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PROPULSION NOISE REDUCTION TECHNOLOGY PROGRAM

CHARLES R. CARTER
BOEING AEROSPACE COMPANY
TACTICAL MISSILES
220 WYNN DRIVE
HUNTSVILLE, ALABAMA 35807

JERROLD H. ARSZMAN
ARMY MISSILE LABORATORY
PROPULSION DIRECTORATE
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA 35898

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PREPARED FOR:

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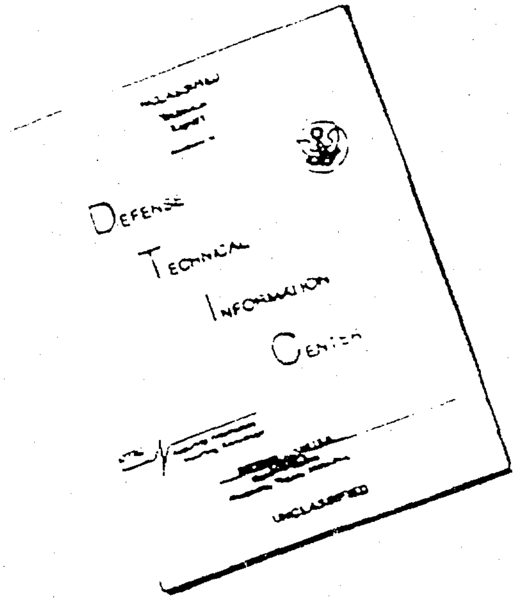

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ABSTRACT

This report describes the design, test and analysis of several types of suppressors being developed for reducing the peak noise produced by a shoulder-fired rocket weapon system. Each suppressor design was tested with an actual firing of the M-72 weapon system. A reusable M-72 launch tube was suspended on a ballistic pendulum and each suppressor was attached to the launch tube for testing. Instrumentation for determining missile muzzle velocity, launch tube recoil and near field noise were installed and recorded during each test.

The results of the tests have verified that an aluminum baffled cylinder suppressor will reduce the peak noise produced at the gunners position by the M-72 weapon system from 2.14 psid/177.5 db to 0.46 psid/164 db. This 78.5% peak noise overpressure reduction was achieved with no effect on missile muzzle velocity and at a launcher recoil level of 2.86 lb-sec. Launcher recoil was reduced to near zero by using yielding baffles in the suppressor. This configuration produced a peak noise overpressure reduction at the gunners position of 76.6%. Extensive testing was done with fabric suppressors to determine their potential for fieldweight suppressors. The fabric suppressors attained a peak noise overpressure reduction of 75% but increased the recoil level to 5 lb-sec. Design modifications have been recommended for reducing this recoil level. Projected carry weight for the fieldweight suppressor for the M-72 weapon has a range of 0.5 and 2.5 pounds for the fabric and aluminum suppressors respectively depending on the peak noise reduction and launcher recoil levels desired.

Based on the data presented, peak noise suppressors can be designed and fabricated that will be effective on rocket powered weapon systems that require a gunner at or near the launch tube when the missile is fired.

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PREPARED BY C. R. CARTER

SUPERVISED BY B. L. OSBORNE

APPROVED BY L. J. MASON

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Billy Wright
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Charles R. Carter
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1. Report T-CR-78-27, Rocket Motor Peak Noise Reduction Program, 30 September 1978.

2. D256-10221, Small Rocket Sound Reduction, 10 January 1977.

3. D256-10523, Noise Reduction Research Program, 21 December 1978.

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1.0 INTRODUCTION AND SUMMARY

This document presents the results of the Propulsion Noise Reduction Technology Program that was conducted between April 1979 and September 1980. The program included the design and test of heavyweight and fieldweight peak noise suppressors for the M-72 shoulder fired anti-tank weapon system. Test fixtures and instrumentation were designed and fabricated to allow testing of the peak noise suppressors with a live firing of the M-72 free flight missile while measuring missile muzzle velocity, launch tube recoil, sound pressure levels and suppressor chamber pressures. All testing was performed by USAMICOM Propulsion Directorate in their Small Rocket Motor Evaluation Facility located at Redstone Arsenal, Alabama.

As a result of this joint MICOM/Boeing program, excellent peak noise reduction has been achieved at the gunners position with both heavyweight and fieldweight peak noise suppressors designed for the M-72 weapon system. A heavyweight baffled cylinder suppressor, with yielding baffles, reduced the peak noise overpressure at the gunners position by 75%. This suppressor had no effect on missile muzzle velocity and a launcher recoil level of zero. A similar fieldweight baffled cylinder suppressor, fabricated from Kevlar fabric and weighing 0.5 pounds, also reduced the peak noise overpressure by 75%. This fieldweight suppressor had no effect on missile muzzle velocity but it did show a recoil level increase to 5 lb-sec.

Fieldable versions of the heavyweight and fieldweight baffled cylinder suppressors for the M-72 are projected to have less than 2.5 pounds carry weight and are predicted to reduce the peak noise overpressures by 75%. Carry weight of less than 1.0 pound can be achieved by using Kevlar fabric to fabricate the fieldable suppressors. These Kevlar fabric suppressors will maintain high peak noise reduction capability but will have the higher recoil levels presently associated with fabric suppressors. These recoil levels can be further reduced with some minor design changes to be evaluated in future programs that will: (1) reduce the Kevlar fabric surface roughness,

1.0 (Continued)

(2) stiffen the forward closure and (3) provide for seamless Kevlar cylinder sections.

In addition to providing a basis for designing a lightweight peak noise suppressor for the M-72, the peak noise reduction technology developed during this program and presented in this report can be used to:

(1) Design lightweight and effective peak noise suppressors for other man-portable shoulder fired rocket powered weapon systems. The suppressor designs developed from these data should have no effect on missile performance and little or no effect on launcher recoil.

(2) Design effective peak noise suppressors for rocket powered weapon systems that require a gunner at or near the launch tube when the weapon is fired.

(3) Develop a straight forward theoretical model that can be used to predict the peak noise overpressure that can be expected at the gunners position when firing a rocket powered weapon system.

The Propulsion Noise Reduction Technology Program described in this Report was conducted in four phases. Each phase was made up of design, test and analyses of specific suppressor hardware designed for use on the M-72 weapon system. The suppressor hardware and test procedures of succeeding phases were highly dependent on the suppressor performance achieved in preceeding phases of the program. The phasing dependence allowed a large number of suppressor configurations to be tested and minimized the number of repeat configurations. The performance data developed during each phase provided configuration dependent suppressor performance trends for a large number of different suppressors, but with a minimum of repeat configurations, absolute performance level was not established for any specific configuration.

1.0 (Continued)

Phase One of the program, Heavyweight Suppressor Design and Evaluation, was conducted primarily with hardware from a previous program reported in Reference 1. Phase Two of the program, Advanced Suppressor Design and Evaluation, utilized configuration dependent data from Phase One such as chamber spacing and orifice diameter along with recommendations from Reference 1 and and research data from Reference 2 and 3. Phase Three of the program, Sound Absorbing Material Suppressor Design and Evaluation, was performed with selected configurations from Phase One and Two. Sound absorbing material recommended from a research program reported in Reference 3 was used to line the selected suppressor configurations. At the conclusion of Phase Three performance data were available that could be used to develop the most promising fieldweight configurations for Phase Four of the program. The lightweight Kevlar fabric suppressors that were tested in Phase Two had good performance characteristics. They were both scaleable and lightweight and since there was very little configuration dependent performance data available for these suppressors, the Kevlar suppressors were selected for test and evaluation during Phase Four of the program.

The remainder of this report will describe the four phases of the design, test and analyses of the M-72 peak noise suppressors. It will begin with the Test Fixture Design that is common in use during each phase. These are followed by recommendations for an analysis and prediction model, the projected capabilities of fieldweight suppressors and recommendations for future programs.

Blank

2.0 TEST FIXTURE DESIGN

Prior attempts to measure peak noise suppressor performance and recoil effects during a static test were made with a dual load cell that was designed to measure both thrust and recoil. A sketch of this fixture is shown in Figure 2-1. This fixture proved to be inadequate for simultaneous measurement of thrust and recoil because of vibrations caused by misalignments inherent in the design. The details of the specific problems encountered with the dual load cell test fixture are reported in Reference 1. The test fixture design selected for the Propulsion Noise Reduction Technology Program is based on the recommendations of Reference 1 that a dynamic test with a pendulum type test fixture be used for further tests of peak noise suppressors. A sketch of the pendulum test fixture is shown in Figure 2-2. This fixture is made up of a reusable M-72 launch tube supported by four cables to an adjustable unistrut frame. In this configuration and with proper instrumentation the fixture can be used to obtain suppressor performance, launch tube recoil and missile velocity during a live firing of the M-72 weapon system with an inert warhead. The operational fixture is shown installed in the USAMICOM Propulsion Directorate Small Motor Evaluation Facility in Figure 2-3. Installed as shown in Figure 2-3, the test fixture arrangement allows simultaneous measurement of suppressor performance, launch tube recoil and missile velocity. Suppressor performance in terms of peak noise was measured with three sound pressure level gages mounted on special fixtures and located as shown in Figure 2-4. Launch tube recoil was calculated from the basic pendulum equations. The mass term in the equation was determined from the total weight of the launch tube, counter weight and the suppressor just prior to firing. The counter weight was varied as required to keep the center of mass at the geometric center of the cable supports. The angle of swing was measured with a calibrated potentiometer attached to the unistrut frame and one of the cables as shown in Figure 2-5.

2.0 (Continued)

The missile designed for these live firing tests was the same weight as the operational M-72 rocket motor and warhead. A reusable inert warhead was fabricated from aluminum and mounted on the motor in the same manner as the live warhead. The M-72 rocket motor and inert warhead assembled into a flight missile are shown in Figure 2-6.

Missile muzzle velocity was determined with the time required for the missile to break two carbon break wires spaced one foot apart. The break wires are shown before and after a firing in Figure 2-7.

Detail drawings of the test fixture components are given in the appendix.

Several test fixture and instrumentation checkout firings were made with the launch tube only configuration. During each firing the test fixture remained stable except for the predicted swing. The missile impacted the predicted aim point and the sound pressure level gage mounting fixtures survived the blast. The data recorded during the checkout firings were used to establish baseline noise levels at the three sound pressure level gage positions, baseline missile muzzle velocity and baseline launcher recoil. The unsuppressed data resulting from firings of the M-72 weapon system in this test fixture are presented in Table 2-I.

Since the motor to motor variation in each measured variable was small, the baseline level for each variable was developed by averaging the data from each of the firings. The average level and standard deviation for the sound pressure levels, missile muzzle velocity and launch tube recoil used throughout this report as baseline level data for the unsuppressed launch of the M-72 weapon system are given in Table 2-II.

