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INVESTIGATION OF AN ATTACHED INFLATABLE DECELERATOR SYSTEM FOR DRAG AUGMENTATION OF THE VOYAGER ENTRY CAPSULE AT SUPERSONIC SPEEDS

David E. A. Reichenau
ARO, Inc.

April 1968

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INVESTIGATION OF AN ATTACHED INFLATABLE DECELERATOR SYSTEM FOR DRAG AUGMENTATION OF THE VOYAGER ENTRY CAPSULE AT SUPERSONIC SPEEDS

David E. A. Reichenau
ARO, Inc.

FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Langley Research Center, Hampton, Virginia, under Program Area 921E.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted in the Propulsion Wind Tunnel, Supersonic (16S) on January 25, 1968, under ARO Project No. PS1809. The manuscript was submitted for publication on March 8, 1968.

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This technical report has been reviewed and is approved.

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ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment, inflation, and steady-state characteristics of an inflatable decelerator attached to the base of a Voyager entry capsule. Deployments were made at Mach numbers of 2.2 and 3.0 at a free-stream dynamic pressure of 120 psfa. The data obtained show that the preinflation method utilizing vaporization of sufficient liquid solution to completely inflate the decelerator volume resulted in full-inflation times of less than 0.25 sec. The decelerator remained fully inflated after each deployment and exhibited excellent stability.

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NOMENCLATURE

C_{D_D}	Drag coefficient with the AIDS deployed, $\frac{F_D}{q_\infty S_D}$
C_{D_u}	Drag coefficient with the AIDS undeployed, $\frac{F_D}{q_\infty S_u}$
F_D	Measured drag force, lb
M_∞	Free-stream Mach number
p_b	Model base pressure, psf
p_i	Decelerator internal pressure, psf
p_∞	Free-stream static pressure, psf
q_∞	Free-stream dynamic pressure, psf
S_D	Reference area with the AIDS deployed, 19.63 ft^2
S_u	Reference area with the AIDS undeployed, 3.14 ft^2
$\bar{T}_a$	Temperature of aeroshell, °F
T_ℓ	Temperature of liquid solution, °F
α	Model angle of attack, deg

SECTION I
INTRODUCTION

There is an immediate need to advance the design technology of augmenting the drag of Voyager entry capsules. Limitations on the size of the Saturn V booster shroud constrain the maximum diameter of the hard aeroshell entry capsule. This constraint, together with the very low surface density atmospheres presently postulated for Mars, limits the entry capsule weight to a value less than that allowed by the launch vehicle capability. Drag augmentation, therefore, is needed to permit the increases in entry weight required for soft landing the payloads that are ultimately desired. There is an upper limit to the drag that can be obtained by aerodynamic and structural refinement of the aeroshell. Inasmuch as this upper limit is presently being approached by current design, any substantial drag increase must come by deploying additional drag area.

Presently a promising method of obtaining drag augmentation is to deploy an expandable afterbody either from the back end of the entry capsule or from the payload. Among the various possibilities for an expanded afterbody, inflatable pressure vessels show the most promise of achieving low structural weight for the low aerodynamic loading environment of Mars entry.

This report presents the results of wind tunnel tests that were made to determine the deployment and performance characteristics of an Attached Inflatable Decelerator System (AIDS) designed to augment the needed drag of the Voyager capsule in supersonic flow. The AIDS was deployed at nominal Mach numbers of 2.2 and 3.0 at a nominal free-stream dynamic pressure of 120 psfa.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel that presently can be operated at Mach numbers from 1.70 to 3.10. The tunnel can be operated over a stagnation pressure range from 200 to approximately 1800 psfa. The test section stagnation temperature can be controlled through a range of from 150 to 435°F. The tunnel specific humidity is controlled by removing tunnel air and supplying conditioned makeup air from an atmospheric dryer.

Details of the test section showing the model location and sting support arrangement are presented in Fig. 1, Appendix I. A more extensive description of the tunnel and its operating characteristics is contained in Ref. 1.

2.2 TEST ARTICLE

The aeroshell and decelerator represent approximately a 1/10-scale model of the Voyager entry capsule. The exact full-scale dimensions have not been determined at this time. The model consisted of a 120-deg conical aeroshell with a base diameter of 24 in. and an attached inflatable textile canopy that extended to a diameter of 60 in. including a 5-percent burble fence. Major model details and dimensions are shown in Fig. 2. Wind tunnel installation photographs of the model with an undeployed decelerator are shown in Figs. 3 and 4.

The conical aeroshell was made of aluminum alloy sheet, spun-form to final shape after an intermediate stabilizing heat treatment. A rigid, close fitting, low carbon steel tube served as the transitional support between the sting-mounted internal balance and the aeroshell.

The AIDS unit was constructed of Nomex® cloth and coated with Viton® (a high temperature rubber). The inflatable afterbody decelerator was designed for minimum weight by applying the concept of isotensoid design as presented in Ref. 2. Four symmetrically located inlets permitted ram air to maintain the necessary inside pressure level after deployment. The maximum diameter of the decelerator is 60.0 in., a basic diameter of 54.6 in. plus a 5-percent burble fence. The decelerator was secured to the aeroshell by clamping the canopy end bands. The outer attachment is made to the aeroshell profile with an aluminum clamping ring, and the inner attachment is made to the balance housing with steel clamping sectors as shown in Fig. 2.

