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AEDC-TR-69-132

INVESTIGATION OF AN ATTACHED INFLATABLE DECELERATOR WITH MECHANICALLY DEPLOYED INLETS AT MACH NUMBERS FROM 2.25 TO 4.75

D. C. Baker
ARO, Inc.

June 1969

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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 F40600-69-C-0001. The test was conducted in the Propulsion Wind Tunnel, Supersonic (16S), on May 2 and 3, 1969, under ARO Project No. PS1961. The manuscript was submitted for publication on May 16, 1969.

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This technical report has been reviewed and is approved.

Richard W. Bradley
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Director of Test

ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment, inflation, and steady-state characteristics of an attached inflatable decelerator with mechanically deployed inlets. Deployments were made at Mach numbers 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psf, respectively. The mechanically deployed inlet system resulted in successful deployments of the three test models with inflation times of from 0.4 to 0.7 sec.

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NOMENCLATURE

C_{D_D}	Drag coefficient with the AID deployed, $F_D/q_\infty S_D$
C_{D_u}	Drag coefficient with the AID undeployed, $F_D/q_\infty S_u$
F_D	Measured drag force, lb
M_∞	Free-stream Mach number
P_r	Permeability, the volume of air that will pass through 1 ft^2 of material in 1 min at 1/2 in. of water pressure, ft^3/min/ft^2
p_i	Decelerator internal pressure, psfa
p_{t_∞}	Free-stream total pressure, psfa
q_∞	Free-stream dynamic pressure, psf
S_D	Reference area with the AID deployed, 19.63 ft^2
S_u	Reference area with the AID undeployed, 3.14 ft^2
t	Time, sec
α	Model angle of attack, deg

SECTION I
INTRODUCTION

Methods of decelerating an aeroshell entry capsule in a low surface density atmosphere are presently under investigation. Since there is an upper limit to the drag that can be obtained by aerodynamic and structural refinement of the aeroshell, there is a need for drag augmentation. At present a promising method of obtaining drag augmentation is to deploy a lightweight expandable afterbody from the aft end of an aeroshell capsule. Among the various possibilities for an expanded afterbody, inflatable pressure vessels show the most promise for a drag augmentation system with a high drag-to-weight ratio.

This test was an extension of two previous tests conducted in Propulsion Wind Tunnel, Supersonic (16S), during April and August of 1968 and reported in Refs. 1 and 2. During these initial tests of the Attached Inflatable Decelerator System (AIDS), a liquid vaporization system was used to initiate the inflation sequence of the AID models. This inflation system resulted in reliable deployment of the decelerators with short inflation times; however, the large quantity of liquid that would be required for a full-scale decelerator system would result in a high weight penalty. The liquid vaporization system was, therefore, replaced by four, lightweight, mechanically deployed inlets located at the trailing edge of the aeroshell. Deployment of these spring-loaded inlets into the airstream initiated the AID inflation sequence which was completed either by the inlets located on the aeroshell or by four additional ram-air inlets located just ahead of the burble fence.

This report presents the results of tests conducted in Tunnel 16S of the Propulsion Wind Tunnel Facility to obtain the deployment and performance characteristics of an AID system with mechanically deployed inlets to initiate the inflation sequence. Two of the AID models were deployed at a nominal free-stream Mach number of 4.4 with a free-stream dynamic pressure of 73 psf. The third model was deployed at a nominal free-stream Mach number of 3.0 with a free-stream dynamic pressure of 120 psf.

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 1.50 to 4.75. The tunnel can be operated over a stagnation pressure range from 200 to approximately 2300 psfa. The test section stagnation temperature can be controlled through a range of from 100 to 620°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 in the Appendix. A more extensive description of the tunnel and its operating characteristics is contained in Ref. 3.

2.2 TEST ARTICLE

The three similar test models 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. Each of the models had four mechanically deployed inlets (see Fig. 2) attached to the base of the aeroshell at 90-deg intervals. In addition, one of the models had four conventional ram-air inlets located just forward of the burble fence and rotated 45 deg with respect to the forward inlets. Major model details and dimensions are shown in Fig. 3, and a sketch showing the inlet locations is presented in Fig. 4. Wind tunnel installation photographs of the aeroshell model with the decelerator stowed are shown in Fig. 5. Photographs of the three models with the decelerator deployed at various free-stream Mach numbers are shown in Fig. 6.

The conical aeroshell was made of aluminum alloy sheet, spun formed into 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 AID unit was constructed of Nomex® cloth and coated with Viton® (a high temperature rubber). The inflatable afterbody was designed for minimum weight by applying the concept of isotensoid design, Ref. 4. 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. 3.

The decelerator was restrained in its package 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. 5c. Pyrotechnic cutters were provided to sever the chain restraining cord so as to completely release the chain restraint on a given electrical signal. Deployment of the AID from the base of the aeroshell was then accomplished by releasing the mechanically deployed inlets which were held in the stowed position (see Fig. 5c) by a restraining cord looped around the balance housing. Release of the inlets was accomplished by severing the restraining cord with a pyrotechnic cutter approximately 0.5 sec after release of the daisy chain.

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. Six 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 and pressure transducer 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 AID 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 AID deployment. 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 mechanically deployed inlet restraining cord. Upon completion of the AID 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

Deployment, inflation, and steady-state data were obtained for three inflatable decelerator models attached to the base of an aeroshell entry capsule. Two of the models were deployed at a free-stream Mach number of 4.4 with a dynamic pressure of 73 psf, and the other model was deployed at a free-stream Mach number of 3.0 with a dynamic pressure of 120 psf. After the deployment sequence was completed, the decelerator performance was investigated at various free-stream Mach numbers and model angles of attack. A summary of the test conditions is presented in Table I.

TABLE I
SUMMARY OF TEST CONDITIONS

Model Number	Deployed Condition	M_∞	q_∞, psf	α, deg	AID Configuration
1	Undeployed	4.40	73	0 to 10	1. Four inlets located on the aeroshell
	Deployed	4.40	73	0	
	Deployed	4.75	60	0 to 10	2. Fabric permeability (P_r) 0.02 $ft^3/min/ft^2$
	Deployed	4.00	120	0	
	Deployed	3.80	120	0	
2	Undeployed	3.00	120	0 to 10	1. Four inlets located on the aeroshell plus four inlets just ahead of the burble fence 2. Fabric permeability (P_r) 0.02 $ft^3/min/ft^2$
	Deployed	3.00	120	0 to 10	
3	Undeployed	4.40	73	0 to 10	1. Four inlets located on the aeroshell
	Deployed	4.40	73	0 to 10	
	Deployed	7.75	60	0 to 10	2. Fabric permeability (P_r) 10.0 $ft^3/min/ft^2$
	Deployed	4.00	80	0	
	Deployed	3.50	120	0	
	Deployed	3.00	115	0	
	Deployed	2.50	80	0	
	Deployed	2.25	85	0	

4.1 DEPLOYMENT CHARACTERISTICS

One of the primary objectives of this test was to determine the deployment characteristics of AID models with a mechanically deployed inlet system for initiation of the inflation sequence. This mechanically deployed inlet system replaced a liquid vaporization inflation system utilized in previous tests of similar models to obtain rapid and reliable deployments.

The deployment-time histories of the decelerator drag load and internal pressure rise are presented in Figs. 7 through 9. The first decelerator deployment (Fig. 7) was made at Mach number 4.4 and required approximately 0.7 sec to reach full inflation. It should be noted, however, that after 0.4 sec the decelerator had reached 80 percent of the maximum drag value and was quite stable. A comparison of the deployment-time history is made in Fig. 7 with an AID model using the liquid vaporization technique for inflation initiation (Ref. 2). The drag and internal pressure rise for the two systems show similar trends and required approximately the same time to reach full inflation. The disagreement in the maximum level of the decelerator drag for the similar AID models at the same test conditions will be discussed under steady-state characteristics (Section 4.2).

The second decelerator deployment (Fig. 8) was made at a free-stream Mach number of 3.0 and required approximately 0.4 sec to reach full inflation. Comparison of this deployment with an AID model using a liquid vaporization system indicated that the mechanically deployed inlet system took approximately 0.2 sec longer to reach full inflation at the same test conditions. It should be noted, however, that the AID deployment with the liquid vaporization system had a sharp pressure rise immediately after initiation of the deployment resulting in a decelerator overpressure. This was the first deployment made with the liquid vaporization system, and all subsequent deployments were made with a 50-percent reduction in the amount of liquid to reduce the initial pressure rise.