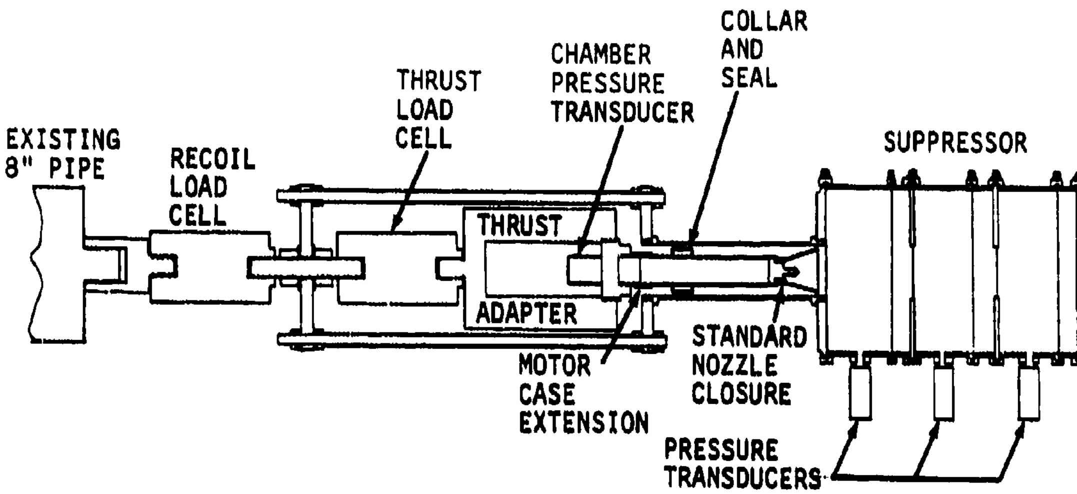


FIGURE 2-1 DUAL LOAD CELL TEST FIXTURE

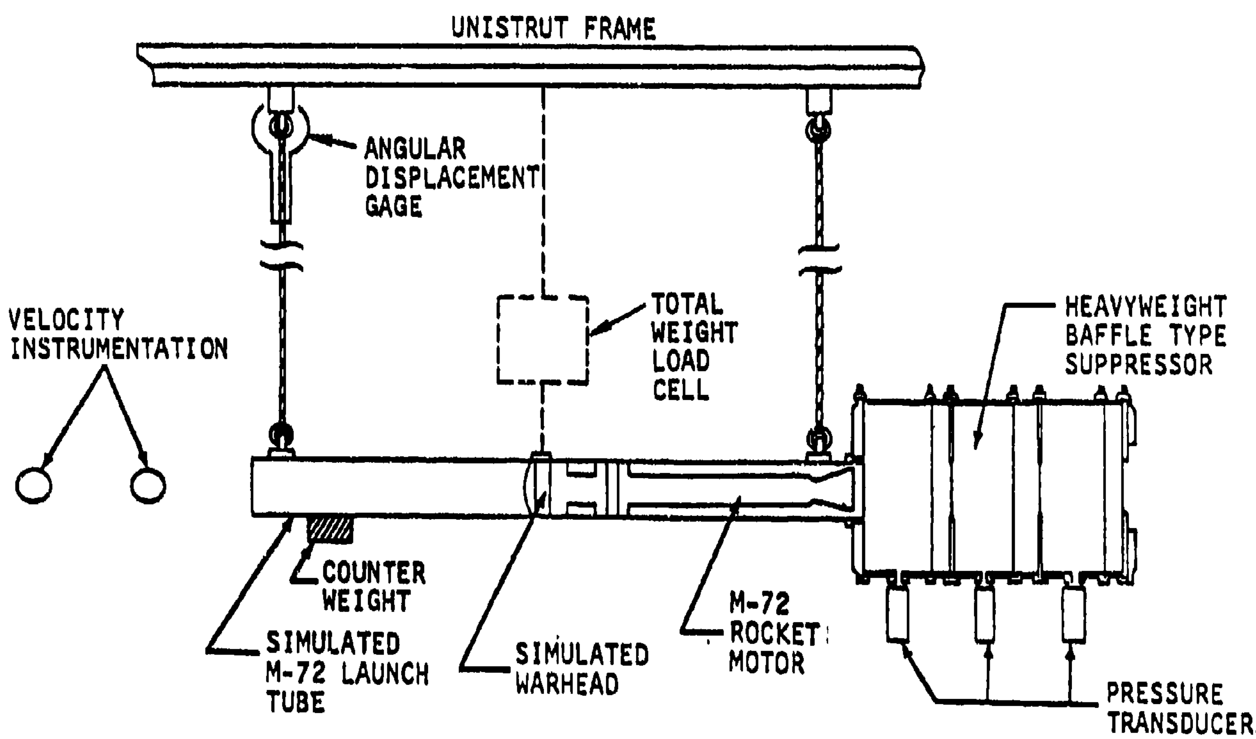


FIGURE 2-2 SKETCH OF PENDULUM TEST FIXTURE

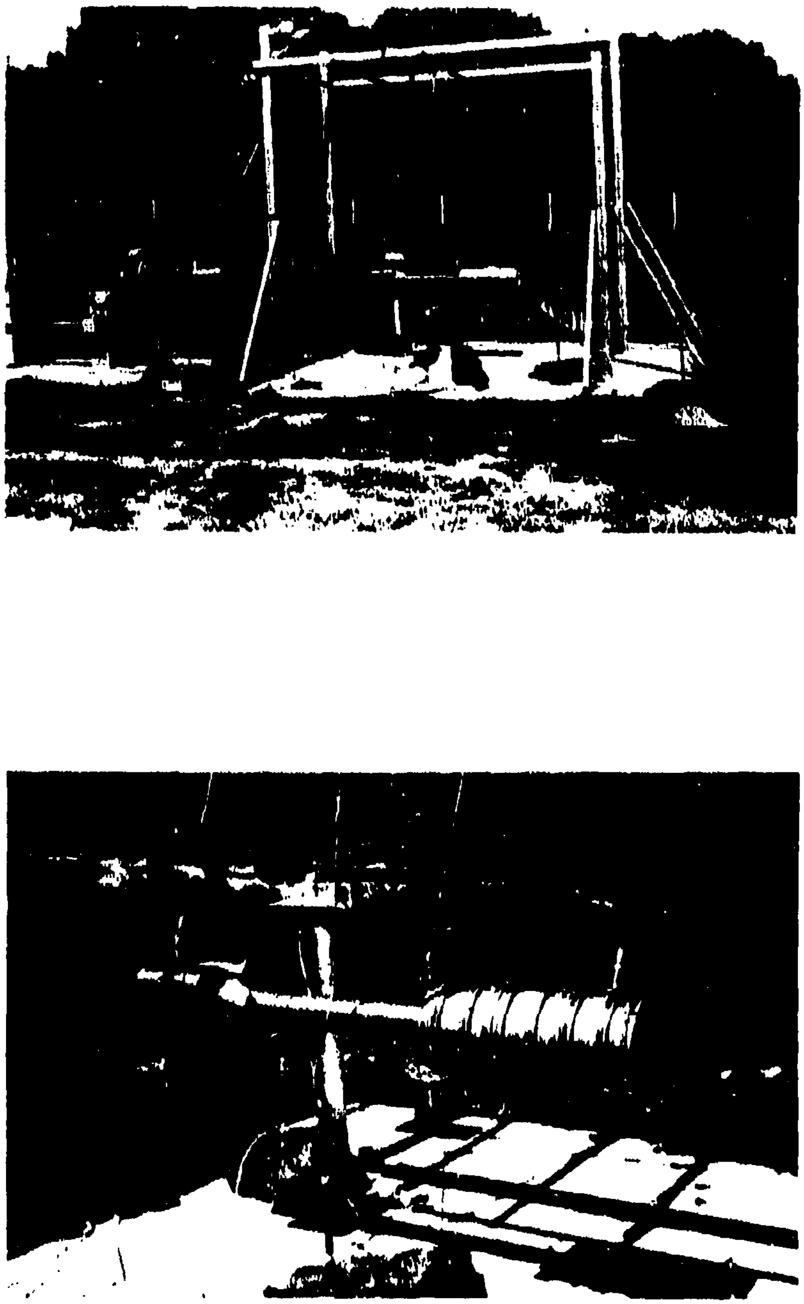
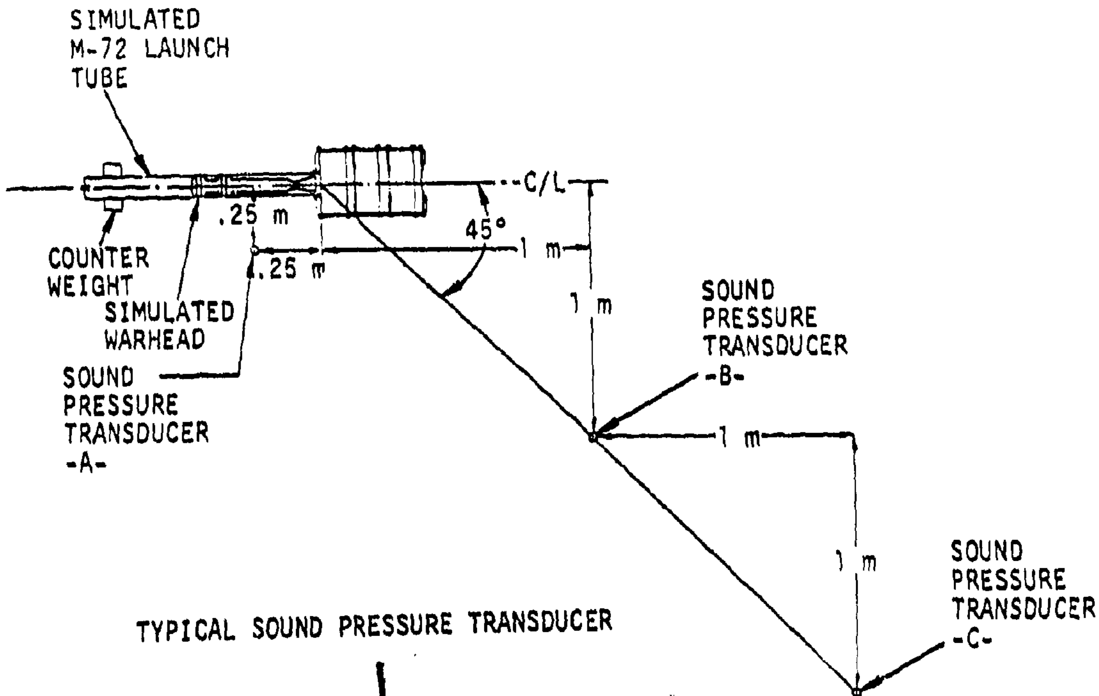


