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FORCE DISTRIBUTION IN THE SUSPENSION LINES OF CROSS PARACHUTES

BY WILLIAM P. LUDTKE

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UNDERWATER SYSTEMS DEPARTMENT

DECEMBER 1989

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FOREWORD

Uneven forces in the several suspension lines of Cross parachutes cause design problems due to lack of engineering force distribution data. A series of Cross parachutes was wind-tunnel tested and the forces in individual suspension lines measured for several lengths of individual lines to determine the load variations.

The pressure distribution adjacent to the canopy center line was also measured ahead of and within the parachute canopy.

Approved by:

C. A. Kalivretenos

C. A. KALIVRETENOS, Deputy Head
Underwater Systems Department

ABSTRACT

The force distribution in the several suspension lines attached to an arm of a Cross-type parachute is nonuniform. The outer suspension lines carry the minimum force. The forces increase in each suspension line as the line attachment approaches the center of the arm with the maximum force carried by the most central lines.

This report describes a series of wind tunnel tests to measure the forces in individual selected suspension lines of Cross type parachutes with 8, 16, and 24 suspension lines. The test results show that lengthening the inner suspension lines tends to equalize the suspension line forces. The static pressure distribution adjacent to the parachute center line was measured for each parachute model. Positive pressures were found to exist ahead of the canopy skirt hem as well as inside of the canopy. The magnitude of the pressures is influenced by the canopy cloth permeability.

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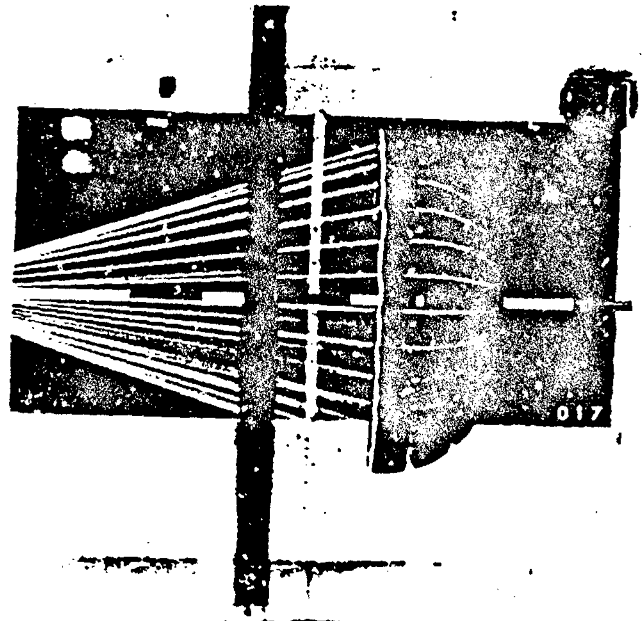
INTRODUCTION

The Cross parachute has been demonstrated to be a reliable retarder for ordnance and other applications. Characteristics of the Cross parachute are low opening shock factor, good parachute stability, good two-body stability, supersonic inflation capability up to Mach 2.5, and a reduced manufacturing cost. An engineering problem with the Cross parachute is the occasional failure of one or more suspension lines when conventional analysis indicates that they were structurally adequate. The cause of the failure is due to the unique inflated shape of the Cross canopy. Conventional parachutes are symmetrically constructed and the forces in the several suspension lines are usually assumed to be uniform. This is a reasonable assumption because all of the suspension lines are of the same design length and elongate equally. The arms of a Cross parachute each have a set of suspension lines which are usually of the same design length. Figure 1 shows that the several suspension lines attached to an arm of the canopy elongate in a uniform, but unequal pattern.

Figure 2 is a typical load elongation test result of tubular braided nylon cord of the type used by the Naval Surface Warfare Center in parachute designs. The samples witness to the repeatability of the cord's performance. The obvious conclusion to be drawn from Figures 1 and 2 is that the tensile force in the Cross parachute's suspension lines varies, and this forced variation manifests itself by the different elongations of the lines. The equal elongation of the ring-slot parachute suspension lines indicates uniform suspension line loading. The suspension line forces can be modified to a uniform distribution by selectively lengthening the inner suspension lines. If the suspension lines were lengthened so that they hang loosely they would not transmit any force.

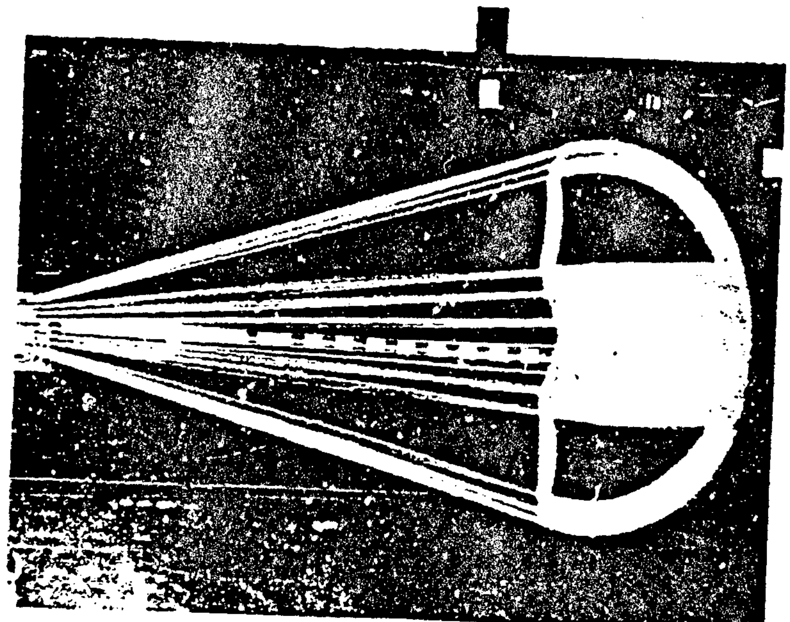
Several approaches are available as solutions to the broken suspension line problem. Each approach has some advantage and disadvantage.

	APPROACH	ADVANTAGE	DISADVANTAGE
1.	All suspension lines same length. Design strength related to maximum suspension line force.	No production line misassembly problems.	Some increase in suspension line cost and required packing volume.



RINGSLOT PARACHUTE WITH EQUALLY ELONGATED SUSPENSION LINES AT 200 MPH

D_0 = 37½ INCH DIA
24 GORE
16% POROSITY



CROSS PARACHUTE WITH UNEQUALLY ELONGATED SUSPENSION LINES AT 200 MPH

L = 40 INCH DIA
W/L = 0.264

FIGURE 1. COMPARISON OF SUSPENSION LINE ELONGATION OF RIBBON AND CROSS PARACHUTES

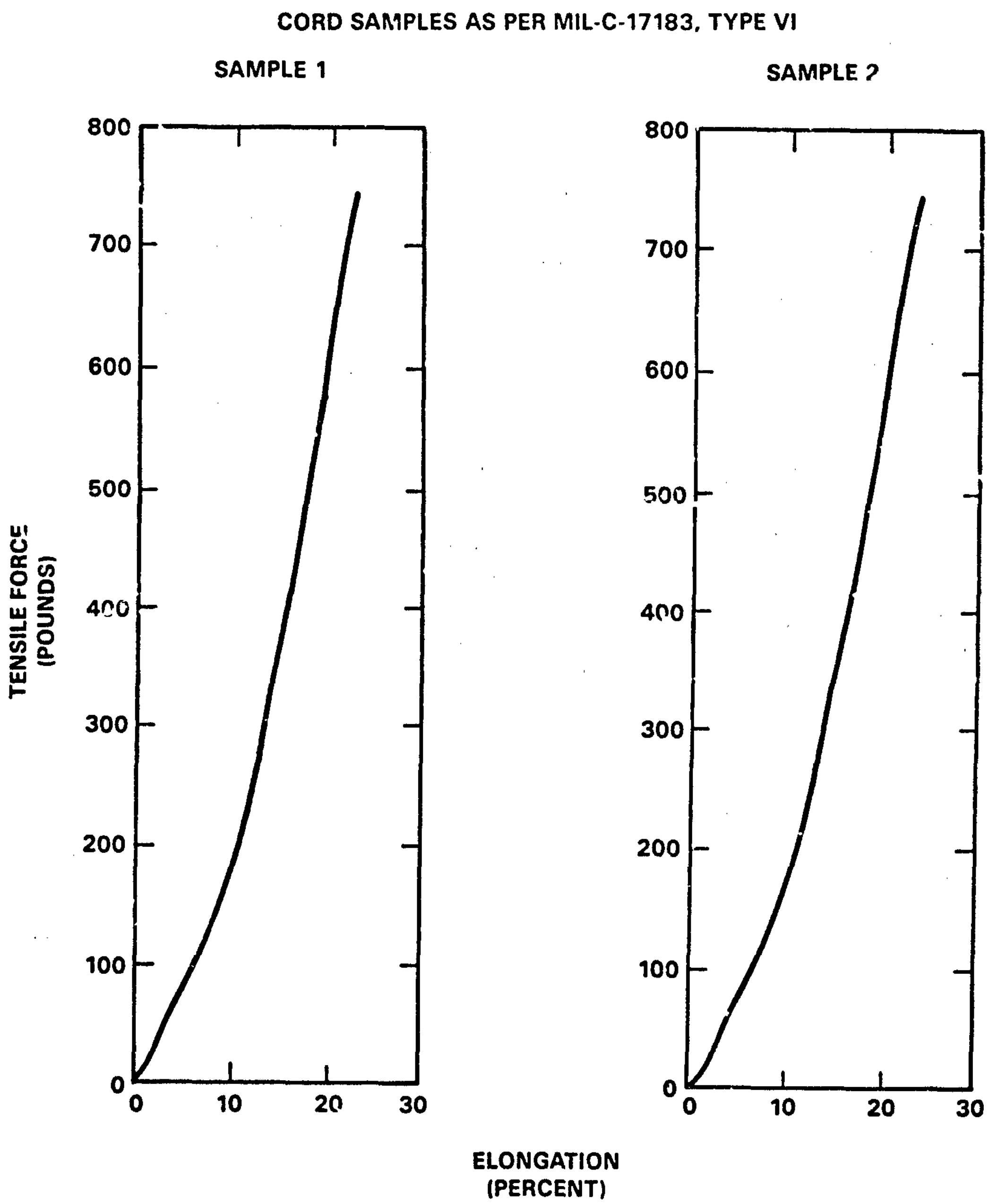


FIGURE 2. TYPICAL FORCE-ELONGATION TEST DATA FOR A TUBULAR BRAIDED NYLON PARACHUTE SUSPENSION LINE CORD

2. All suspension lines same length. Design strengths tailored to various maximum suspension line forces	Less weight and packing volume than approach No. 1	Possible production line problems with suspension line misassembly
APPROACH	ADVANTAGE	DISADVANTAGE
3. Suspension line lengths varied. Design strength of all lines constant	Less weight and packing volume than approach No. 1	Possible production line problems with suspension line misassembly
4. All suspension lines are the same length and strength. Respace reinforcement tapes on the canopy to vary pressurized canopy area to produce uniform suspension line forces.	Best possibility for a minimum weight system.	Less likely production line problems.

From the standpoint of potential production problems, approach number one is best. Any suspension line may be correctly assembled to any attachment point on the arm. This is also true of approach number four. The possibility of misassembly of the canopy reinforcements to the canopy in approach number four can be controlled in the layout and marking of the canopy cloth. Spot inspections of the reinforcement to canopy assembly are easily accomplished. Misassemblies should be obvious. Approaches two and three have the possibility of assembling either the wrong length or wrong strength suspension line to the attachment point. This possibility exists for each line attached and may not be obvious. Approach number four appears to be the best candidate for achieving a minimum weight system.

The first step in the analysis of the problem of unequal loading was to conduct a 200-mile-per-hour wind-tunnel test where the tension force was measured in individual Cross parachute suspension lines. A series of parachutes were constructed with suspension line lengths predetermined from existing data. The models were attached to the force measuring instrumentation. A stadia rod was attached to the wind-tunnel mount and extended along the wind-tunnel center line into the inflated canopy. The stadia rod was marked to provide a reference for measurements and was also rigged to measure static pressures at various points within the canopy and immediately ahead of the skirt hem.

A second objective of the wind tunnel tests is to examine the static pressure distribution along the canopy center line within the canopy and in the zone immediately ahead of the skirt hem. Figure 23 of Appendix A of Reference 1 presents photographs of airflow patterns around parachute profiles. The volume of air associated with an inflated parachute is shown to extend ahead of the canopy skirt hem. This volume of air must also be collected during the inflation time interval in order to have a fully inflated parachute. As a demonstration that this air mass actually exists a stadia rod with ten pressure taps was mounted along the parachute center line to measure the static local pressure distribution ahead of and inside of the canopy. Elevated static pressures are indicative of air masses with less than free stream velocity.

APPROACH

The best way to investigate the Cross parachute suspension line variable force problem is to conduct a wind-tunnel test wherein the forces in designated suspension lines can be measured simultaneously under controlled test conditions. Seven, 40-inch-diameter model parachutes were designed and manufactured. The seven models built with the materials of Table 1, consisted of one parachute with two suspension lines per arm, three parachutes with four suspension lines per arm, and three parachutes with six suspension lines per arm. The models were built as per Figures 3 and 4 with uniform suspension line spacing on the canopy as a baseline force distribution which is representative of our current design technique. Each of the parachutes had different suspension line length distributions which were derived from existing data. Three 41.7 percent scale models of the parachute MK 38 MOD 0 were also constructed as per Figure 5. These parachutes, numbered 8, 9, and 10, were tested to determine the effects of the rate of airflow of the production canopy cloth on the drag coefficient of the parachute. Parachute materials are listed in Table 1. The particular suspension line lengths for every model parachute test are listed in the test data summary of Table 2.

The 200 mph test was conducted at the University of Maryland Subsonic Wind Tunnel at College Park, Maryland. Wind tunnel engineering personnel designed and constructed the 24 attachment point suspension line force measuring device of Figure 6. Twelve of the sensing elements were instrumented to measure force data. The instrumented active load cell channels were located as indicated in Figure 7. Each parachute was attached to the load cell with two complete sets of adjacent lines connected to active channels. The active channels were continuously recorded by instrumentation which determined the average value of the tensile force and the one sigma variation.