The third decelerator deployment (Fig. 9) was made at a free-stream Mach number of 4.4 and required approximately 0.7 sec to reach the maximum level of drag load and internal pressure. This third decelerator was constructed with a fabric having a permeability 500 times greater than the two previous models to investigate the effect of porosity on the decelerator performance. The leak rate of the third model was so great that the decelerator never reached what is considered full inflation and exhibited excessive fabric flutter at all test conditions. Photographs showing various stages of the three deployments are presented in Fig. 10.

4.2 STEADY-STATE CHARACTERISTICS

Steady-state drag data were obtained for the AID models at free-stream Mach numbers from 2.25 to 4.75 and at angles of attack from 0 to 10 deg. The drag coefficients presented for the undeployed configuration are based on the aeroshell reference area, S_u, and the drag coefficients of the deployed configurations are based on the AID reference area, S_D. Photographic coverage and oscillograph traces obtained during tests of models 1 and 2 indicated that, for all test conditions including angles of attack through 10 deg, the fully inflated decelerator was very stable with no oscillating forces or moments. Model 3 had a high fabric permeability (P_r) and did not reach full inflation.

The decelerator drag coefficient and corresponding pressure ratio (p_i/p_{t_∞}) are presented in Figs. 11 and 12, respectively, for the three models investigated. The data obtained with model 2 at a free-stream Mach number of 3.0 shows close agreement with previous test data of a similar model (Ref. 2). No further data were obtained for model 2 because of an inadvertent tunnel flow unstart during a Mach number transient from 3.0 to 2.5.

Steady-state drag data (Fig. 11) were obtained for model 1 at Mach numbers from 3.8 to 4.75. Comparison of these data with previous test data of a similar model (Ref. 2) shows a 6-percent reduction in the drag coefficient. The photographic coverage of the deployment of model 1 shows that the daisy chain loops did not separate smoothly during the deployment sequence. As a result, several 2- to 3-in. slits were torn in the decelerator fabric parallel to the meridian tapes where the daisy loops were attached. The AID pressure ratio presented in Fig. 12 shows that model 1 had a reduced internal pressure compared with a previous test model; and, as a result, the model was not as fully inflated, causing the reduction in drag coefficient.

Steady-state drag data (Fig. 11) were obtained for model 3 at Mach numbers from 2.25 to 4.75. The fabric permeability of model 3 was much greater (500/1) than for the previous models; and, as a result, the decelerator had poor inflation and approximately 35-percent reduction in the steady-state drag coefficient. As shown in Fig. 12, the leak rate of model 3 was so great that the pressure ratio (p_i/p_{t_∞}) was approximately 50 percent lower than obtained with other models.

The drag coefficients of the aeroshell without and with the decelerator deployed are presented in Figs. 13 and 14, respectively, for angles of attack from 0 to 10 deg. An increase in angle of attack decreased the drag coefficient of both the deployed and undeployed configurations. However, the decrease in the deployed drag coefficient (Fig. 14) with angle of attack was less than two percent at all test Mach numbers showing good decelerator performance at angles of attack through 10 deg. Comparison of these data with results from previous tests show close agreement between the similar models.

SECTION V
CONCLUDING REMARKS

Tests were conducted to investigate deployment, inflation, and steady-state characteristics of an AID system with mechanically deployed inlets. Deployments were made at Mach numbers 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psf, respectively. The following observations are a result of these tests:

1. Inflation of the AID models with the mechanically deployed inlet system resulted in successful deployment of the three models with inflation times of from 0.4 to 0.7 sec.
2. Deployment and inflation characteristics of the models with mechanically deployed inlets compared favorably with the liquid vaporization inflation system used in previous tests.
3. The AID models 1 and 2 remained fully inflated and exhibited excellent stability characteristics at all test Mach numbers and angles of attack through 10 deg.
4. Increasing the fabric permeability from 0.02 to 10 $ft^3/min/ft^2$ resulted in poor decelerator inflation and a 35-percent reduction in drag coefficient.
5. The steady-state drag coefficient of the deployed decelerators decreased less than two percent as the angle of attack was increased to 10 deg.

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3. Test Facilities Handbook (7th Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, July 1968.
4. Houtz, N. E. "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.