FIGURE 2-3 PENDULUM TEST FIXTURE INSTALLATION



TYPICAL SOUND PRESSURE TRANSDUCER

FIGURE 2-4 SOUND PRESSURE LEVEL INSTRUMENTATION

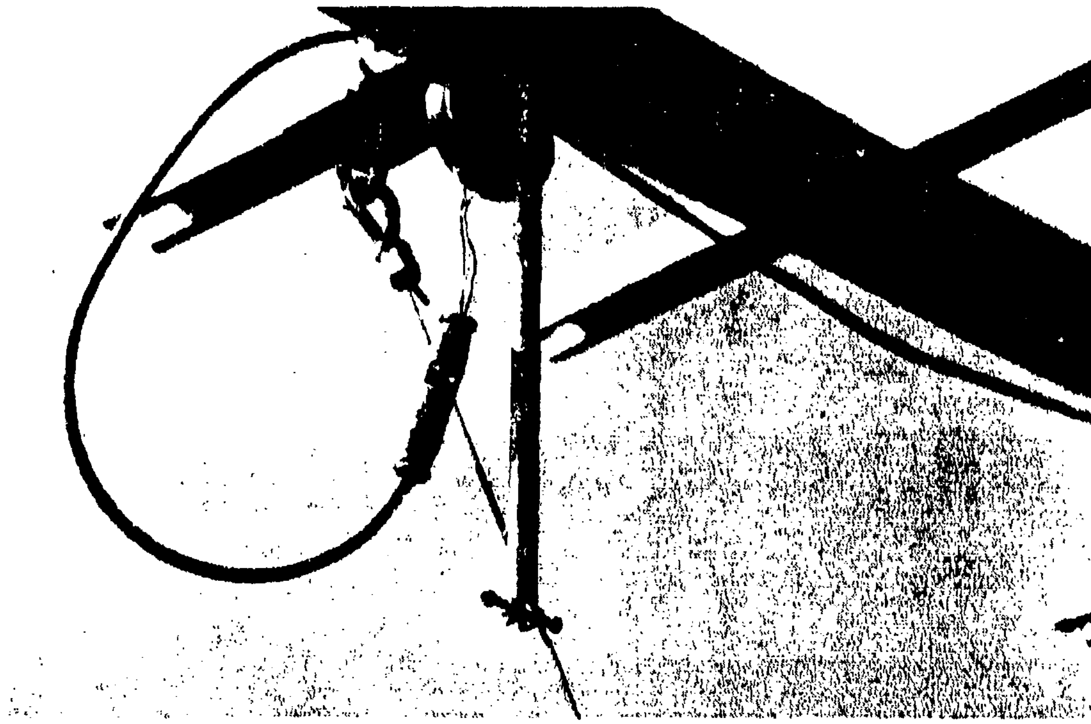


FIGURE 2-5 SWING ANGLE POTENTIOMETER

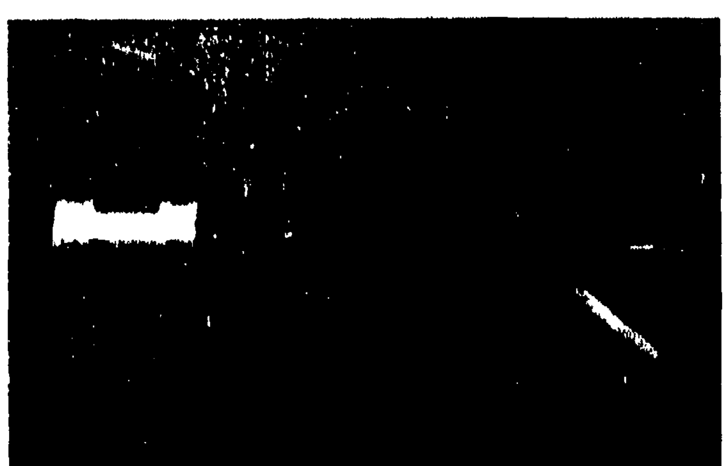


FIGURE 2-6 M-72 ROCKET MOTOR AND INERT WARHEAD

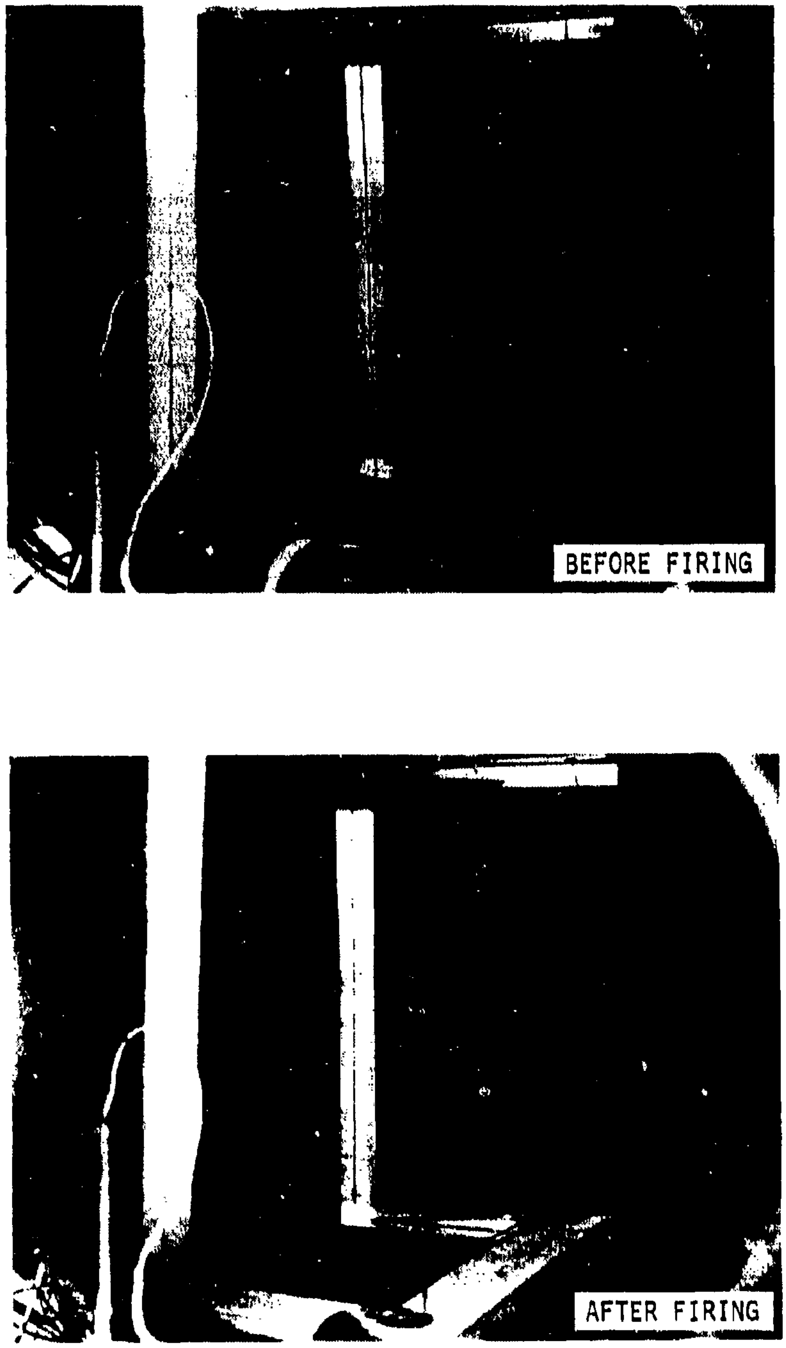


FIGURE 2-7 MUZZLE VELOCITY BREAK WIRE FIXTURE

TABLE 2-I M-72 WEAPON SYSTEM DATA

ROUND #	PEAK NOISE PRESSURE LEVEL GAGE POSITION A P-PSID	A db	B P-PSID	B db	C P-PSID	C db	LAUNCHER RECOIL IMPULSE LB-SEC	MISSILE MUZZLE VELOCITY FT/SEC
1	2.05	177	2.58	179	1.82	176	0	NO DATA
2	2.05	177	2.3	178	1.82	176	0	NO DATA
3	1.82	176	2.6	179	1.62	175	0	NO DATA
4	2.05	177	2.6	179	1.62	175	0	NO DATA
5	2.58	179	2.3	178	1.45	174	.63	434.8
6	2.3	178	2.6	179	1.62	175	0	435.0

TABLE 2-II BASELINE DATA

INSTRUMENTED VARIABLE	NO. DATA POINTS	BASELINE LEVEL	STANDARD DEVIATION
SOUND PRESSURE GAGE A	6	2.14 PSID (177.5db*)	± .263
SOUND PRESSURE GAGE B	6	2.53 PSID (178.8db*)	± .1182
SOUND PRESSURE GAGE C	6	1.66PSID (175.2db*)	± .1414
LAUNCHER RECOIL IMPULSE	6	0.105 LB-SEC	± .2572
MISSILE MUZZLE VELOCITY	2	434.9 FT/SEC	± .1414

$$* \ db = 20 \log_{10} \frac{\text{PRESSURE}}{2.9008 \times 10^{-9}}$$

3.0 HEAVYWEIGHT SUPPRESSOR DESIGN AND EVALUATION

The peak noise reduction program, started in 1978 and reported in Reference 1, evaluated the peak noise reduction capability of several baffled cylinder suppressor concepts during a static firing of the M-72 weapon system rocket motor. Complex vibrations in the static test fixture prevented measurement of usable recoil data, therefore the total capability of the baffled cylinder suppressors were not determined. The Heavyweight Suppressor Design and Evaluation part of this program is a continuation of the previous test with the specific purpose of obtaining the baffled cylinder suppressor capability and its effect on launcher recoil and missile performance.

In general, the baffled cylinder hardware designed for the earlier static tests were used for the Heavyweight Suppressor tests. Some minor design changes were made in the number and size of the baffle orifices and in the yielding baffle configuration. All testing was done with the test fixture and instrumentation described in Paragraph 2.0.

The following paragraphs will discuss the design, test and performance analysis of the heavyweight baffled cylinder suppressors. It will be shown that the heavyweight baffled cylinder suppressors are very effective for peak noise reduction. One configuration, with yielding baffles reduced the peak noise overpressure at the gunners position by 75% with no effect on missile muzzle velocity or launch recoil.

3.1 Heavyweight Suppressor Design

Several suppressor design concepts for weakening peak noise pressure waves before they reach the gunners position have been tested and the results presented in Reference 1 and 2. Test results verified that the expansion-reflection process inherent in the baffled cylinders effectively weakens the pressure wave before it reaches the gunner. Based on the results of the test and analyses presented in References 1 and 2, the baffled cylinder design was selected for further tests with live firings of the M-72 weapon system.

3.1 (Continued)

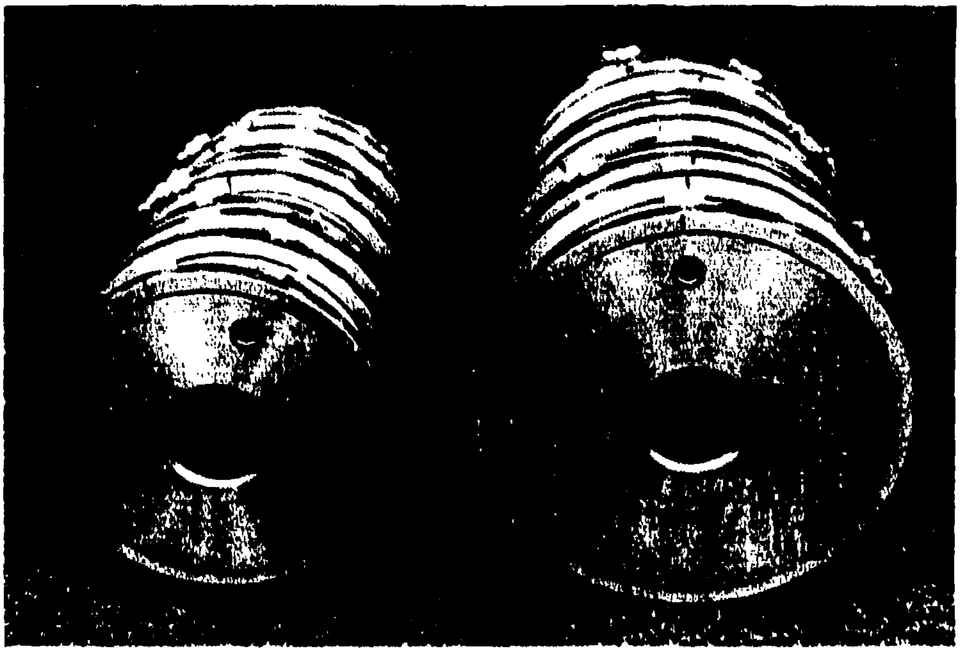
The two baffled cylinder suppressor configurations shown in Figure 3-1 were designed to evaluate their capability to reduce the peak noise produced by the M-72 weapon system. These suppressors were designed with reusable heavyweight structural components suitable for evaluating the suppressor concept in several configurations. The inside diameters of the two suppressors were set at eight (8) inches and ten (10) inches.

Each suppressor is designed so that by selecting a combination of the cylinder sections shown in Figure 3-2, the chamber length between the baffles could be varied in one (1) inch increments. Bosses were installed in each two (2) and three (3) inch cylinder sections for installation of pressure transducers. The baffle orifice size could be varied from 2.5 to 5 inches and in addition, rigid, flexible and yielding baffles shown in Figure 3-3 were fabricated. The cylinder sections and baffle combinations were held together with a four piece band clamp shown in Figure 3-4.

Detailed design drawings of the suppressors are included in the Appendix.

3.2 Heavyweight Suppressor Test

The objective of the heavyweight suppressor test was to determine the capability of the baffled cylinder suppressor to reduce peak noise and at the same time determine the suppressor effects on launcher recoil and missile performance. This test objective was satisfied by selecting several heavyweight baffled cylinder configurations from the hardware described in Paragraph 3.1. Each of the suppressor configurations was attached to the reusable launch tube with a threaded connection in the forward end plates. Testing was performed with a dynamic firing of the M-72 rocket motor and inert warhead. A heavyweight suppressor configuration attached in the manner used for each test is shown in Figure 2-3.