Deployment of the AIDS from the base of the aeroshell was accomplished by preinflation using vaporization of sufficient liquid to completely inflate the decelerator volume. A 0.5-in.-ID hose, coiled within the nose of the conical aeroshell, served as the liquid reservoir until severed at its center by a pyrotechnic cutter mechanism. The decelerator was restrained in its packaged configuration in the aeroshell stowage compartment by a series of loops assembled together to form a "daisy chain" hoop around the balance housing as shown in Fig. 5. Pyrotechnic cutters were provided to sever the chain retaining cord on a given electrical signal to completely release the chain restraint.

2.3 INSTRUMENTATION

An internally mounted, six-component, strain-gage balance was used to measure the model forces to within ±10 lb for the range of loads measured during these tests. The decelerator internal pressure was measured with a model-mounted, 5-psid transducer. The internal temperature of the decelerator was measured by iron-constantan (IC) thermocouples. Five motion-picture cameras and a television camera, installed in the test section walls, were used to document and monitor the test.

Outputs from the balance, pressure transducer, and thermocouples were digitized and code punched on paper tape for on-line data reduction. These inputs were also continuously recorded on direct-writing and film pack oscillographs for monitoring model dynamics.

SECTION III
PROCEDURE

The AIDS unit was carefully packed into the aeroshell stowage compartment before wind tunnel test operation was initiated. Once the prescribed test conditions were established, steady-state data were obtained for the undeployed configuration. A countdown procedure was used to sequence data acquisition during the AIDS deployment. The deployments were made at free-stream Mach numbers of 2.2 and 3.0 at a free-stream dynamic pressure of 120 psfa. The deployment procedure consisted of activating the recording oscillographs and test section cameras, followed by energizing an automatic sequencer system which initiated the signal to the daisy chain pyrotechnic cutters 0.5 sec before severing the liquid reservoir. Upon completion of the AIDS deployment sequence, steady-state loads were calculated by averaging the analog signals from the balance over a 1-sec interval.

SECTION IV
RESULTS AND DISCUSSION

An inflatable decelerator attached to the base of a Voyager entry capsule was deployed at free-stream Mach numbers of 2.2 and 3.0 at a free-stream dynamic pressure of 120 psfa. Deployment, inflation, and steady-state data were obtained from both deployments. The decelerator was deployed with the Voyager capsule at zero angle of yaw and angle of attack. The steady-state data obtained after deployment at M_∞ = 2.2 were in error as a result of a tunnel-induced normal shock wave located near the base of the decelerator. This shock wave resulted from a partial unstart of the test section flow which allowed the normal shock to move upstream from the tunnel diffuser. After test conditions were changed to $M_\infty = 2.0$, dynamics encountered during a momentary unstart of test section flow caused failure of the canopy. Data at $\alpha = 2$ and 5 deg were obtained after deployment at $M_\infty = 3.0$. At $\alpha = 5$ deg dynamics occurred that resulted in canopy failure. These dynamics were similar to the dynamics at $M_\infty = 2.0$; however, there was no indication of the tunnel flow unstarting. A summary of test conditions is presented in Table I (Appendix II).

4.1 DEPLOYMENT AND INFLATION CHARACTERISTICS

The decelerators were equipped with a method of preinflation by vaporization of sufficient liquid to completely inflate the decelerator volume upon being exposed to the low static pressure of the wind tunnel. The vapor inflation is intended not only to prevent the lightweight fabric from excessive rubbing against itself during the unfolding process but also to provide for quick erection of the ram-air inlets into the air stream for immediate transfer from pressurization by self-inflation to ram-air pressurization.

The deployment-time histories of the decelerator drag load and internal pressure rise presented in Fig. 6 were found to vary for the two deployments. The deployment at $M_\infty = 2.2$ exhibits essentially a uniform increase in drag force to the steady-state value. However, the deployment at $M_\infty = 3.0$ shows an oscillating opening shock force with a peak load reaching the magnitude of the steady-state drag value. It is believed that the opening shock forces encountered are primarily a function of the amount of liquid stored in the scaled reservoir. As noted in Table I, twice the amount of liquid was used to inflate the decelerator deployed at $M_\infty = 3.0$ as compared to the deployment at $M_\infty = 2.2$. Differences in the model temperature and Mach number prior to each deployment may also contribute to the different deployment characteristics.

The force-time curves presented in Fig. 6 and the photographic coverage obtained by motion-picture cameras show that the AIDS deployment and inflation to maximum steady-state drag loads at $M_\infty = 2.2$ and 3.0 required approximately 0.25 and 0.20 sec, respectively. Inflatable decelerators previously tested at AEDC at similar test conditions attained full inflation in approximately 1.25 sec using ram air only and approximately 0.50 sec when ram air was augmented by vaporization of a liquid solution (Ref. 3). Photographs showing various stages of the two deployments are presented in Fig. 7.

4.2 STEADY-STATE CHARACTERISTICS

The drag coefficients for the Voyager capsule with and without the AIDS deployed are shown in Table I. The drag coefficients of the undeployed configuration are based on the aeroshell reference area, and the drag coefficients of the deployed configuration are based on the AIDS reference area. Photographic coverage and oscillograph traces obtained during the tests indicated that the fully inflated decelerator was very stable in the wake of the aeroshell with no oscillating forces or moments.

The drag coefficients for various model angles of attack with and without the AIDS deployed are presented in Fig. 8 for a free-stream Mach number of 3.0. The AIDS failed after data were obtained at $\alpha = 5$ deg. An increase in angle of attack decreased the drag coefficient of both deployed and undeployed configurations.