APPENDIX
ILLUSTRATIONS

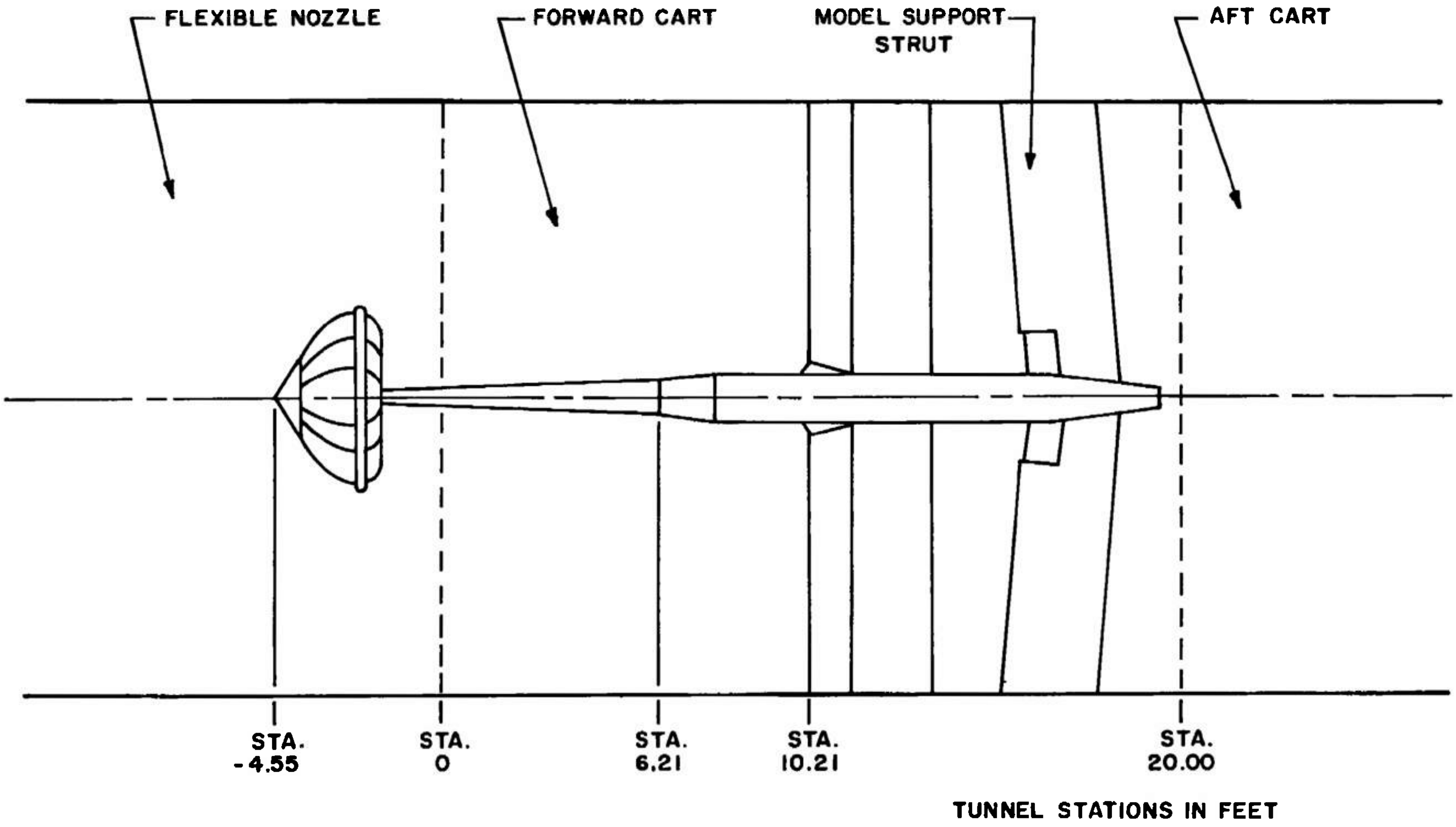
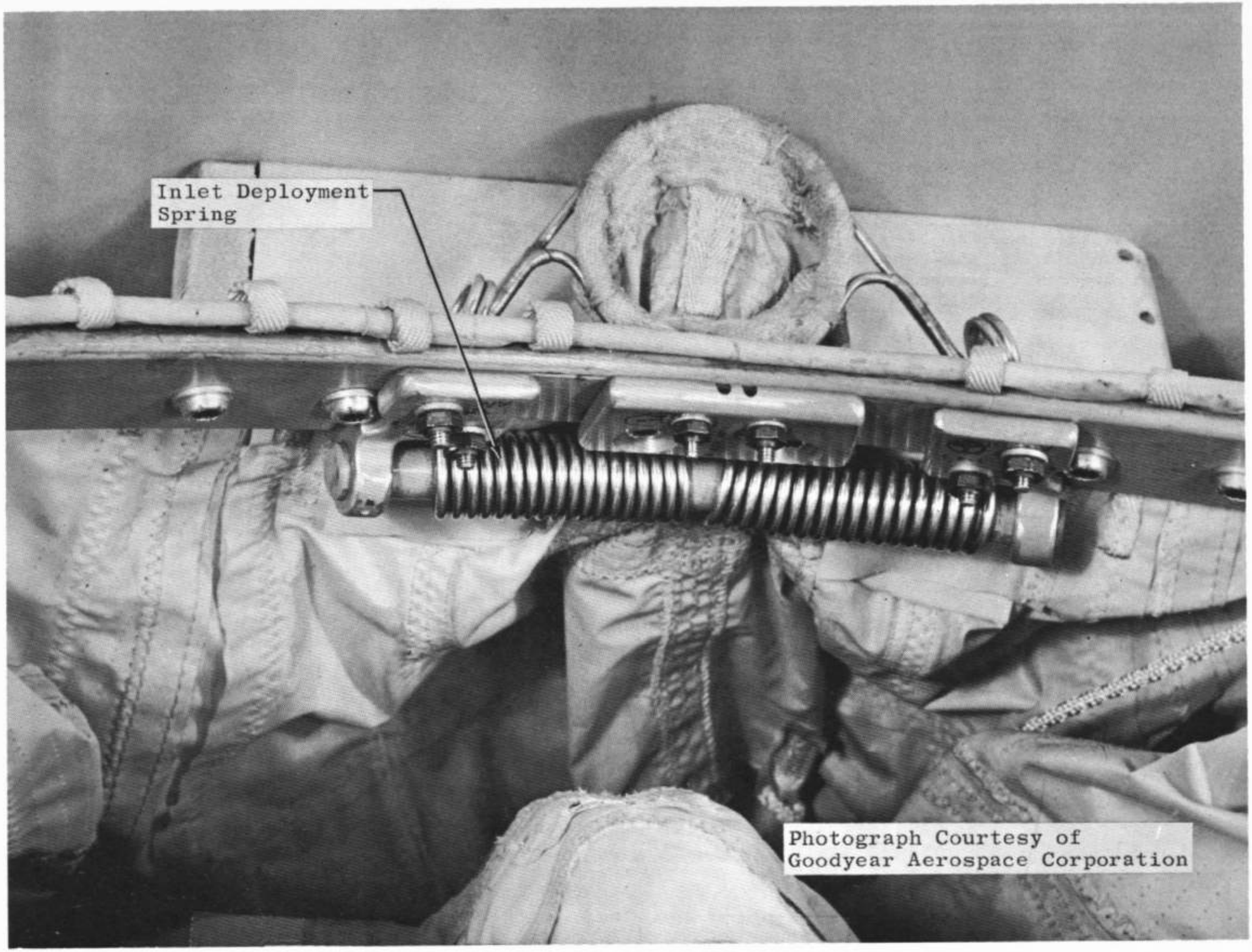
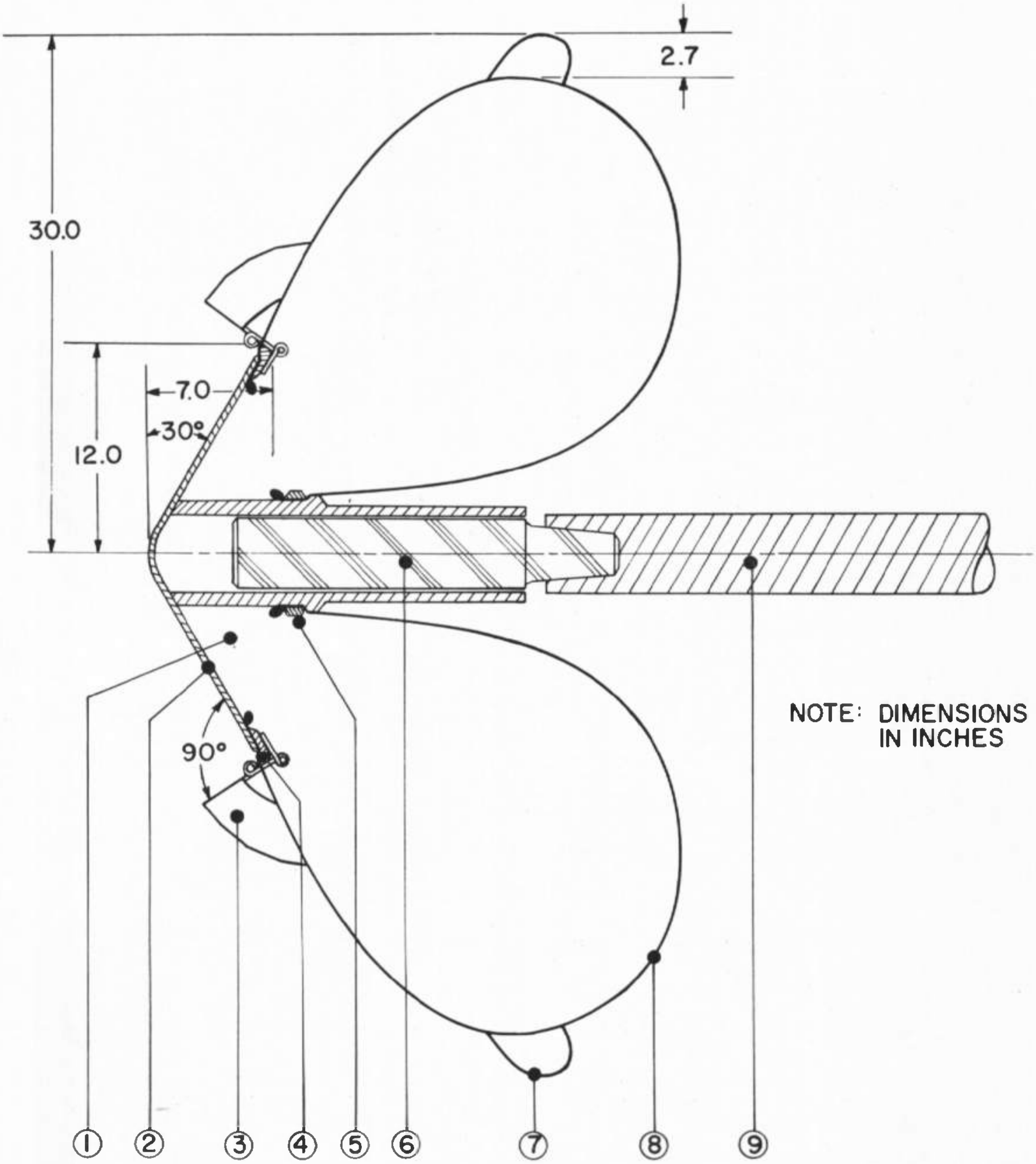