The stadia rod of Figure 8 was attached to the aft end of the force sensing gauge. The stadia rod was marked with contrasting stripes to permit measurements of the inflated models, and also fitted with ten static pressure sensing taps to measure the static pressures within the inflated canopy and the zone directly ahead of the canopy skirt hem. Orthogonal photographs of the several parachutes under test were obtained by still cameras positioned as shown in Figure 9.

TABLE 1. MATERIALS USED IN MODEL PARACHUTE CONSTRUCTION

ITEM	MATERIAL	PARACHUTE SERIES		
		MODELS NUMBERED 1 THRU 7	MODELS NUMBERED 8 & 9	MODEL NUMBER 10
1	CLOTH	MIL-C-7020, TYPE I AIR PERMEABILITY 90 $FT^3/FT^2/MIN$ @ 1/2 INCH WATER PRESSURE DIFFERENTIAL	MIL-C-17208, TYPE I, CLASS B AIR PERMEABILITY 325 $FT^3/FT^2/MIN$ @ 1/2 INCH WATER PRESSURE DIFFERENTIAL	3 MOMME SILK AIR PERMEABILITY 428 $FT^3/FT^2/MIN$ @ 1/2 INCH WATER PRESSURE DIFFERENTIAL
2	TAPE	MIL-T-5038, TYPE III, 1/2 INCH WIDE	MIL-T-5038, TYPE III, 3/4 INCH WIDE	MIL-T-5038, TYPE III, 3/4 INCH WIDE
3	TAPE, HEM	MIL-T-5038, TYPE III, 1/2 INCH WIDE	MIL-T-5038, TYPE III, 3/8 INCH WIDE	MIL-T-5038, TYPE III, 3/8 INCH WIDE
4	SUSPENSION LINE	MIL-C-17183, TYPE III	MIL-C-17183, TYPE III	MIL-C-17183, TYPE III
5	STITCHES[1]	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, 2 ROWS ON 1/4 INCH NEEDLE GAUGE.		
6	STITCHES[1]	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, 3 ROWS ON 1/4 INCH NEEDLE GAUGE.		
7	STITCHES[1]	TYPE 301, FED STD 751, 9 TO 12 STITCHES PER INCH, SINGLE ROW		

[1]ALL THREAD, V-T-295. TYPE I OR II, CLASS 1 OR 2, SIZE B

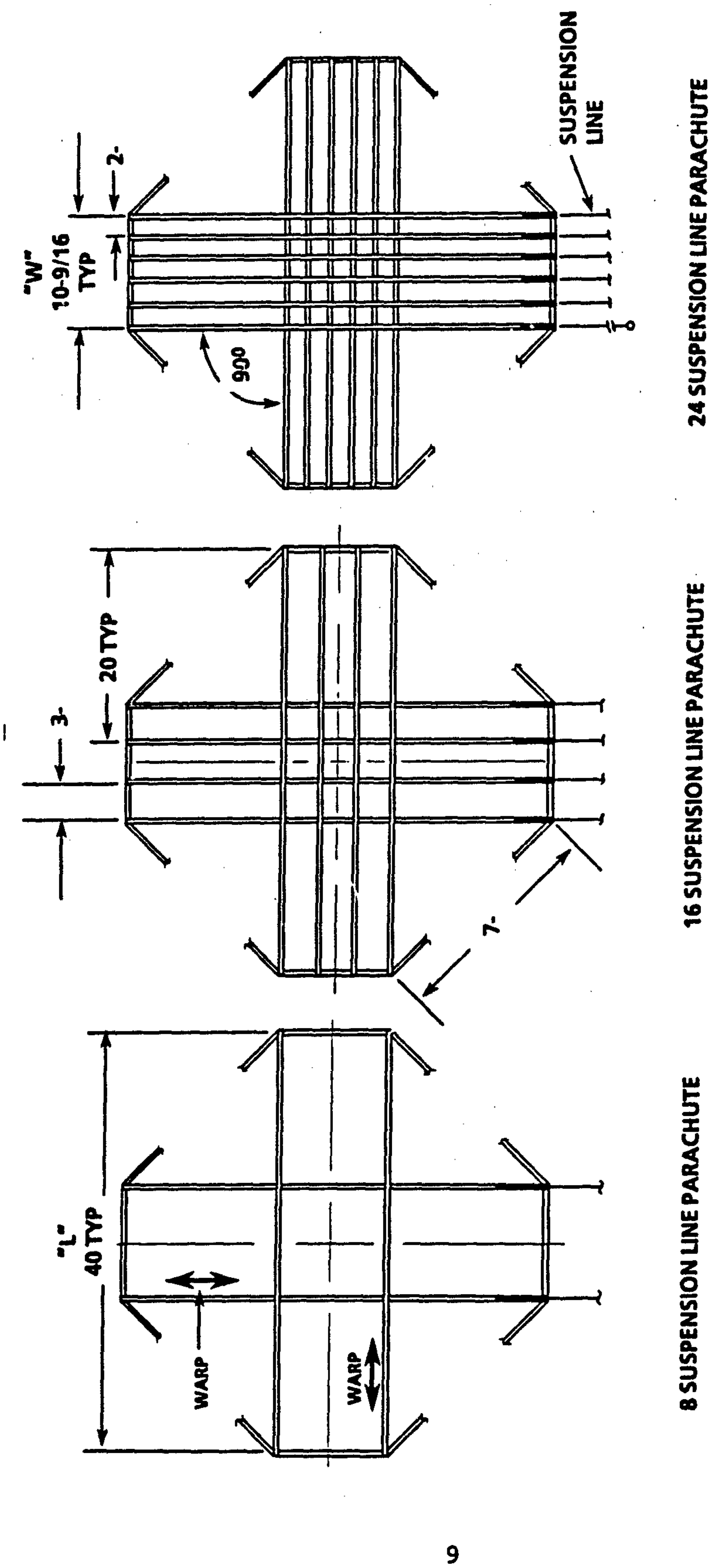
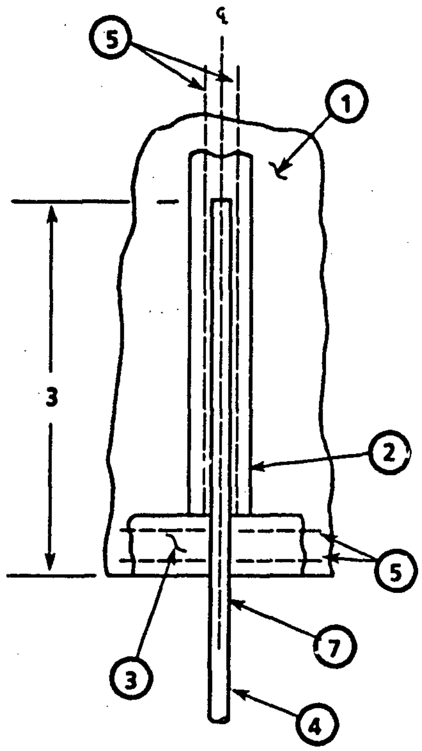
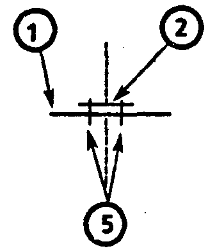


FIGURE 3. PARACHUTE CONFIGURATIONS FOR MODELS NO. 1 THROUGH 7

SEE TABLE 1 FOR MATERIALS IDENTIFICATION AND TABLE 2 FOR SUSPENSION LINE LENGTHS

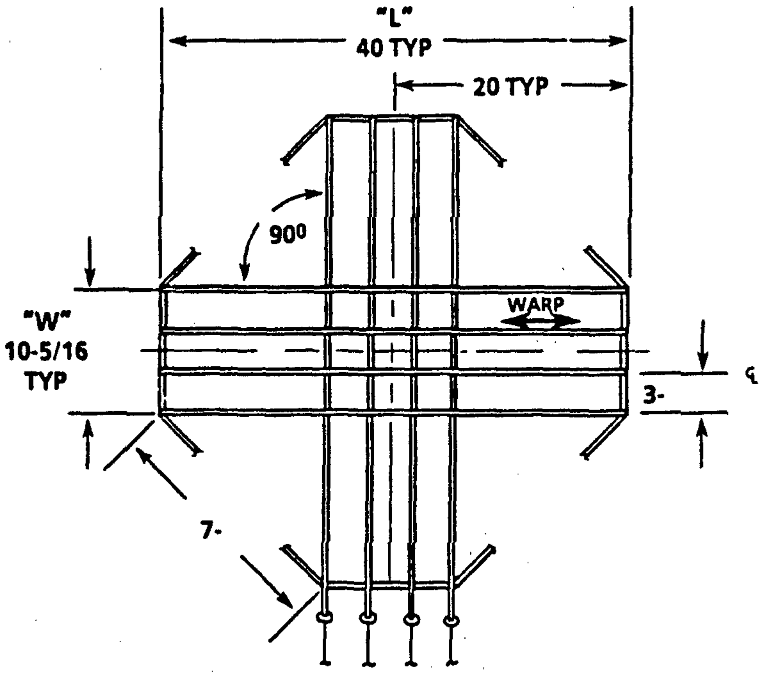


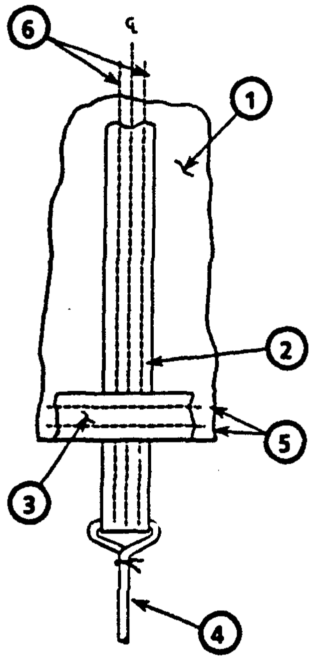
SKIRT HEM - SUSPENSION LINE ASS'Y

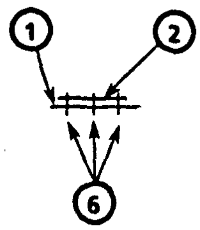


TYPICAL TAPE - CANOPY CROSS SECTION

FIGURE 4. MODEL PARACHUTE CONSTRUCTION DETAILS FOR MODEL PARACHUTES NUMBERED 1 THROUGH 7







TYPICAL TAPE - CANOPY CROSS SECTION

SEE TABLE 1 FOR MATERIALS IDENTIFICATION
AND TABLE 2 FOR SUSPENSION LINE LENGTHS

CONSTRUCTION DETAILS FOR MODEL PARACHUTES NUMBERED 8, 9, AND 10

FIGURE 5. 41.7 PERCENT SCALE MODEL OF THE PARACHUTE MK 38 MOD 0

TABLE 2. SUMMARY OF SUSPENSION LINE LENGTHS AND MEASURED WIND TUNNEL SUSPENSION LINE FORCE DATA

RUN NO.	PARACHUTE MODEL NO.	NO. LINES	SUSPENSION LINE LENGTHS INCHES	LOAD CELL CHANNEL, DRAG COEFFICIENT 1	2	3	4	5	6	7	8	9	10	11	12	CD SUM	CD SUMx2	CD WIND TUNNEL BALANCE
4	1	8	34 34		.068			.070			.071			.069		.278	.556	.535
5	2	16	34 34 34 34		.030	.047	.048	.035			.032	.046	.047	.031		.315	.631	.575
6	3	16	34 35.2 35.2 34		.035	.040	.041	.040			.040	.041	.039	.040		.317	.633	.659
7	4	16	34 35.57 35.57 34		.038	.037	.037	.043			.042	.039	.039	.042		.317	.634	.598
8	5	24	34 34 34 34 34 34	.023	.026	.033	.034	.029	.023	.023	.026	.031	.033	.028	.021	.330	.659	.642
9	6	24	34 35.02 35.53 35.53 35.02 34	.034	.026	.026	.028	.028	.028	.025	.039	.023	.026	.023	.030	.335	.670	.573
10	7	24	34 35.08 35.63 35.63 35.08 34	.031	.024	.028	.030	.022	.031	.031	.025	.027	.028	.024	.028	.329	.658	.621
11	8	16	40 40 40 40		.030	.042	.047	.031			.035	.043	.040	.029		.297	.594	.541
12	9	16	50 50 50 50		.030	.043	.043	.035			.031	.043	.041	.029		.295	.591	.552
13	10	16	50 50 50 50		.019	.031	.035	.024			.023	.034	.029	.024		.219	.438	.401
14	TARE RUN – STRUT + FORCE MEASUREMENT ASSEMBLY +LONG STADIA ROD																	
15	TARE RUN –STRUT + FORCE MEASUREMENT ASSEMBLY +SHORT STADIA ROD																	
16	TARE RUN – STRUT + FORCE MEASUREMENT ASSEMBLY																	

TEST VELOCITY – 200 MPH
TEST DYNAMIC PRESSURE – 102.32 PSF
STADIA ROD LENGTH – RUNS 4 THRU 11 & 15 = 41.25 IN.; RUNS 12, 13, & 14 = 55.25 IN.
PARACHUTE REFERENCE AREA, S_o=5.092 FT^2

