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AFFDL-TR-69-112

OPENING DYNAMICS OF A T-10 PARACHUTE WITH INFLATION AIDS

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TECHNICAL REPORT AFFDL-TR-69-112

MARCH 1970

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FOREWORD

This report was prepared by the Department of Aerospace Engineering and Mechanics of the University of Minnesota in compliance with U. S. Air Force Contract No. F33615-68-C-1227, "Theoretical Deployable Aerodynamic Decelerator Investigations," Task 606503, "Parachute Aerodynamics and Structures," Project 6065, "Performance and Design of Deployable Aerodynamic Decelerators." The work on this report was performed between June 2, 1968 and June 1, 1969.

The work accomplished under this contract was sponsored jointly by U. S. Army Natick Laboratories, Department of the Army; Bureau of Aeronautics and Bureau of Ordnance, Department of the Navy; and Air Force Systems Command, Department of the Air Force, and was directed by a Tri-Service Steering Committee concerned with Aerodynamic Retardation. The work was administered under the direction of the Recovery and Crew Station Branch, Air Force Flight Dynamics Laboratory, Research and Technology Division. Mr. James H. DeWeese was the project engineer.

The study was conducted in cooperation with Mr. Robert A. Noreen and several students of Aerospace Engineering of the University of Minnesota. The authors wish to express their gratitude to all who rendered their services to the accomplishment of this work.

This report was submitted by the authors in September, 1969.

This technical report has been reviewed and is approved.

George A. Solt, Jr.

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Chief, Recovery and Crew Station Branch
Air Force Flight Dynamics Laboratory

ABSTRACT

The characteristic times and maximum opening forces were studied for various inflation aid configurations of a model T-10 parachute. Finite mass wind tunnel tests were conducted in the horizontal return wind tunnel at a snatch velocity of 70 fps with a suspended load of 1.1 lbs. Compared with results of the standard T-10 parachute, the percentage decrease in the characteristic time and the corresponding percentage increase in the peak force are presented for five centerline, three internal parachutes and two centerline-internal parachute combinations.

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SYMBOLS

D	drag
D_I	nominal diameter of internal parachute
D_o	nominal diameter
D_{max}	maximum width of the suspended canopy
D_{STAND}	drag of standard T-10 model parachute
F_o	maximum opening force
$\bar{F}_o$	average maximum opening force of n tests
$\bar{F}_{oSTAND}$	average maximum opening force of n tests of standard T-10 parachute model
F^*	maximum opening force ratio, $\bar{F}_o/\bar{F}_{oSTAND}$
L_c	centerline length
L_s	suspension line length
m_i	canopy included mass
m_s	suspended mass
t	instantaneous time
t'	characteristic time, from snatch to peak force
$\bar{t}'$	average characteristic time of n tests
$\bar{t}'_{STAND}$	average characteristic time of n tests of standard T-10 parachute model
t_f	filling time
$\bar{t}_f$	average filling time
T	dimensionless time, t/t_f
T^*	average characteristic time ratio, $\bar{t}'/\bar{t}'_{STAND}$
W_c	weight of canopy in grams
w_{cl}	weight of cloth per ft^2

x distance between the plane of the mouth area of the fully inflated primary and secondary parachutes

η canopy stiffness index, $\frac{D_{max}}{D_o} \cdot \frac{W_c}{S_o \cdot w_{cl}}$

σ standard deviation

I. INTRODUCTION

For certain parachute operations a very fast opening parachute is desirable, but the opening force has to be within acceptable limits. It is known that the parachute inflation can be expedited by means of so-called inflation aids such as centerlines, internal canopies, (Ref 1); internal ballutes, (Ref 2); and combinations of centerlines with internal canopies or ballutes.

In view of practical aspects of parachute operations with inflation aids, wind tunnel tests with finite mass systems (Ref 3) were made in which the effects of centerlines, internal parachutes, and combinations of centerlines and internal chutes on the opening dynamics of a model T-10 parachute were studied. Characteristic times, force-time histories, and opening shock data were evaluated for five different centerlines, three internal parachutes, and two centerline-internal chute combinations and compared with the opening characteristics of a standard T-10 parachute. The standard filling time, t_f, from snatch force to the initially fully opened canopy shape (Ref 4) was not measured because of the effort involved and the large number of tests to be conducted. Instead a characteristic time, t', from snatch to maximum force, was measured directly off the force-time recordings. A few test cases were performed in which the force and projected area ratios were determined as a function of dimensionless time, T. These studies indicated that the force-time characteristics for all configurations were essentially similar, and that the time interval, t', is a characteristic feature.

The characteristic times and maximum opening forces were determined and compared with those of the standard T-10 parachute.

All finite mass opening tests were conducted with a wind tunnel dynamic pressure of 5.2 lb/ft^2 or about 70 fps. The suspended weight was 1.1 lb corresponding to a ratio of included to suspended mass, m_i/m_s, of approximately 0.26. The corresponding ratio of a prototype T-10 parachute with 250 lbs suspended weight amounts to 1.18. The canopy included mass is assumed to equal the mass enclosed by a hemisphere which surface area equals S_o having a diameter of 0.707 D_o.

II. MODELS AND TEST CONFIGURATIONS

Wind tunnel tests were conducted on a 1/10 scale, D_o = 41.8 in. model of a T-10 parachute with 30 gores. Table I gives model details and a comparison to the prototype parachute. The model was built conventionally and a flexibility comparison with a full scale T-10 parachute performed as indicated in Ref 5. The suspended model T-10 with stiffness-weight indexes for both prototype and model are given in Fig 1. The internal canopies, D_o = 6 in., 7½ in., and 9½ in. were constructed of nylon cloth of 5 to 9 nominal porosity.

Wind tunnel tests of the T-10 parachute with inflation aids were conducted for the following configurations:

A) Centerlines, L_c, which located the vent of the canopy towards the suspension line confluence point having the following lengths, L_c/D_o = 1.05, 0.98, 0.90, 0.82, and 0.75.

These centerline ratios were chosen because respective measurements indicated that most of these configurations developed at zero degrees angle of attack considerably more drag than the standard parachute. Details of these efforts are shown in Fig 2.

B) Internal flat circular parachutes with various diameters, D_I/D_o = 0.14, 0.18, and 0.23, were located at x/D_o = 0.05, 0.03, and 0.05 respectively.

Table II gives a description of the internal parachutes.

C) Centerlines combined with internal chutes: L_c/D_o = 0.90, D_I/D_o = 0.18 and L_c/D_o = 0.90 and D_I/D_o = 0.23.

The medium length centerline, L_c/D_o = 0.90, configuration was chosen for the centerline canopy combination because of geometric limitation in combining an internal chute with the shortest centerline and slower opening times with the longer centerlines.

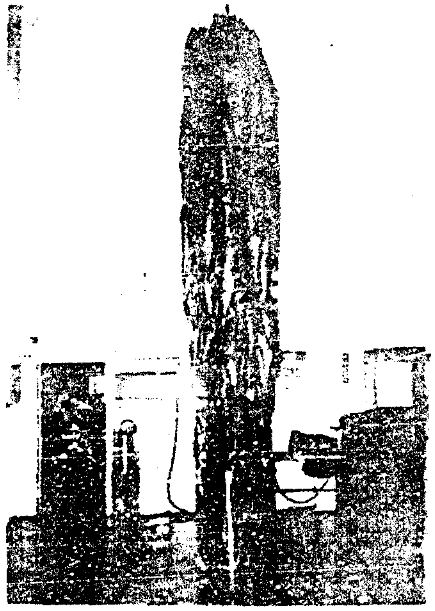
Profile and frontal views of the T-10 standard with and without inflation aids can be seen in Figs 3, 4, and 5.

A deployment bag as shown in Fig 6 was used in all wind tunnel tests. Its dimensions as well as those of the full size deployment bag are given in Table III.

TABLE I
PHYSICAL COMPARISON OF MODEL AND FULL SCALE T-10 PARACHUTES

Physical Parameters	Model	Prototype*
D_o	41.8 in	35 ft
Suspended Load	1.1 lb**	250 lb
Canopy Weight***	0.14 lb	11.70 lb
Canopy Material	1.1 oz Ripstop Nylon MIL-C-7020D, Type I	
Suspension Lines	50 lb Nylon	MIL-C-5040 Type II
Suspension Line Length, L_s	30.6 in	25.5 ft
Riser Length	3.6 in	3 ft

*Ref 6
**includes cable
***includes suspension lines

	Model T-10, D_o = 41.8 in	Full Scale* T-10, D_o = 35 ft
D_{max}	13.3 in	2.62 ft.
$\frac{D_{max}}{D_o}$	0.32	0.075
W_c**	65 gm	5310 gm
η	0.63	0.12

*Suspended at Wright-Patterson AFB, Ohio
**Includes suspension lines

Fig.1 Suspended T-10 Parachute Model and Prototype with Measured Stiffness Indexes.

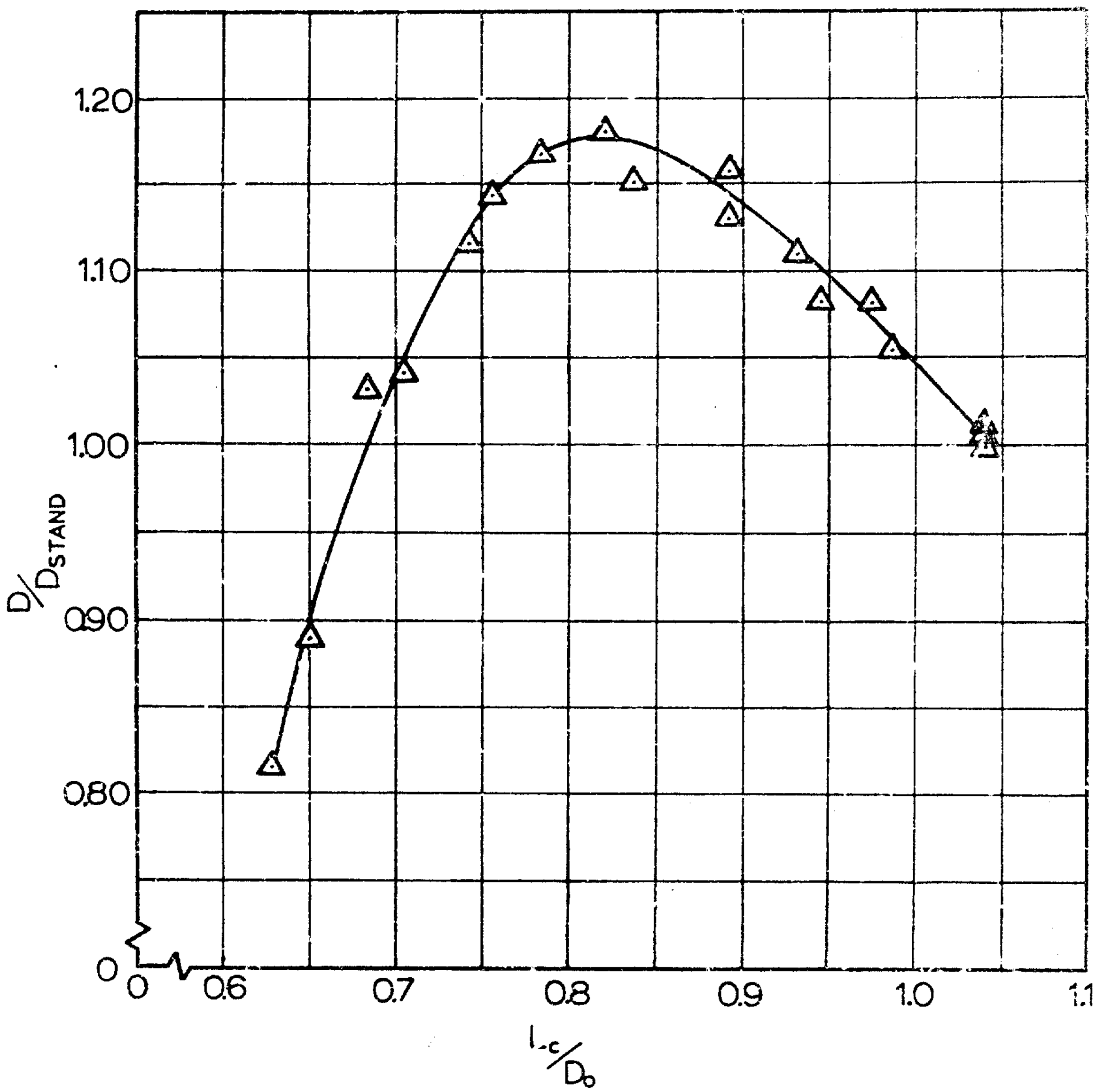
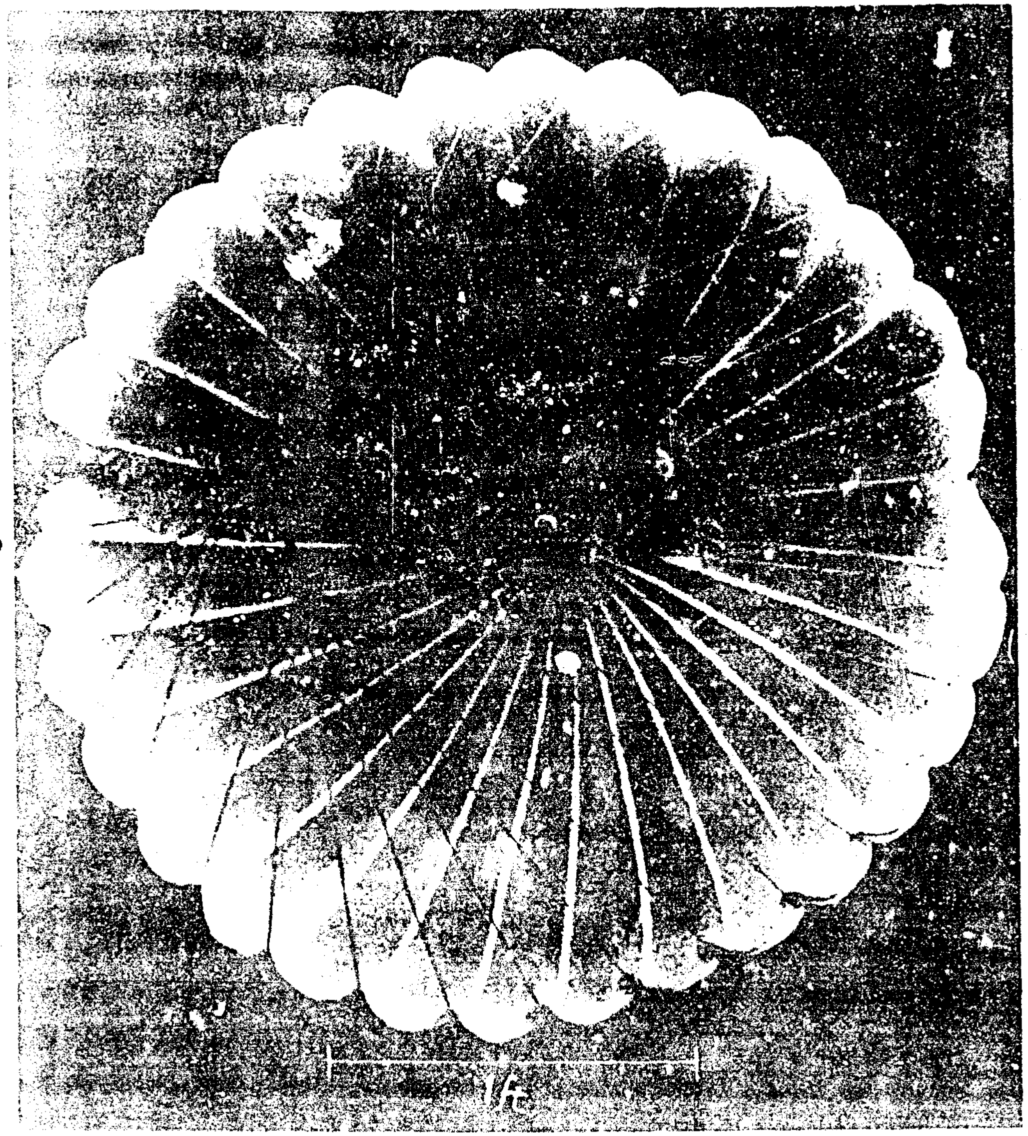


Fig 2 Drag Ratio of a T-10 Parachute Model with Various Length Centerlines.