8" ID SUPPRESSOR 10" ID SUPPRESSOR

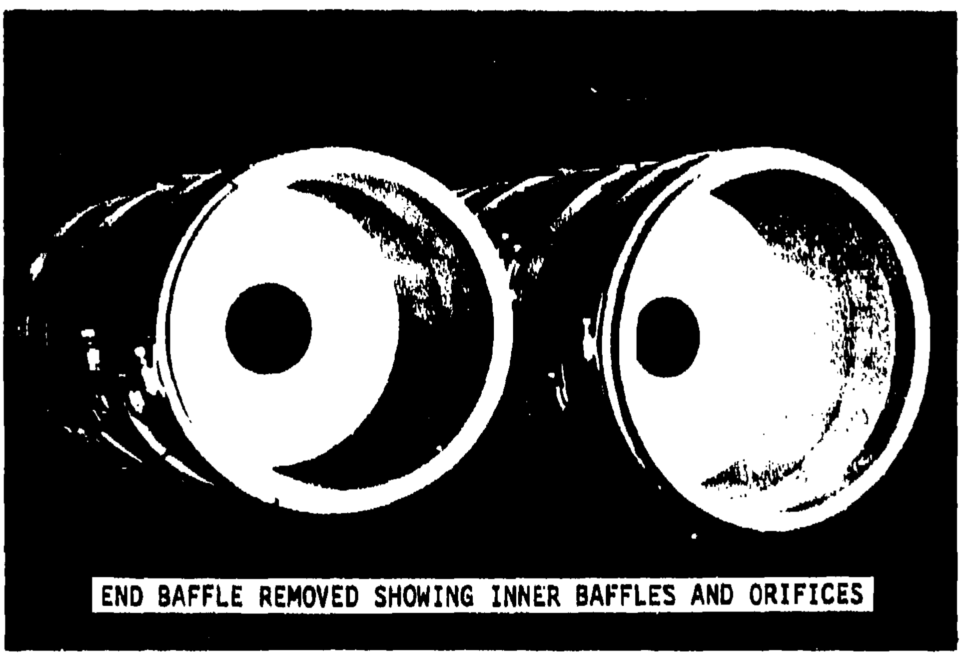


FIGURE 3-1 BAFFLED CYLINDER SUPPRESSORS

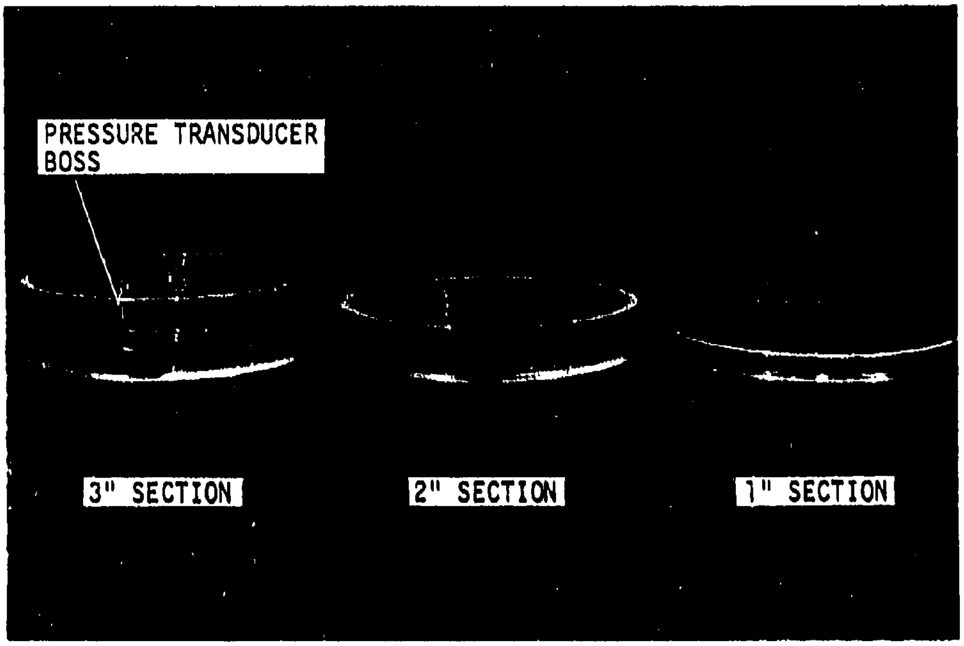


FIGURE 3-2 SUPPRESSOR CYLINDER SECTIONS

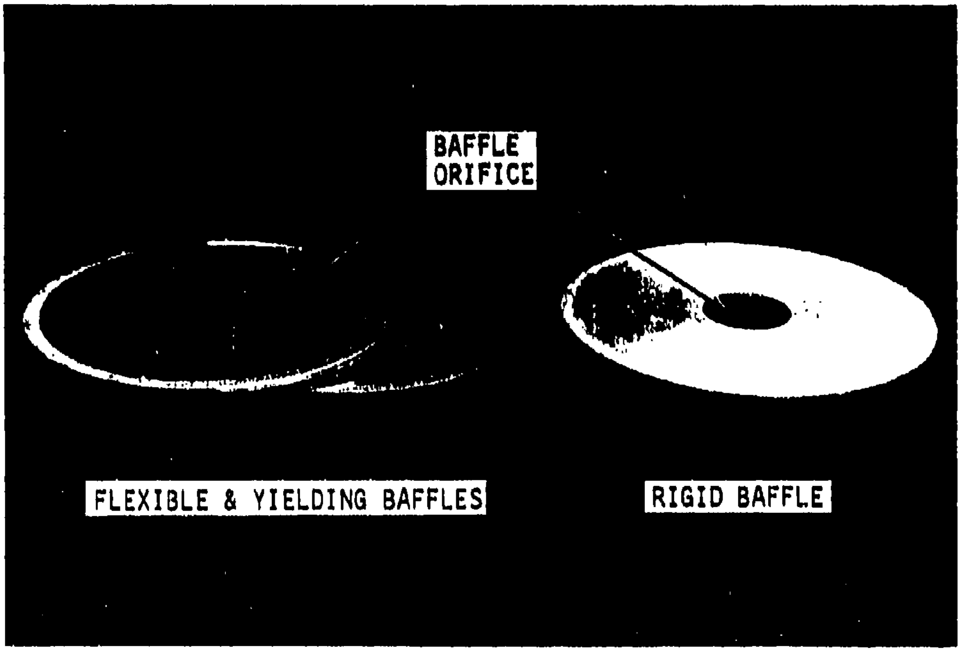
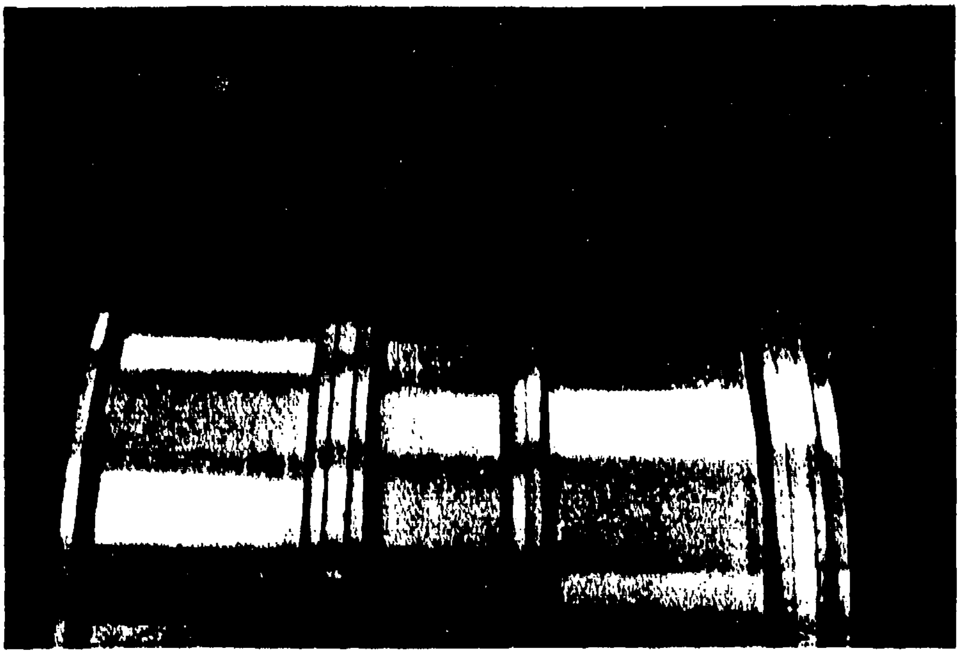


FIGURE 3-3 SUPPRESSOR BAFFLES



BAND CLAMP INSTALLATION

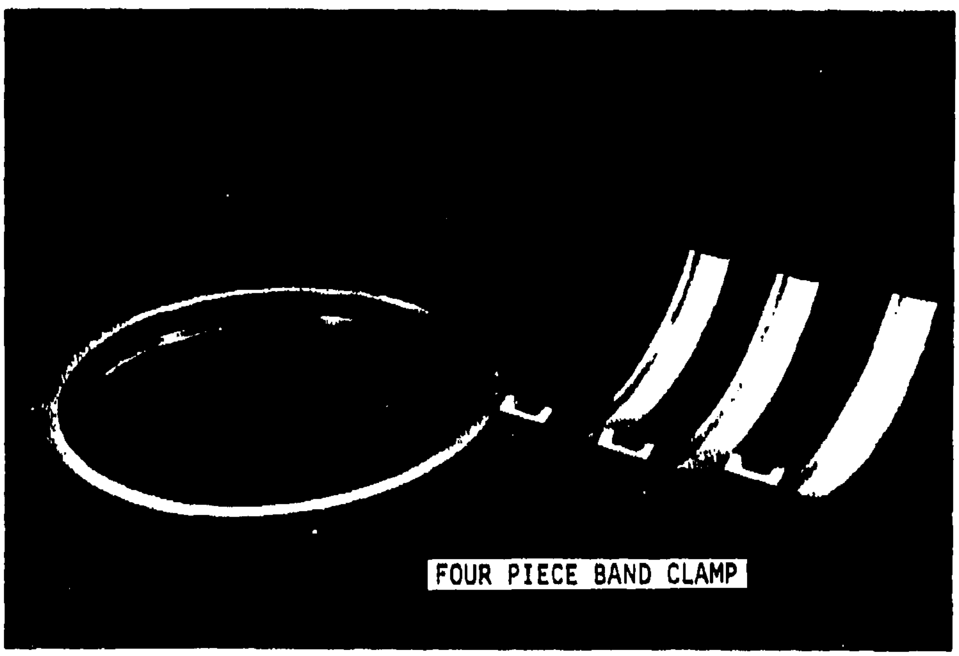


FIGURE 3-4 SUPPRESSOR BAND CLAMP

3.2 (Continued)

A typical test sequence included the following items.

1. Load the motor with the standard M-72 propellant.
2. Install head end closure and inert warhead assembly.
3. Check instrumentation for proper operation.
4. Install motor and inert warhead assembly into reusable launch tube.
5. Route igniter cable through hole provided in side of reusable launch tube.
6. Attach selected suppressor configuration to reusable launch tube.
7. Support reusable launch tube and suppressor assembly at centriod of support cable attachment.
8. Adjust counterweight until center of gravity is at centriod of support cable attachment.
9. Record weight of supported assembly.
10. Remove centriod support and allow support cables to function as designed.
11. Arm motor for firing.
12. Fire motor and record data.
13. Recover the reusable inert warhead.

3.2 (Continued)

The data for each instrumented variable was recorded on magnetic tape and on a recording oscillograph from the time just prior to the firing command until the test fixture reacted to any recoil forces that were imparted to it. A representative oscillograph recording of a firing is shown in Figures 3-5 and 3-6. The sound pressure level, timed gates for muzzle velocity and chamber pressure are shown in Figure 3-5. A separate recording of the pendulum swing angle was necessary because of the time required for recording the total period of swing. The swing angle data are shown in Figure 3-6.

3.3 Heavyweight Suppressor Data Analyses

The data recorded during testing of the heavyweight suppressor has been analyzed to determine the suppressor capability to reduce peak noise produced by a live firing of the M-72 weapon system. The analysis included determining the effects of the suppressor on missile performance in terms of missile muzzle velocity and on launcher recoil. Typical examples of the raw data are given in Figures 3-5 and 3-6. The sound pressure level data shown in Figure 3-5 represents a pressure versus time trace generated at gages A, B and C during a firing of the M-72 weapon system. The pressure trace remains at zero until the pressure wave passes the gage position. The initial pressure peak associated with the pressure wave passing a gage is usually interpreted as the peak noise pressure level. The peak noise pressure level on each oscillograph recording made during the test of each heavyweight suppressor configuration has been tabulated in Table 3-I.

3.3 (Continued)

Pressure data were also recorded for each of the chambers in a heavyweight suppressor configuration. Data typical of that recorded for the interior of the chamber are shown in Figure 3-5.

The recoil impulse was derived from the swing angle data shown for a typical heavyweight suppressor test in Figure 3-6 and the combined weight of the launch tube, counter weight and the suppressor. These data were used in the pendulum equation along with the test fixture geometry. The calculated recoil data in terms of recoil impulse are also shown in Table 3-I.

Missile muzzle velocity was determined by using timed gates located one foot apart. The time required for the missile to travel between gate one and gate two was determined from the time between the two break wire signals shown on Figure 3-5. The muzzle velocity derived from this time lapse is recorded in Table 3-I. The missile muzzle velocity data recorded during testing of the heavyweight suppressors show no evidence that the suppressors affect missile performance in terms of muzzle velocity.

The interior chamber pressure versus time trace shown in Figure 3-5 is typical of that recorded for each heavyweight suppressor configuration. The peak of highest pressure recorded in each chamber has also been tabulated in Table 3-I.

The data reduced to engineering units that are presented in Table 3-I were then used to analyze the overall suppressor peak noise reduction capability along with effects on launcher recoil and missile muzzle velocity.