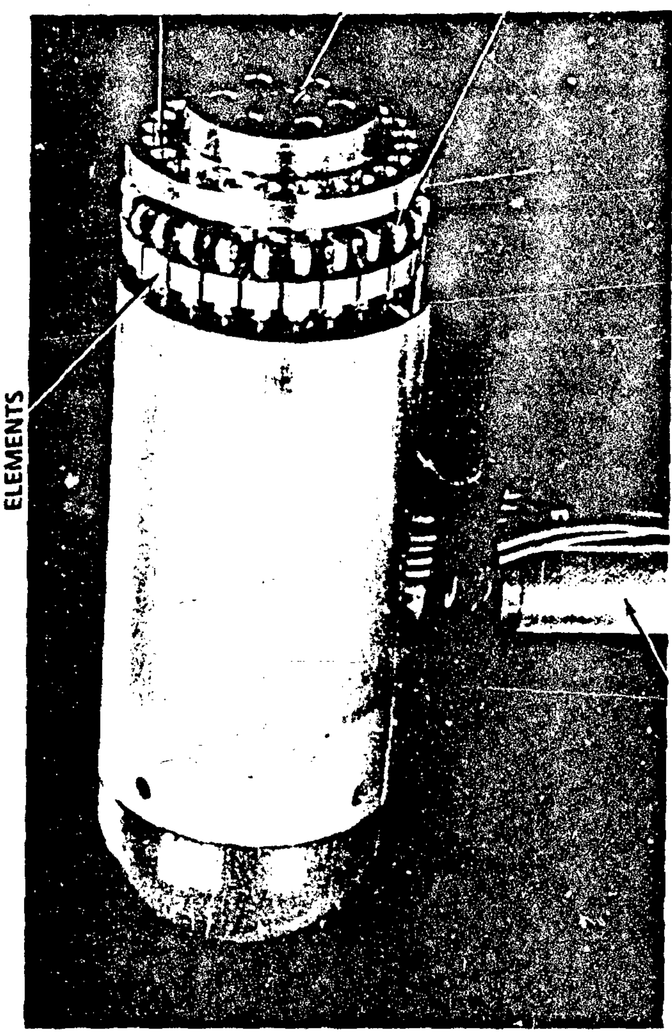
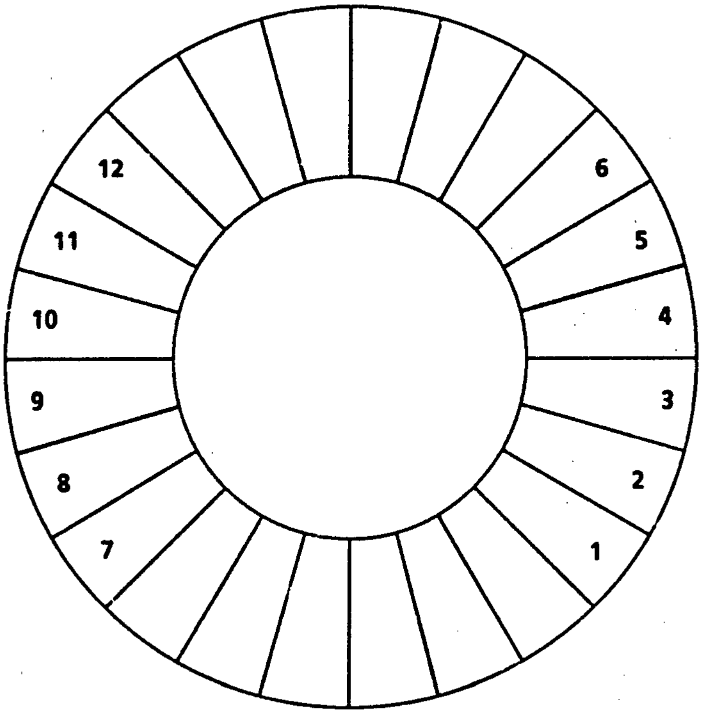


FIGURE 6. SUSPENSION LINE FORCE SENSING GAUGE INSTALLED IN THE WIND TUNNEL



ACTIVE LOAD CELL CHANNELS
LOOKING UPSTREAM

RUN NO.	LINES PER ARM	PARACHUTE CONNECTED TO ACTIVE CHANNELS NO.
4	2	2, 5, 8, 11
5, 6, 7	4	2, 3, 4, 5, 8, 9, 10, 11
8, 9, 10	6	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
11, 12, 13	4	2, 3, 4, 5, 8, 9, 10, 11

FIGURE 7. LOCATIONS OF ACTIVE LOAD CELL CHANNELS

LENGTH "A"	USED IN RUNS
41.25	4 TO 11 AND 15
55.25	12, 13, 14

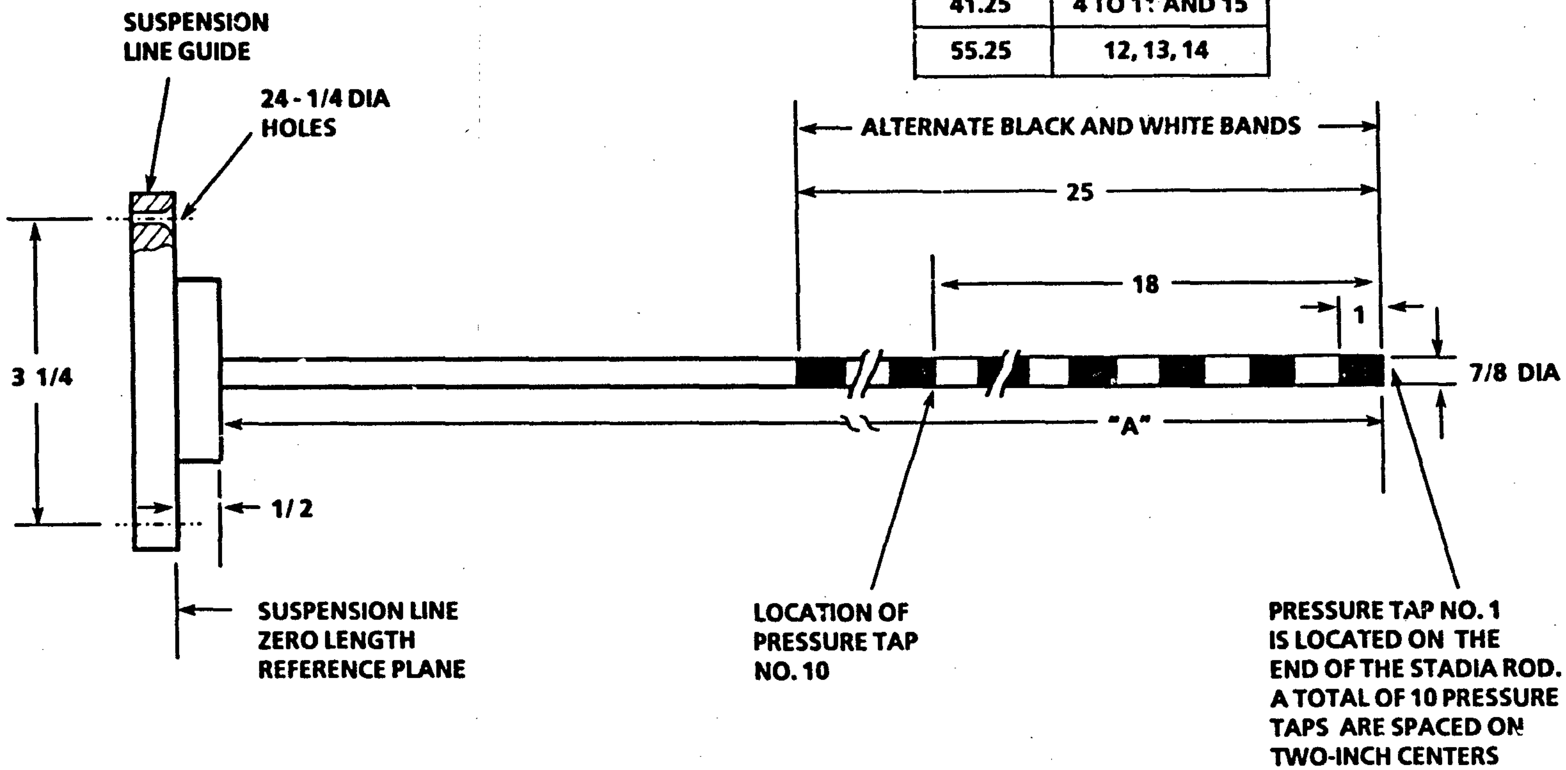
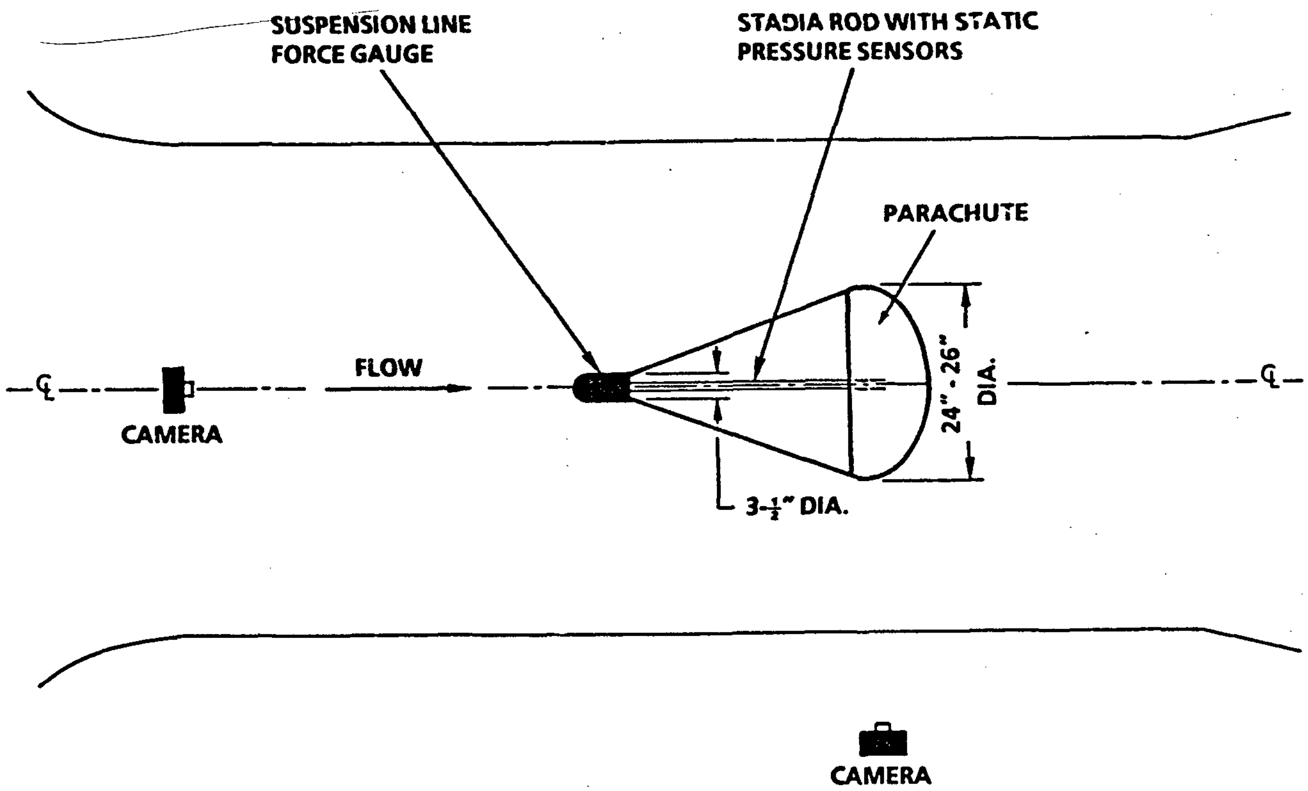


FIGURE 8. STADIA ROD AND PRESSURE SENSOR LAYOUT



WIND TUNNEL CROSS SECTION DIMENSIONS 7 FT x 11 FT

FIGURE 9. PLAN VIEW OF WIND TUNNEL SUPPORT AND PHOTOGRAPHIC SYSTEMS

TEST METHOD

The suspension line force and static pressure instrumentation were mounted on the support and aligned with the center line of the wind tunnel. A 20-mph run was conducted without a parachute installed to obtain the system aerodynamic tare and a reference static pressure distribution along the stadia rod. A parachute was then installed on the force sensor with the parachute suspension lines connected to active channels as listed in Figure 7. The wind tunnel was accelerated to 200-mph and the suspension line forces were recorded. The steady state drag force of the parachute was also recorded by the wind tunnel balance system. The static pressure distribution together with front and side view still photographs of the test configuration completed the data. This procedure was followed for each parachute. Some parachutes had the inner line lengths modified and the test was repeated to measure changes in the suspension line force distribution.

RESULTS

SUSPENSION LINE FORCES

Test results confirm that selectively lengthening the Cross parachute inner suspension lines redistributes the forces and improves the uniformity of the force distribution. The test data and calculations are summarized in Table 2. Note that the suspension lines are attached and distributed around the circumference of a 3-1/4-inch-diameter circle. The length of the suspension lines in this study is taken to be the actual length of the cord and not the projected effective length of all the suspension lines to a single confluence point.

With reference to the list of suspension line force coefficients in Table 2 the following conclusions may be drawn.

1. The force distribution in the eight suspension line parachute of run number 4 is uniform.

2. The addition of four more evenly spaced suspension lines (16 lines total) of equal length as in run number 5 generally reduces the force distribution in the outer lines by 50 percent. However, the force distribution is not uniform. The inner pair of suspension lines are bearing tensile forces which exceed the outer suspension line forces by 1.47.

3. As the inner suspension lines are lengthened, as in runs number 6 and 7, the suspension line loads in the several lines are redistributed with an increase in the outer line forces and a decrease in the inner line forces which results in a more uniform force distribution among the lines.
As the inner lines were extended the ratio of suspension line tension to outer suspension line tension decreases linearly as shown in Figure 10.

4. The 24 suspension line parachutes of runs number 8, 9, and 10 show the same force distribution trends as the 16 line parachute. The linearity is not as easily seen with the additional two suspension lines per arm. It is obvious that as the number of suspension lines increase the evaluation of the most efficient suspension line length distribution becomes increasingly difficult.