TABLE II
MODEL INTERNAL CANOPIES

Physical Parameters	Internal Canopies		
Nominal diameter, D_I (inches)	6.0	7.5	9.5
Canopy Material	Nylon 5 to 9 nominal porosity		
Canopy Weight (grams)	1.3	3.1	4.9
Suspension Lines	50 lb Nylon cord		
Suspension Line Length (inches)	6.0	7.5	9.5
D_I/D_o	0.14	0.18	0.23
No. of Gores	4	5	6



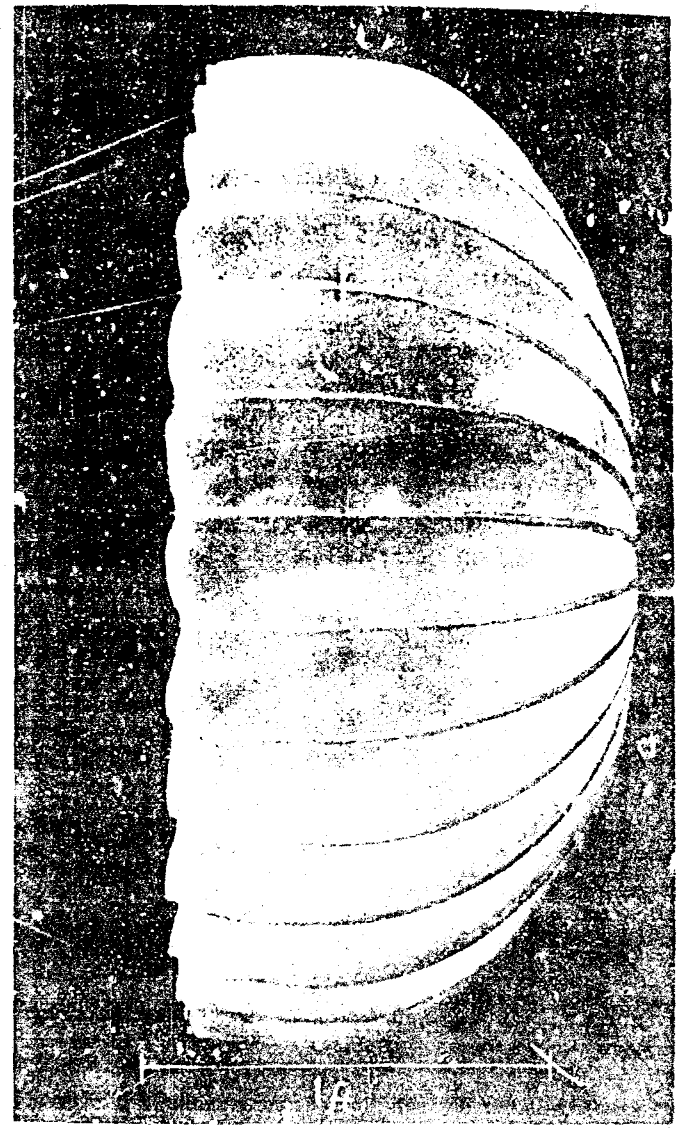


Fig. 3 T-10 Parachute Model, $D_o = 41.8$ in

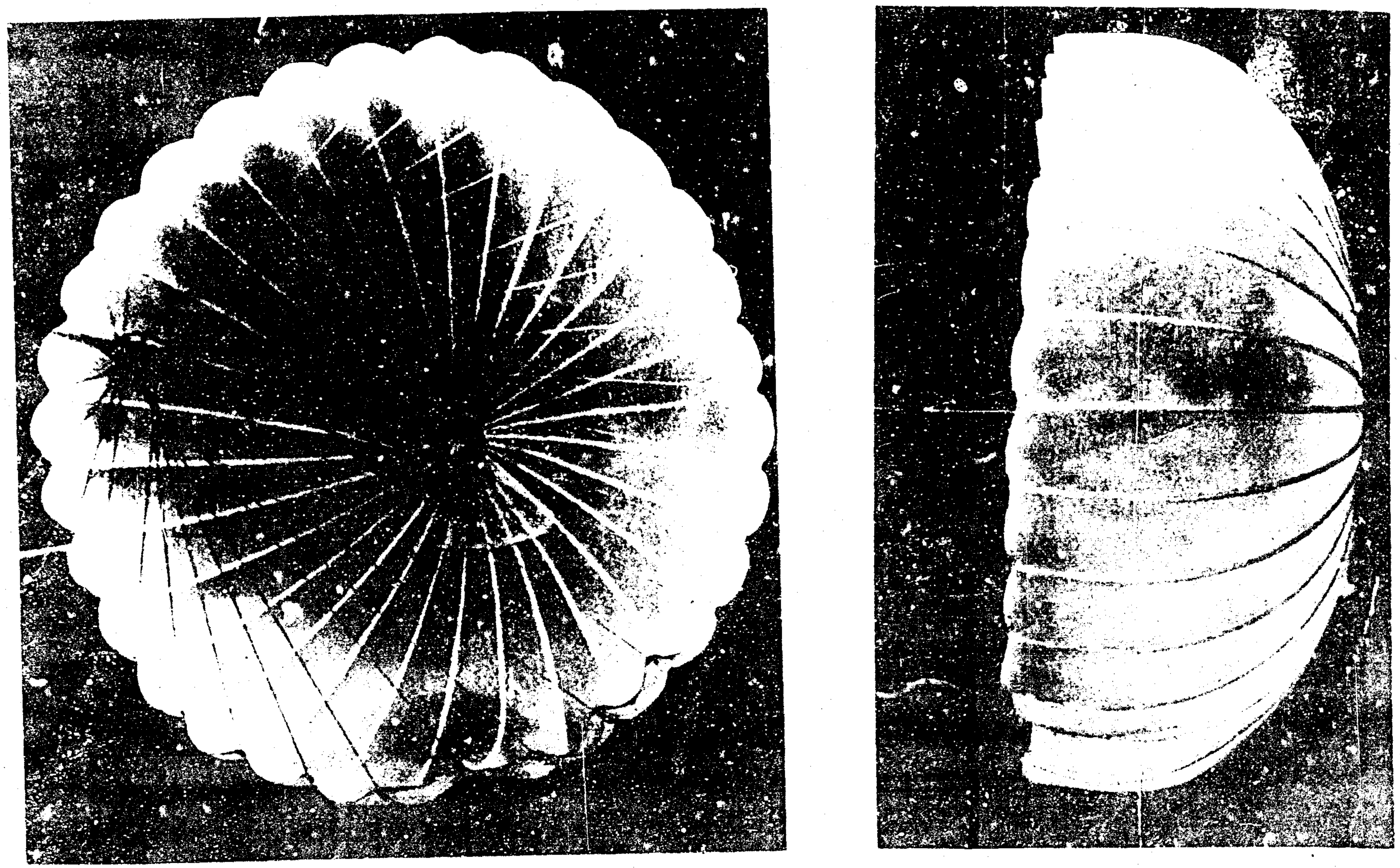


Fig. 4 T-10 Parachute Model, $D_O = 41.8$ in with Internal Parachute, $D_I/D_O = 0.14$

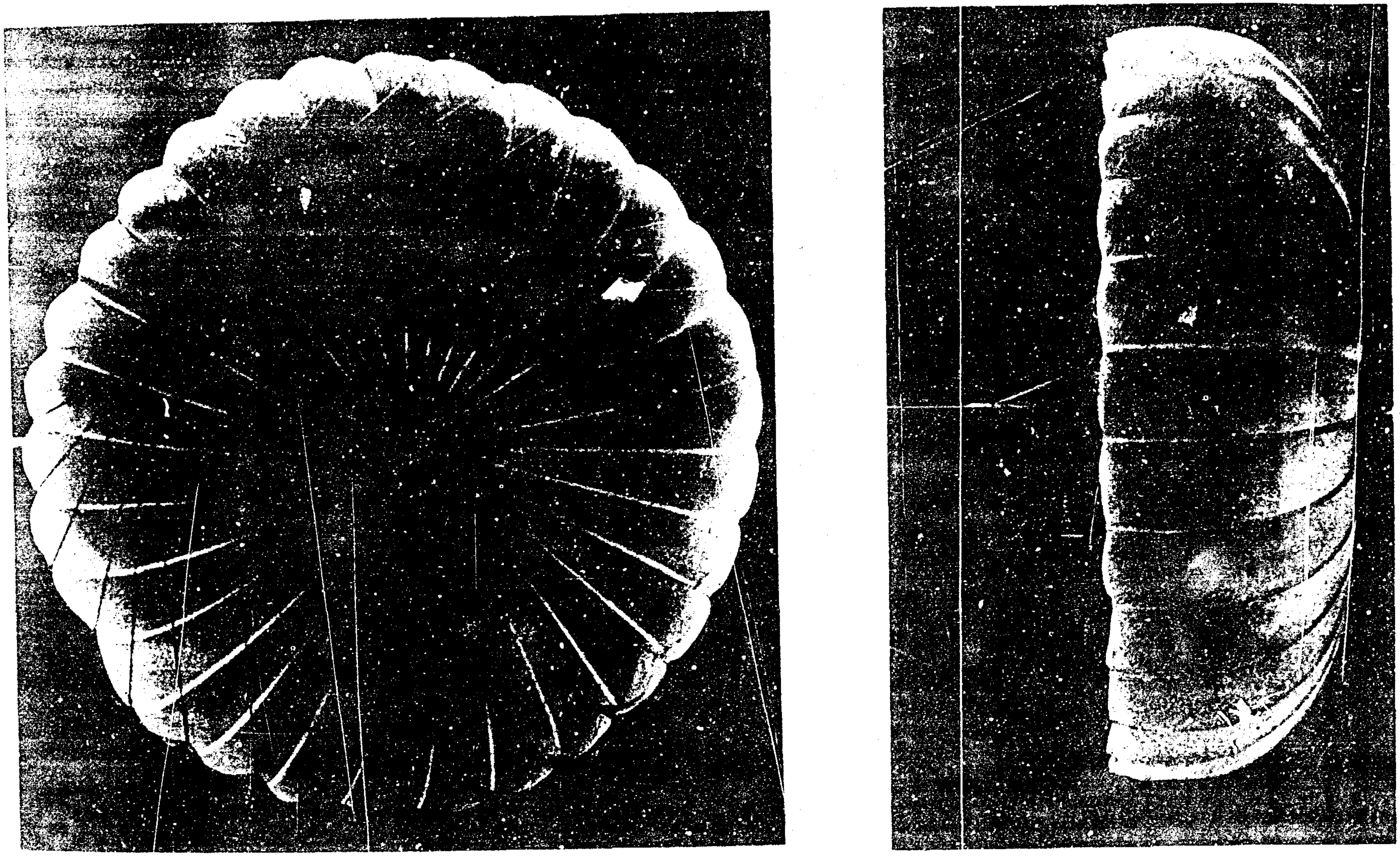


Fig. 5 T-10 Parachute Model, $D_O = 41.8$ in with Centerline, $L_c/D_O = 0.90$ and Internal Parachute, $D_I/D_O = 0.23$

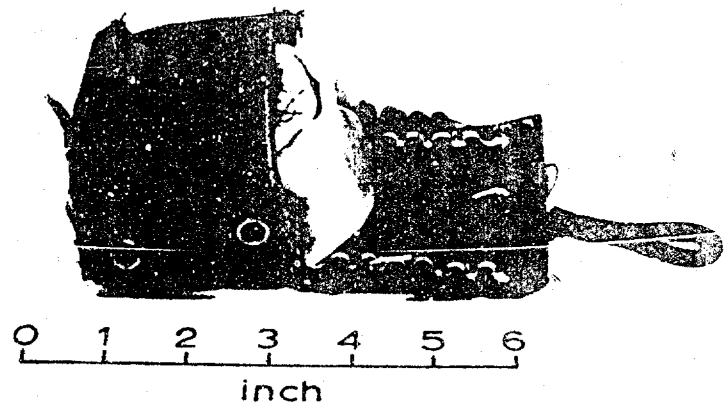


Fig 6a Parachute Enclosed in Bag

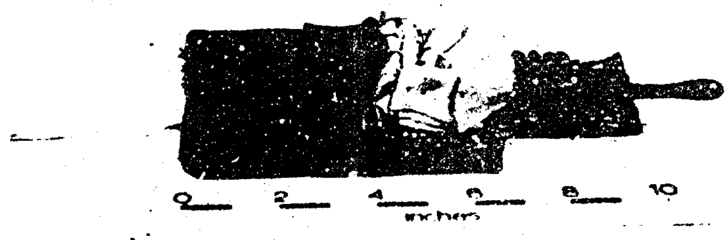


Fig 6b Bag Unfolded

Fig. 6 Parachute Deployment Bag

TABLE III

DIMENSIONS OF MODEL AND FULL SCALE DEPLOYMENT BAG

Bag Dimensions	Model	Prototype
Length (in)	3.4	22
Width (in)	3.2	12
Height (in)	1.7	5

III. EXPERIMENTAL APPARATUS AND PROCEDURE

All configurations of the T-10 were packed in an accordian-like fashion for a lines first deployment.

Following the deployment by an inflated pilot parachute, the main T-10 canopy traveled downstream as dictated by the aerodynamic forces and was restrained only by the 1.1 lb suspended payload weight connected by means of cable over the pulley force sensor, Figs 7 and 8. Instantaneous forces were measured by means of a strain gage attached to a tension member incorporated in the pulley support and recorded versus a time scale on the diagram of a Honeywell visicorder. Front and side movies were taken during at least two runs of each configuration and the photocell distance device was operated for all tests to provide velocity indications. Related to the parachute canopy diameter, the Reynolds Number of the tests was 1.56×10^6. In order to provide reliable average values at least 10 valid tests were evaluated and the results shown below represent such averages.