Fig. 1 Location of Model in Test Section



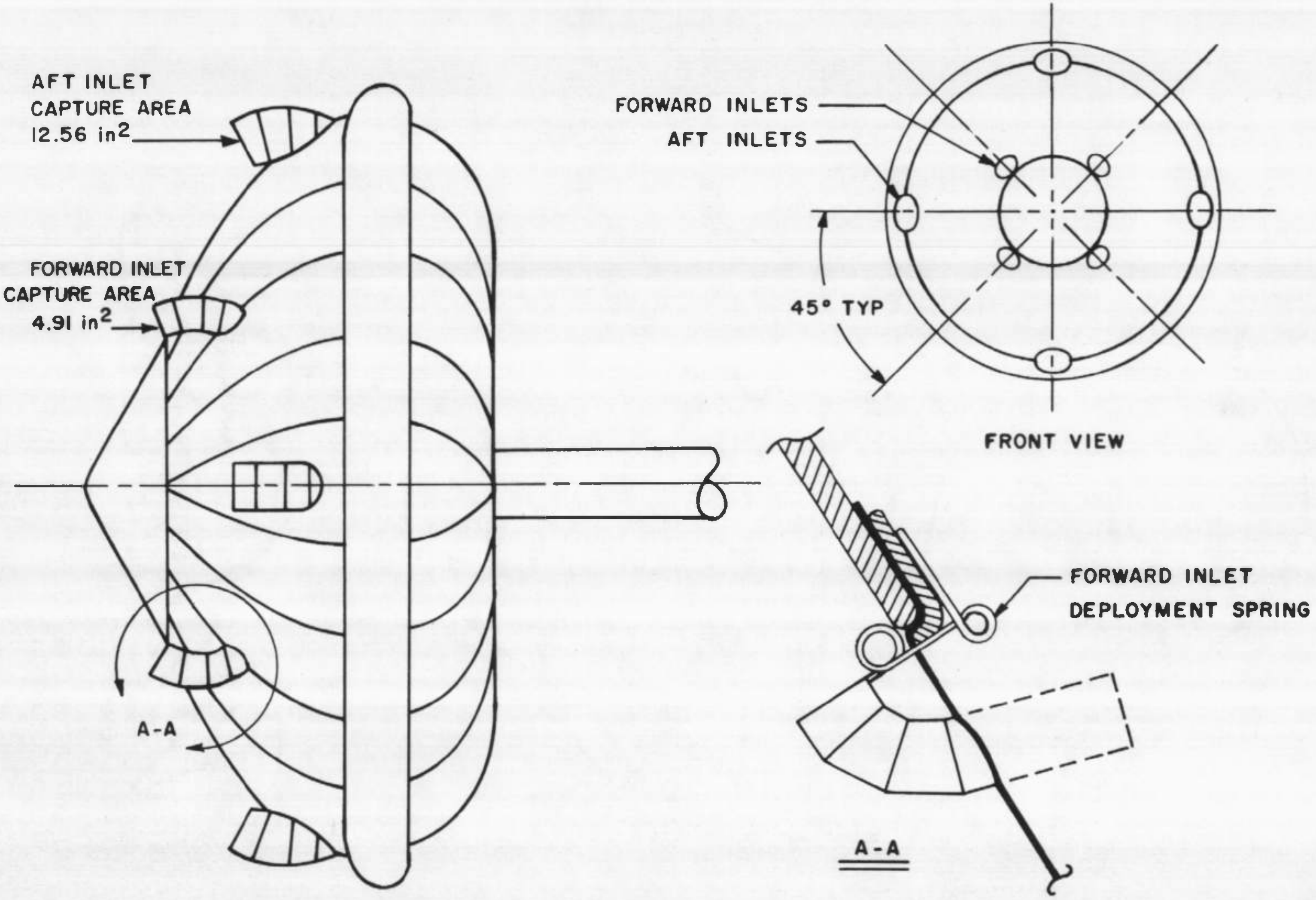
Photograph Courtesy of Goodyear Aerospace Corporation

Fig. 2 Inlet Deployment Spring



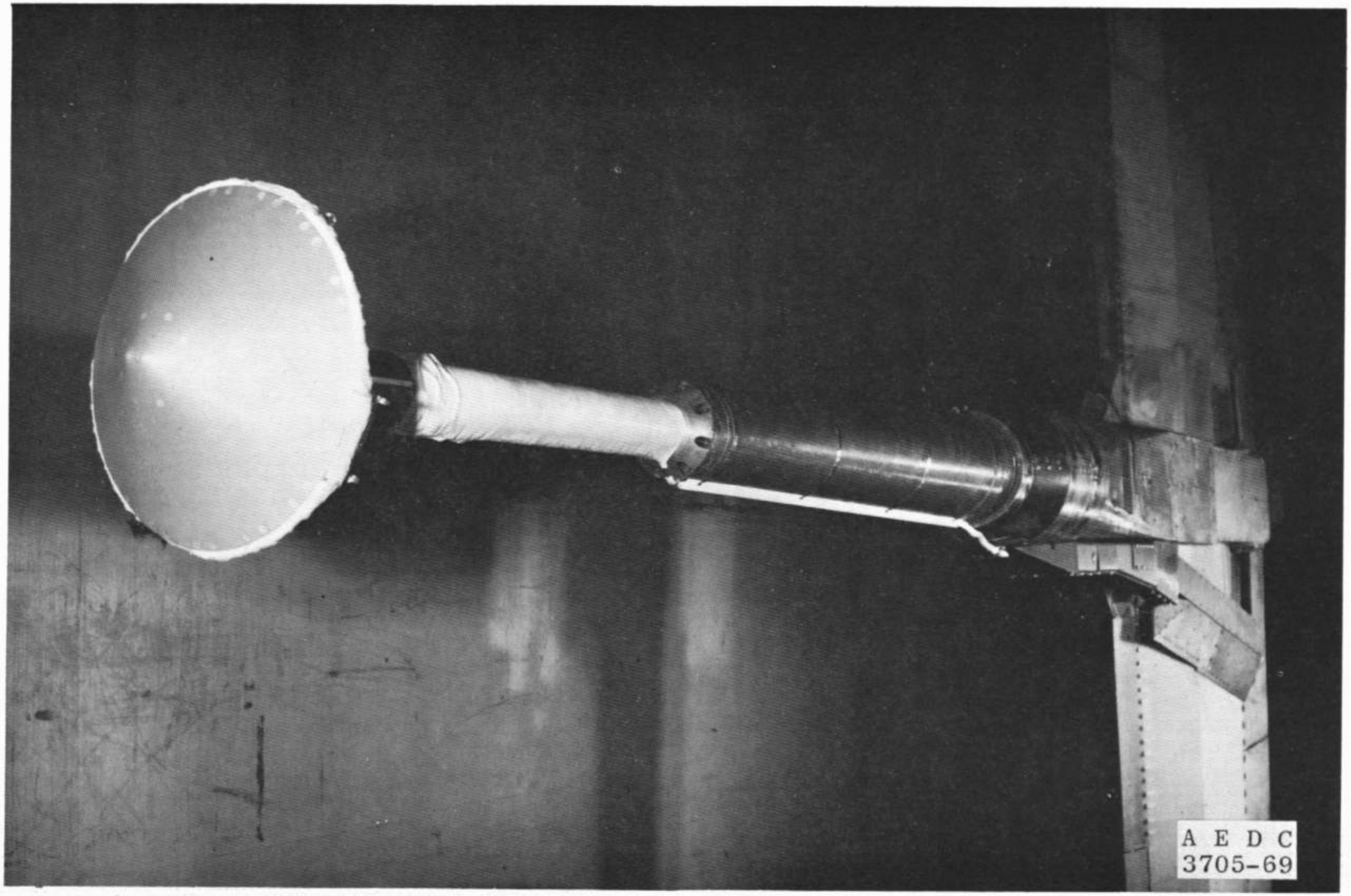
1. DECELERATOR STOWAGE COMPARTMENT
2. AEROSHELL
3. DECELERATOR RAM-AIR INLETS (TYP. 4 PLACES)
4. DECELERATOR CLAMP (OUTER)
5. DECELERATOR CLAMP (INNER)
6. SIX-COMPONENT BALANCE
7. BURBLE FENCE
8. INFLATABLE DECELERATOR
9. STING SUPPORT

