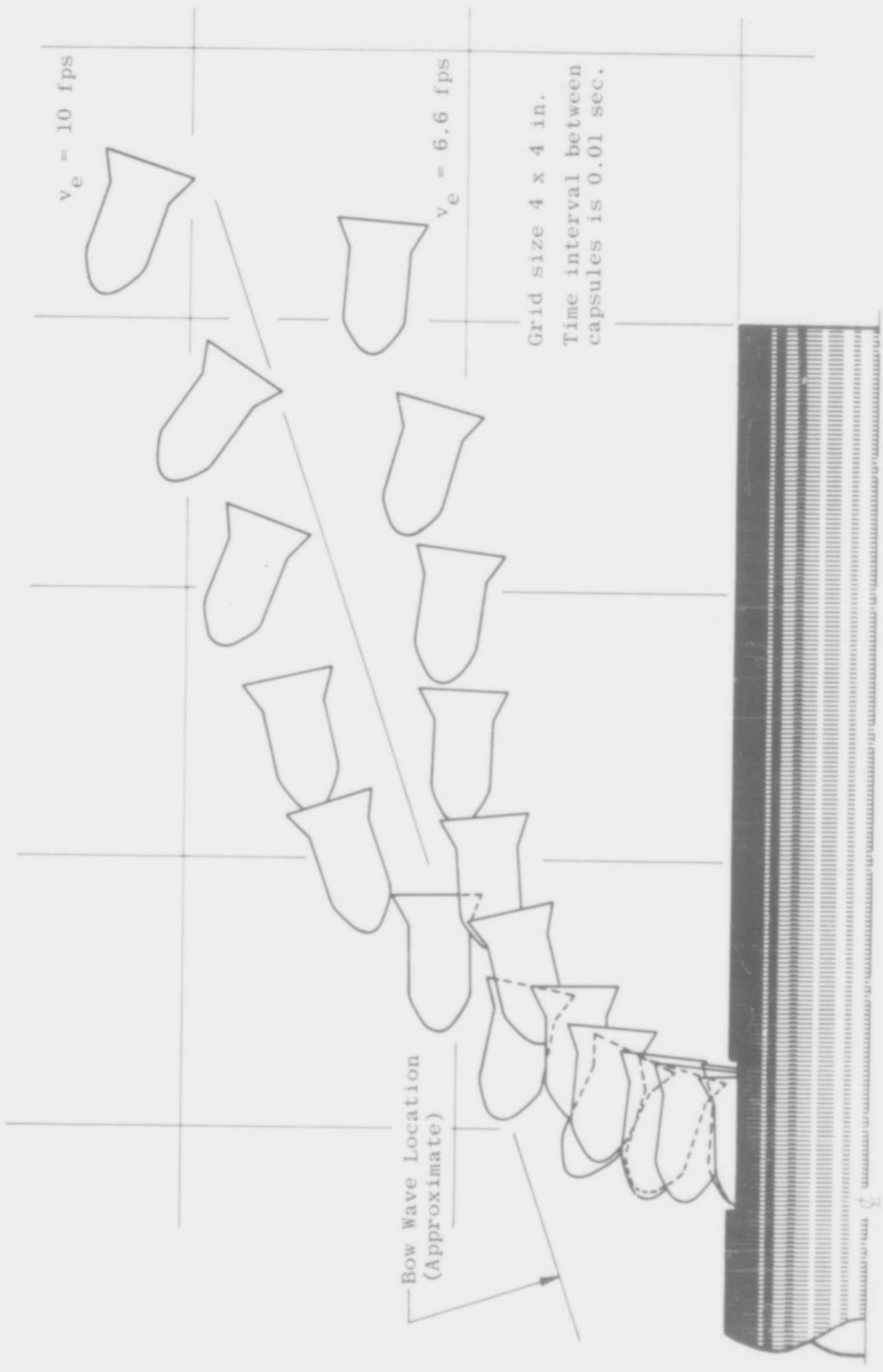
Fig. 6 Side Ejection



M_∞	$\bar{M}$	$\bar{q}$	C_D	$C_D\bar{q}$
2	2	5	1.375	6.9
5	4.8	2.54	1.594	4.0
8	7.5	3.93	1.625	6.4