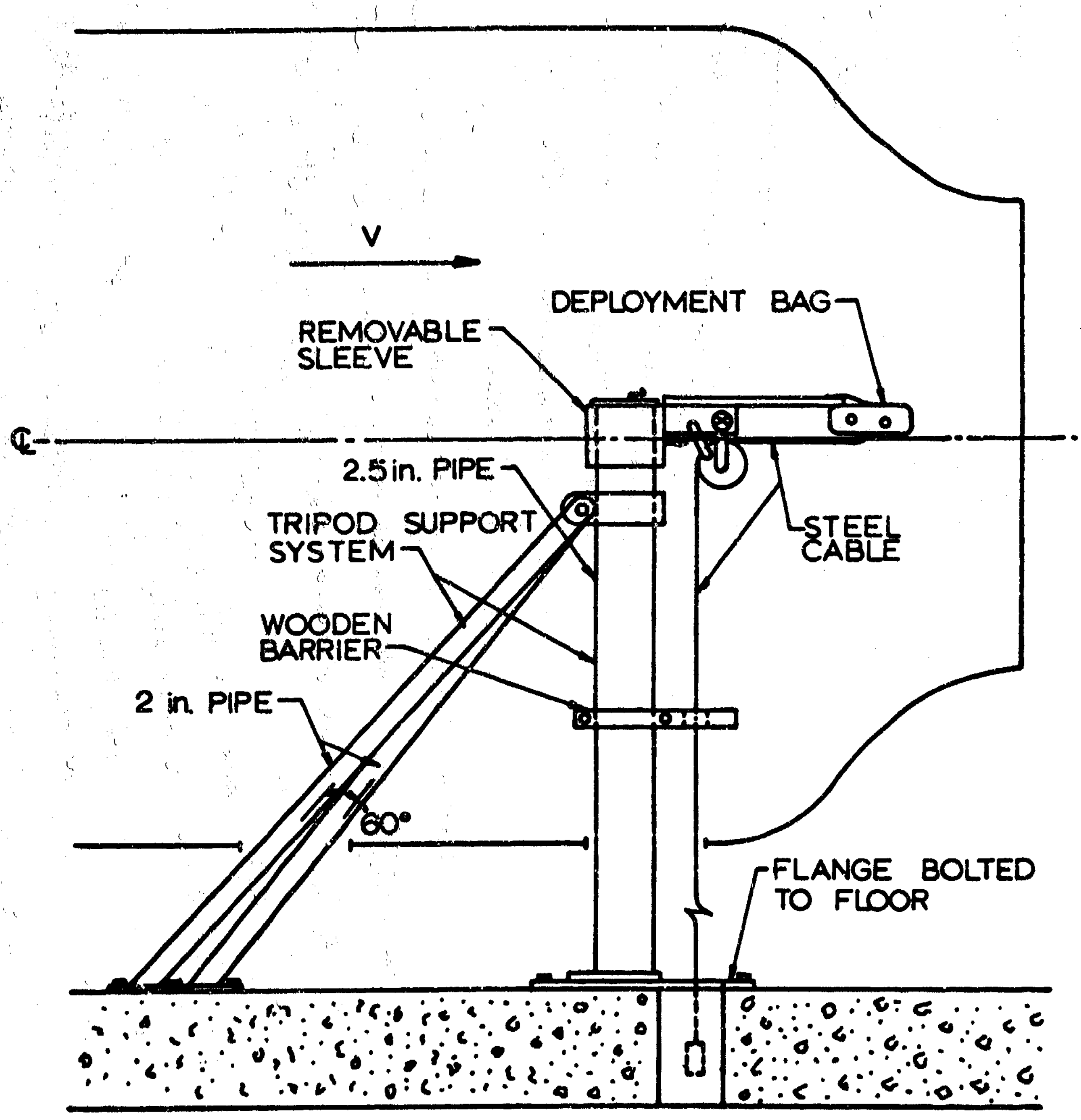


Fig 7 Finite Mass Opening Shock Windtunnel System

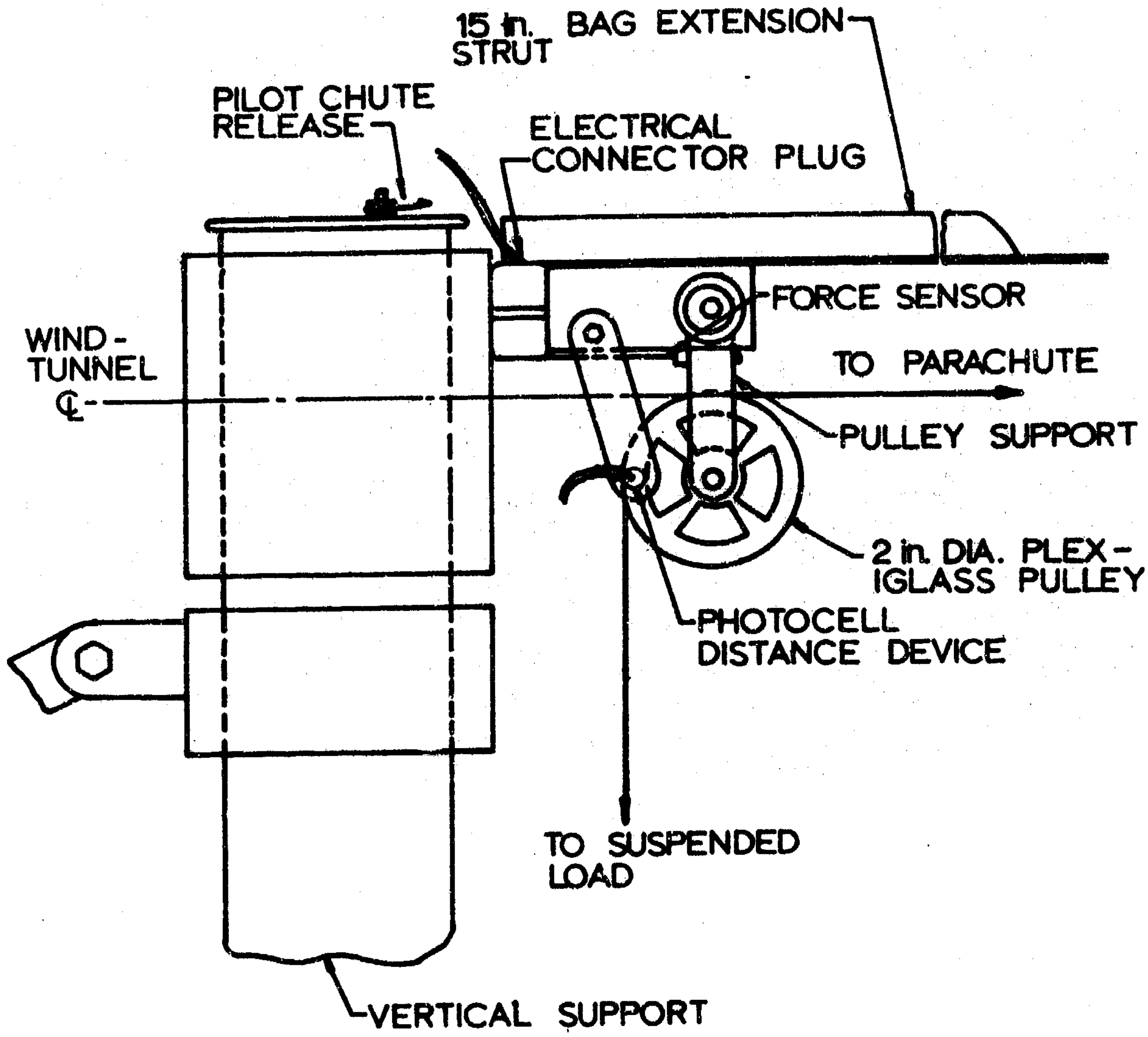


Fig 8 Parachute Test Apparatus

IV. RESULTS

The test evaluations provided diagrams as shown in Fig 9. The curves shown represent average values obtained from five individual tests. The filling times related to the instant at which the projected area equals for the first time the projected area under steady state conditions, T = 1, are marked. The values were obtained from an area-time analysis as shown in Fig 10. A further analysis also indicated that the ratios $\bar{t}'/\bar{t}_f$ of all configurations were about the same. Therefore, it was concluded that the value $\bar{t}'$ could be taken as characteristic for the rate of the canopy inflation.

Figure 9 indicates that with inflation aids the opening time of the T-10 parachute is shorter but that this time saving is connected with a significant increase in opening force. Furthermore, it is noticed that a relatively short centerline reduces the opening time materially and that a combination of a centerline and an internal canopy provides opening times, t_f, or characteristic times, $\bar{t}'$, less than half as long as those of the standard T-10 parachute.

These and additional information are given numerically in Tables IV and V. In these tables one notices that the relatively short centerlines of L_c/D_o = 0.90, 0.82, and 0.75 provide about the same short time intervals as the three internal canopies (Table IV), but that the internal canopies produce smaller maximum forces (Table V). Combinations of centerlines and internal canopies reduce the time further but raise relatively high opening forces.

The most important results are shown in more detail and maybe in more impressive form in Figs 11 and 12. For example, Fig 11 indicates that for certain given times the T-10 parachute canopy produces higher forces with centerlines than with internal parachutes. Figure 12 shows that the T-10 parachute with inactive or long centerlines has the highest time deviations but lower force deviations than the same canopy with shorter centerlines or internal canopies.

Figures 13 through 17 are back-up data showing the individual curves and their specific deviations. For comparison a force-time diagram of a full size test is also included (Fig 18). The form of this diagram differs slightly from those averaged model diagrams of Fig 9. This difference may be caused by the relative model stiffness and the difference of included to suspended masses of the model and the full size parachute (Ref 5). Further supporting data are given in the appendix in the form of originally recorded force-time diagrams. These data give qualitative information on the same nature as gained from the numerical evaluation. Also stability pendulum tests were made, but all configurations moved so much at random that conclusive statements cannot be made.

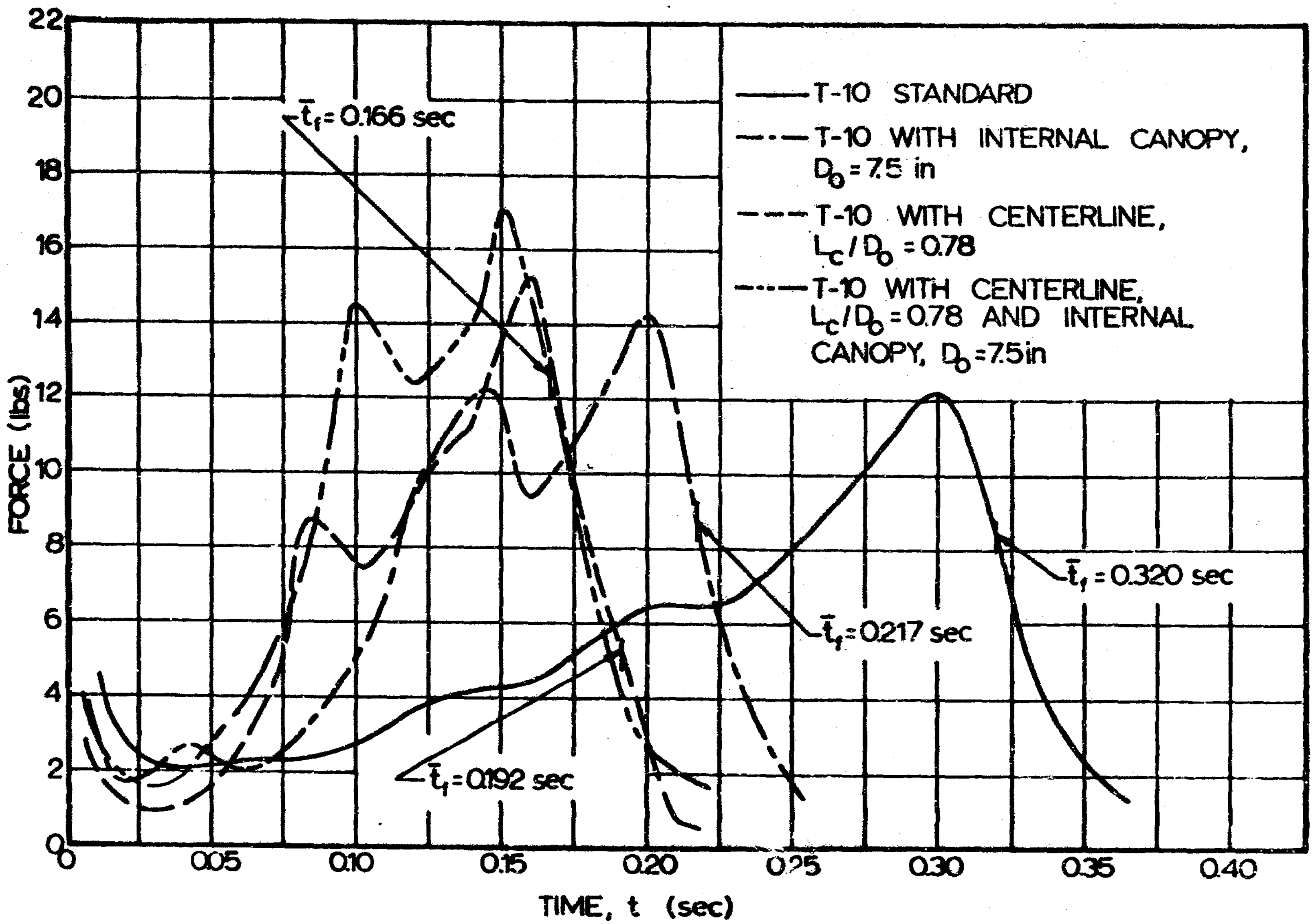


Fig 9 Average Opening Forces vs Real Time for the T-10 Model with Various Inflation Aids

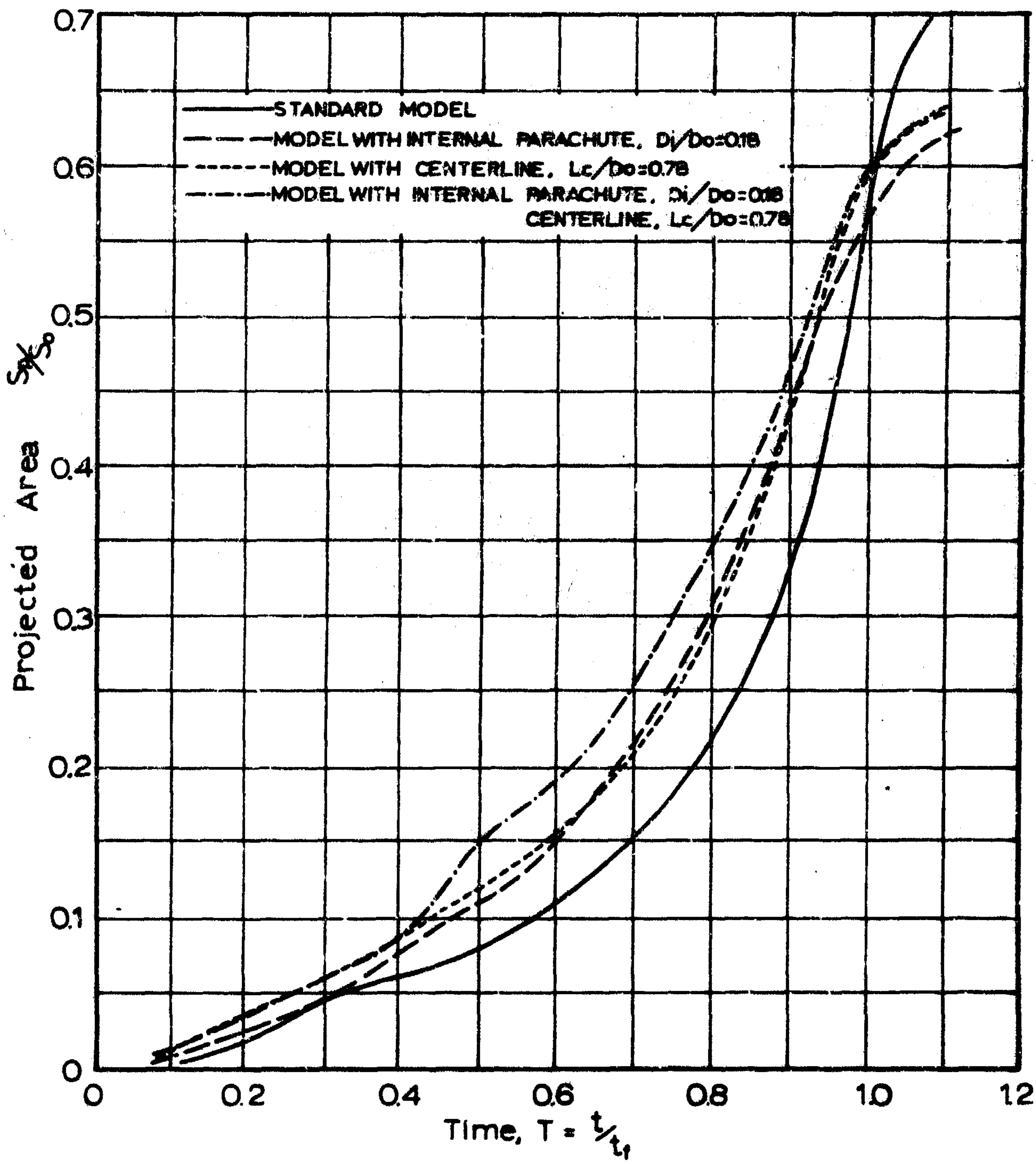


Fig 10 Projected Area-Time History of T-10 Parachute Model with and without Inflation Aids, Snatch Velocity V_s = 70 fps, Mass Ratio m_i/m_s = 0.26.