SECTION V
CONCLUDING REMARKS

Tests were conducted to investigate the deployment, inflation, and steady-state characteristics of an inflatable decelerator attached to the base of a Voyager entry capsule. Deployments were made at Mach numbers of 2.2 and 3.0 at a free-stream dynamic pressure of 120 psfa. The following observations are a result of these tests:

1. A preinflation method utilizing vaporization of sufficient liquid solution to completely inflate the decelerator volume resulted in full inflation times of less than 0.25 sec. This rapid inflation prevented excessive rubbing of the canopy fabric during the unfolding and inflation process.
2. The AIDS remained fully inflated and exhibited excellent stability after each deployment.

REFERENCES

1. Test Facilities Handbook (Sixth Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, November 1966.
2. Houtz, N. "Optimization of Inflatable Drag Devices by Isotensoid Design." AIAA Paper No. 64-437, First Annual AIAA Meeting, Washington, D. C., June 29 through July 2, 1964.
3. MacLanahan, D. A, Jr. "An Investigation of Various Types of Decelerators at Mach Number 2.8." AEDC-TR-66-136 (AD485279), July 1966.

APPENDIXES

I. ILLUSTRATIONS

II. TABLE

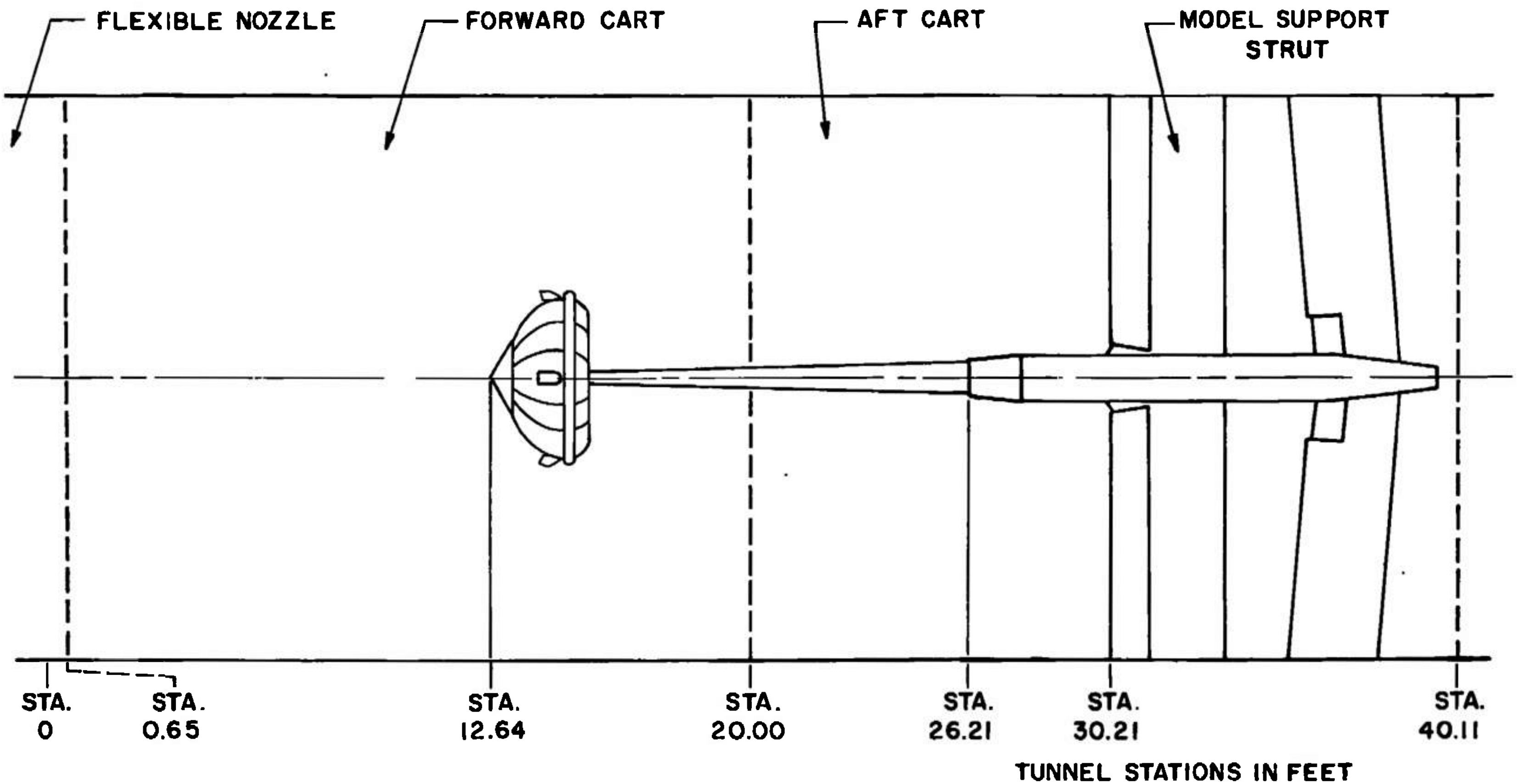
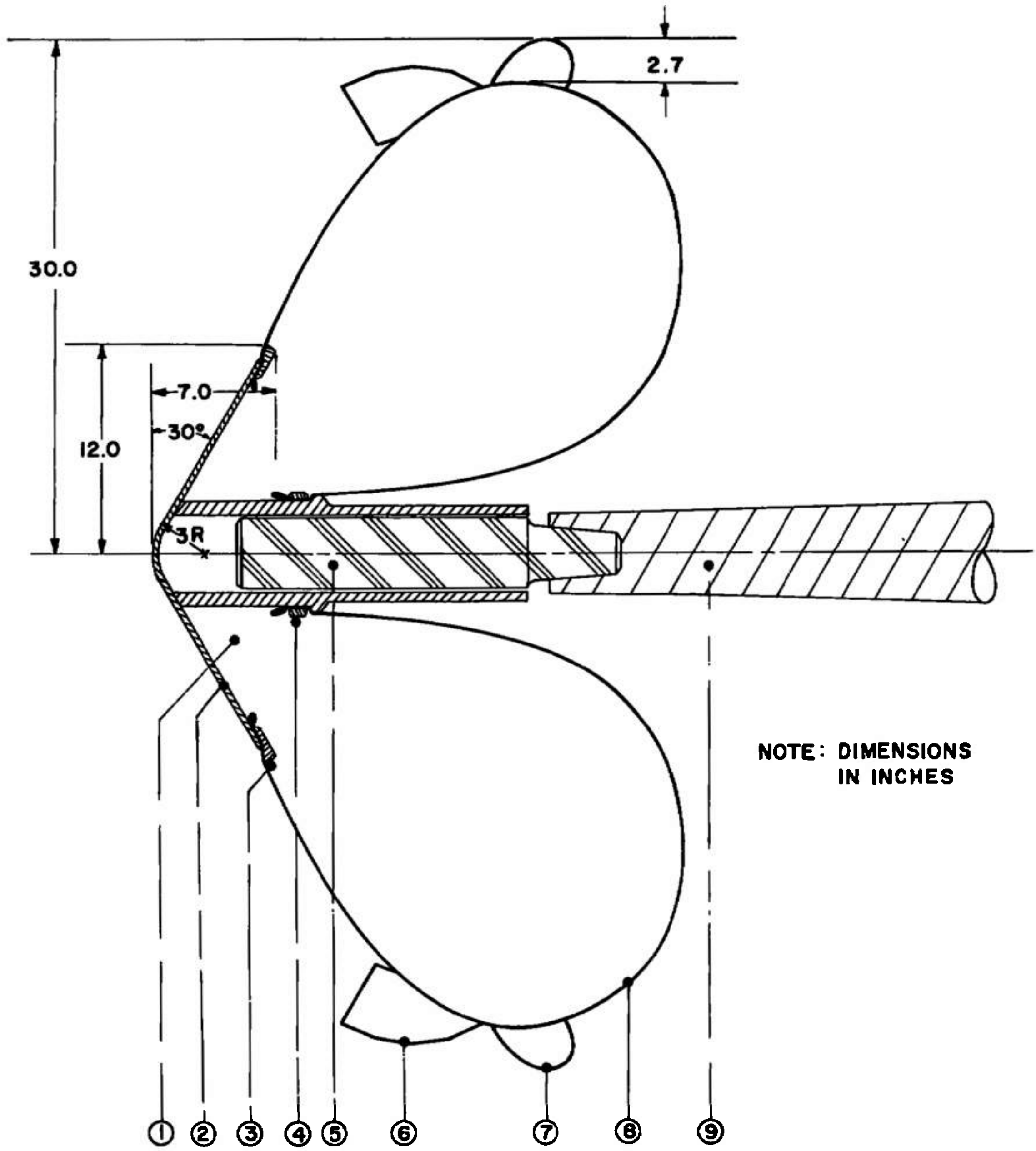