Fig. 3 Details of AID Model



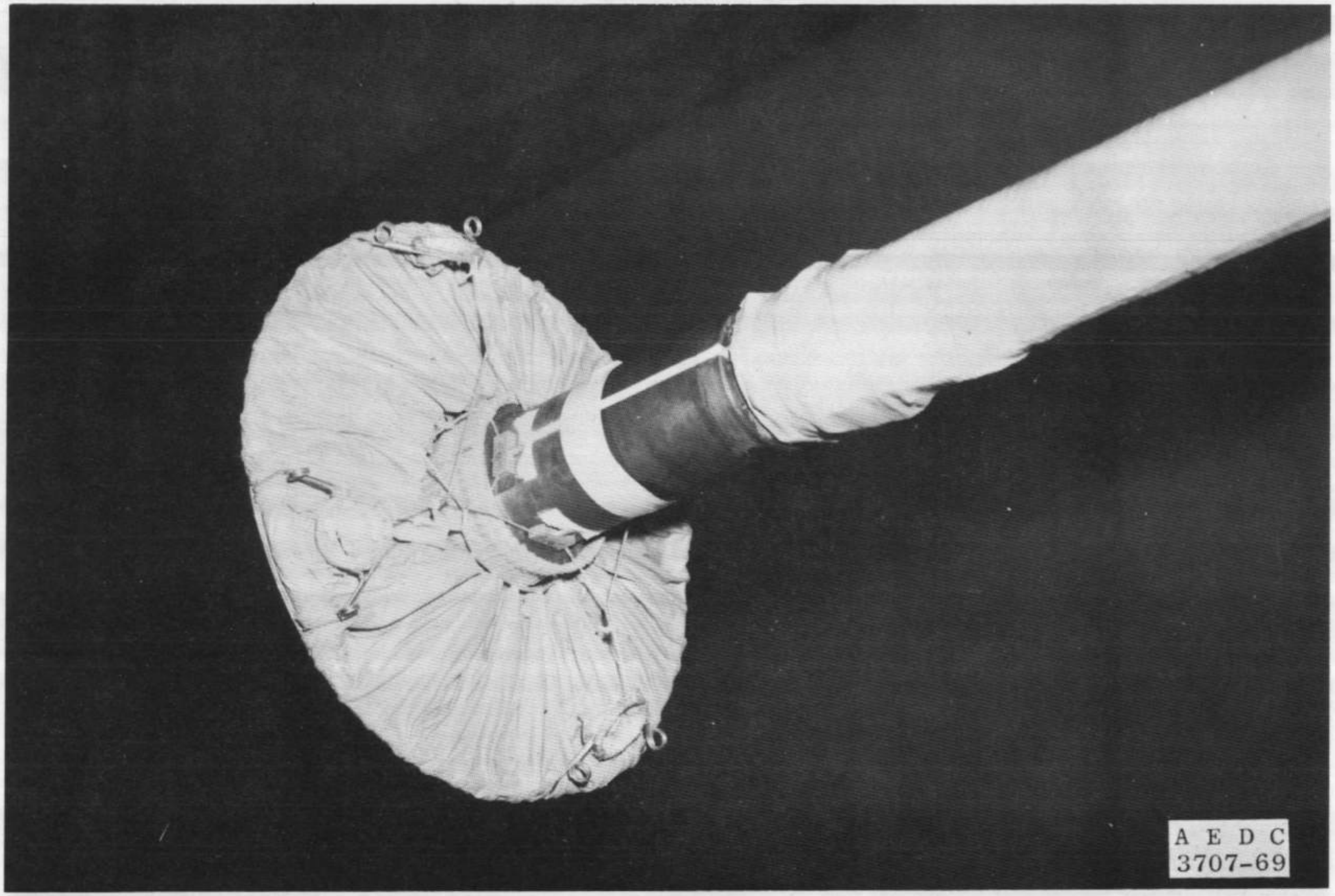
NOTE: AFT INLETS ON MODEL 2 ONLY

Fig. 4 Inlet Locations



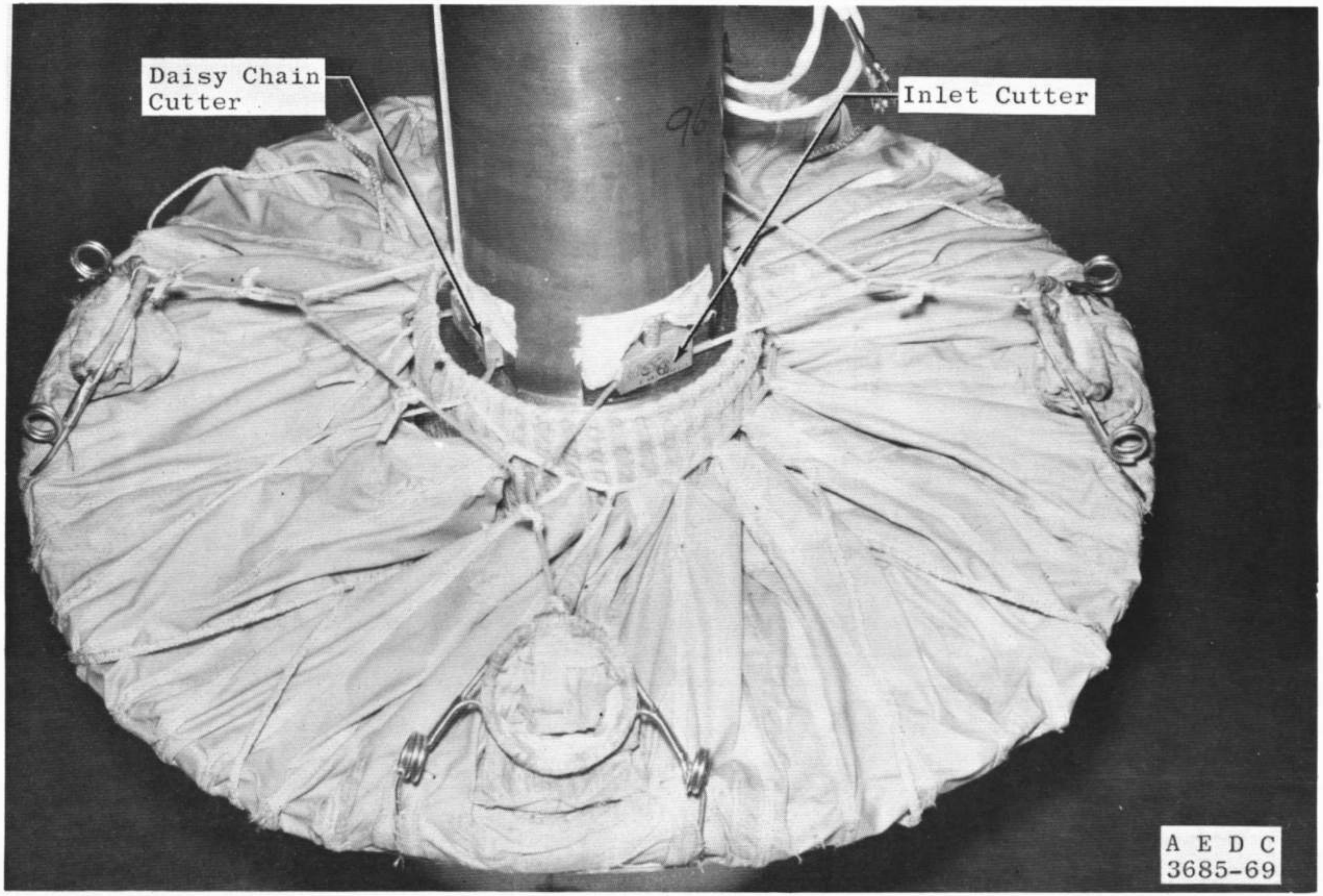
a. Front Three-Quarter View

Fig. 5 Installation of Undeployed Model in Test Section



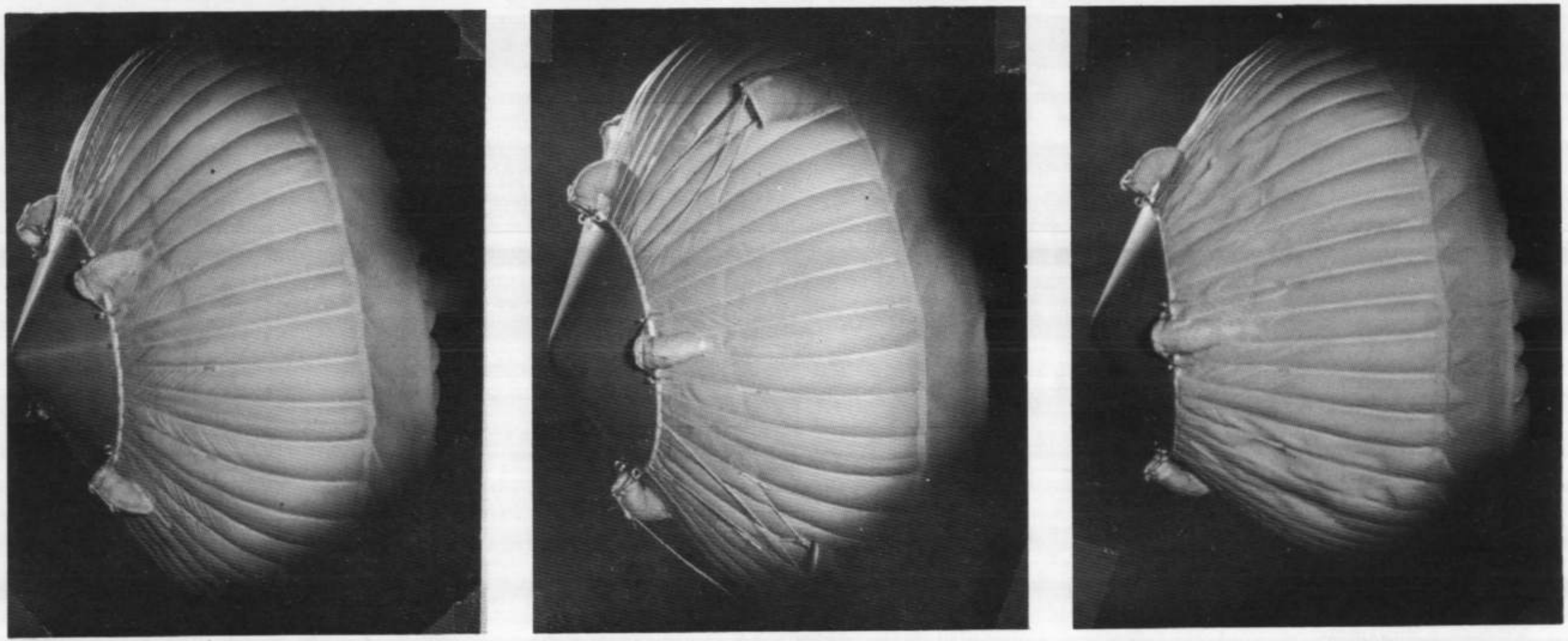
b. Rear Three-Quarter View

Fig. 5 Continued



c. Aft View

Fig. 5 Concluded



a. Model 1
$M_\infty = 4.4$
$q_\infty = 73$ psf