TABLE IV

AVERAGE, $\bar{t}'$, AND DIMENSIONLESS, T^*, CHARACTERISTIC TIMES FOR T-10 PARACHUTES

Configuration	No. Tests	$\bar{t}' \pm \sigma$ (sec)	$T^* = \bar{t}'/\bar{t}'_{STD} \pm \sigma$
Standard	12	0.272 ± 0.044	1.000 ± 0.161
Centerlines			
L_c/D_o = 1.05	9	0.284 ± 0.034	1.044 ± 0.125
L_c/D_o = 0.98	10	0.189 ± 0.048	0.695 ± 0.176
L_c/D_o = 0.90	10	0.142 ± 0.043	0.522 ± 0.158
L_c/D_o = 0.82	10	0.164 ± 0.039	0.603 ± 0.143
L_c/D_o = 0.75	10	0.129 ± 0.019	0.474 ± 0.070
Internal Parachute			
D_I/D_o = 0.14	14	0.137 ± 0.032	0.504 ± 0.118
D_I/D_o = 0.18	11	0.147 ± 0.041	0.540 ± 0.151
D_I/D_o = 0.23	13	0.128 ± 0.018	0.470 ± 0.066
Centerline and Internal Chute			
L_c/D_o = 0.90 D_I/D_o = 0.18	11	0.120 ± 0.017	0.441 ± 0.062
L_c/D_o = 0.90 D_I/D_o = 0.23	12	0.119 ± 0.021	0.438 ± 0.077

$$\sigma = \left[\frac{\Sigma(x_i - \bar{x})^2}{n}\right]^{\frac{1}{2}}$$

$*D_o$ = 41.76 in

TABLE V

AVERAGE, $\bar{F}_o$, AND DIMENSIONLESS, F^*, MAXIMUM OPENING FORCE FOR T-10 PARACHUTE

Configuration	No. Tests	$\bar{F}_o \pm \sigma$ (lb)	$F^* = \bar{F}_o / \bar{F}_{STD} \pm \sigma$
Standard	12	13.2 ± 1.9	1.000 ± 0.144
Centerline			
L_c/D_o = 1.05	9	11.9 ± 2.6	0.902 ± 0.197
L_c/D_o = 0.98	10	16.2 ± 2.5	1.227 ± 0.189
L_c/D_o = 0.90	10	18.8 ± 3.0	1.424 ± 0.227
L_c/D_o = 0.82	10	18.8 ± 2.7	1.424 ± 0.205
L_c/D_o = 0.75	10	21.2 ± 2.7	1.606 ± 0.205
Internal Parachute			
D_I/D_o = 0.14	14	17.5 ± 1.6	1.326 ± 0.121
D_I/D_o = 0.18	11	16.3 ± 3.1	1.235 ± 0.235
D_I/D_o = 0.23	13	20.2 ± 1.9	1.530 ± 0.144
Centerline and Internal Chute			
L_c/D_o = 0.90 D_I/D_o = 0.18	11	22.1 ± 2.3	1.674 ± 0.174
L_c/D_o = 0.90 D_I/D_o = 0.23	12	21.5 ± 2.3	1.629 ± 0.174

$$\sigma = \left[\frac{\Sigma (x_i - \bar{x})^2}{n}\right]^{\frac{1}{2}}$$

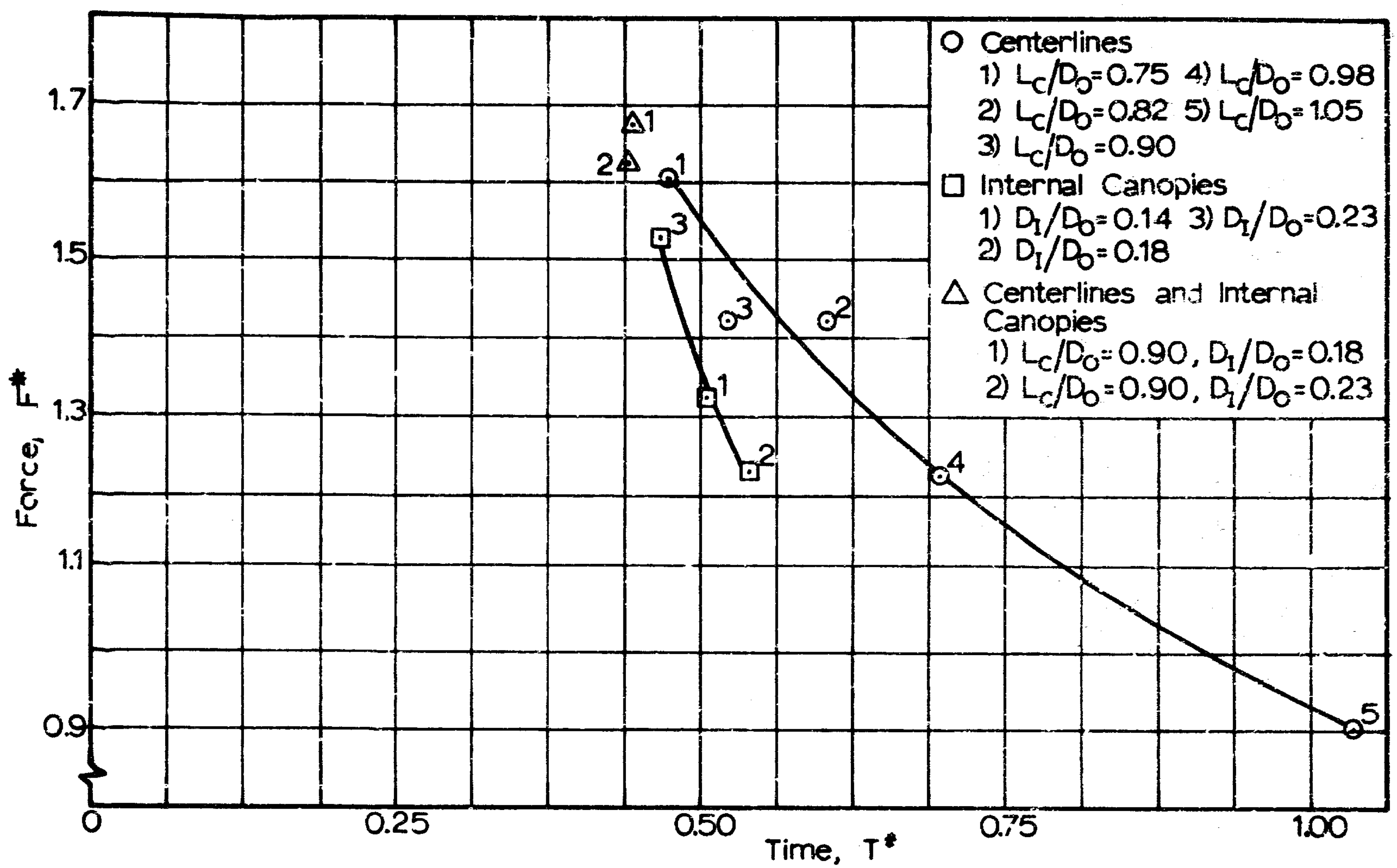


Fig 11 Force vs Time Ratios for All Inflation Aid Configurations of the T-10 Model, $D_o = 41.8$ in

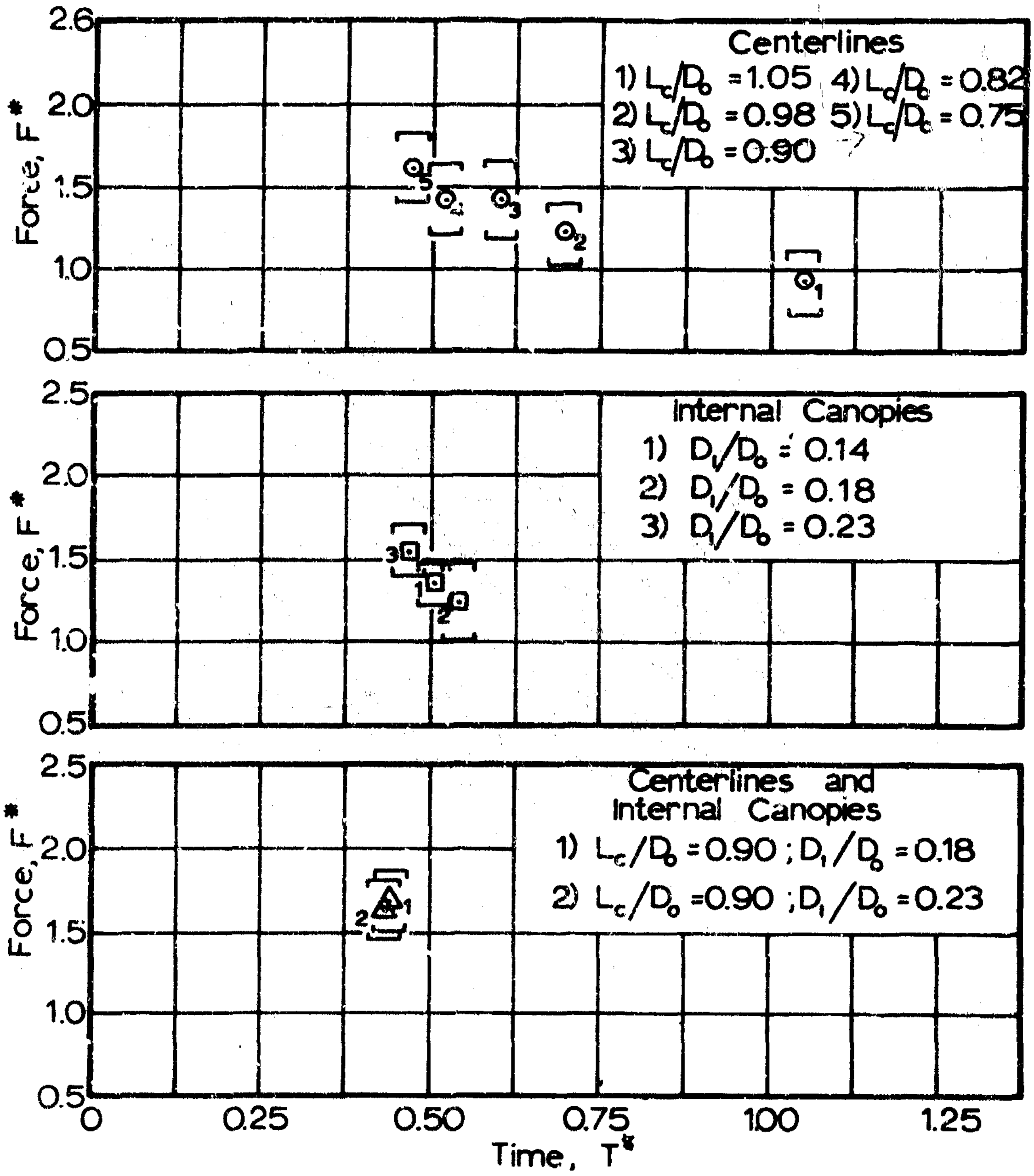


Fig. 12 Force vs. Time Ratios with Their Deviations for all Inflation Aid Configurations