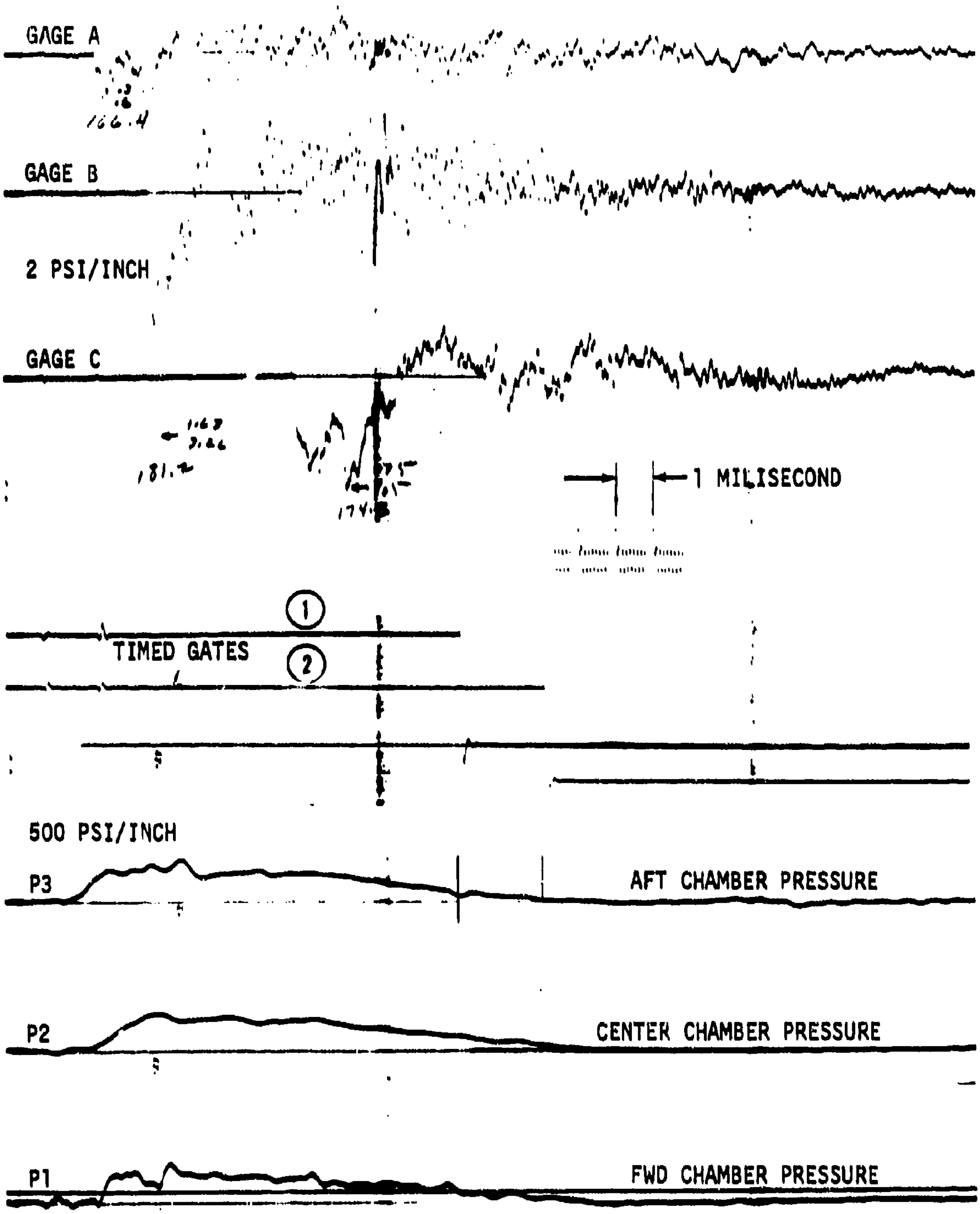


FIGURE 3-5 PRESSURE & VELOCITY OSCILLOGRAPH DATA RECORDED DURING THE HEAVYWEIGHT SUPPRESSOR TESTS

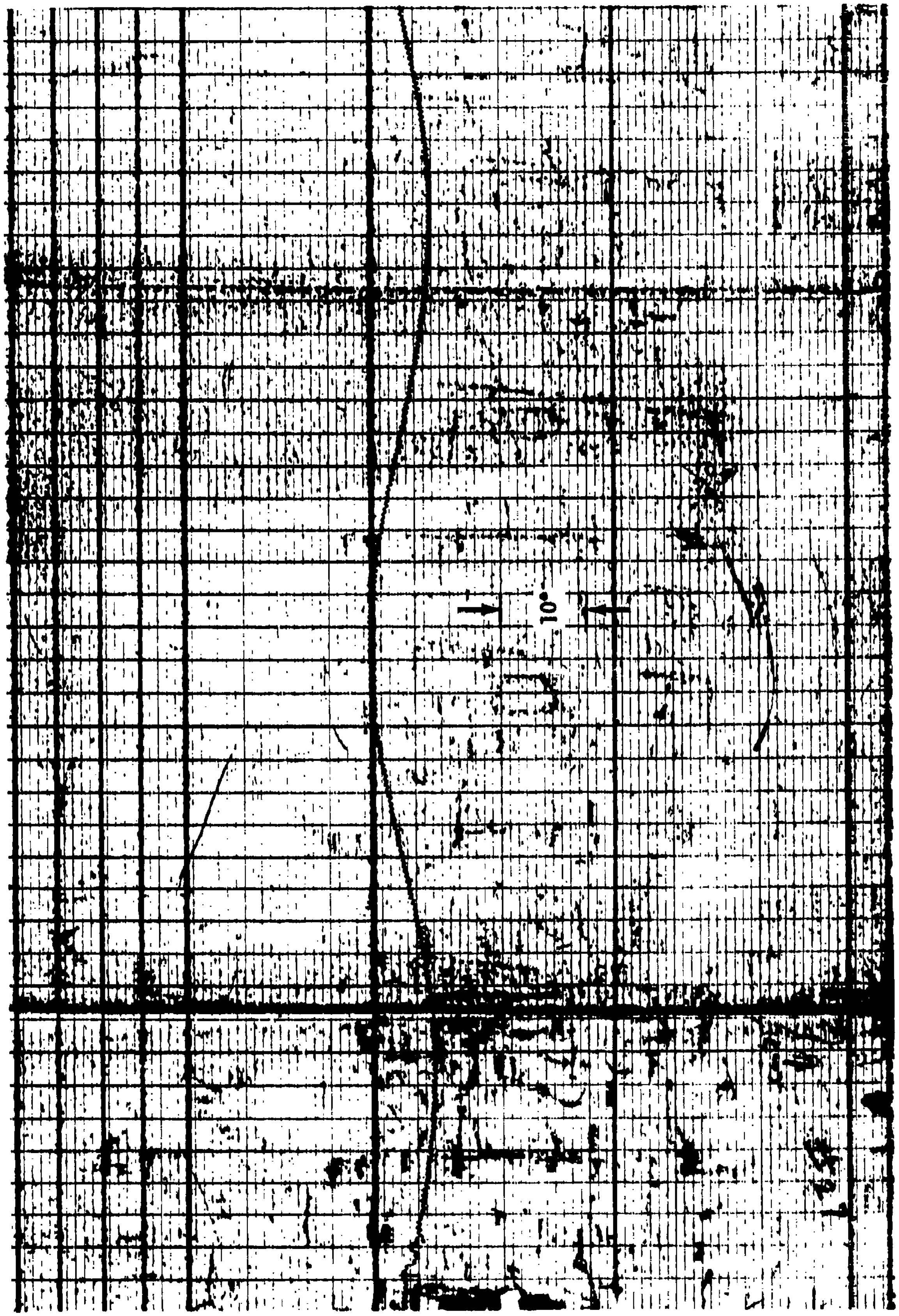


FIGURE 3-6 SWING ANGLE OSCILLOGRAPH DATA RECORDED DURING THE HEAVYWEIGHT SUPPRESSOR TESTS

TABLE 3-I HEAVYWEIGHT SUPPRESSOR TEST TABULATED DATA

ROUND #	INSIDE DIAMETER INCHES	HEAVYWEIGHT SUPPRESSOR CONFIGURATION: CHAMBER LENGTH (INCHES) FORWARD	CHAMBER LENGTH CENTER	CHAMBER LENGTH AFT	BAFFLE ORIFICE DIAMETER (INCHES) FORWARD	BAFFLE ORIFICE CENTER	BAFFLE ORIFICE AFT	GAGE POSITION PEAK NOISE PRESSURE LEVEL A: dB (177.5)*	A: PSID (2.4)*	B: dB (180.8)*	B: PSID (2.53)*	C: dB (175.2)*	C: PSID (1.66)*	MISSILE MUZZLE VELOCITY FT/SEC (434.9)*	LAUNCHER RECOIL IMPULSE LB-SEC (.105)*	SUPPRESSOR INTERNAL CHAMBER PRESSURE PSIG FORWARD	CENTER	AFT
---	10	6	6	6	2.5	2.5	2.5	165	.52	179	2.6	172	1.15	454.5	---	425	200	50
8	8	6	6	6	2.5	2.5	2.5	160	.73	178	2.3	173	1.3	454.5	10.5	200	200	125
9	8	5	5	5	2.5	2.5	2.5	165	.52	181	3.25	174	1.45	436.0	8.4	375	216	30
10	8	4	4	4	2.5	2.5	2.5	167	.65	182	3.65	174	1.45	454.5	6.64	425	160	150
11	10	6	6	6	2.5	2.5	2.5	164	.46	174	1.46	170	.42	453	11.43	230	200	110
12	10	5	5	5	2.5	2.5	2.5	165	.52	176	1.62	169	.82	400	9.28	230	200	100
13	10	4	4	4	2.5	2.5	2.5	164	.46	179	2.6	171	1.02	435	6.05	175	175	110
14	10	4	4	4	3	3	3	168	.73	176	1.82	172	1.15	---	2.37	175	100	90
15	10	4	4	4	4	4	4	172	1.15	176	1.82	174	1.65	440	0	115	50	135
16	10	4	4	4	5	5	5	172	1.16	178	2.3	175	1.62	442	0	75	100	115
17	10	4	4	4	2.5F	2.5F	2.5F	165	.52	176	1.46	171	1.02	440.5	5.97	225	250	100
18	8	6	6	6	3	3	3	164	.46	176	1.82	171	1.02	436	6.60	150	325	85
19	8	6	6	6	4	4	4	168	.73	177	2.85	173	1.3	442.7	2.12	150	190	75
20	8	6	6	6	2.5Y	2.5Y	2.5Y	163	.41	175	1.62	170	1.02	438.6	9.31	150	235	50
21	8	3	3	3	2.5	2.5	2.5	168	.7	179	2.6	174	1.45	436.6	3.75	125	100	175
22	10	3	3	3	2.5	2.5	2.5	165	.6	181	3.4	171	1.02	442.2	4.13	125	85	160
23	8	6	6	6	2.5Y	2.5Y	2.5Y	165	.5	183	4.0	175	1.62	435.4	.52	140	---	---
24	10	4	4	4	2.5Y	2.5Y	2.5Y	165	.5	180	2.96	175	1.62	436.5	0	75	75	0
25	8	6	6	6	None	None	None	168	.84	181	4.5	175	1.62	441.5	1.59	0	35	0
26	10	4	4	4	None	None	None	175	1.7	181	3.14	174	1.45	431.5	3.65	0	0	50
27	10	2	2	2	2.5	2.5	2.5	166	.6	181	3.26	174	1.45	434.8	3.10	50	135	150
28	8	2	2	2	2.5	2.5	2.5	170	.9	182	3.46	174	1.45	430.5	3.0	100	110	135
29	10	3	3	3	3	3	3	170	.86	183	4.2	173	1.3	436.7	2.4	100	110	---
30	8	3	3	3	3	3	3	171	1.0	182	3.6	173	1.3	426.8	1.72	125	125	90
31**	10	4	4	4	#	#	#	172	1.14	182	3.6	177	2.06	437.5	3.07	75	75	70
32	8	6	6	6	#	#	#	170	.9	182	3.6	175	1.62	435.7	1.13	150	115	60

\# 4 ORIFICES AT 1.275 INCHES DIAMETER IN A YIELDING BAFFLE
F FLEXIBLE
Y YIELDING

* BASELINE LEVELS FROM TABLE 2-II
** THE AFT SECTION OF THE SUPPRESSOR SEPARATED. ROUND 31 IS A REPLAY
*** THE AFT SECTION SEPARATED LATE IN ROCKET FIRING

3.3 (Continued)

Basic heavyweight baffled cylinder suppressor peak noise reduction capability at the gunners position (gage A) is shown in Figure 3-7. These suppressors have rigid baffles, three chambers, 2.5 inch orifice diameters and are eight (8) and ten(10) inches inside diameter. The data for both suppressors show similar trends where recoil increases and peak noise reduction decreases with increasing chamber spacing. These data show that chamber spacing has a significant effect on launcher recoil. When compared to the unsuppressed baseline level (2.14 psid/177.5 db) the suppressors have a peak noise reduction capability of up to 1.7 psid/13.5 db. At minimum launcher recoil (≈3 lb-sec) the suppressor peak noise reduction capability is somewhat lower. The minimum recoil peak noise reduction capability for the eight (8) inch suppressor is 1.24 psid/7.5 db and the ten (10) inch suppressor is 1.54 psid/11.5 db.