b. Model 2
$M_\infty = 3.0$
$q_\infty = 120$ psf

c. Model 3
$M_\infty = 4.4$
$q_\infty = 73$ psf

Fig. 6 Photograph of the AID Models at Various Test Conditions

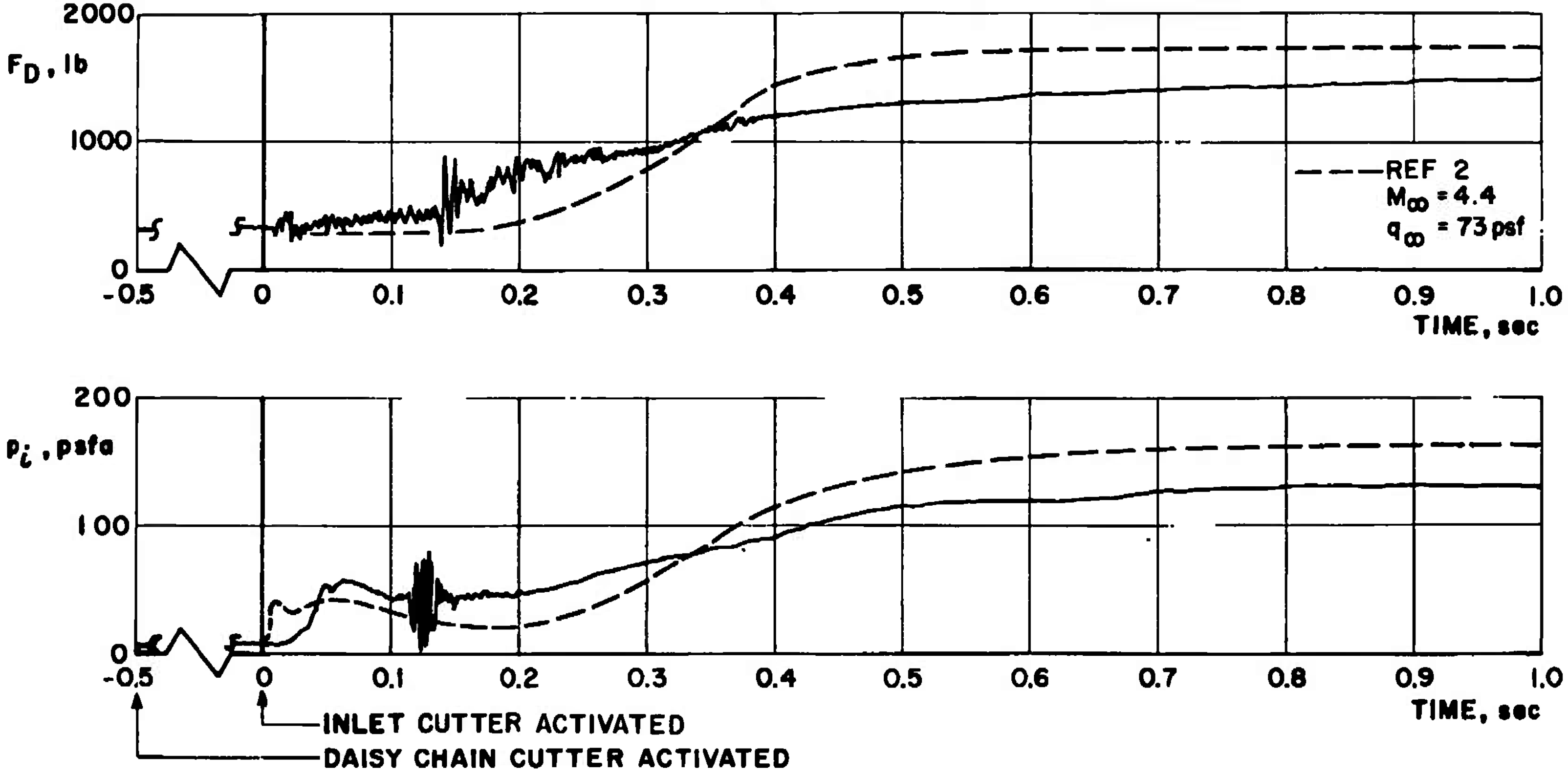


Fig. 7 Decelerator Deployment Characteristics at Mach Number 4.4, Model 1, q_∞ = 73 psf, α = 0

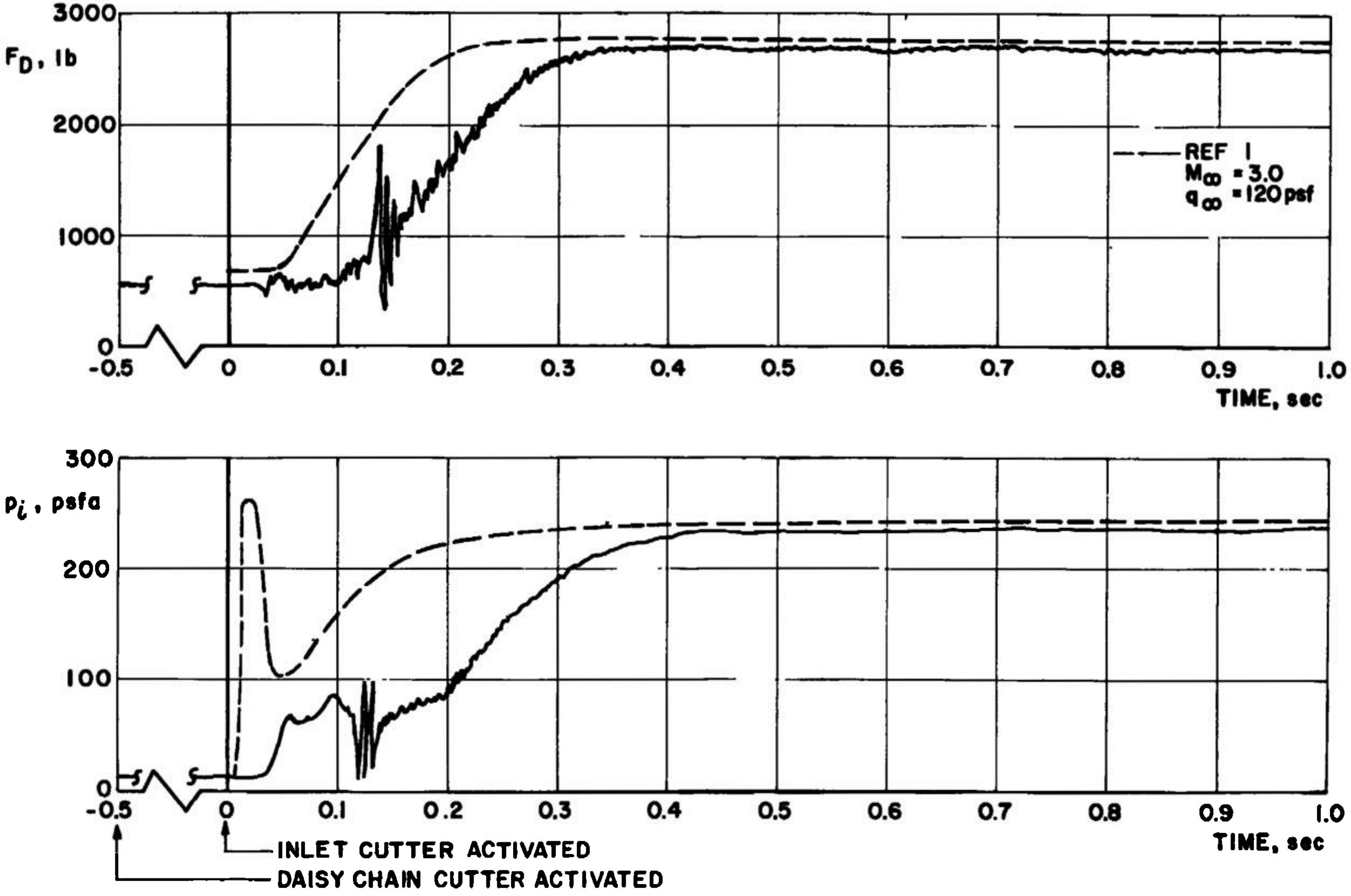


Fig. 8 Decelerator Deployment Characteristics at Mach Number 3.0, Model 2, q_∞ = 120 psf, α = 0