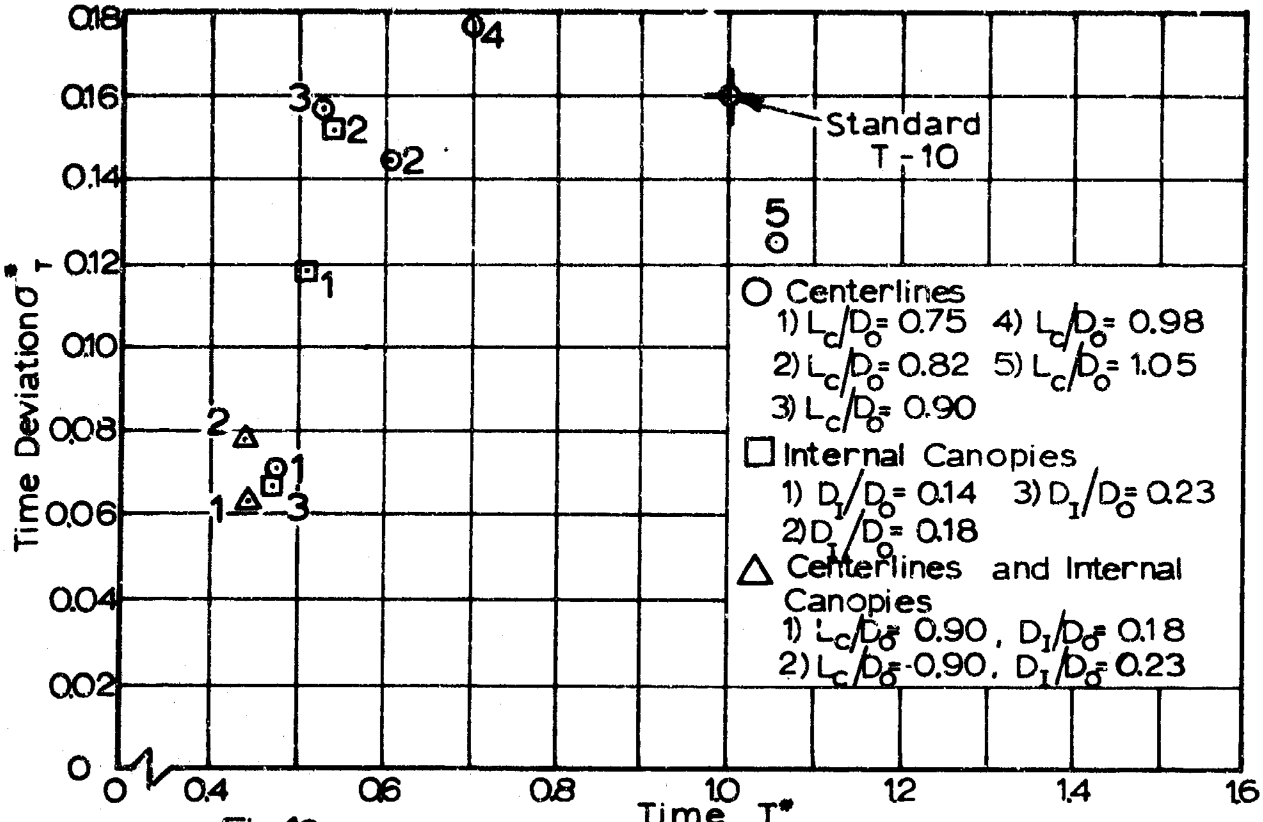


Fig 13a

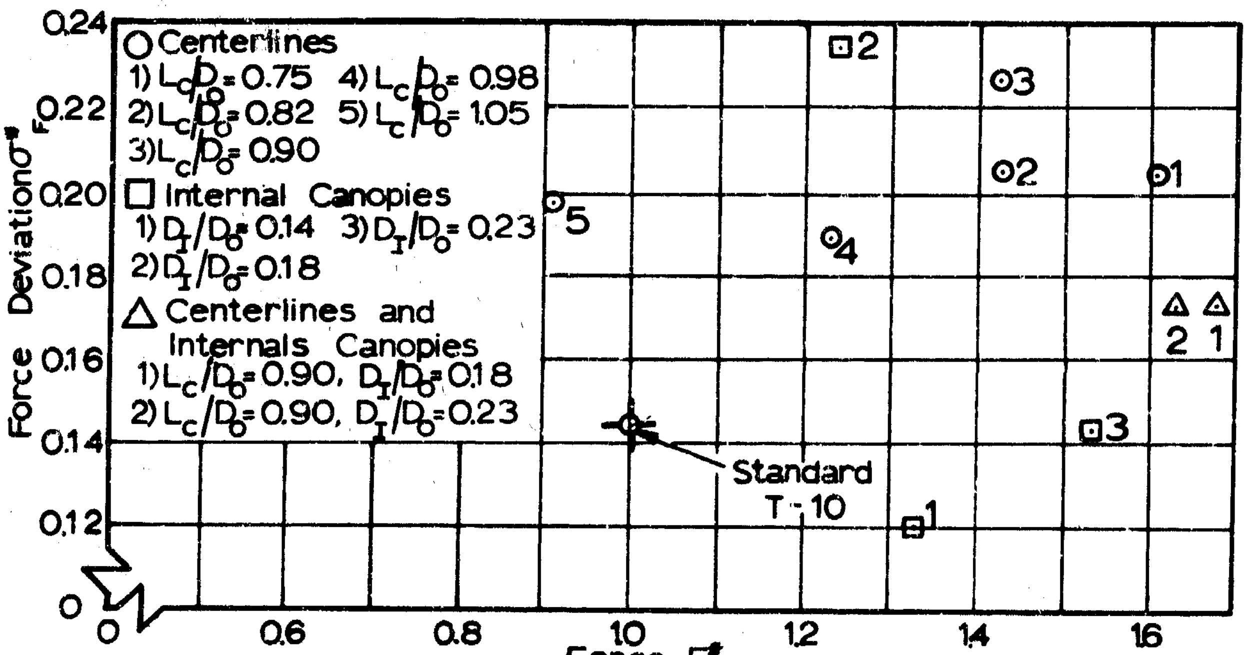


Fig 13b

Fig 13 Force and Time Deviations of the T-10 Parachute Model with Inflation Aids

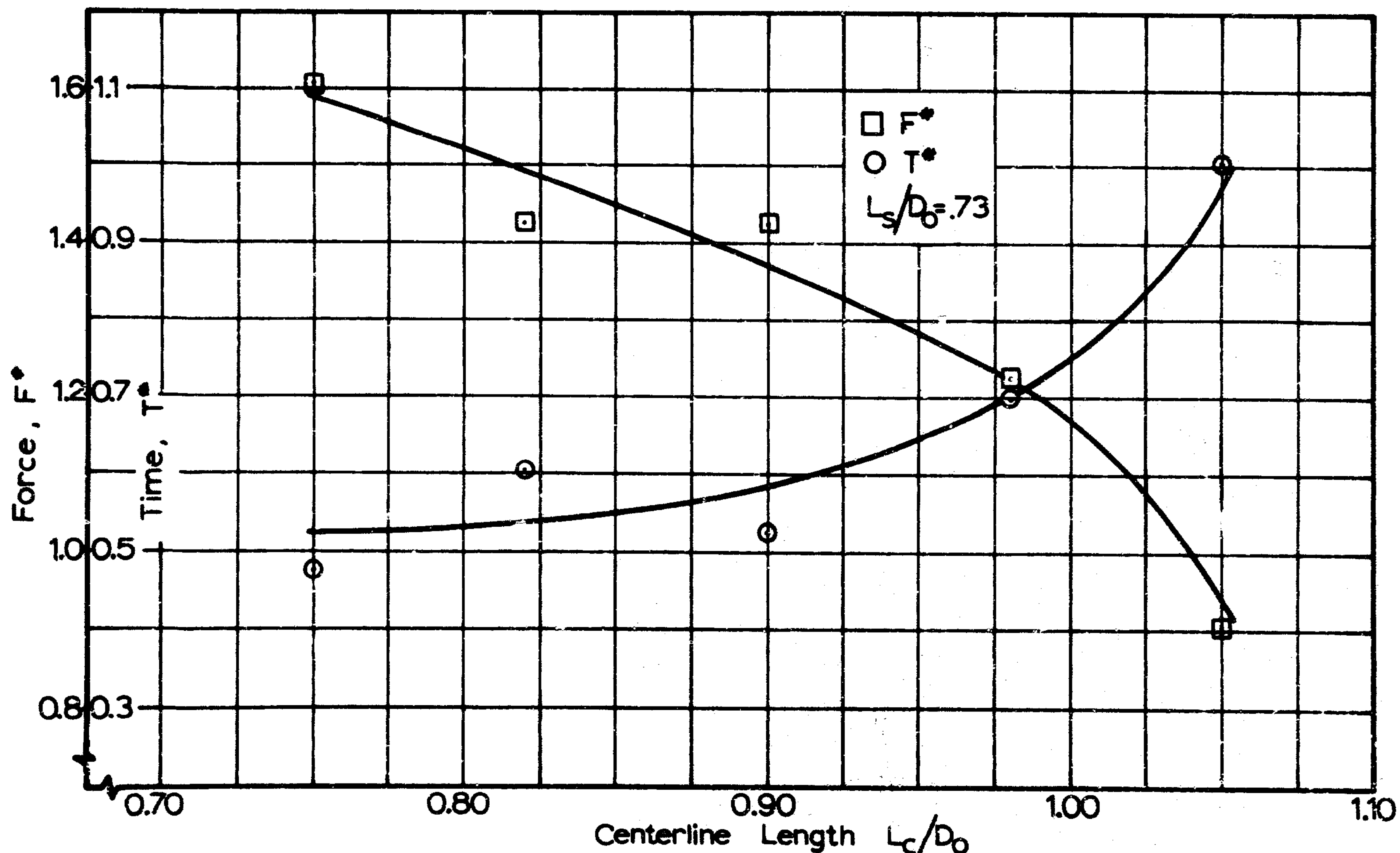


Fig 14 Force and Time Ratios of T-10 Parachute Model with Various Centerlines

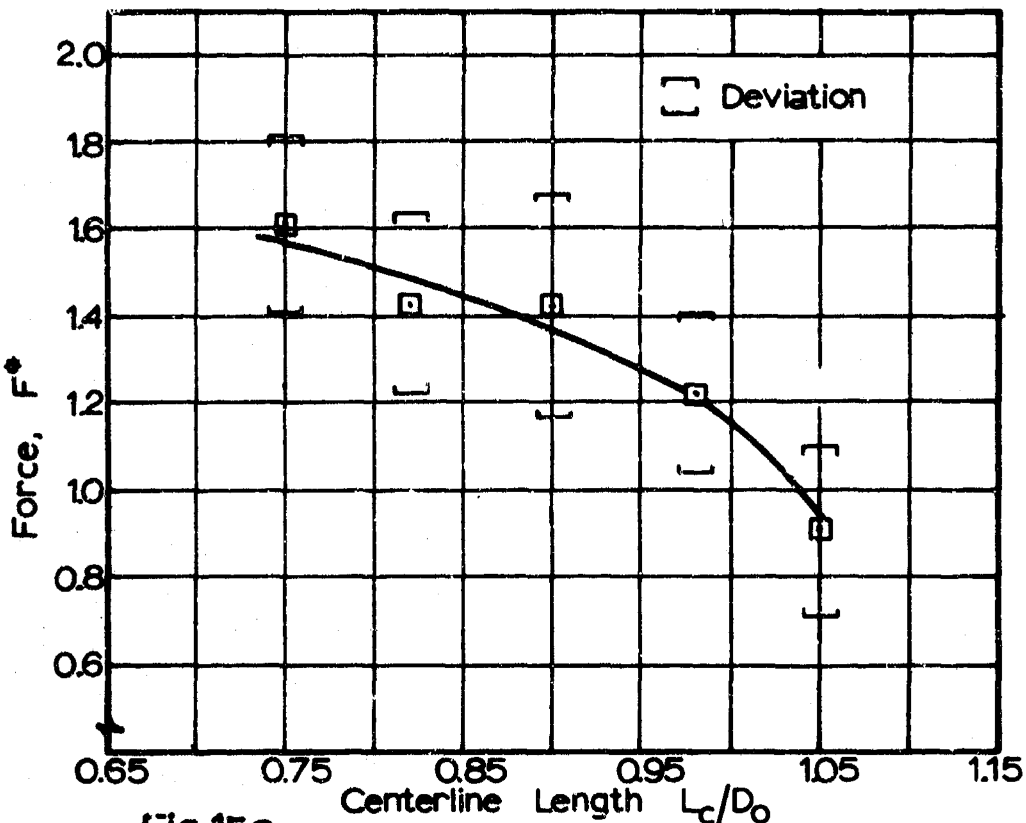


Fig 15a

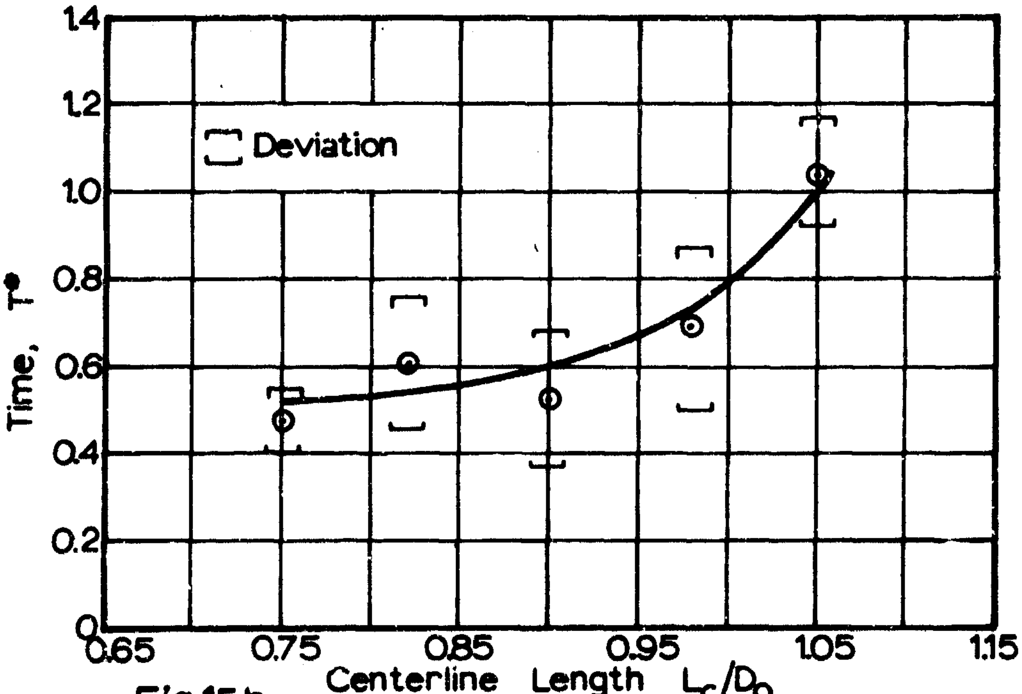


Fig 15b

Fig 15 Characteristic Forces and Times of T-10 Parachute Model with Various Centerlines

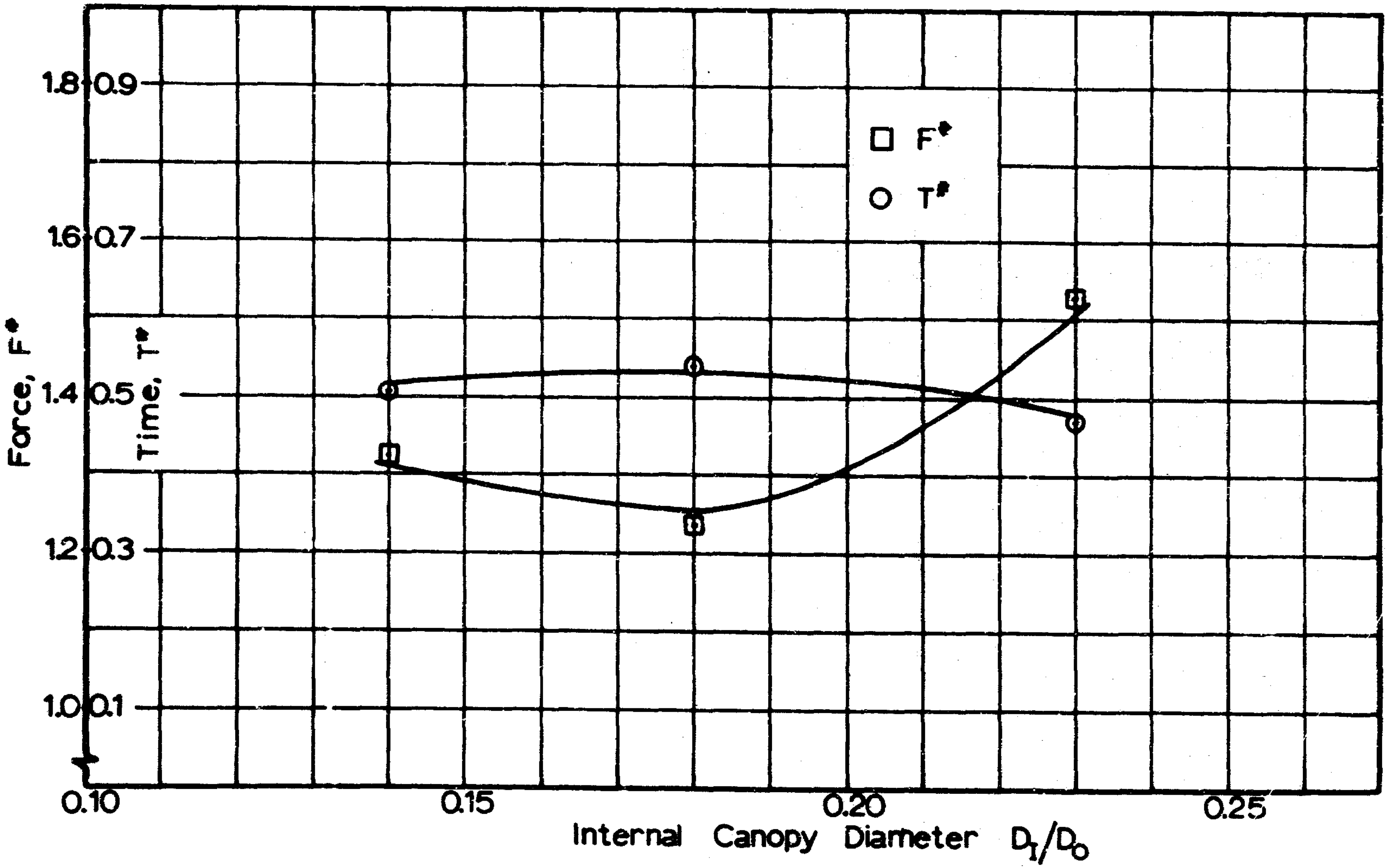


Fig 16 Force and Time Ratios of T-10 Parachute Model with Various Internal Canopies