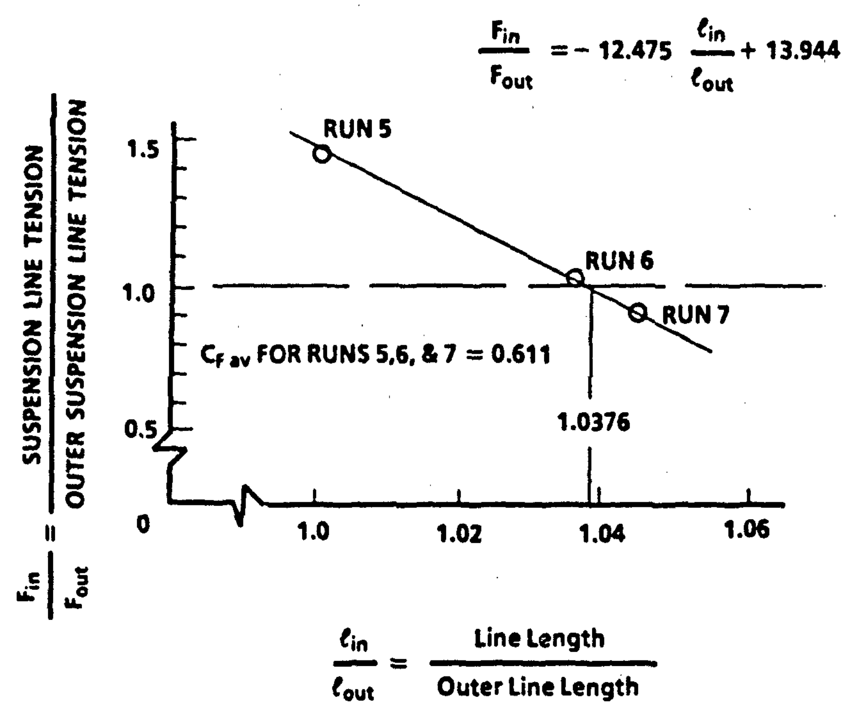


FIGURE 10. VARIATION OF SUSPENSION LINE FORCE COEFFICIENT FOR THE VARIED SUSPENSION LINE LENGTHS OF THE 16 SUSPENSION LINE PARACHUTE

5. The equal suspension line length MK 38 MOD 0 parachute has similar load distributions as run 4. Lengthening the suspension lines, run 12, did not improve the drag coefficient due to the hem tape limiting the canopy diameter. The partial collapse of the 4 momme silk cloth parachute of run 13 is reflected in the reduced suspension line force readings. The load distribution shows the same trends even when only partially inflated.

The load cell channel suspension line force coefficients have been added up for each run, multiplied by 2, and compared to the wind tunnel balance reading. The sum of the suspension line force coefficients generally exceeds the balance reading because the load cells measure the tensile force in the suspension lines and the balance measured the parachute axial aerodynamic force.

For each run the ratio of suspension line length to length of the outer suspension line was calculated. The suspension line force coefficients for each set of lines were averaged to minimize test variations and ratioed to the line force coefficients of the outer lines. These data are plotted in Figures 10 and 11. The suspension line length variation of Figure 10 is a linear variation of force ratio since all of the inner lines were modified by the same amount. Equation (1) was fitted to the data and shows that the force distribution in all lines should be uniform when the inner line lengths are 1.0376 times the outer line length.

As the number of suspension lines in the parachute increase the effects of varying the lengths of the inner lines complicates the data analysis. The interaction of the inner sets of lines causes a scatter in the data. For each set of lines the data has been averaged for runs 9 and 10 and plotted on Figure 11. A uniform suspension line load distribution in a 24 suspension line requires that the first inner set of lines be 1.020 times the length of the outer suspension line and that the lengths of the central set of lines be 1.0386 times the length of the cuter suspension line.

CANOPY INTERNAL STATIC PRESSURE DISTRIBUTION

Most inflation time calculation approaches assume that the volume of air that is to be collected lies inside of the inflated canopy between the skirt hem and the vent. There is evidence in Appendix A of Reference 1 that the total volume of air associated with a fully inflated canopy extends ahead of the canopy skirt hem. This additional volume of air was derived in References 2 and 3 which presented a method for estimating the total volume of air, V_o, to be collected. Utilization of the V_o air volume in subsequent inflation reference time, t_o, calculations shows excellent agreement with inflation times calculated using accepted empirical methods.

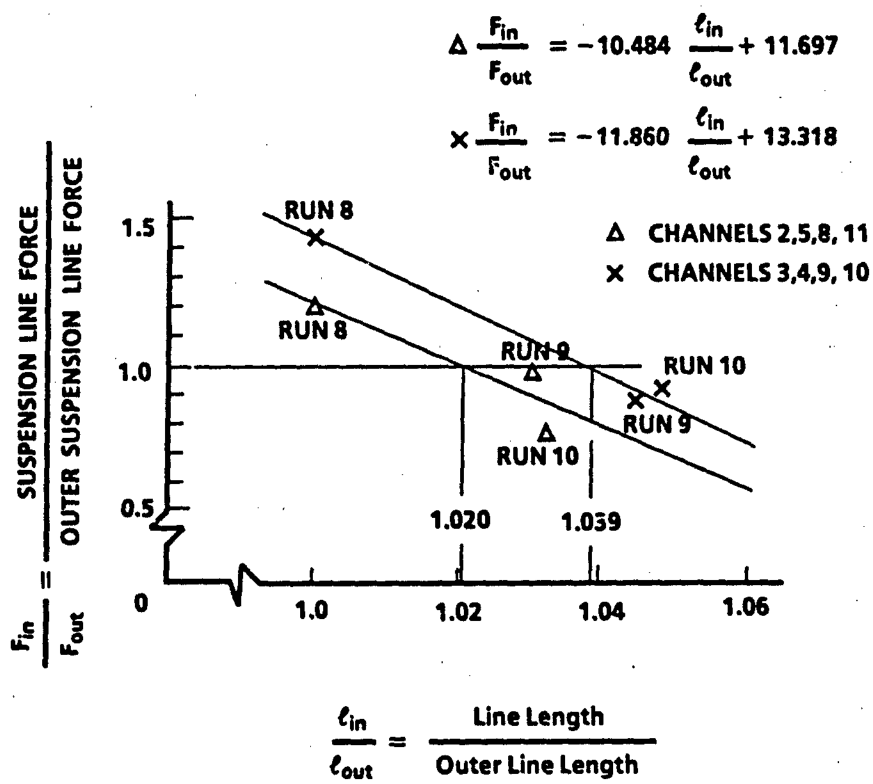


FIGURE 11. VARIATION OF SUSPENSION LINE FORCE COEFFICIENT FOR THE VARIED SUSPENSION LINE LENGTHS OF THE 24 SUSPENSION LINE PARACHUTE

As the flow enters the mouth of an uninflated parachute the velocity head of the flow is reduced and transformed into a pressure head. If the flow were at a complete stagnation the canopy internal pressure coefficient, $\Delta P/q$, would be a maximum. As the rate of canopy outflow increases the internal pressure is reduced. Eventually, the internal pressure is too weak to support full inflation and inflation instability develops.

Figures 12 through 21 are profile views of the test parachutes with the pressure coefficient distributions superimposed at the particular pressure tap locations along the the stadia rod. In each of the tests elevated static pressure, ahead of the parachute skirt hem, was detected as well as within the canopy. These partial stagnation pressures increase in intensity as the flow approaches the parachute skirt hem and reach a maximum value inside of the canopy. The elevated pressure profile ahead of the canopy skirt hem is indicative of an additional mass of air associated with the inflated canopy.

Figures 22 through 25 present the effects of the number of parachute suspension lines and canopy cloth rate of airflow on the measured pressure distributions. Due to the various parachute suspension line lengths in the tests, pressure distributions cannot be compared by orienting the pressure taps. For each test the plane containing the locations of the joint of the canopy skirt hem and the outer most suspension lines on each arm was established. The pressure distributions were shifted to align the canopy hem planes which compares the canopy pressure distributions relative to the hem of the canopies.

The pressure profiles of Figure 22 indicate a rise in pressure distribution with an increase in the number of suspension lines in the assembly. The dominant change occurs between the eight and 16 suspension line configurations with a smaller pressure increase between 16 and 24 lines. The pattern of increase indicates that the effects of increasing the number of suspension lines approaches a limiting value. This is similar to the known effects of the number of suspension lines on the Cross parachute drag coefficient. Comparing the pressure levels of Figures 23 and 24 generally shows the same effects as Figure 22.

Figures 23 and 24 show the pressure distributions for 16 and 24 suspension line configurations respectively for lines of equal length and two different distributions of inner suspension line lengths. Lengthening the inner suspension lines appears to cause a small reduction in the pressure distribution.

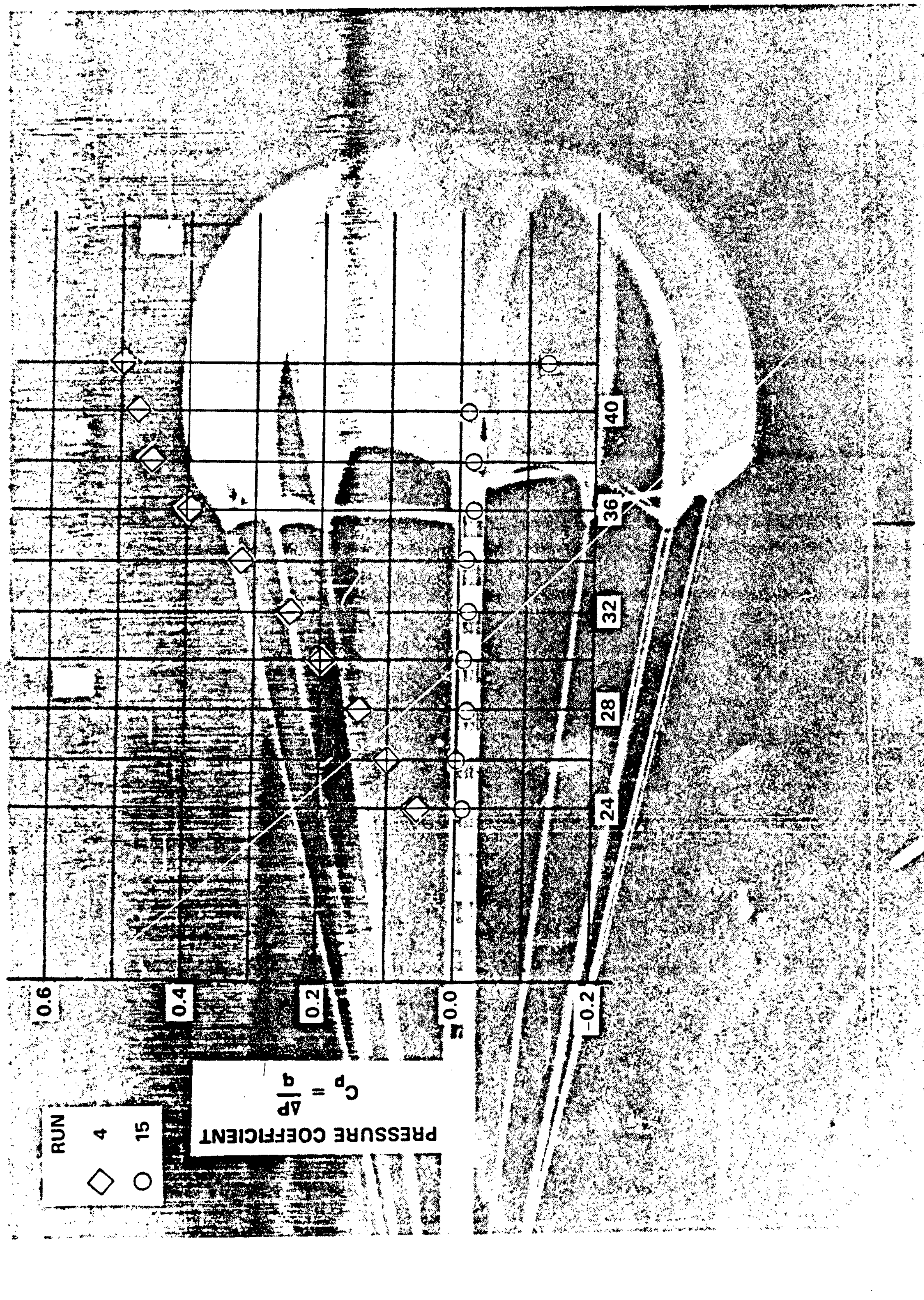


FIGURE 12 MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD. WIND TUNNEL RUN NO. 4 PARACHUTE MODEL NO. 1 WITH 8 EQUAL LENGTH SUSPENSION LINES

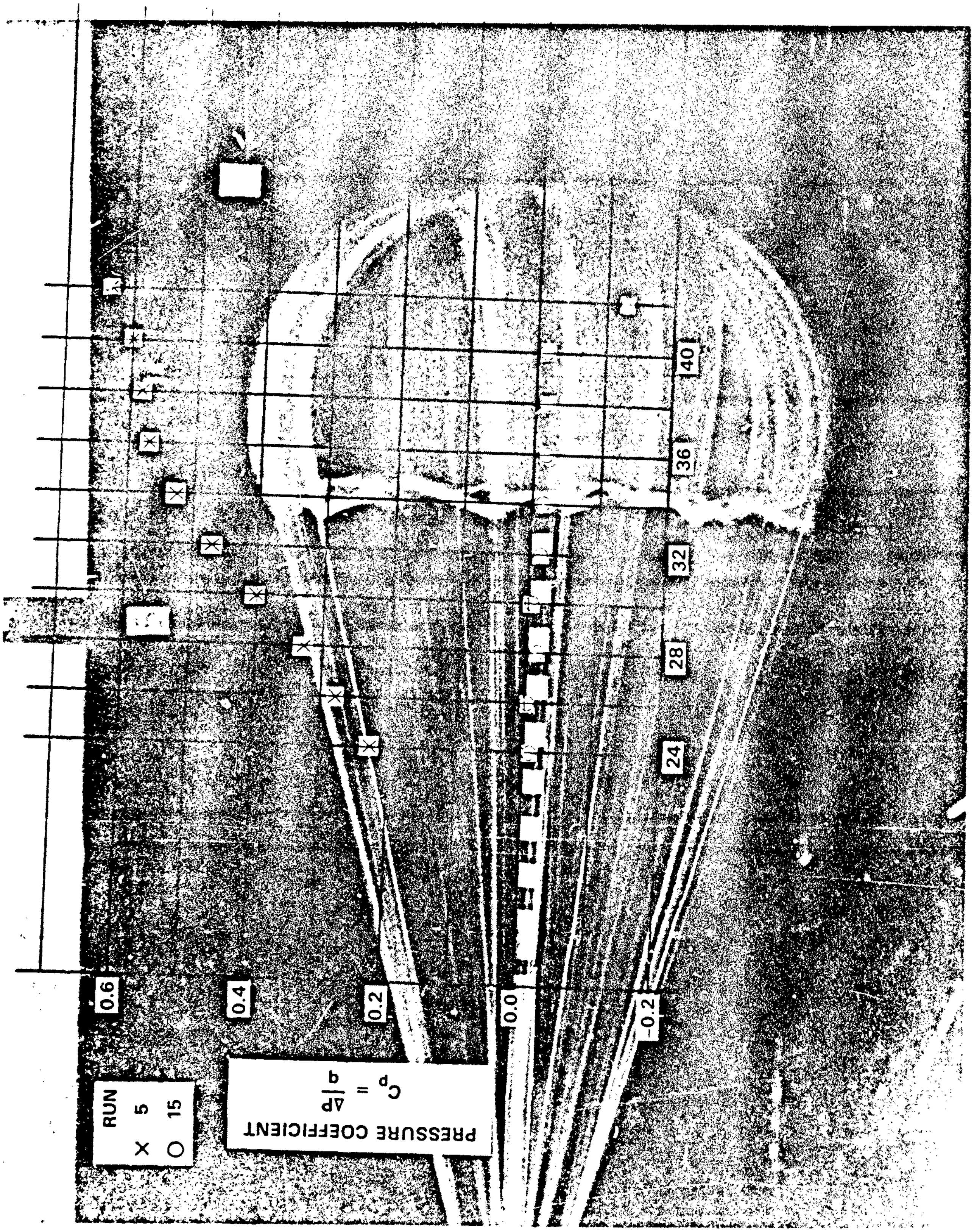


FIGURE 13. MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD WIND TUNNEL RUN NO. 5, PARACHUTE MODEL NO. 2 WITH 16 EQUAL LENGTH SUSPENSION LINES