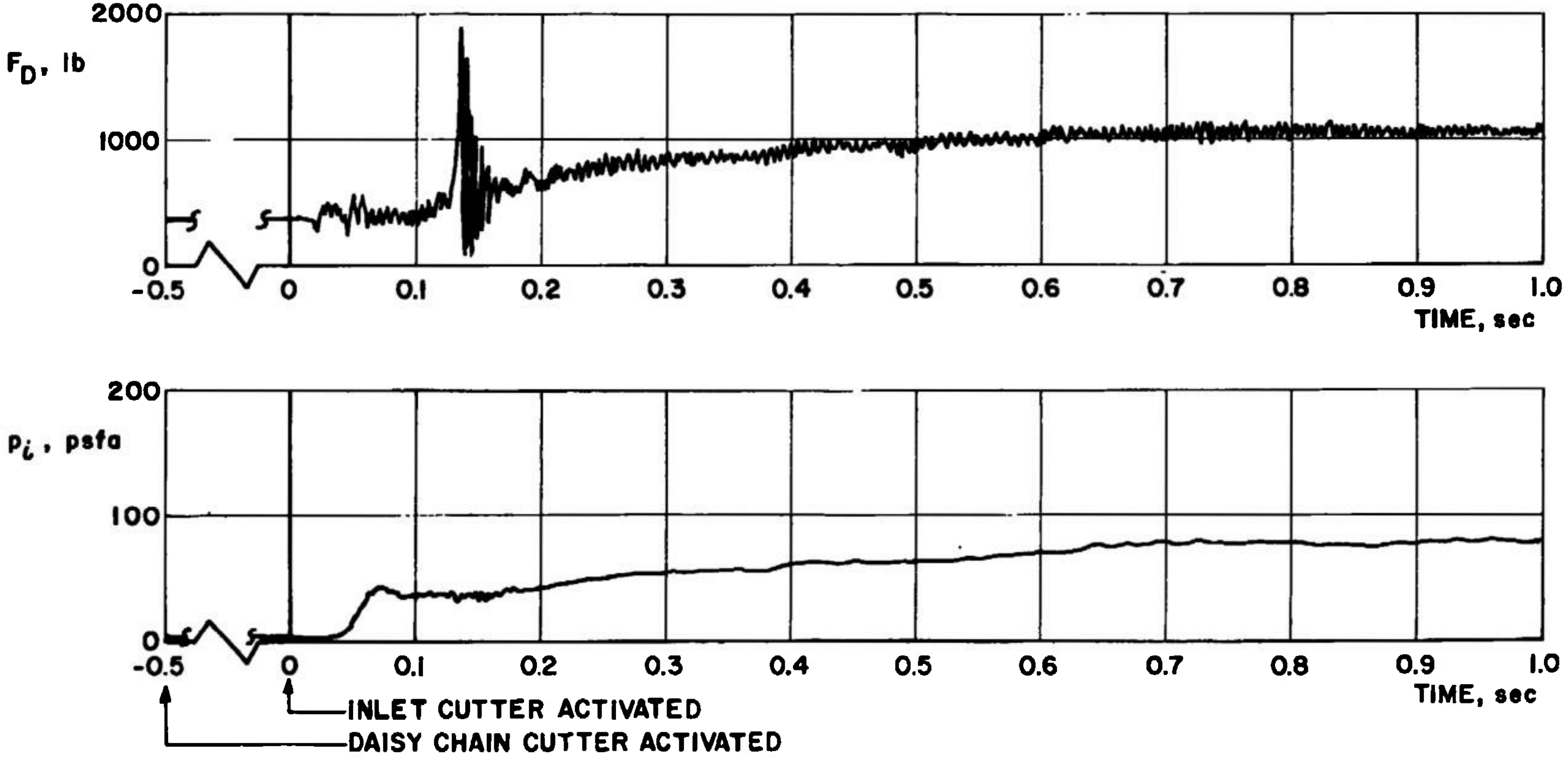


Fig. 9 Decelerator Deployment Characteristics at Mach Number 4.4, Model 3, $q_\infty \approx 73$ psf, $\alpha = 0$