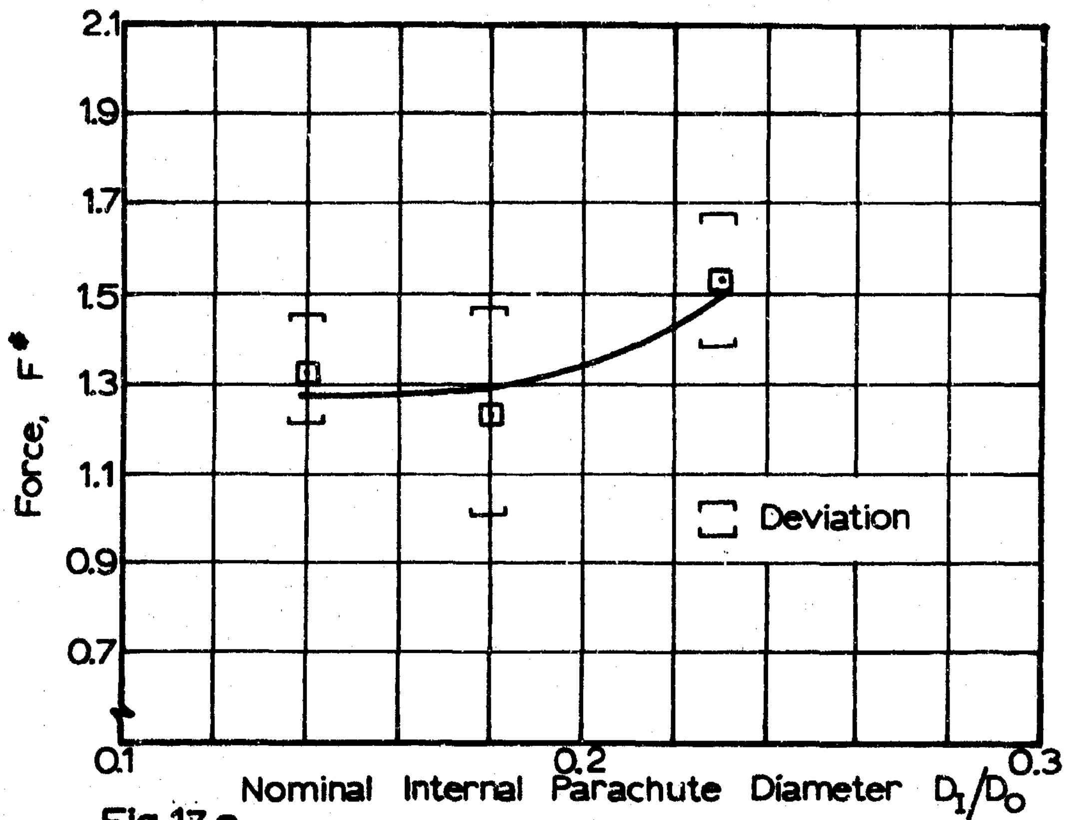


Fig 17 a

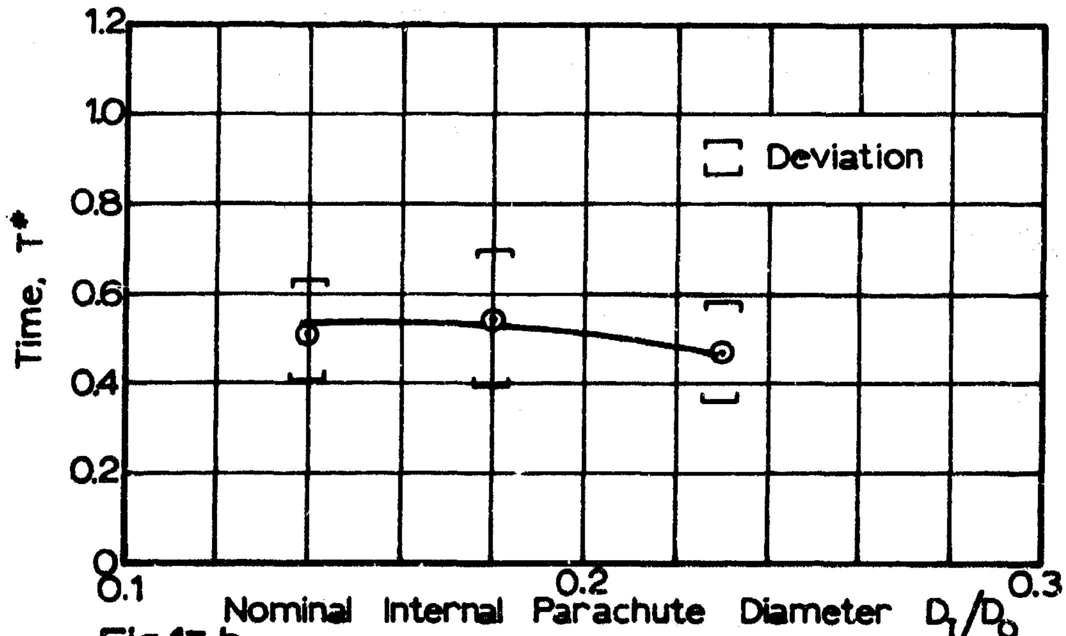


Fig 17 b

Fig 17 Characteristic Forces and Times of T-10 Parachute Model with Various Internal Canopies

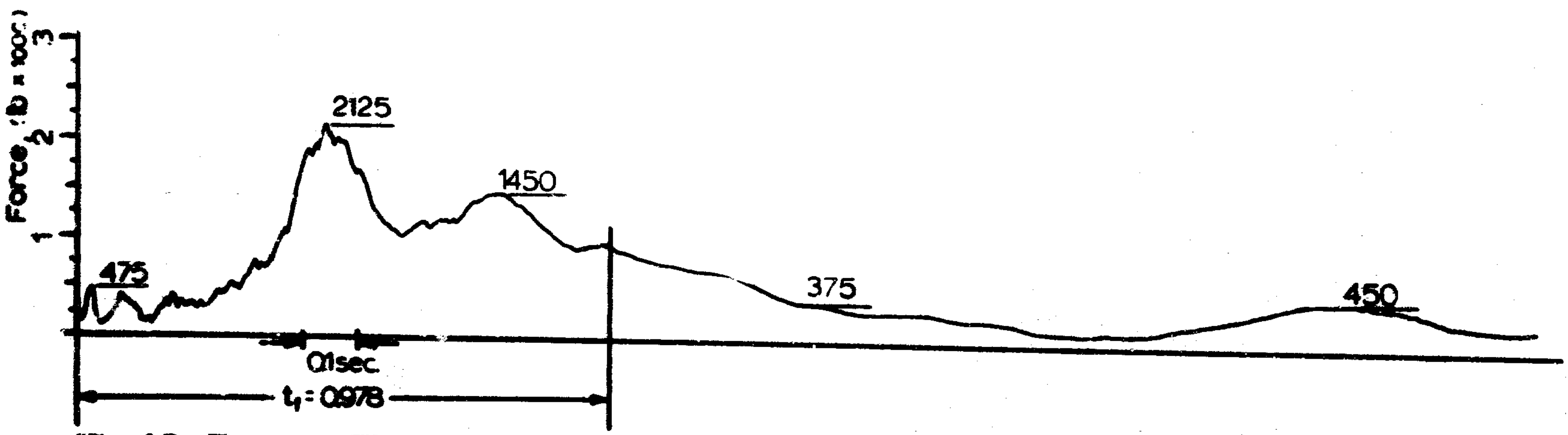


Fig. 18 Force-Time History of Standard T-10 Parachute, Snatch Velocity V_S = 221 fps, Suspended Weight = 210 lb, Altitude, h = 6000 ft.

V. SUMMARY

In parachute model tests, it was shown that the characteristic time of the T-10 parachute can be reduced significantly by means of inflation aids. Shorter opening times are accompanied by higher opening forces. From all inflation aids studied, the internal canopies produced within a certain region the smallest opening forces at a given opening time. The T-10 parachute model had with all but one inflation aid smaller deviations of the characteristic time than the standard configuration.

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VII. APPENDIX - FORCE-TIME DIAGRAMS
(Figs 19 through 29)

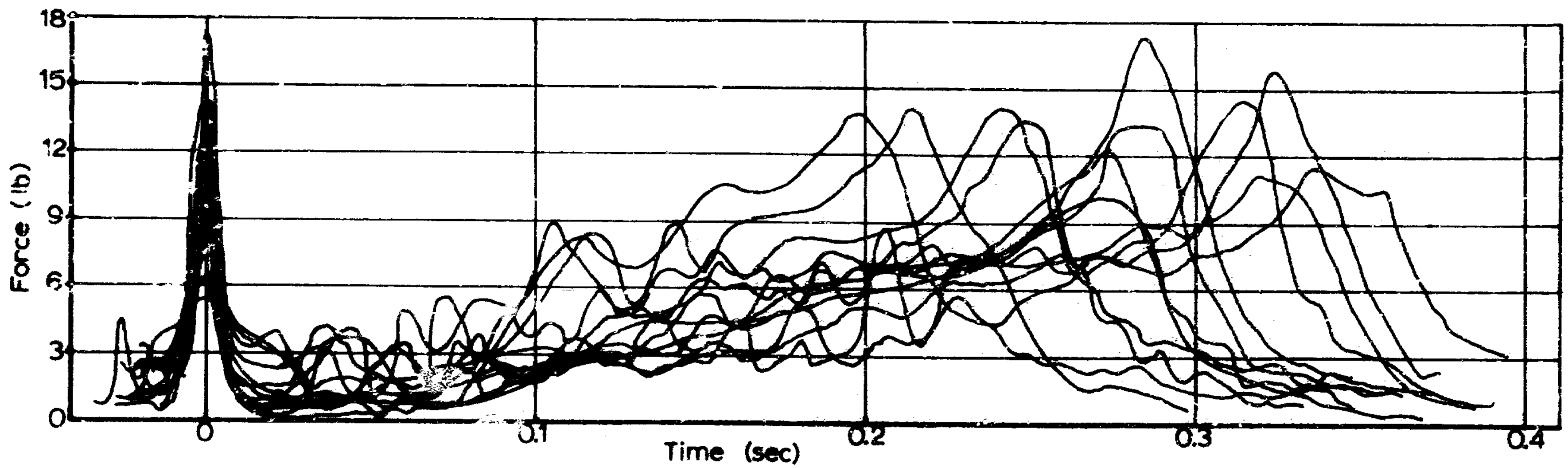

Fig 19 Force Recordings of Standard T-10 Model Parachute, $D_o = 41.8$ in.