The sound pressure level data at the nearby (gage B) and area (gage C) positions for the basic heavyweight suppressor are shown in Figures 3-8 and 3-9. The data shown for the nearby position (gage B) in Figure 3-8 indicate that the presence of the suppressor can cause local peak noise pressures to be higher than the baseline unsuppressed level. The data for the area position (gage C) shown in Figure 3-9 indicate that the pressure level is lower when the suppressors are installed.

The data shown in Figures 3-10 and 3-11 are the results of a series of tests made to determine the effect of increasing orifice diameter. The data for the eight (8) inch inside diameter suppressor with the three (3) inch baffle spacing indicate that a baffle orifice diameter of 3.5 inches would provide a peak noise reduction of .96 psid/5.3 db at near zero recoil. The same suppressor with a six (6) inch baffle spacing

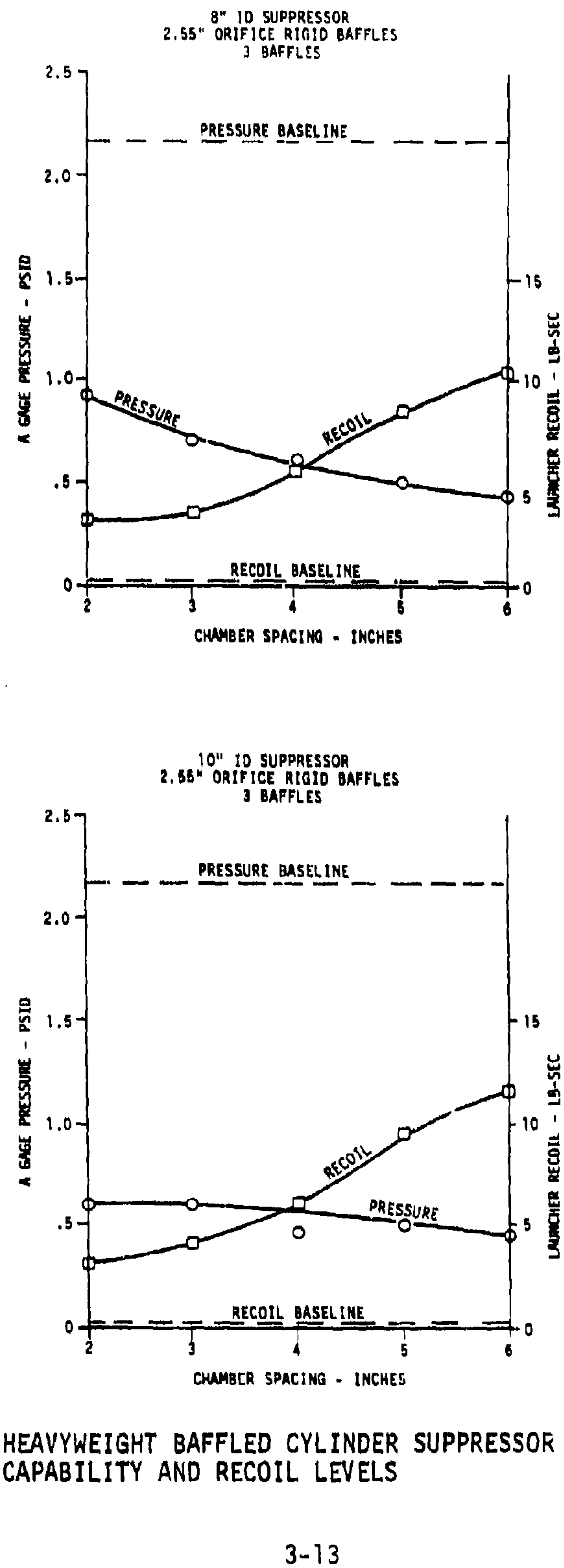
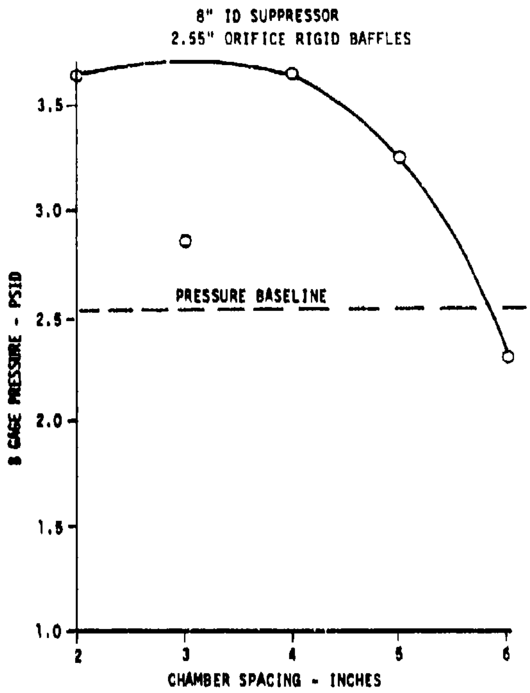


FIGURE 3-7 HEAVYWEIGHT BAFFLED CYLINDER SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY AND RECOIL LEVELS



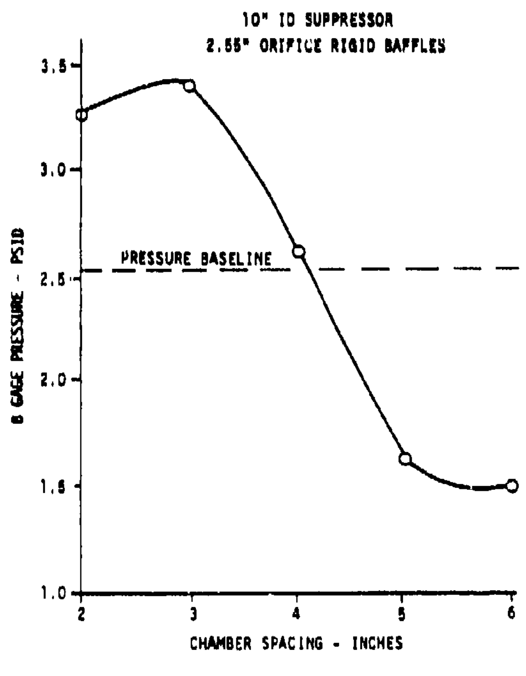
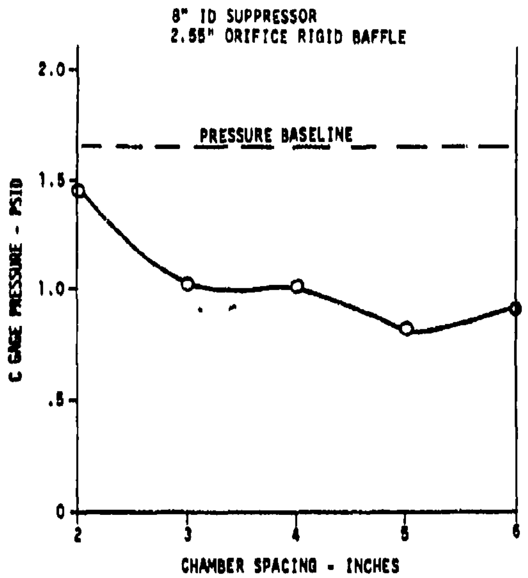


FIGURE 3-8 HEAVYWEIGHT BAFFLED CYLINDER SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY AT THE NEARBY POSITION (GAGE B)



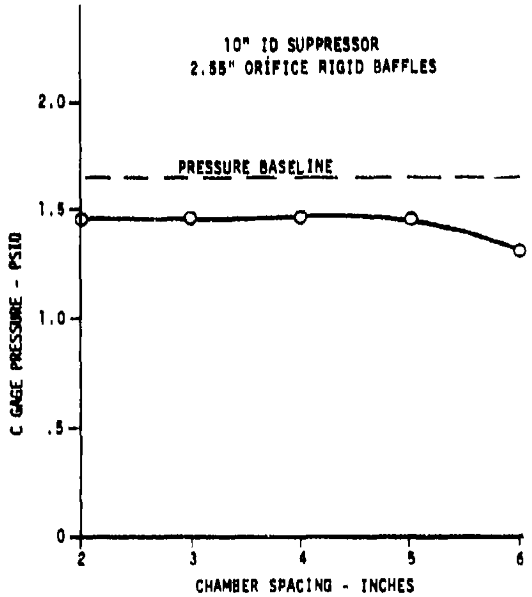


FIGURE 3-9 HEAVYWEIGHT BAFFLED CYLINDER SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY AT THE AREA POSITION (GAGE C)

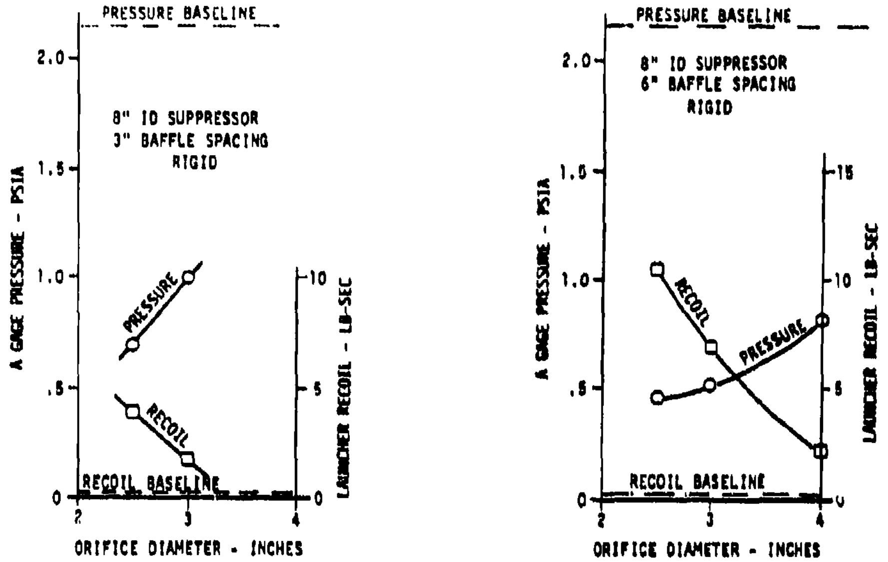


FIGURE 3-10 EIGHT INCH INSIDE DIAMETER HEAVYWEIGHT BAFFLED CYLINDER SUPPRESSOR PERFORMANCE WITH VARYING ORIFICE DIAMETER

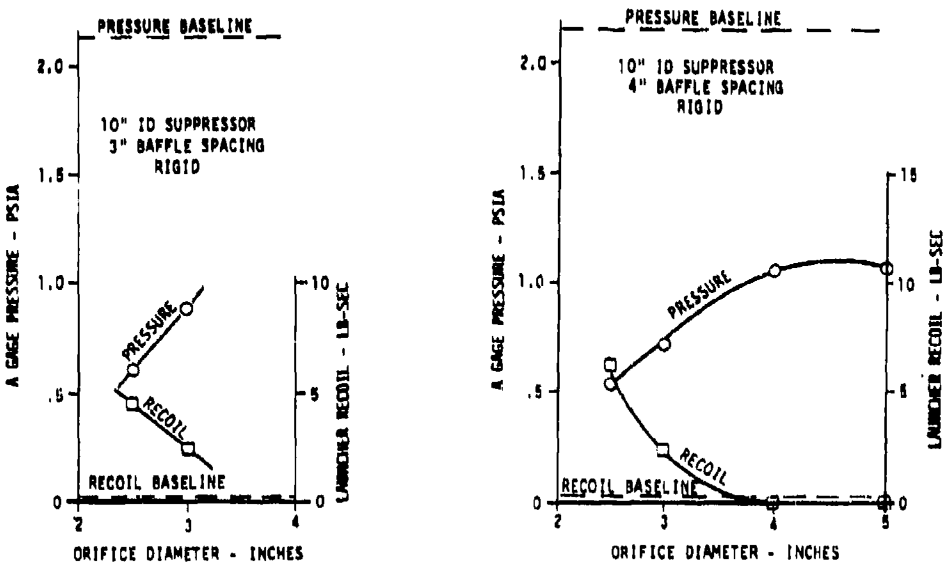


FIGURE 3-11 TEN INCH INSIDE DIAMETER HEAVYWEIGHT BAFFLED CYLINDER SUPPRESSOR PERFORMANCE WITH VARYING ORIFICE DIAMETER

3.3 (Continued)

would require a 4.5 inch baffle orifice diameter for near zero recoil. This configuration would produce a peak noise reduction of 1.11 psid/6.5 db.