Fig. 1 Location of Model in Test Section



1. DECELERATOR STOWAGE COMPARTMENT
2. AEROSHELL
3. DECELERATOR CLAMP (OUTER)
4. DECELERATOR CLAMP (INNER)
5. SIX-COMPONENT BALANCE
6. DECELERATOR RAM-AIR INLETS (TYP. 4 PLACES)
7. BURBLE FENCE
8. INFLATABLE DECELERATOR
9. STING SUPPORT

Fig. 2 Details of Voyager-AIDS Model

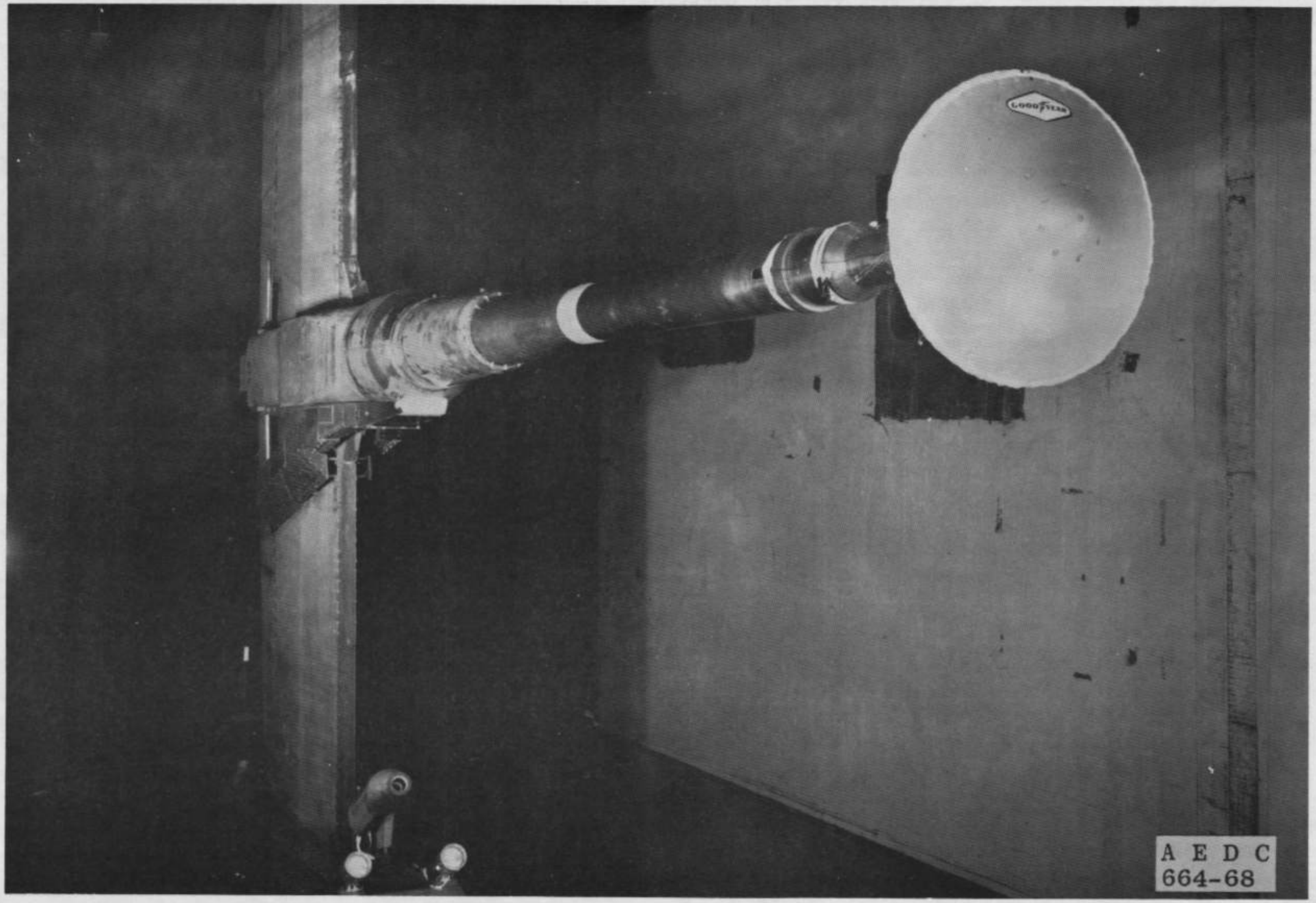


Fig. 3 Installation of Undeployed Model in Test Section

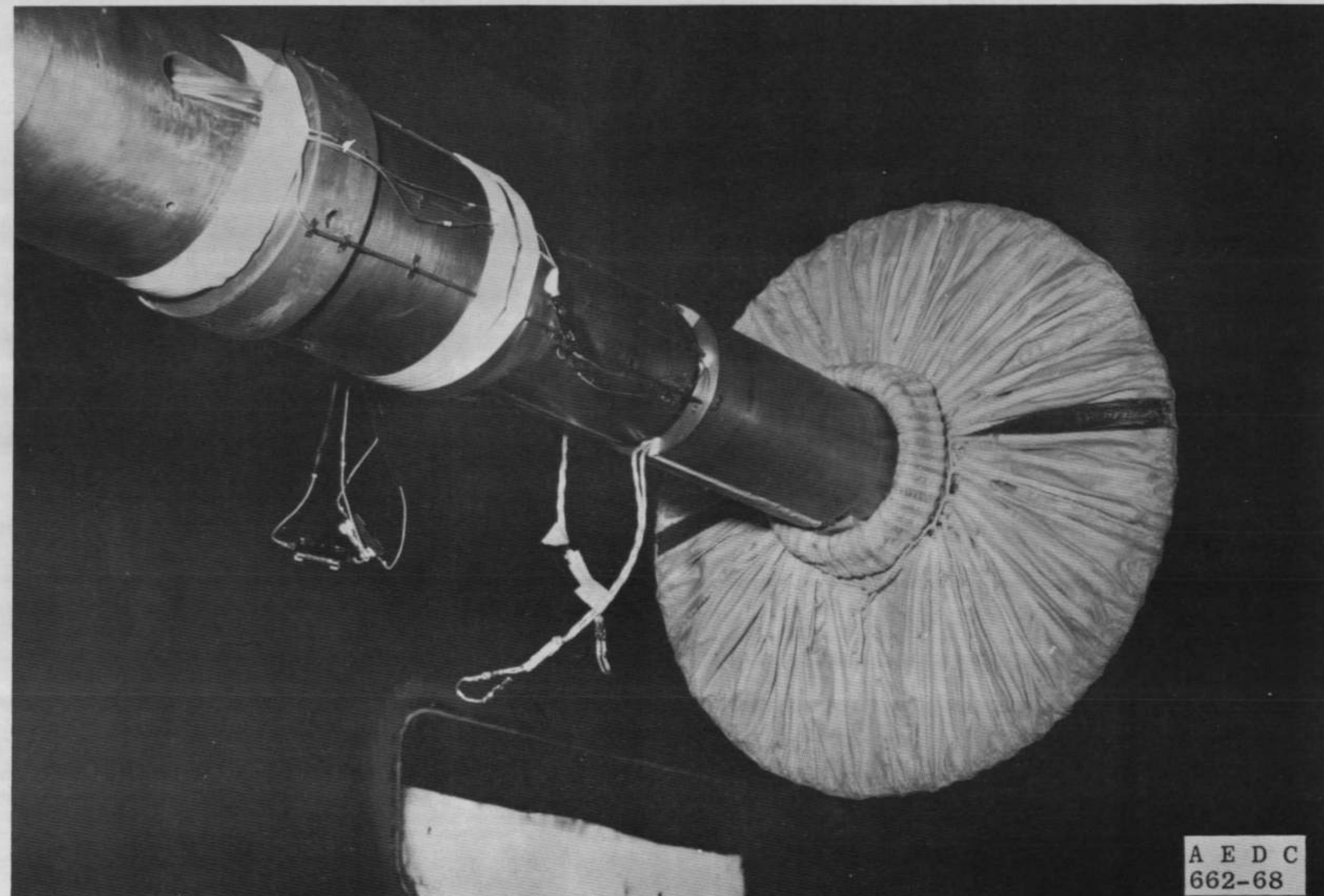
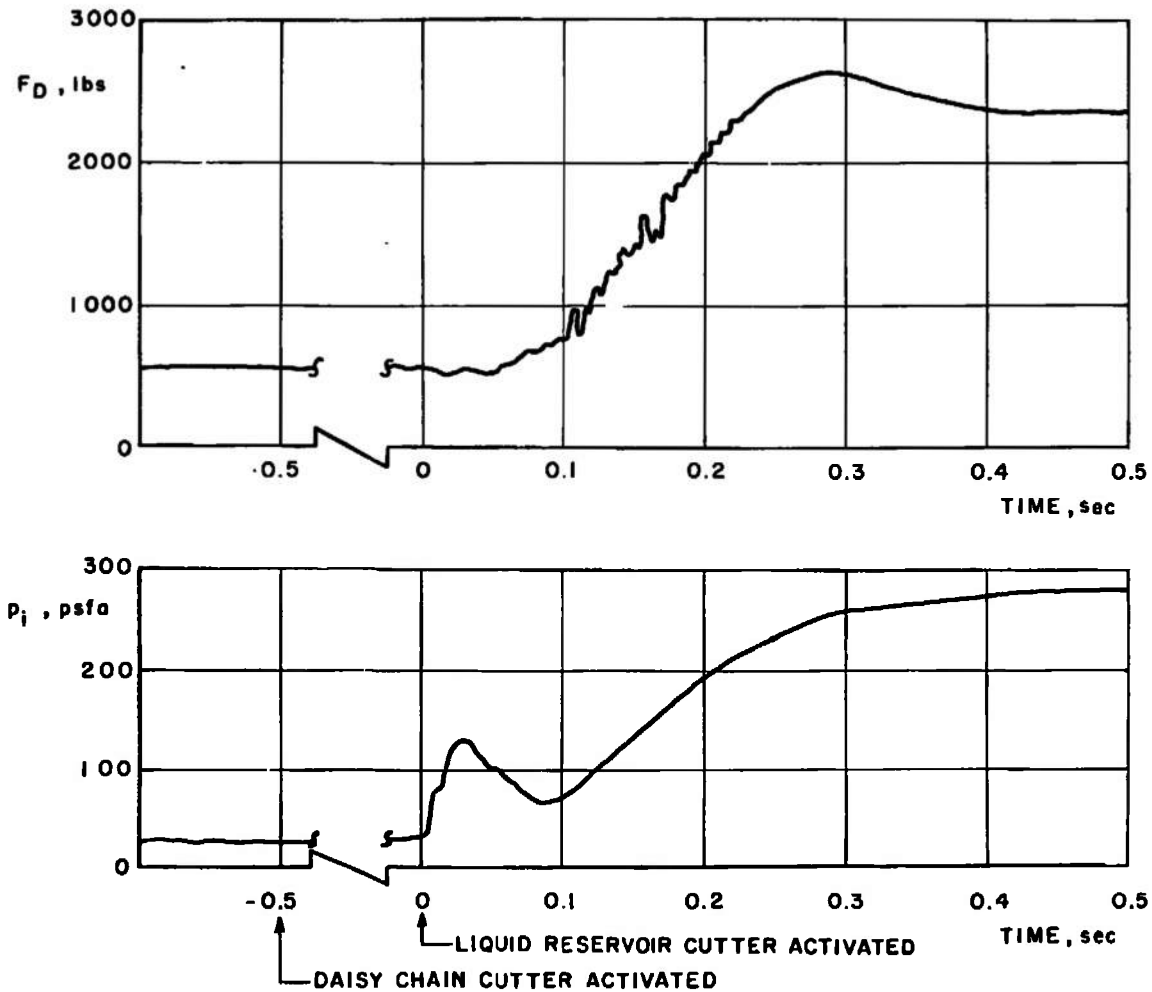