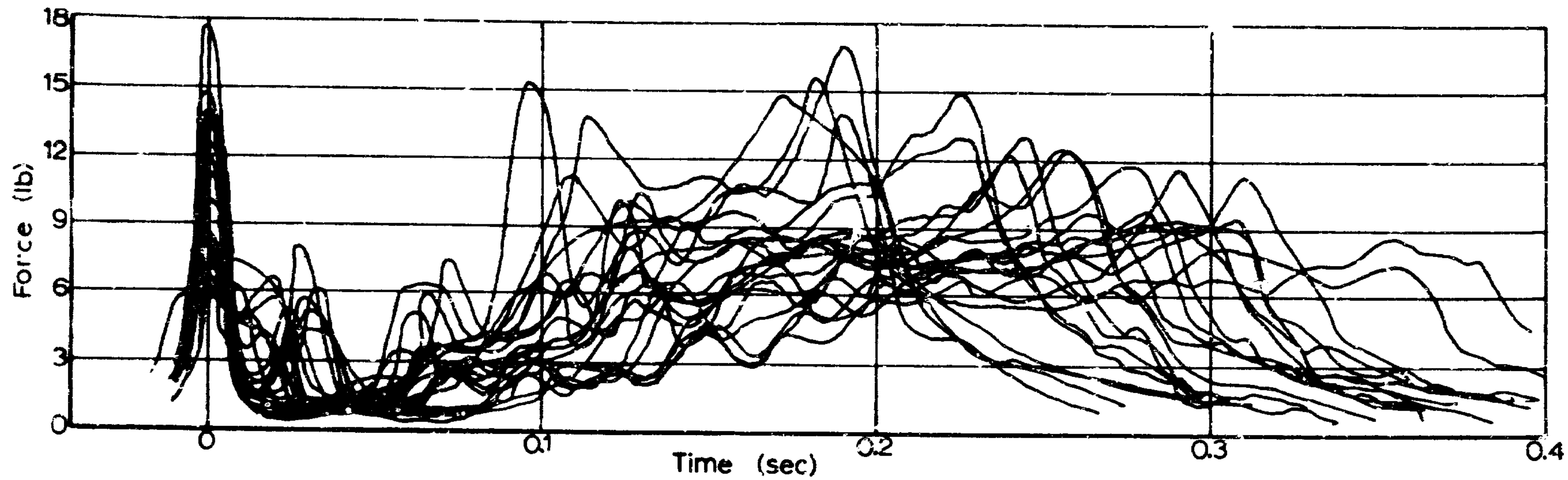

Fig 2.0 Force Recordings of T-10 Model with Centerline, $L_c/D_o = 1.05$

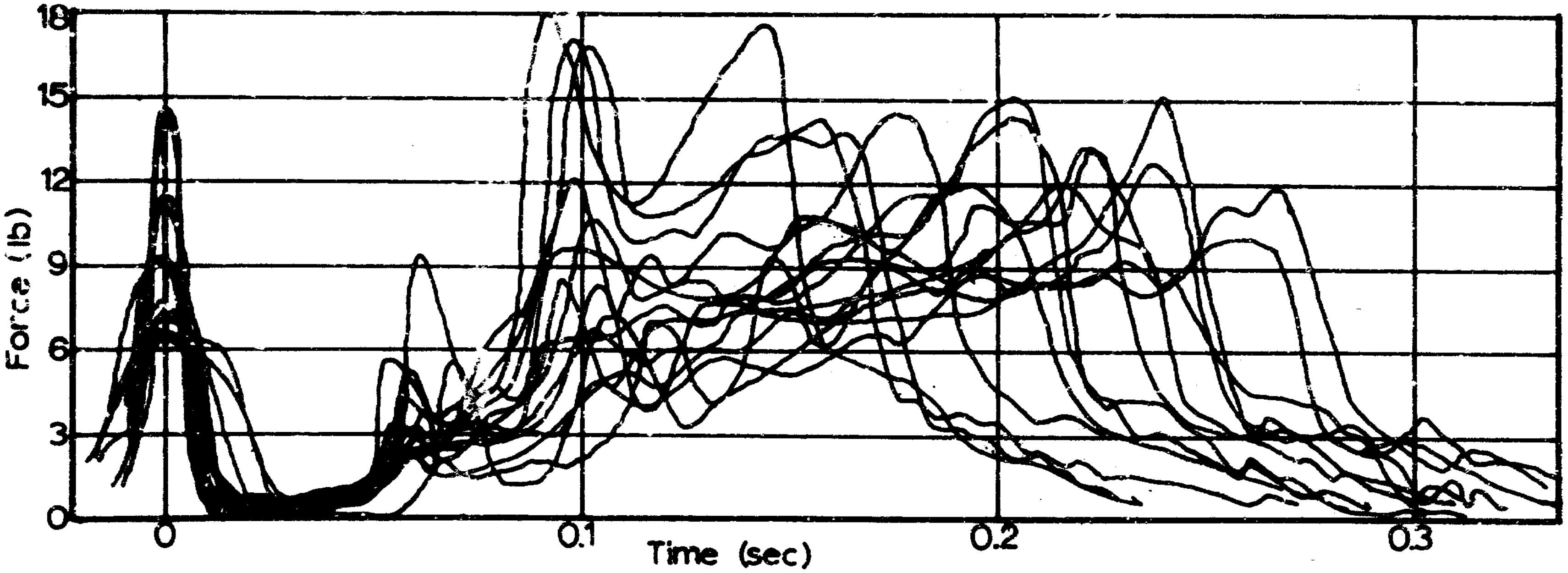

Fig 21 Force Recordings of T-10 Model with Centerline $L_c/D_o = 0.98$

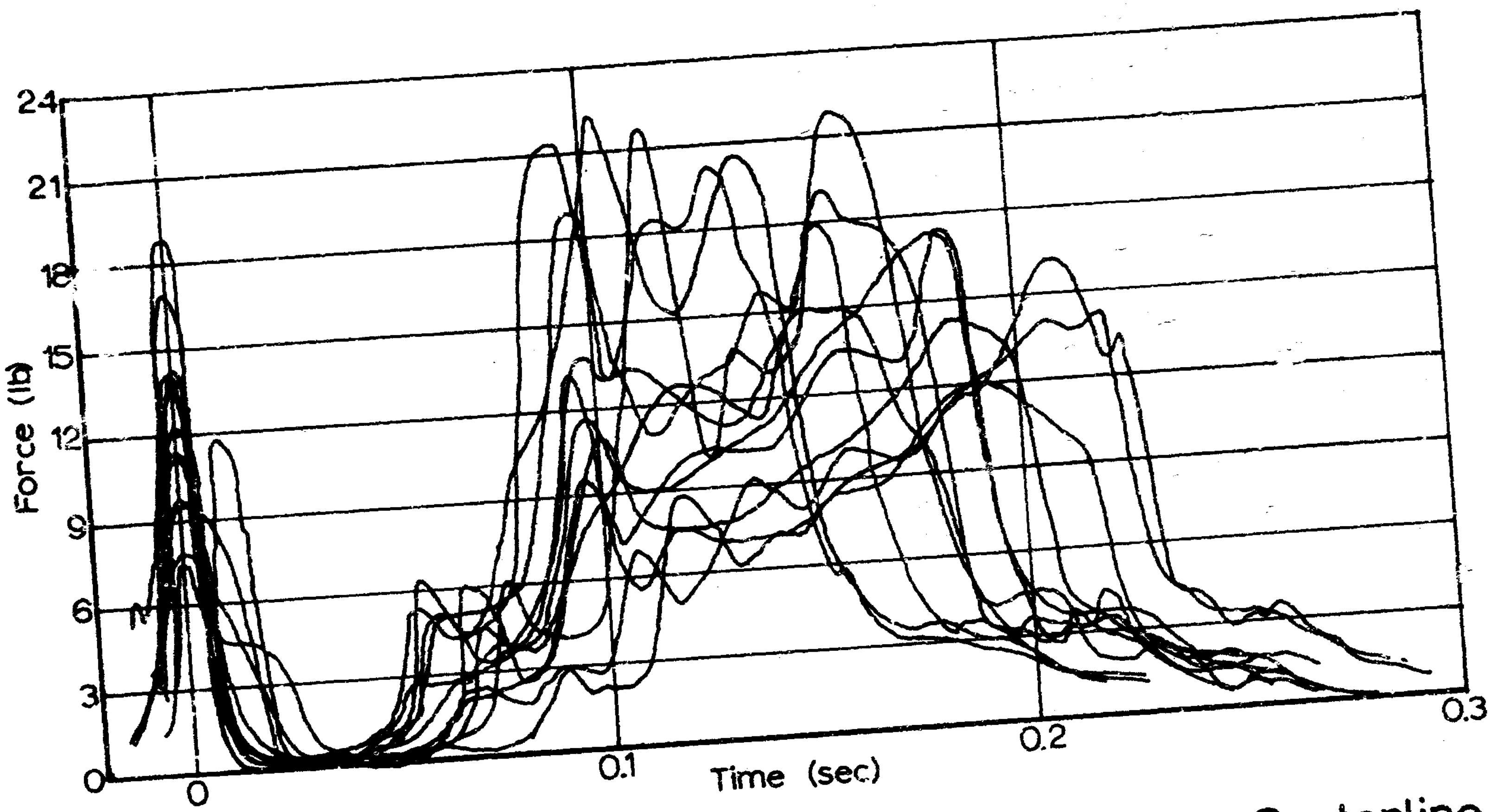

Fig 22 Force Recordings of T-10 Model with Centerline, $L_c/D_o = 0.90$

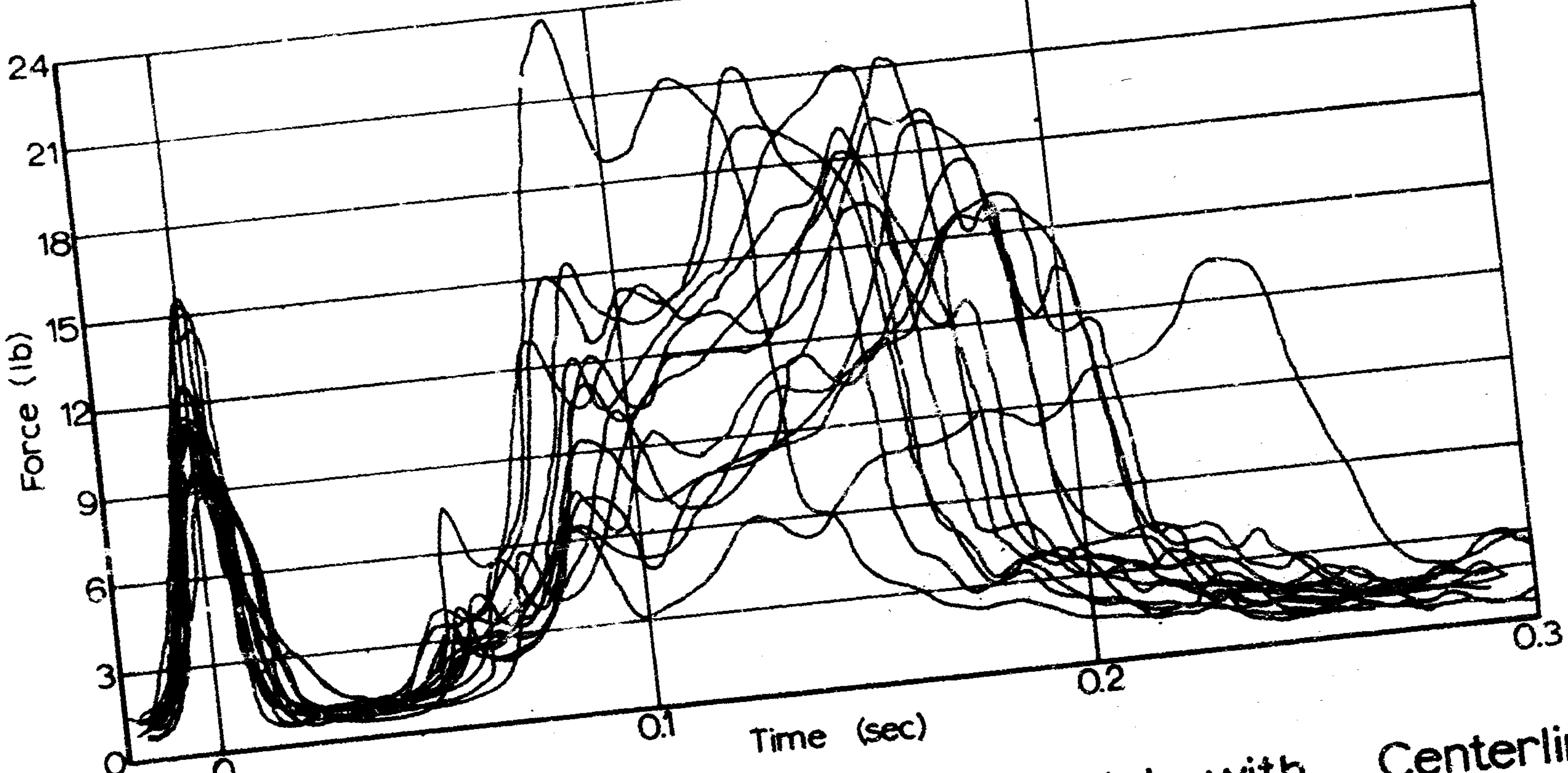

Fig 23 Force Recordings of T-10 Model with Centerline, $L_c/D_o = 0.82$

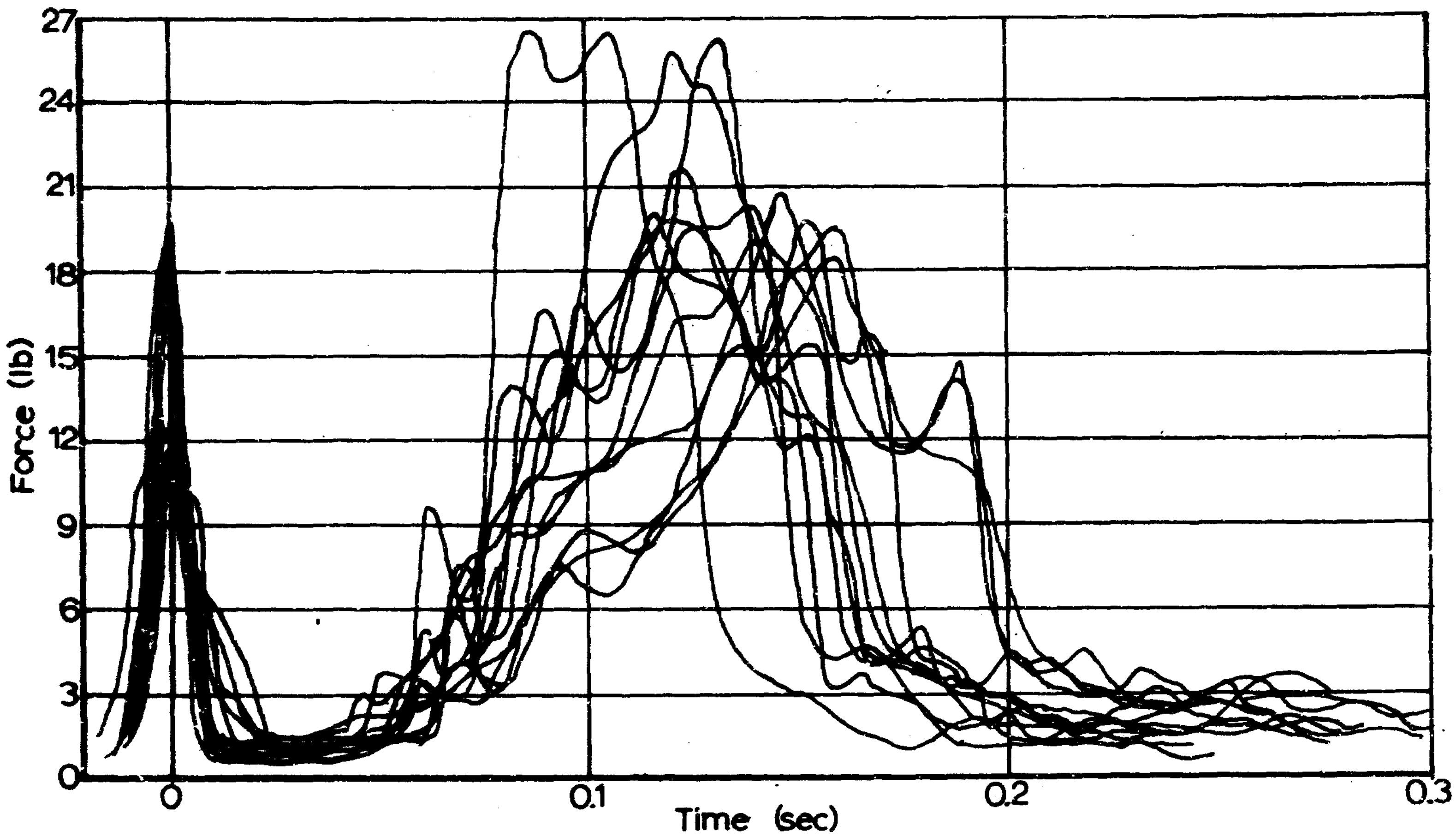

Fig 2.4 Force Recordings of T-10 Model with Centerline, $L_c/D_o=0.75$

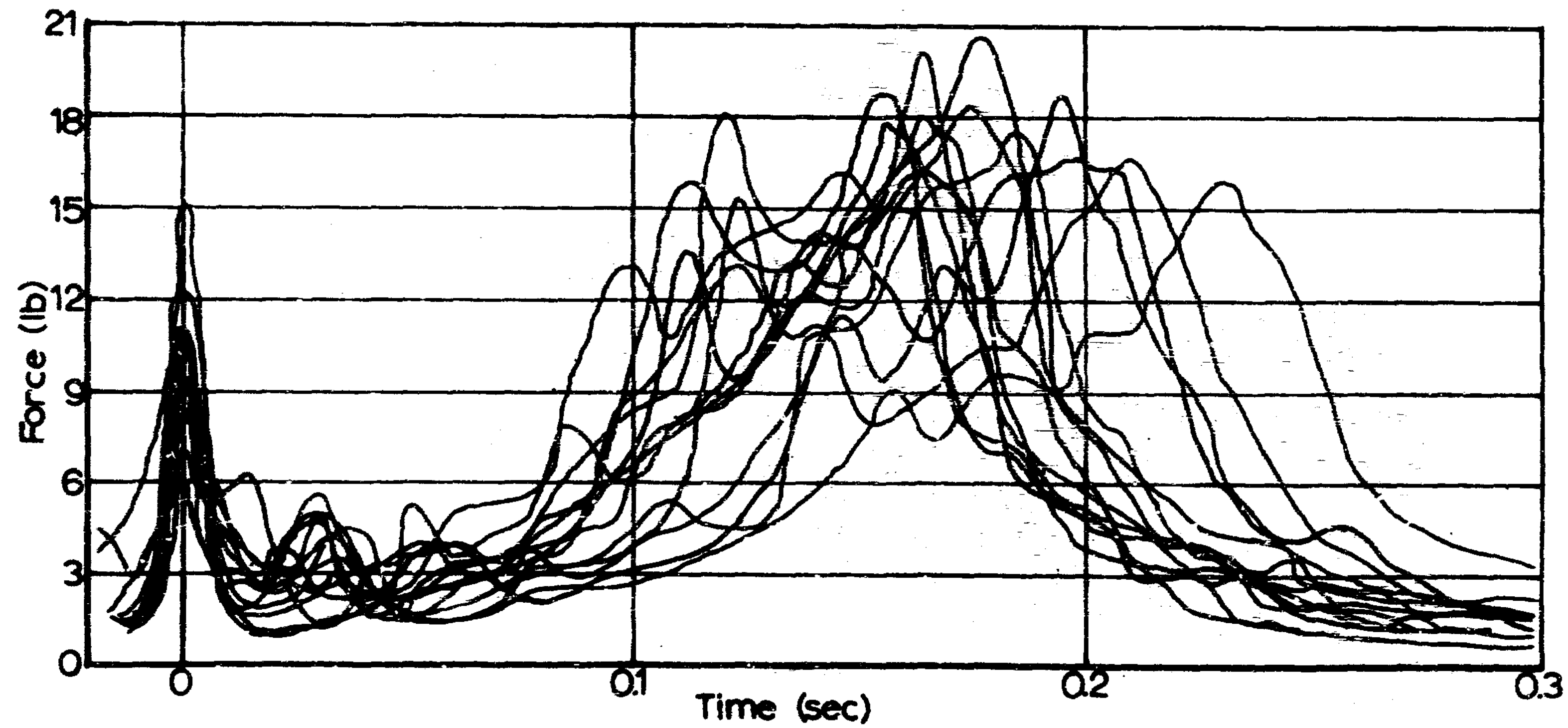

Fig 25 Force Recordings of T-10 Model with Internal Canopy, $D_I/D_O = 0.14$

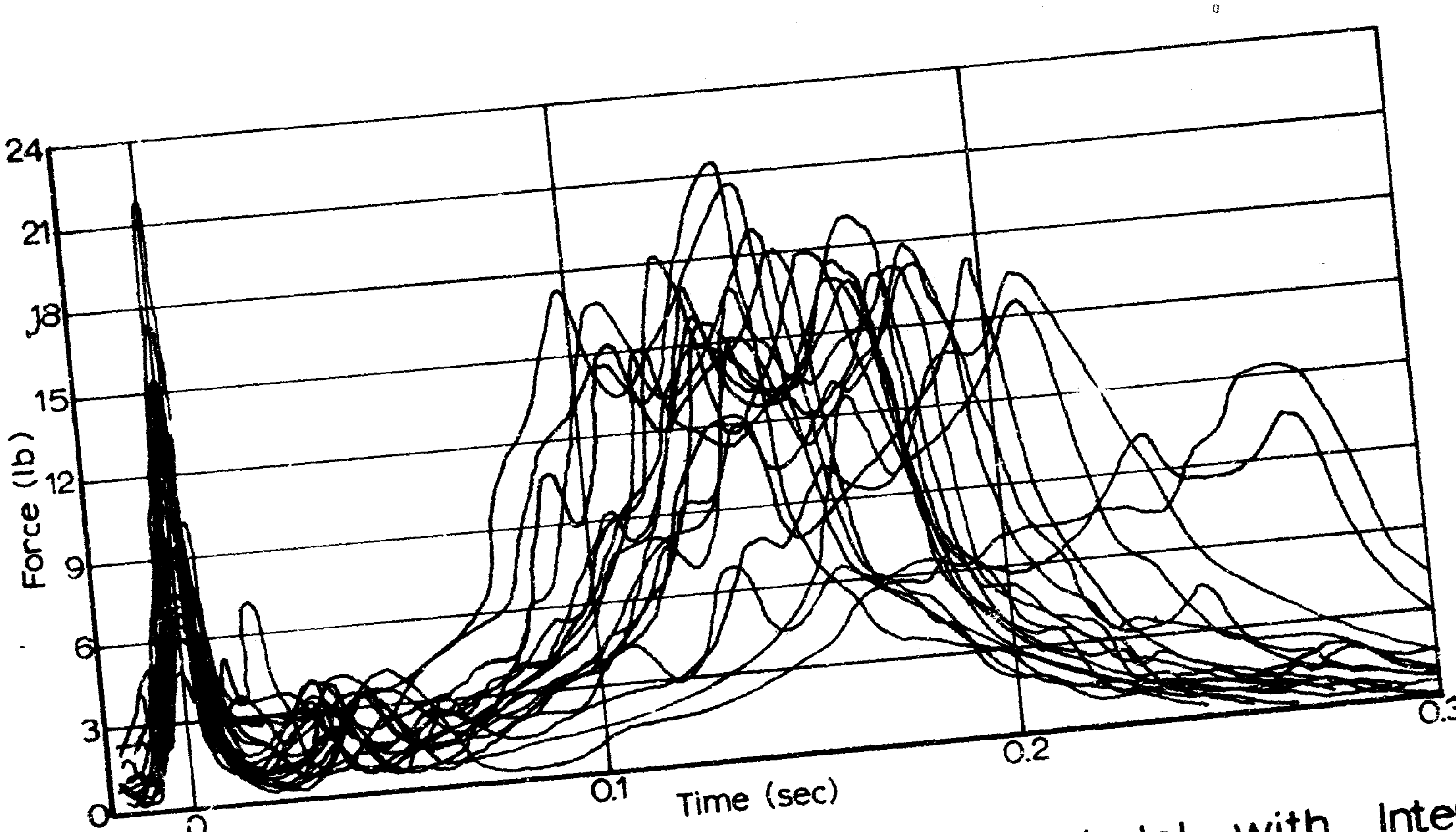

Fig 26 Force Recordings of T-10 Model with Internal Canopy, $D_I/D_O = 0.18$

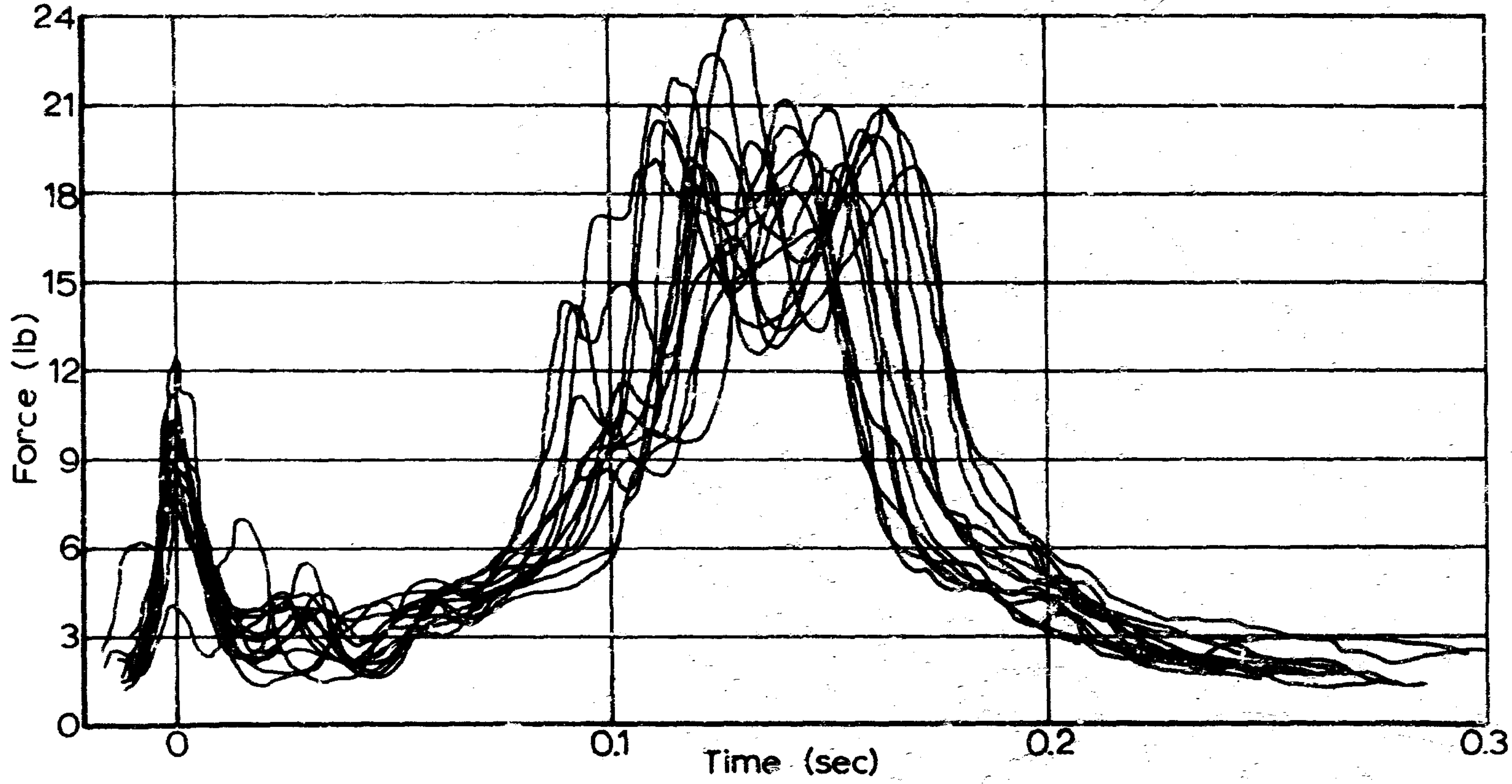

Fig 27 Force Recordings of T-10 Model with Internal Canopy, $D_I/D_O = 0.23$

Fig 28 Force Recordings of T-10 Model with Centerline, $L_c/D_o = 0.90$ and Internal Canopy, $D_I/D_o = 0.18$

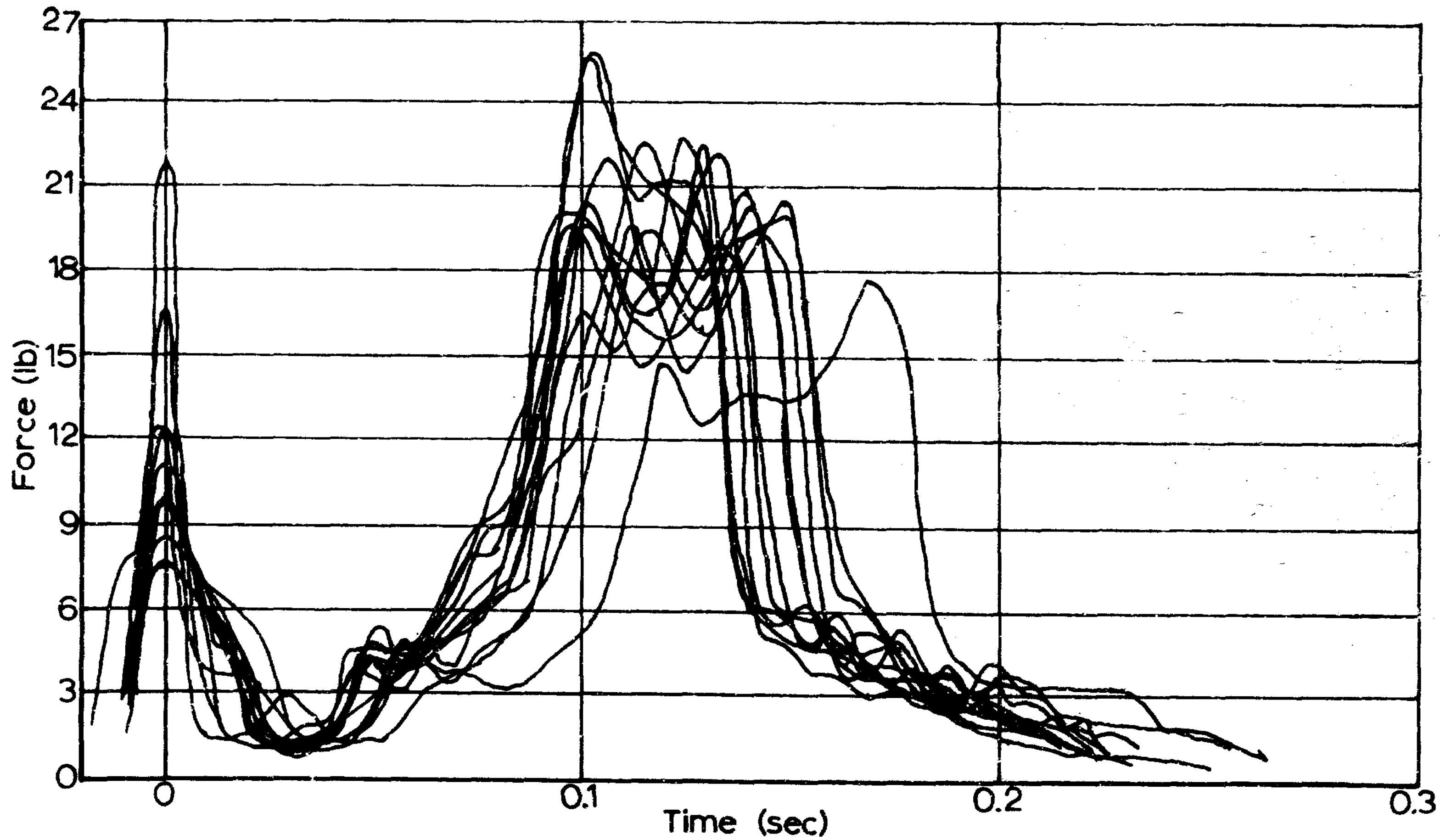

Fig 29 Force Recordings of T-10 Model with Centerline, $L_C/D_O = 0.90$ and Internal Canopy, $D_I/D_O = 0.23$

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1. ORIGINATING ACTIVITY (Corporate author) University of Minnesota Minneapolis, Minn. 55455	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