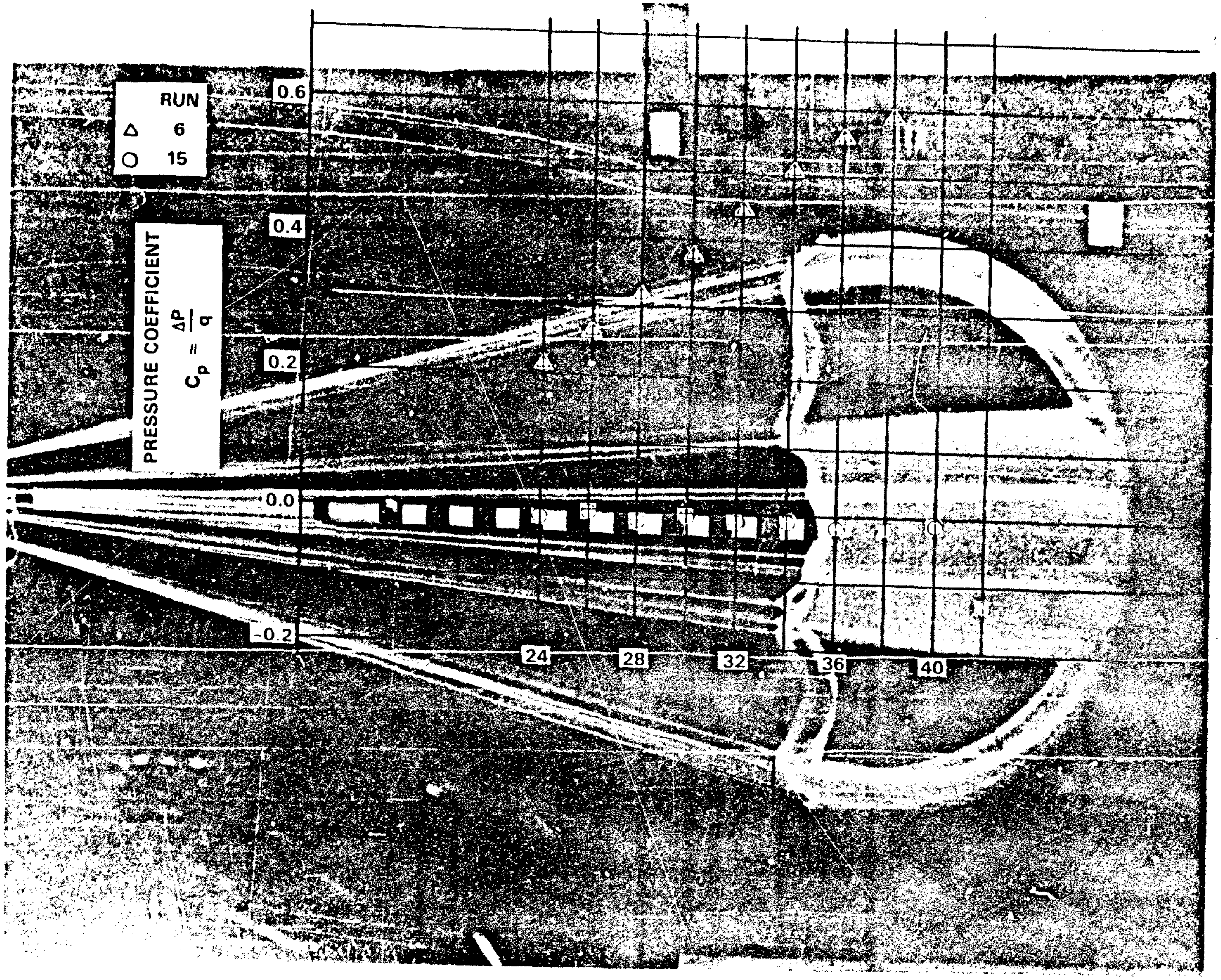
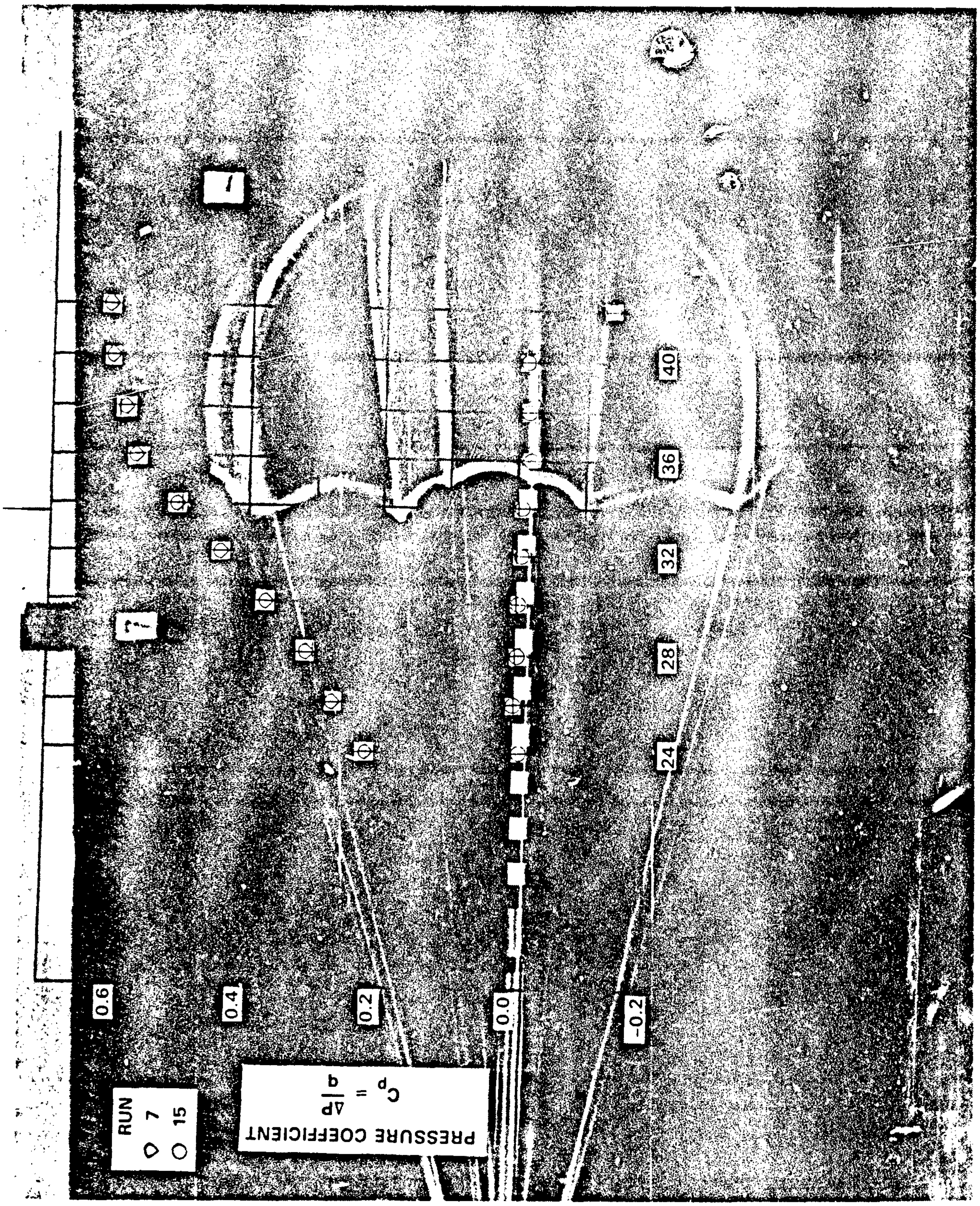


FIGURE [illegible]. MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD. WIND [illegible] PARACHUTE MODEL NO. 3 WITH 16 MODIFIED [illegible]



... ALONG THE STADIA ROD WIND ...

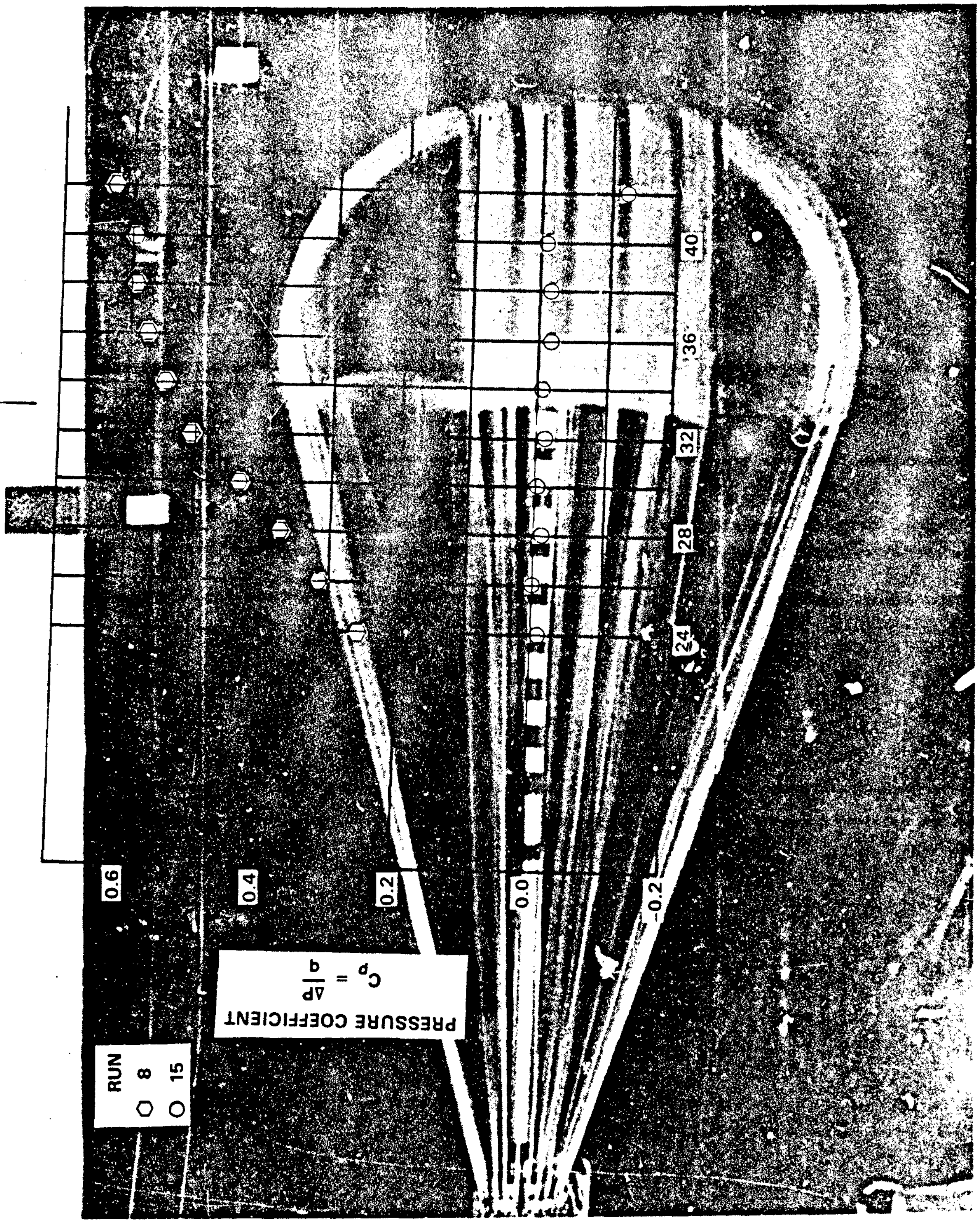


FIGURE 16. MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD. WIND TUNNEL RUN NO. 8, PARACHUTE MODEL NO. 5 WITH 24 EQUAL LENGTH SUSPENSION LINES.