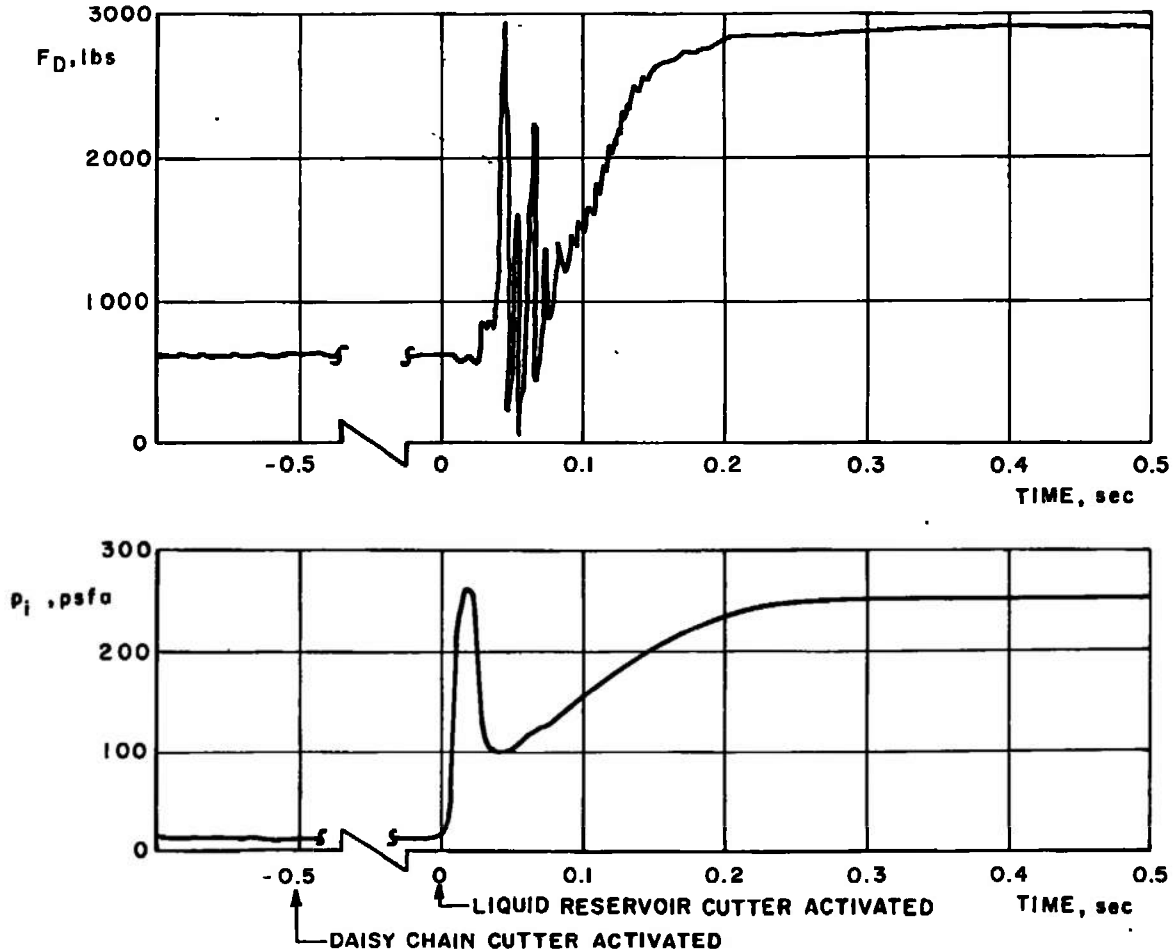
Fig. 4 Three-Quarter Rear View of Undeployed Model