The data for the ten (10) inch inside diameter suppressor given in Figure 3-11 show similar trends as the eight (8) inch suppressor except that the four (4) inch baffle spacing and four (4) inch orifice diameter configuration are shown to have a peak noise reduction capability of 1.09 psid/6.3 db with zero recoil.

Two of the heavyweight baffled cylinder suppressor configurations were selected for a series of tests to determine the effects of replacing the rigid baffles with flexible and yielding baffles. Test results for the ten (10) inch inside diameter suppressor with three (3) baffles at a four (4) inch spacing and with orifice diameters of 2.5 inches are shown for the rigid, flexible and yielding baffles in Figure 3-12. These data show that flexible baffles have little effect on peak noise reduction capability or the recoil level when compared to the rigid baffle configuration. In contrast the data also show that the use of yielding baffles maintains the peak noise reduction capability while reducing the recoil to zero.

Test results from the eight (8) inch inside diameter suppressor with three (3) baffles at six (6) inch spacing and with orifice diameters of 2.5 inches are shown for the rigid, flexible and yielding baffles in Figure 3-13. These data trends are similar to the ten (10) inch suppressor except that peak noise reduction capability is improved and recoil is reduced but is still high, by installing the flexible baffles. The yielding baffles maintain the rigid baffle peak noise reduction capability and reduces the launcher recoil to one (1) lb-sec.

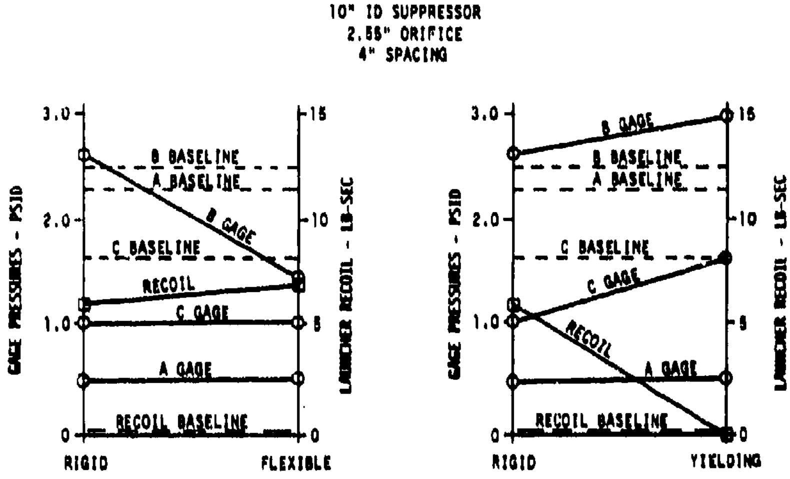


FIGURE 3-12 TEN INCH INSIDE DIAMETER BAFFLED CYLINDER SUPPRESSOR PERFORMANCE WITH FLEXIBLE AND YIELDING BAFFLES

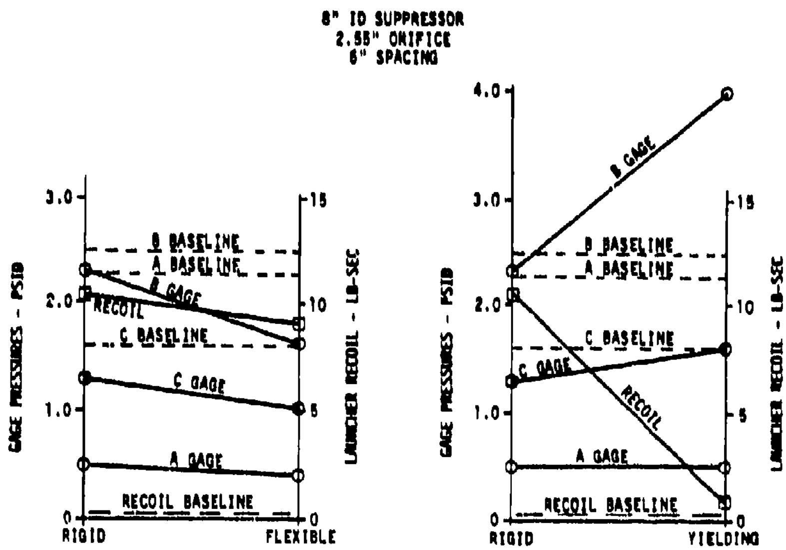


FIGURE 3-13 EIGHT INCH INSIDE DIAMETER BAFFLED CYLINDER SUPPRESSOR PERFORMANCE WITH FLEXIBLE AND YIELDING BAFFLES

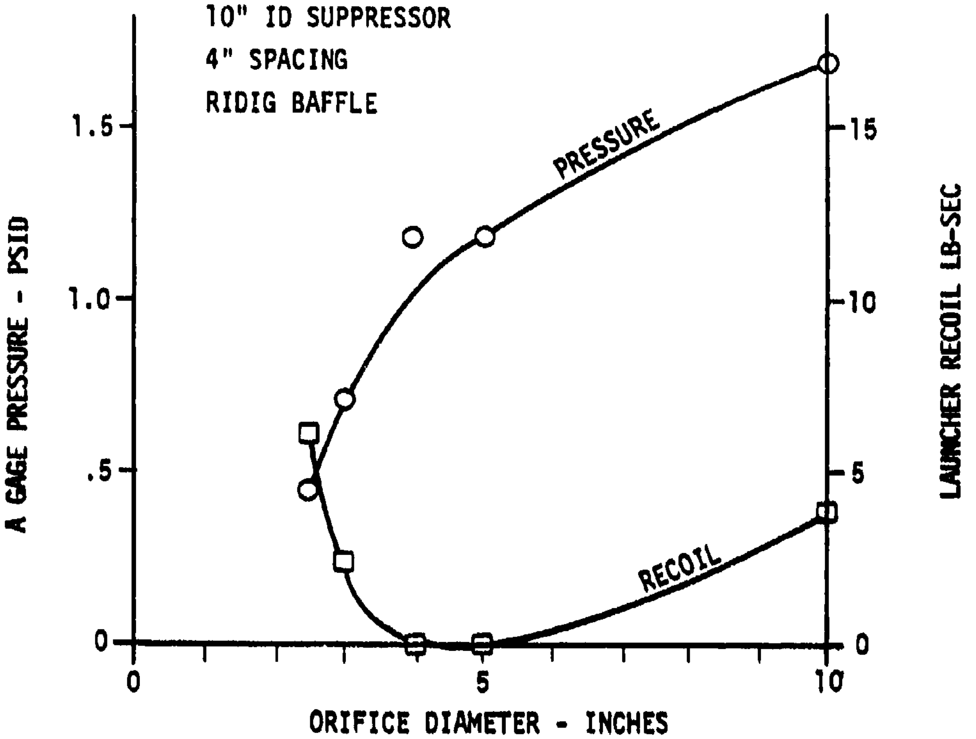
3.3 (Continued)

Extending the data for the eight (8) and ten (10) inch suppressor orifice diameter up to the open cylinder configuration illustrated the need for baffles to keep recoil impulse to a minimum. The data in Figure 3-14 show that the baffle orifice diameter of four (4) to five (5) inches is required for zero recoil in both the eight (8) and ten (10) inch suppressors. Using the zero recoil data from Figure 3-13, an extrapolation plot has been made to determine the optimum suppressor configuration with zero recoil. The optimization data shown in Figure 3-15 predict that a suppressor six (6) inches inside diameter with orifice diameter of six (6) inches will reduce the peak noise pressure level at the gunners position to .7 psid. The suppressor length would be predicted to be 24 inches.

The missile muzzle velocity measured during the testing of each heavyweight suppressor configuration is listed in Table 3-I. These data vary only within the round to round muzzle velocity expected for the M-72 weapon system. It has been concluded that the missile performance was unaffected by the presence of the heavyweight suppressors.

3.4 Heavyweight Suppressor Data Correlation with Explosion

The closest similarity between firing an M-72 weapon system and other experiments where data are plentyful is the firing of a gun. This similarity is very helpful, since we find sadowgraph pictures (Reference 4) to assist in visualizing the process. Figures 3-16, 3-17 and 3-18 are from Reference 4. In Figure 3-16 we observe that before the bullet leaves the gun barrel there are some gases leaving the barrel. These gases produce a weak but almost spherical shock, S_1. In Figure 3-17 we observe the strong blast wave, S_2, near the muzzle, generated after the bullet has left the barrel. It is important to notice that within a short distance of the muzzle, the blast wave S_2 is not to be considered as a spherical shock. However, as the blast