b. Ejection of Cylindrical Capsule at M_∞ = 2, 5, and 8

Fig. 6 Continued

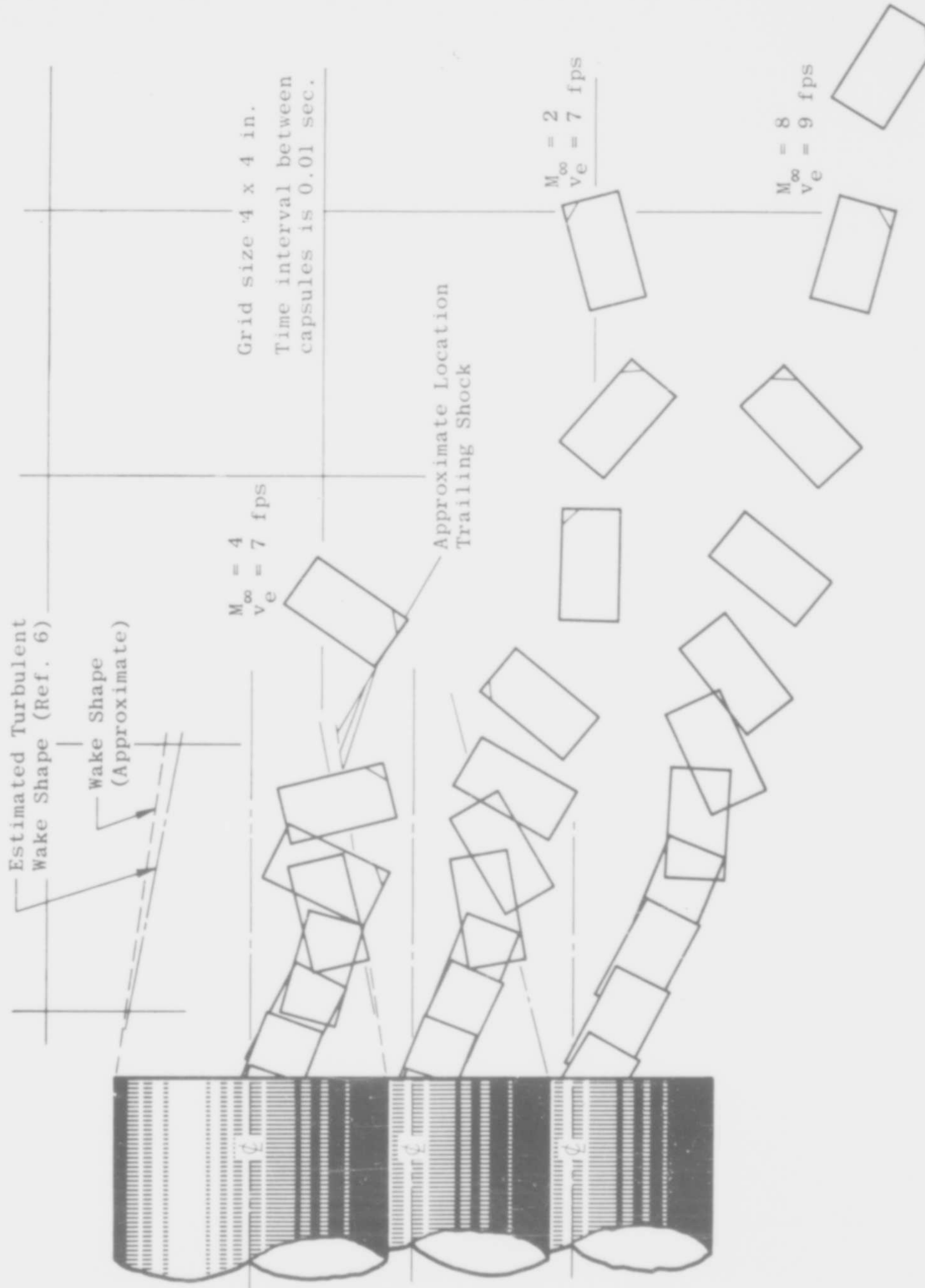


c. Effect of Ejection Velocity on the Trajectory of the Low Frequency Capsule at $M_\infty = 5$

Fig. 6 Concluded

a. Wake Core Ejection of Cylindrical Capsule at M_∞ = 2, 4, and 8

Fig. 7 Base Ejection



b. Wake Penetration of Cylindrical Capsule at M_∞ = 2, 4, and 8

Fig. 7 Concluded

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1. Blunt bodies
2. Ejection
3. Supersonics
4. Vehicles
5. Stability
6. Moments

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Rpt. No. AEDC-TDR-62-79. WIND TUNNEL INVESTIGATION OF CAPSULE EJECTIONS FROM THE SIDE AND BASE OF A CARRIER VEHICLE AT MACH NUMBERS 2, 4, 5, AND 8. April 1962, 23 p. incl 6 refs., illus.
Unclassified Report

Tests were conducted in the 40-Inch Supersonic and 50-Inch Mach 8 Tunnels of the von Kármán Gas Dynamics Facility to determine the separation characteristics of ejected capsules while in the influence of the flow field of the carrier vehicle. High-speed movies were obtained of cylindrical and cone-cylinder flared capsules ejected at Mach numbers 2, 4, 5, and 8 with a constant free-stream Reynolds number of 3.4×10^6 per ft. The capsule orientations along their trajectories are presented to illustrate the results obtained.

1. Blunt bodies
2. Ejection
3. Supersonics
4. Vehicles
5. Stability
6. Moments

I. AFSC Program Area 806A, Project 7856, Task 78548
II. Contract AF 40(600)-800 S/A 24(61-73)
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. L. A. Morgan
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