Fig. 5 Packaged Decelerator and "Daisy Chain" Restraint System



a. $M_\infty = 2.2$

Fig. 6. Decelerator Deployment Characteristics



b. $M_\infty = 3.0$

Fig. 6 Concluded

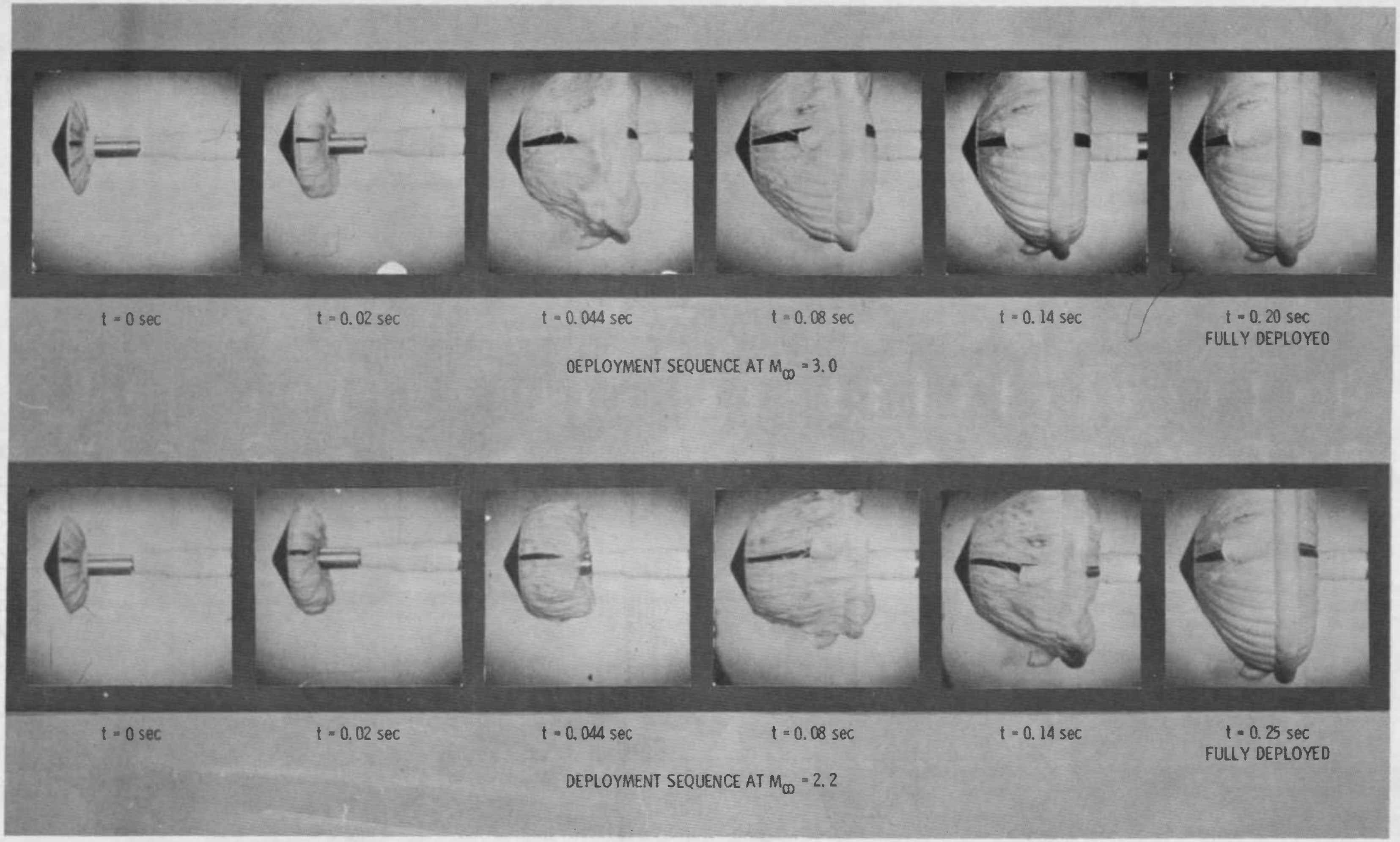


Fig. 7 Photographs of the Deployment Sequence

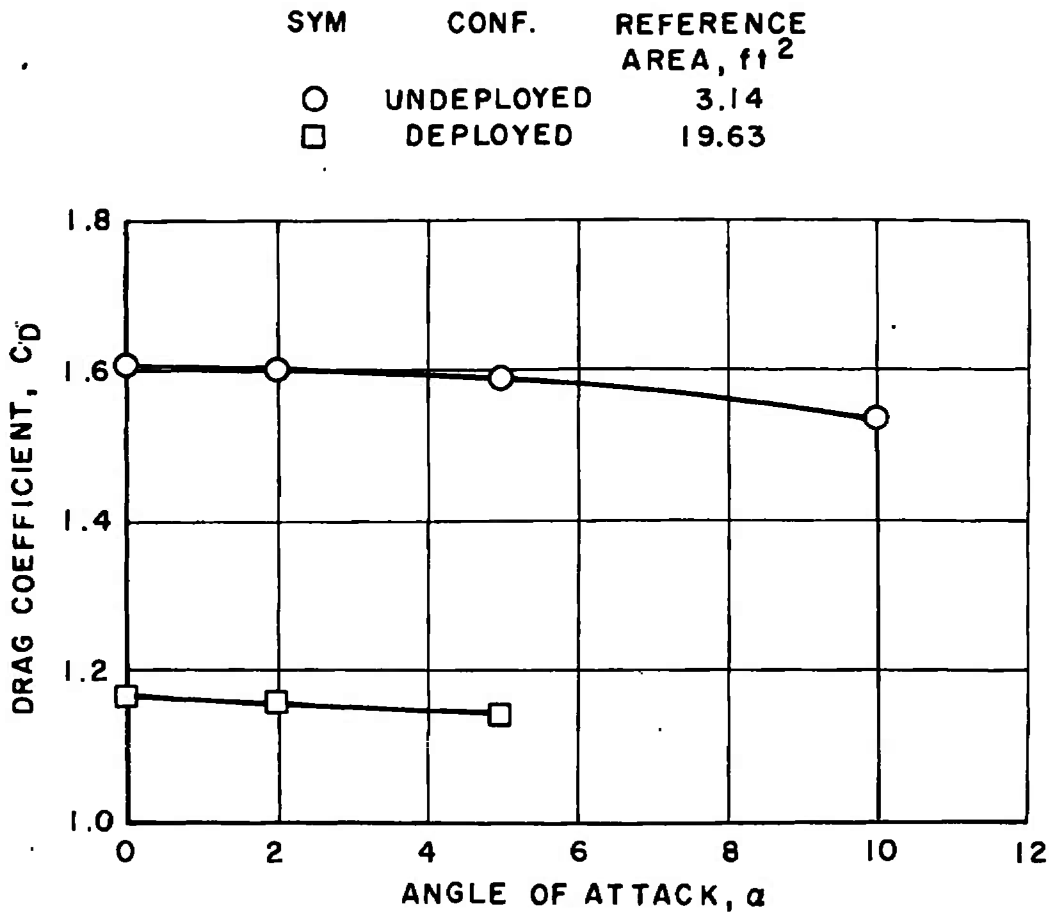


Fig. 8 The Effect of Angle of Attack on the Model Drag Coefficient, $M_\infty = 3.0$, $q_\infty = 120$ psfa

TABLE I
SUMMARY OF TEST CONDITIONS

Configuration	M_∞	q_∞, psfa	α, deg	Reference Area, ft^2	Amount of Liquid Solution, Fluid oz*	Temperature, °F		Pressure, psfa			C_D
						T_ℓ	T_a	p_∞	p_b	p_i	
Undeployed	2.2	120.8	0	3.14	6	113	153	35.7	18.2	29	1.49
Deployed	2.2	120.5	0	19.63	---	---	153	35.6	---	212	---
Undeployed	3.0	120.2	0	3.14	12	123	160	19.1	10.2	14	1.61
Deployed	3.0	120.2	0	19.63	---	---	156	19.1	9.9	238	1.16
Deployed	3.0	120.3	2	19.63	---	---	156	19.1	10.1	238	1.16
Deployed	3.0	120.5	5	19.63	---	---	157	19.1	10.2	237	1.14

*The liquid utilized was 50-percent methyl alcohol (CH_3OH) and 50-percent water (H_2O) by volume.

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13. ABSTRACT

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entry vehicles						
decelerator systems						
supersonic flow						

1. Decelerators -- Reentry
2 Reentry bodies -- Deceleration
"
3 "

19-4