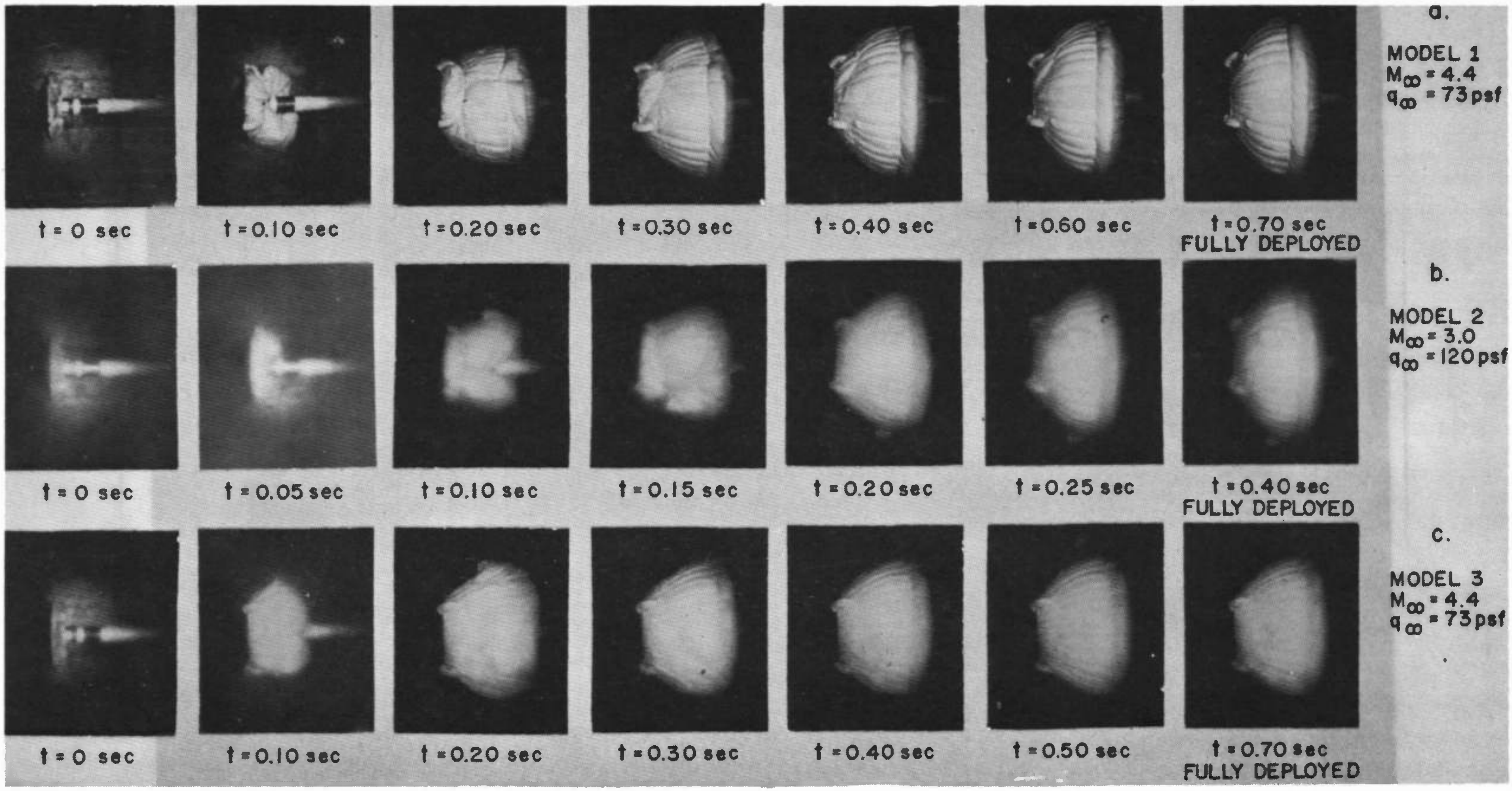


Fig. 10 Photographs of the Deployment Sequence

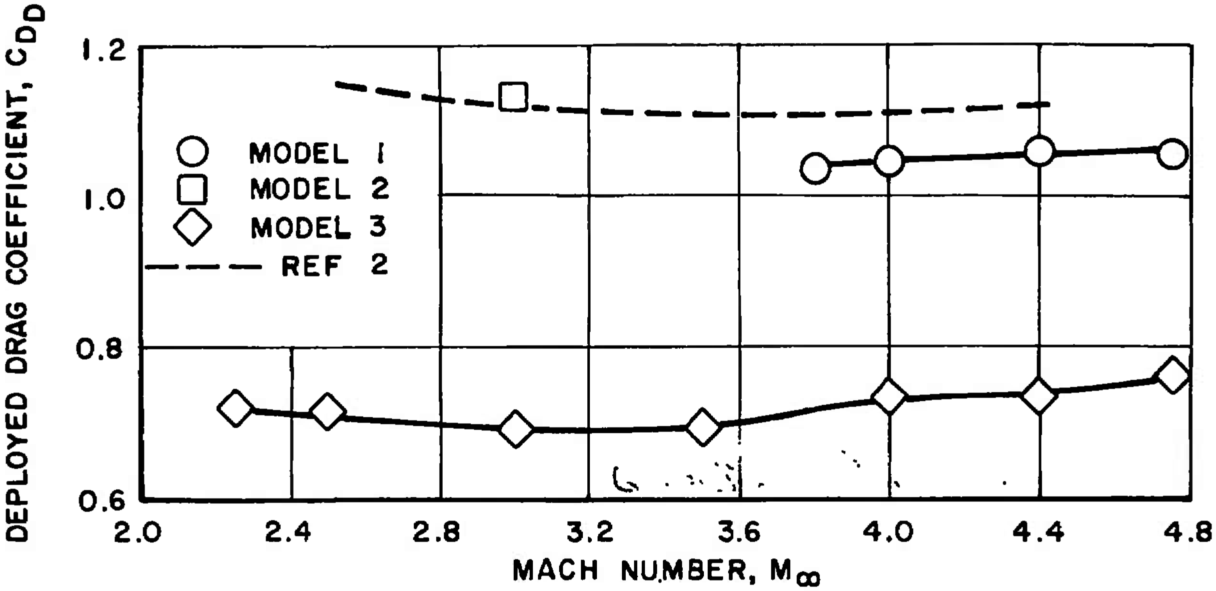


Fig. 11 Effect of Free-Stream Mach Number on the AID Drag Coefficient, $\alpha = 0$

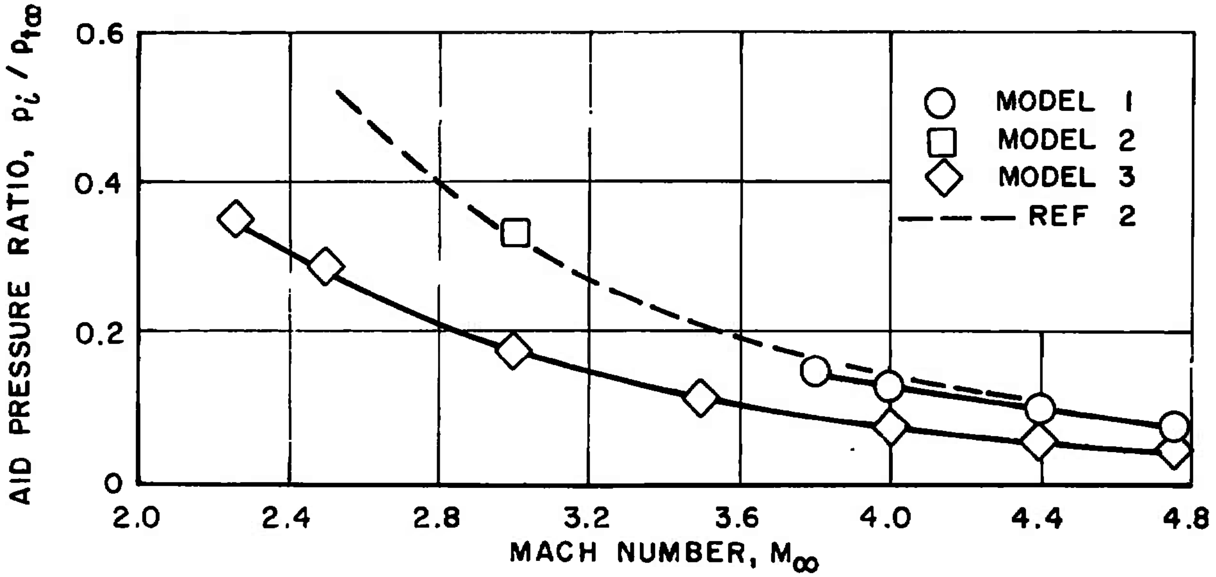


Fig. 12 Effect of Free-Stream Mach Number on the AID Pressure Ratio, $\alpha = 0$

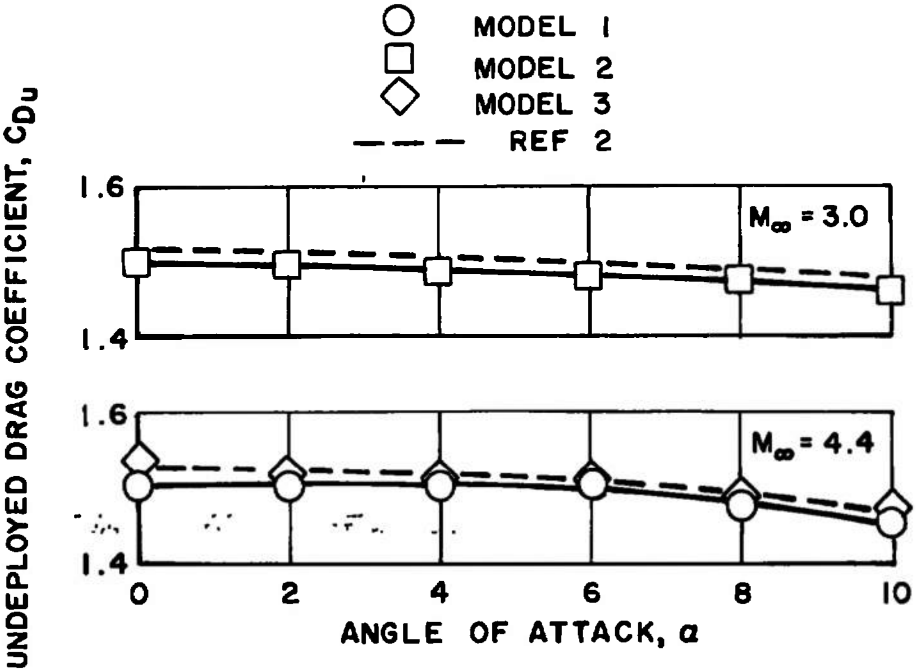


Fig. 13 Effect of Angle of Attack on Drag Coefficient with the AID Model Undeployed

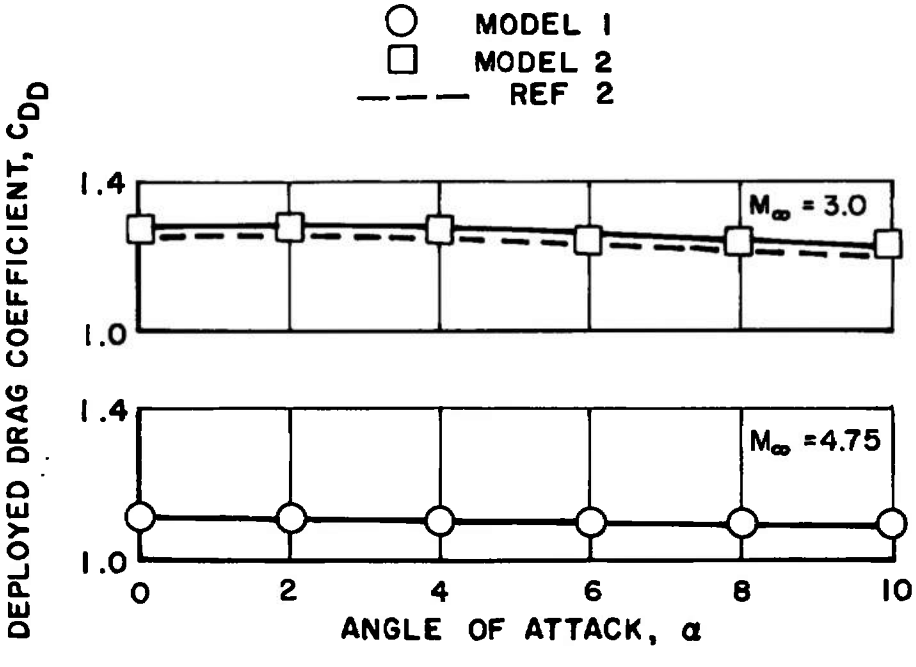


Fig. 14 Effect of Angle of Attack on Drag Coefficient with the AID Model Deployed

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13. ABSTRACT

A test was conducted in the 16-ft supersonic wind tunnel to obtain deployment, inflation, and steady-state characteristics of an attached inflatable decelerator with mechanically deployed inlets. Deployments were made at Mach numbers 3.0 and 4.4 at free-stream dynamic pressures of 120 and 73 psf, respectively. The mechanically deployed inlet system resulted in successful deployments of the three test models with inflation times of from 0.4 to 0.7 sec.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1 inflatable decelerators						
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deployment						
inflating						
steady state						
deceleration						
intake systems						
drag						
2. Decelerators						
1-15						

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