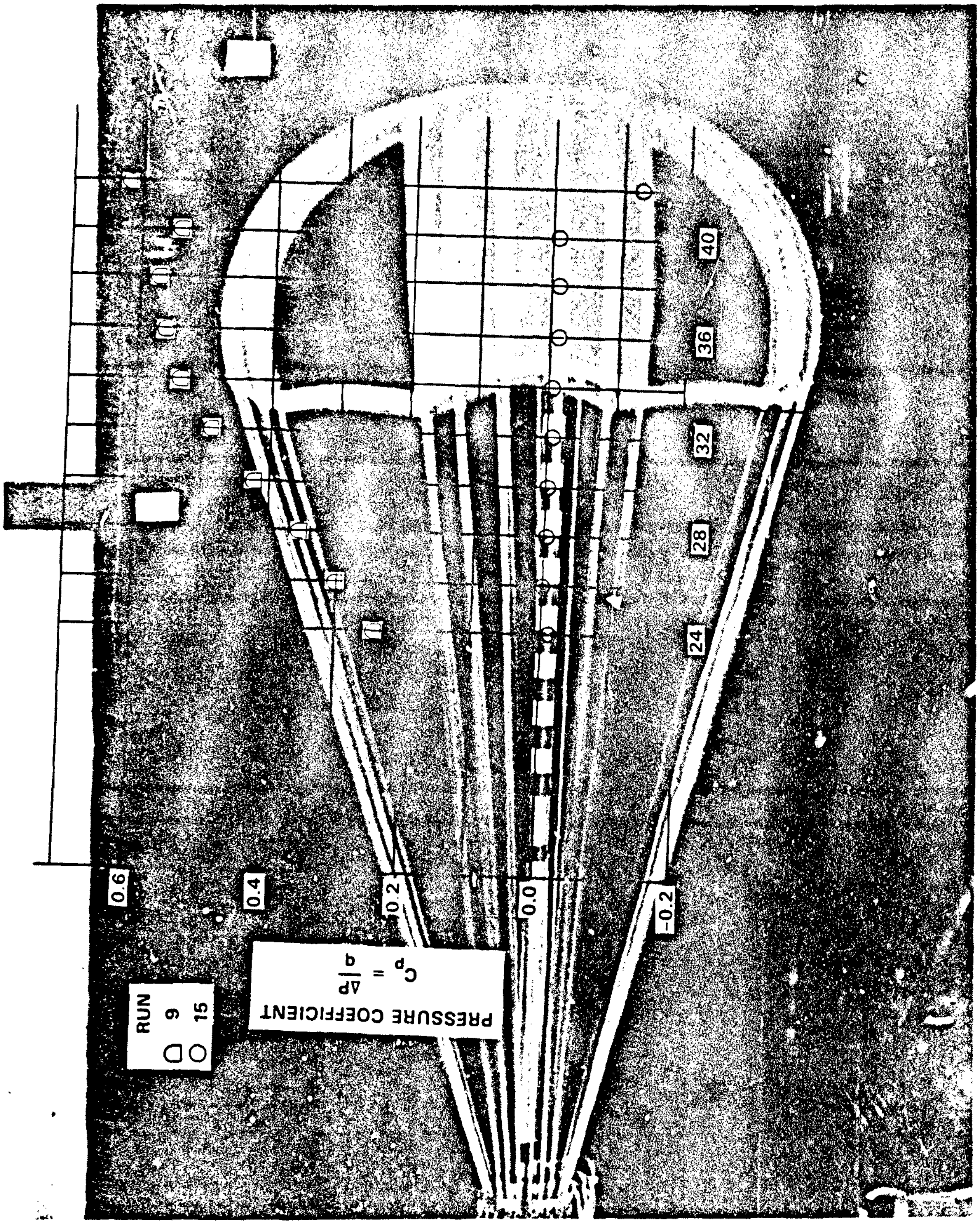


FIGURE 17 MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD WIND TUNNEL RUN NO 9, PARACHUTE MODEL NO 6 WITH 24 MODIFIED LENGTH SUSPENSION LINES

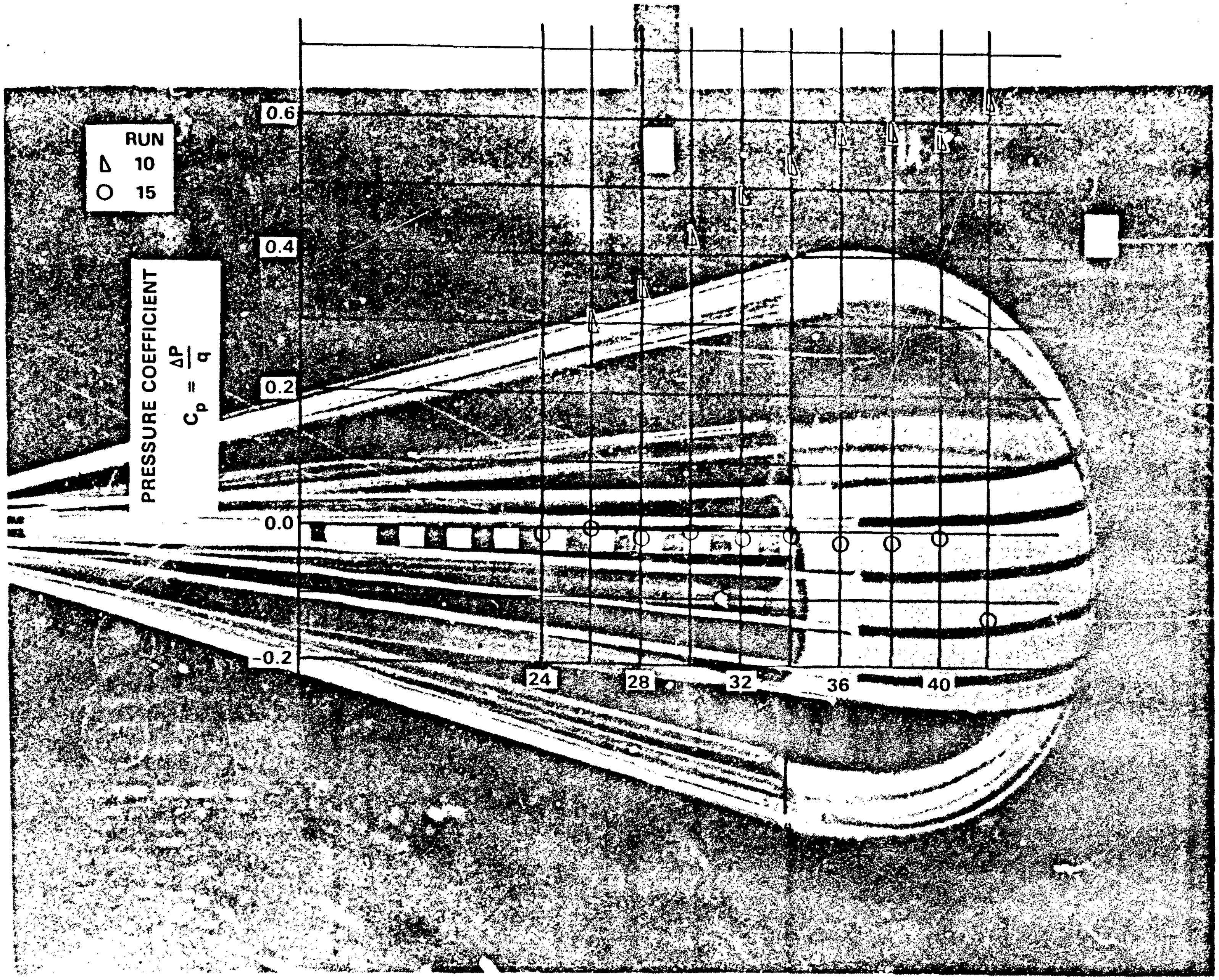


FIGURE [illegible]. MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD WIND TUNNEL RUN NO. 10 PARACHUTE MODEL NO. 7 WITH 24 MODIFIED [illegible] SUSPENSION LINES

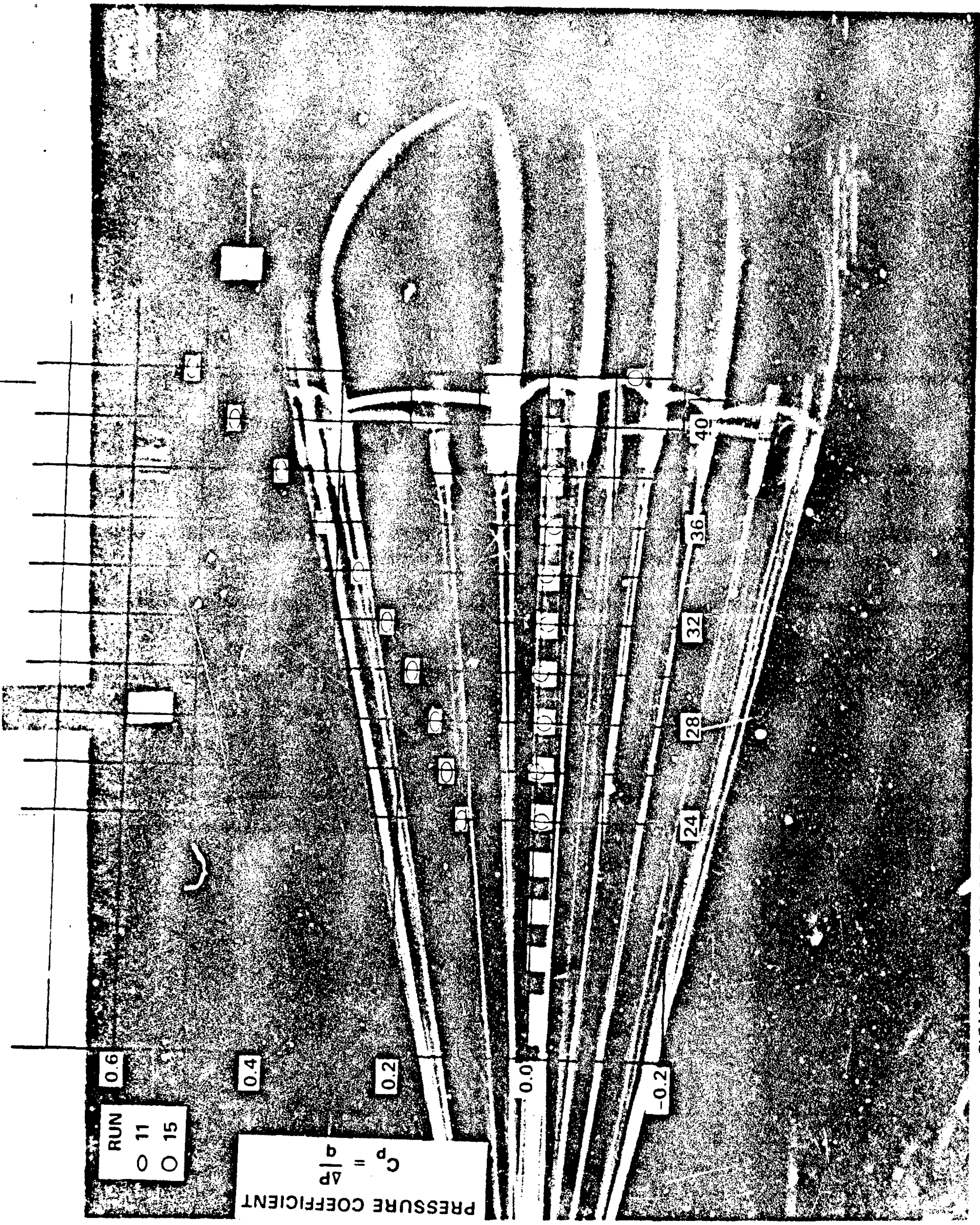


FIGURE 19. MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD. WIND TUNNEL RUN NO. 11, PARACHUTE MODEL NO. 8 WITH 16 EQUAL LENGTH SUSPENSION LINES.

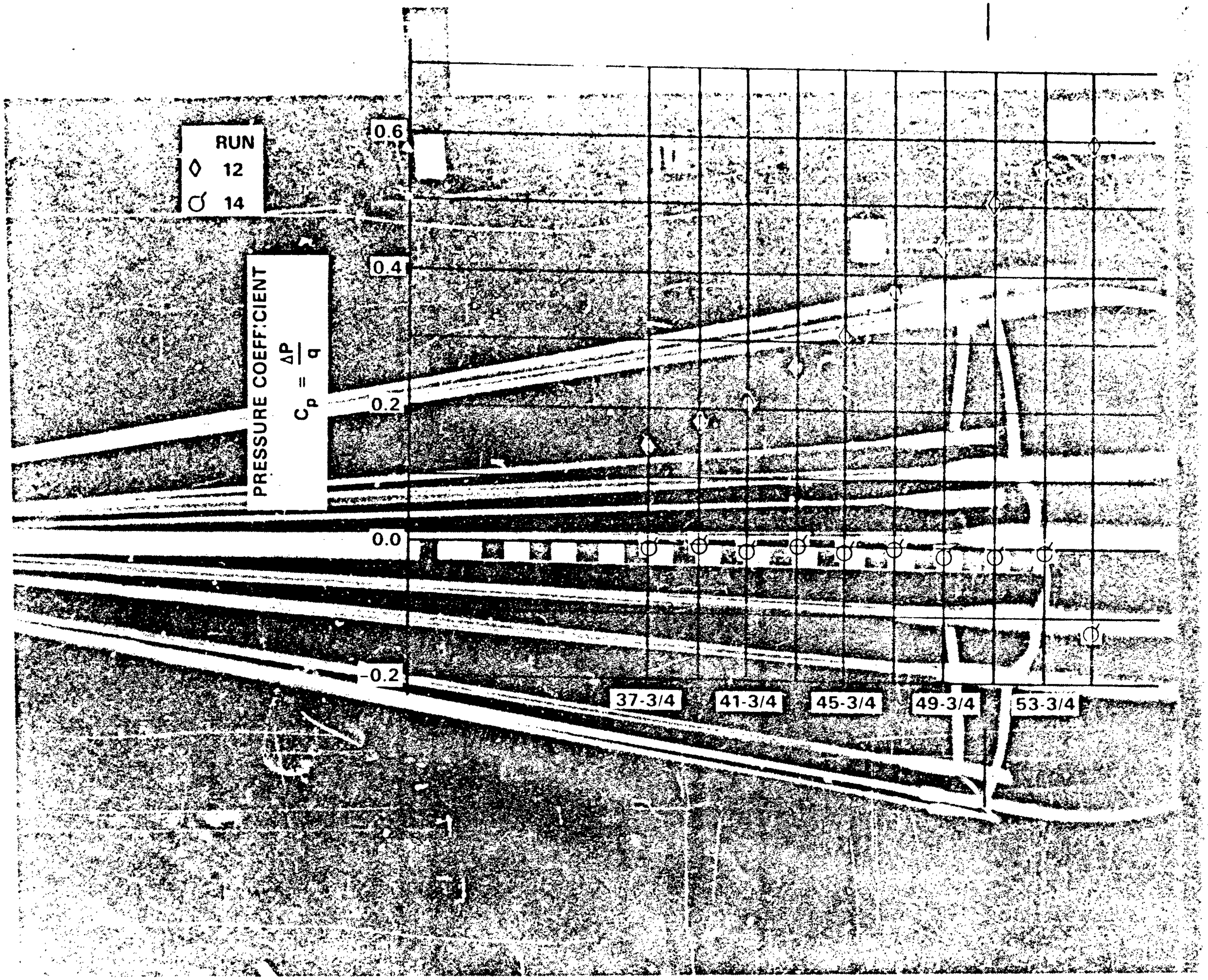


FIGURE 20. MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD. WIND TUNNEL RUN NO. 12, PARACHUTE MODEL NO. 9 WITH 16 EQUAL LENGTH SUSPENSION LINES