Opening Dynamics of a T-10 Parachute With Inflation Aids

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report June 68 - June 69

5. AUTHOR(S) (Last name, first name, initial)

Heinrich, Helmut G.

Hektner, Thomas R.

6. REPORT DATE February 70	7a. TOTAL NO. OF PAGES 43	7b. NO. OF REFS 6
8a. CONTRACT OR GRANT NO. F33615-68-C-1227 b. PROJECT NO. 6065 c. Task No. 606503 d.	9a. ORIGINATOR'S REPORT NUMBER(S) NONE 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFFDL-TR-69-112	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY AF Flight Dynamics Laboratory AFFDL (FDFR) Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

The characteristic times and opening forces were studied for various inflation aid configurations of a model T-10 parachute. Finite mass wind tunnel tests were conducted in the horizontal return wind tunnel at a snatch velocity of 70 fps with a suspended load of 1.1 lbs. Relative to results of the standard T-10 parachute, the percentage decrease in the characteristic time and the corresponding percentage increase in the peak force were presented for five centerline, three internal parachutes and two centerline-internal combinations.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
T-10 Canopy						
Extended Skirt Canopy						
Internal Canopy						
Pulled-Down Vent						
Opening Force						
Filling Time						
Finite Mass Wind Tunnel Tests						

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