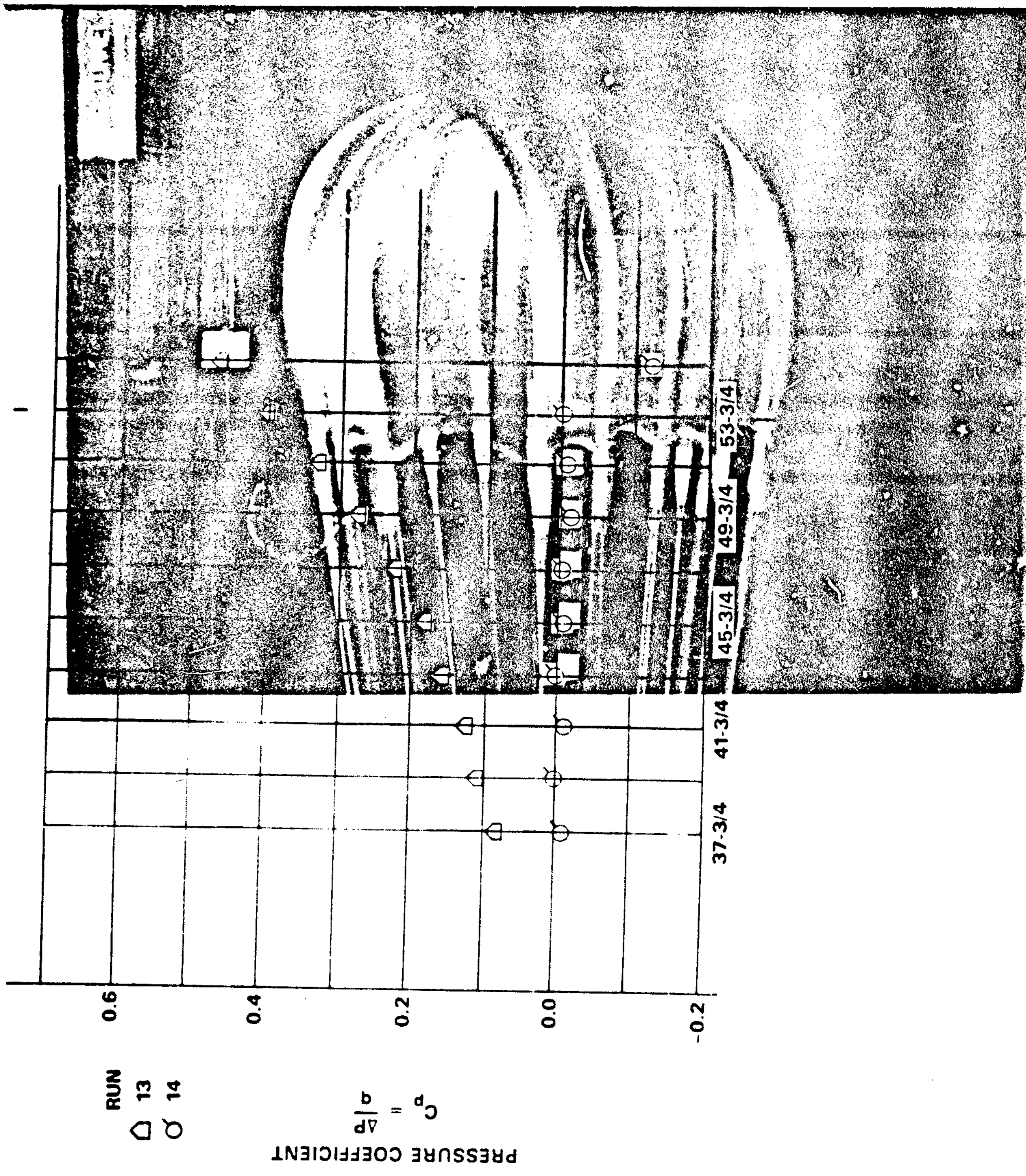
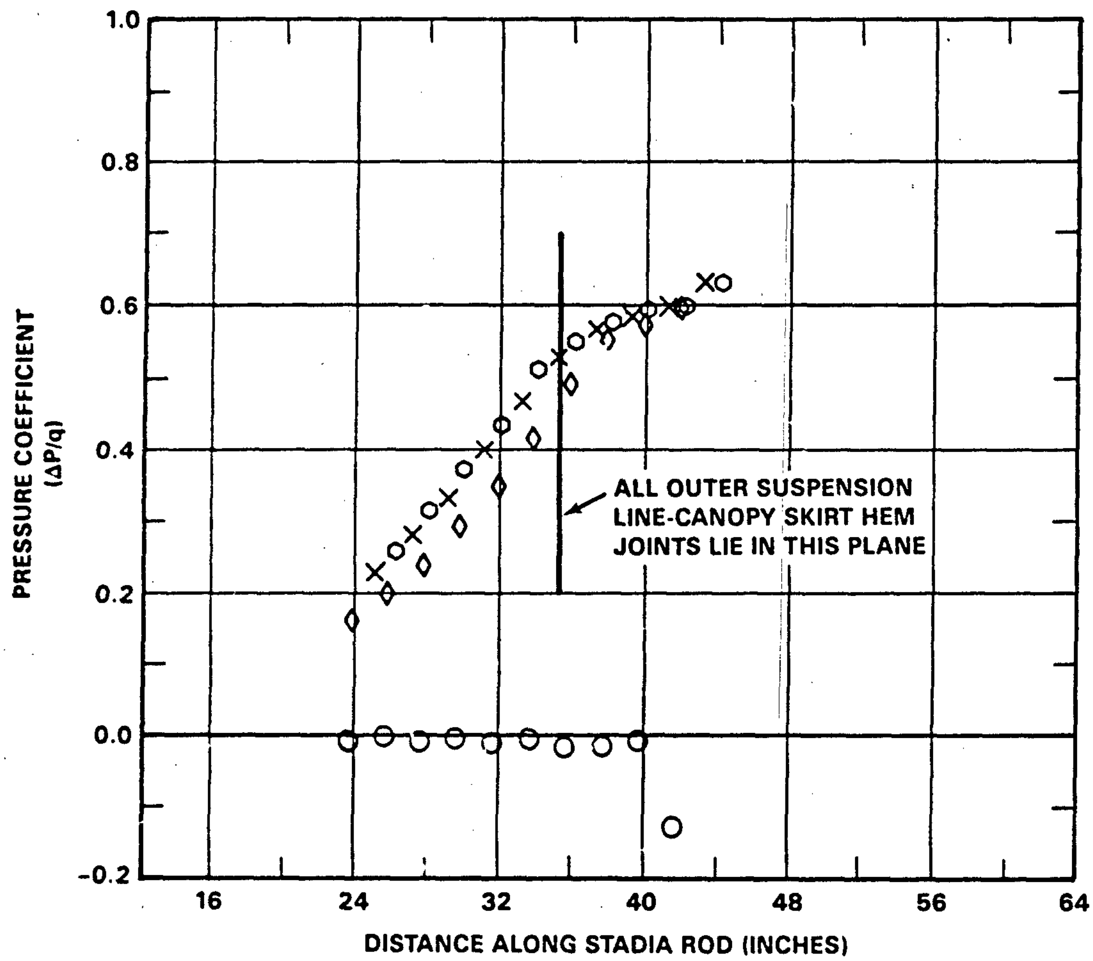


FIGURE 21 MEASURED PRESSURE DISTRIBUTION ALONG THE STADIA ROD. WIND TUNNEL RUN NO. 13. PARACHUTE MODEL NO 10 WITH 16 EQUAL LENGTH SUSPENSION LINES.

	RUN NO.	PARACHUTE NO.	NO.* LINES	CANOPY CLOTH	PERMEABILITY (CFM/FT²)
◊	4	1	8	MIL-C-7020, TYPE I	90
×	5	2	16	MIL-C-7020, TYPE I	90
o	8	5	24	MIL-C-7020, TYPE I	90
O	15	STRUT AND FIXTURE TARE RUN WITH SHORT STADIA ROD			



* ALL SUSPENSION LINES ARE 34 INCHES LONG.

FIGURE 22. EFFECT OF THE NUMBER OF SUSPENSION LINES ON THE MEASURED STATIC PRESSURE DISTRIBUTION ALONG THE STADIA ROD SHOWING ELEVATED LOCAL STATIC PRESSURES AHEAD OF THE CANOPY SKIRT HEM. TEST VELOCITY 200 MPH.

	RUN NO.	PARACHUTE NO.	NO. LINES	CANOPY CLOTH	PERMEABILITY (CFM/FT²)
×	5	2	16	MIL-C-7020, TYPE I	90
△	6	3	16	MIL-C-7020, TYPE I	90
◇	7	4	16	MIL-C-7020, TYPE I	90
○	15	STRUT AND FIXTURE TARE RUN WITH SHORT STADIA ROD			

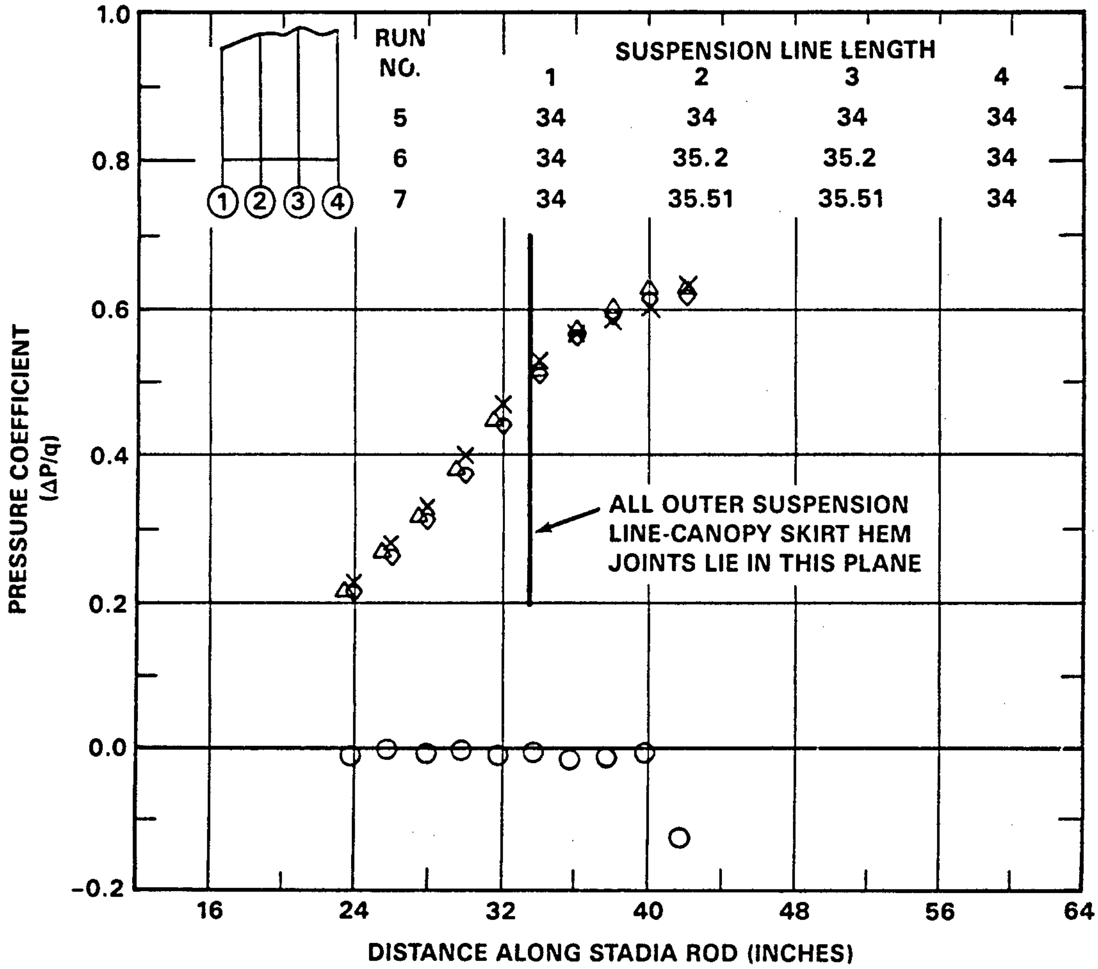


FIGURE 23. EFFECTS OF VARYING THE INNER SUSPENSION LINE LENGTHS ON THE MEASURED STATIC PRESSURE DISTRIBUTION ALONG THE STADIA ROD SHOWING ELEVATED LOCAL STATIC PRESSURES AHEAD OF THE CANOPY SKIRT HEM. TEST VELOCITY 200 MPH.

	RUN NO.	PARACHUTE NO.	NO. LINES	CANOPY CLOTH	PERMEABILITY (CFM/FT²)
⬡	8	5	24	MIL-C-7020, TYPE I	90
⌂	9	6	24	MIL-C-7020, TYPE I	90
△	10	7	24	MIL-C-7020, TYPE I	90
○	15	STRUT AND FIXTURE TARE RUN WITH SHORT STADIA ROD			

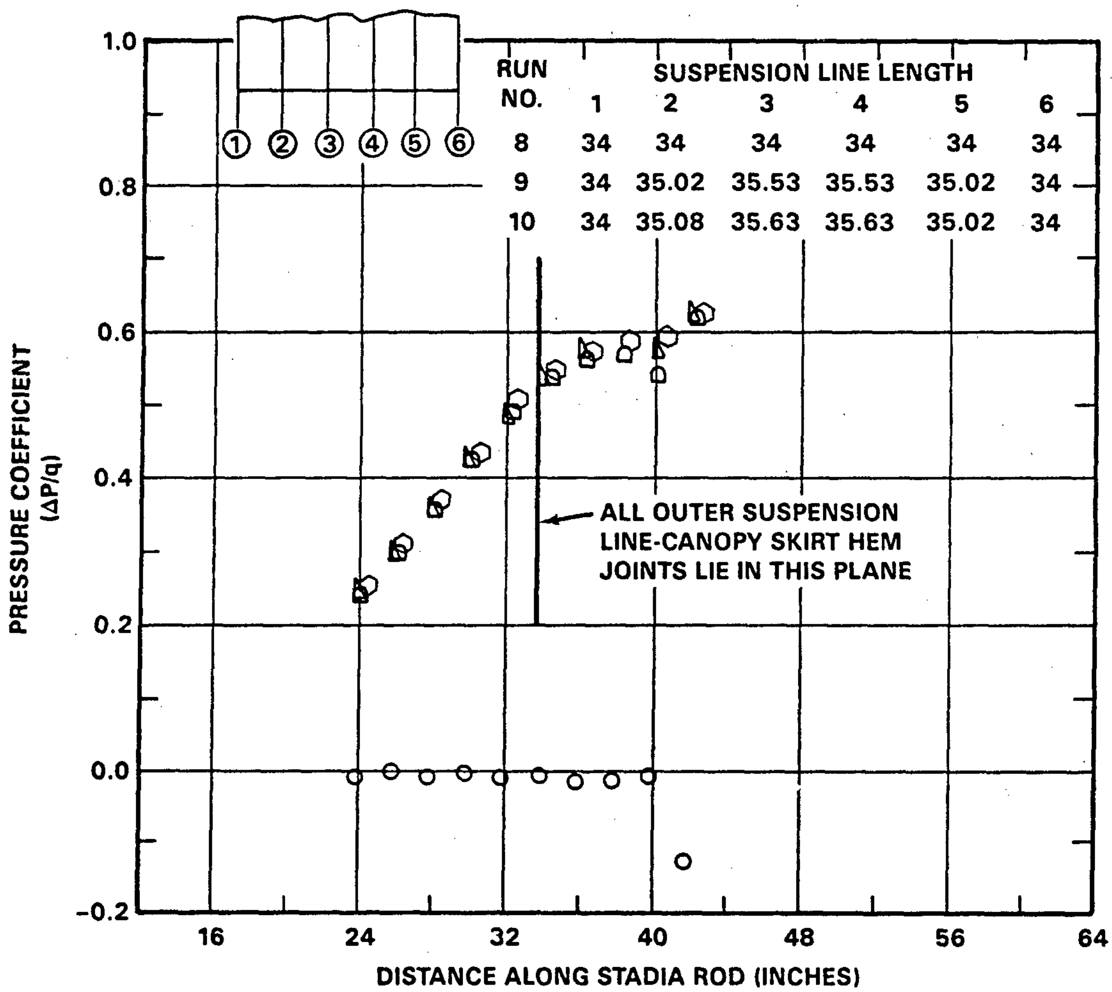


FIGURE 24. EFFECT OF THE NUMBER OF SUSPENSION LINES ON THE MEASURED STATIC PRESSURE DISTRIBUTION ALONG THE STADIA ROD SHOWING ELEVATED LOCAL STATIC PRESSURES AHEAD OF THE CANOPY SKIRT HEM. TEST VELOCITY 200 MPH.

	RUN NO.	PARACHUTE NO.	NO. LINES	CANOPY CLOTH	PERMEABILITY (CFM/FT²)
×	5	2	16	MIL-C-7020, TYPE I	90
○	11	8	16	MIL-C-17208, TYPE I, CLASS B	325
◊	12	9	16	MIL-C-17208, TYPE I, CLASS B	325
⌂	13	10	16	3 MOMME SILK	428
σ	14	STRUT AND FIXTURE TARE RUN WITH LONG STADIA ROD			

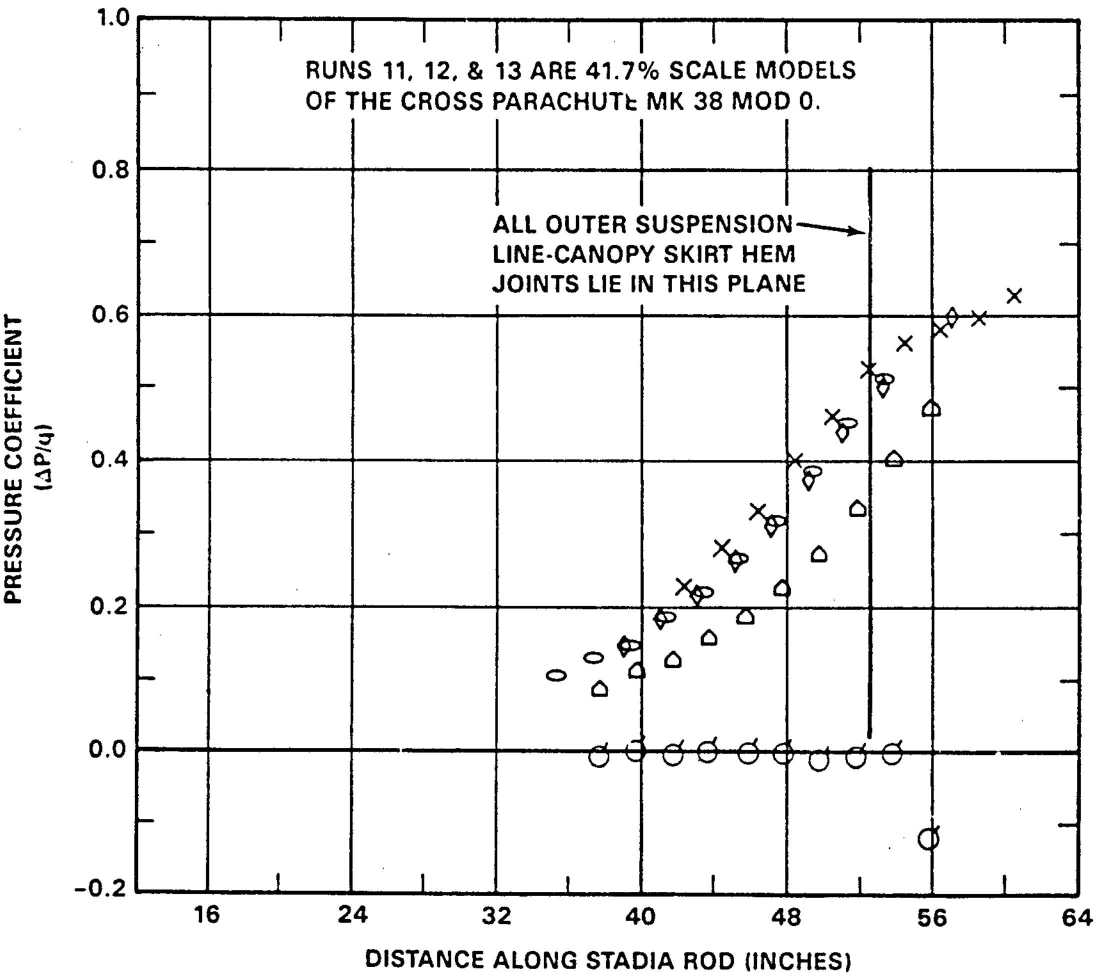


FIGURE 25. EFFECT OF CLOTH PERMEABILITY ON THE MEASURED STATIC PRESSURE DISTRIBUTION ALONG THE STADIA ROD SHOWING ELEVATED LOCAL STATIC PRESSURES AHEAD OF THE CANOPY SKIRT HEM. TEST VELOCITY 200 MPH.

Figure 25 presents the effects of canopy cloth rate of airflow on the pressure distribution of 41.7 percent scale model of the Parachute MK 38 MOD 0. Runs 11 and 12 which had suspension line lengths of 40 inches and 50 inches, respectively, indicated essentially identical pressure variations. The three momme silk model of run 13 was included to evaluate canopy cloth permeability on canopy full inflation. The silk model of the MK 38 parachute inflated to 75 percent of the design drag area at the test velocity of 200 mph. The wind tunnel onset of inflation instability is somewhere between the 325 CFM/FT^2 production MIL-C-17208, Type I, Class B cloth rate of airflow and the 428 CFM/FT^2 silk cloth rate of airflow, see Figures 18, 19, and 20. The greater rate of airflow of the silk cloth used in run 13 of Figure 25 has reduced the internal canopy pressure to a degree that full inflation of the parachute cannot be maintained. It is consistent that the lower cloth rate of airflow of run 5 results in a slight increase in the pressure distribution. The effects of canopy rate of airflow on the Parachute MK 38 MOD 0 drag coefficient are shown in Figure 26.

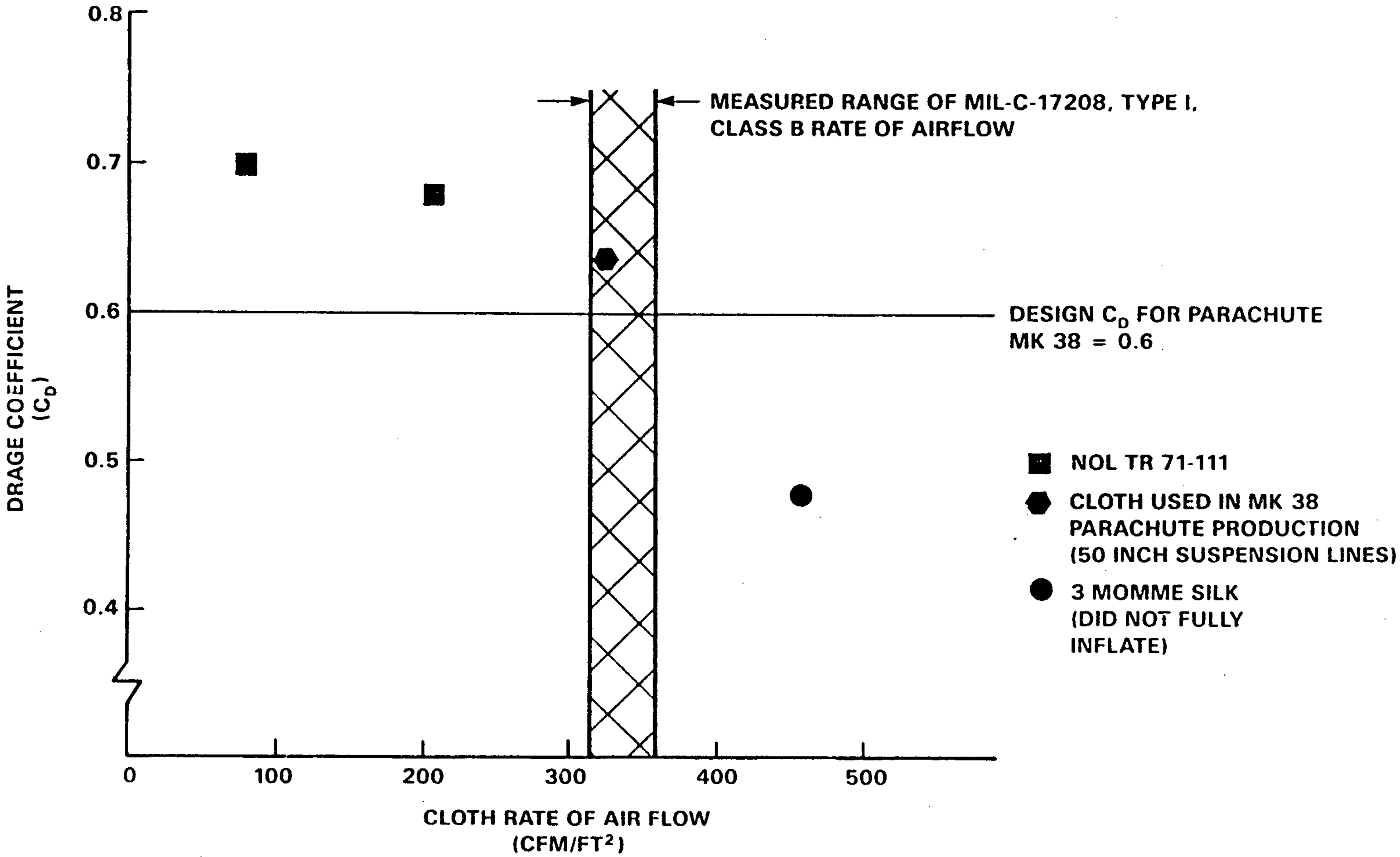


FIGURE 26. EFFECT ON THE CLOTH RATE OF AIRFLOW ON THE DRAG COEFFICIENT OF THE MK 38 MOD 0 PARACHUTE

CONCLUSIONS

1. Conventional round parachutes have a uniform steady state suspension line force distribution in the several equal length suspension lines because all lines elongate equally under load.

2. Equal length suspension lines attached to an arm of a Cross parachute elongate nonuniformly in steady state. This indicates a nonuniform force distribution in the lines with the maximum force occurring in the longest line(s).

3. The suspension line forces can be reduced by progressively lengthening the several lines. The longer lines modify the force distribution in the suspension line system.

4. The optimum way to make the suspension line force distribution uniform is to adjust the spacing of the suspension lines on the canopy. This approach will permit use of a single strength and length of suspension line and minimize inspection during manufacture.

5. Measurements of the axial steady state static pressure distribution adjacent to the parachute center line indicate that the associated air mass of the inflated parachute extends ahead of the canopy skirt hem.

6. As the canopy cloth permeability is increased the pressure distribution is similar in form but the magnitude is reduced. This also applies to partially inflated canopies.

7. Excessive canopy cloth rate of airflow results in incomplete canopy inflation.

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13. ABSTRACT *(Maximum 200 words)*

The force distribution in the several suspension lines attached to an arm of a Cross-type parachute is nonuniform. The outer suspension lines carry the minimum force. The forces increase in each suspension line as the line attachment approaches the center of the arm with the maximum force carried by the most central lines.

This report describes a series of wind tunnel tests to measure the force in individual selected suspension lines of Cross-type parachutes with 8, 16, and 24 suspension lines. The test results show that lengthening the inner suspension lines tend to equalize the suspension line forces. The static pressure distribution adjacent to the parachute center line was measured for each parachute model. Positive pressures were found to exist ahead of the canopy skirt hem as well as inside the canopy. The magnitude of the pressures is influenced by the canopy cloth permeability.

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