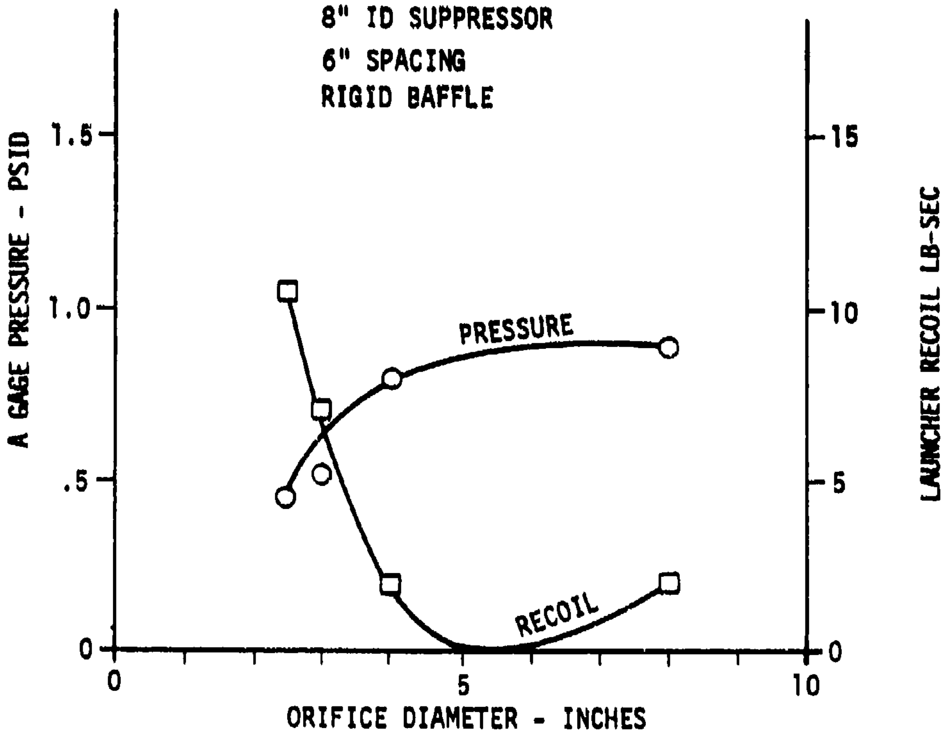


FIGURE 3-14 HEAVYWEIGHT SUPPRESSOR PEAK NOISE SUPPRESSION CAPABILITY WITH VARYING ORIFICE DIAMETERS

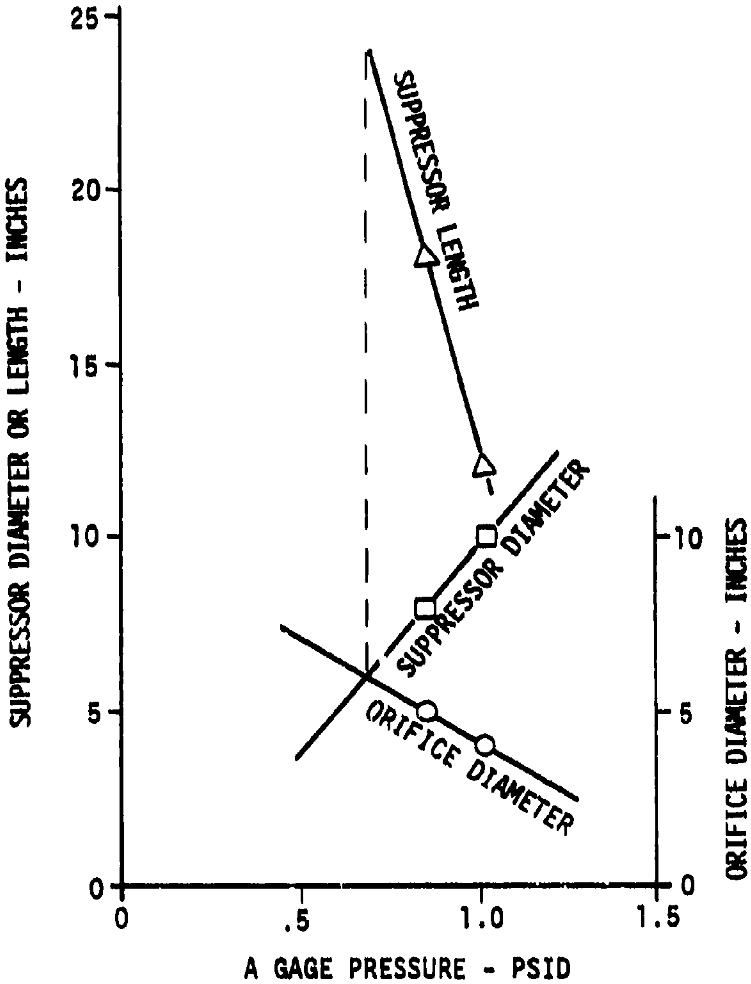


FIGURE 3-15 HEAVYWEIGHT SUPPRESSOR OPTIMUM CONFIGURATION WITH ZERO RECOIL

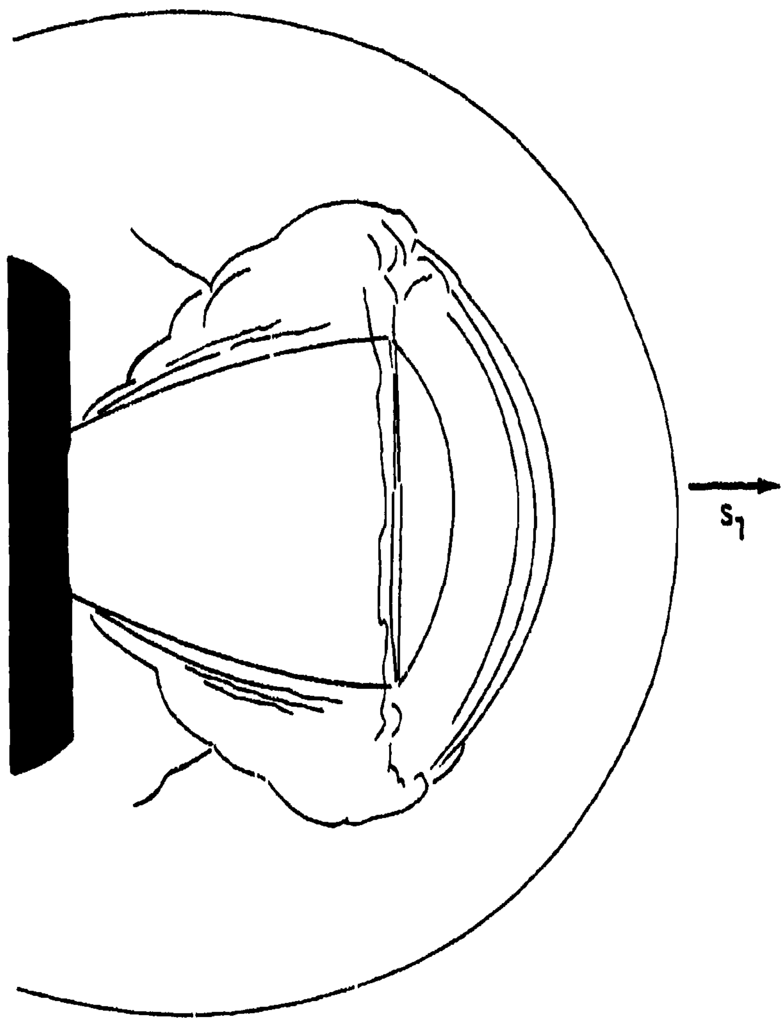


FIGURE 3-16 SHOCK WAVES PRODUCED 75 MICROSECONDS AFTER FIRING A .30 CALIBER BULLET (FROM REFERENCE 4)

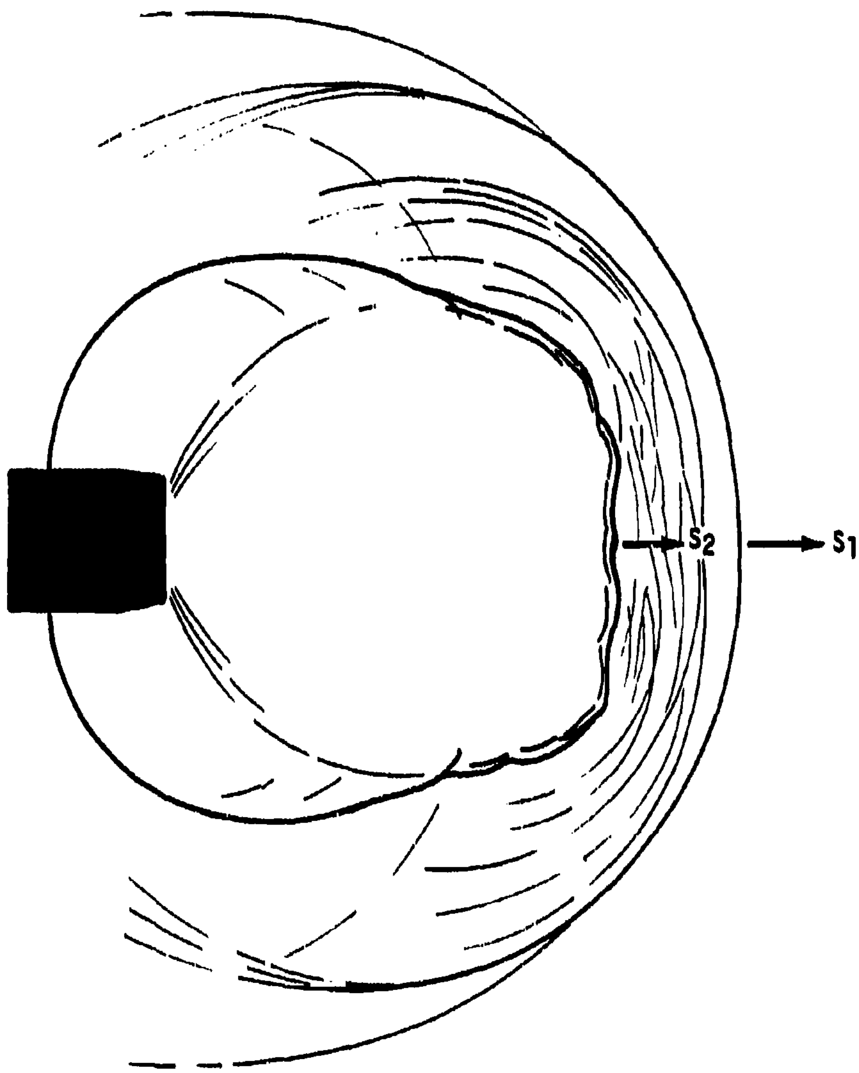


FIGURE 3-17 SHOCK WAVES PRODUCED 250 MICROSECONDS AFTER FIRING A .30 CALIBER BULLET (FROM REFERENCE 4)

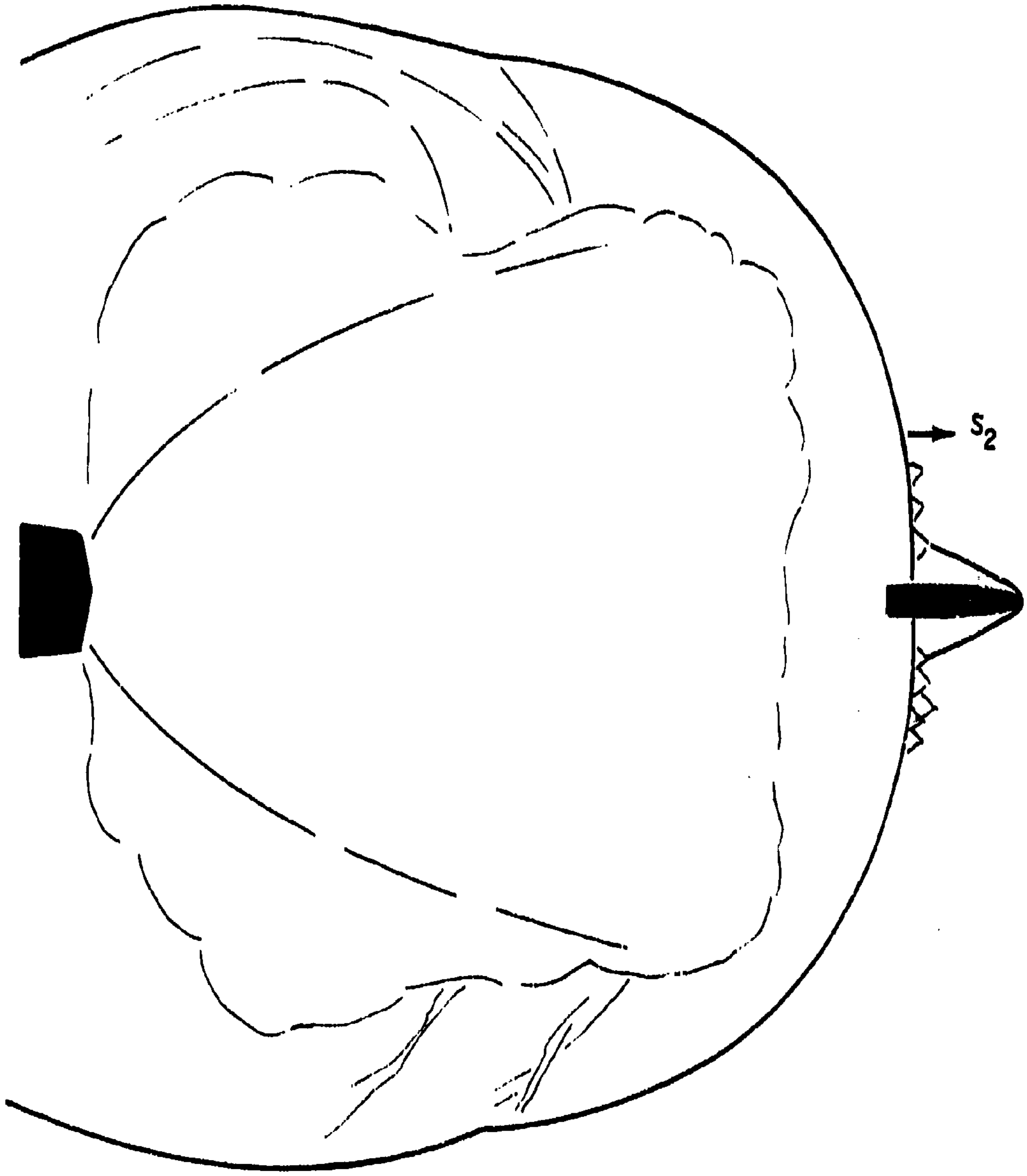


FIGURE 3-18 SHOCK WAVES PRODUCED 400 MICROSECONDS AFTER FIRING A .30 CALIBER BULLET (FROM REFERENCE 4)

3.4 (Continued)

front S_2 expands it approaches a spherical blast wave which overtakes the weaker shock S_1 as shown in Figure 3-18. The shock front produced by the firing of the M-72 rocket motor has been assumed to be similar to S_2 in Figure 3-18 and has been assumed to be spherical at the noise pressure level instrumentation locations shown in Figure 2-4.

The parameters such as total energy of detonation E_0, ambient static pressure p_1, and ambient density ρ_1 from spherical blast wave theory are all necessary to associate the peak noise produced by the firing of the M-72 weapon system with explosion theory. The following is the method used to derive the equation for calculating the total energy of detonation E_0. The nomenclature used in the derivation given in the following list.

a_1	Speed of sound in undisturbed flow
A_0	Reference area
$A(x)$	Area of duct function of distance x
E_0	Total energy released
J	Energy flux
M_0	Reference Mach number
$M(x)$	Mach number in the duct, function of distance x
P	Acoustic pressure
p_1	Ambient static pressure
$p(x)$	Ambient static pressure in the duct, function of distance x
p_0	Stagnation pressure
r	Radius, distance
$\overline{R}$	Nondimensionalized distance (characteristic distance)
t	time

3.4 (Continued)

T	Time intervals
u	Velocity
ε	Energy density
γ	Specific heat ratio
ρ_1	Ambient density
τ	Nondimensional time (characteristic time)

A characteristic length and a characteristic time can be defined. Note that τ can be written as

$$\tau = \frac{t}{t_0}$$

where

$$t_0 = E_0^{1/5} \rho_1^{1/2}/p_1^{5/6}$$

is a characteristic time.

Using this time in the nondimensional distance $\bar{R}$ gives

$$\bar{R} = \frac{r}{r_0}$$

where

$$r_0 = (E_0/p_1)^{1/3}$$

is a characteristic distance. Notice that r_0 and t_0 can be determined only after E_0 has been determined, assuming that the ambient conditions (p_1 , ρ_1) are known.

3.4 (Continued)

The energy release, E_o, associated with the expulsion of the nozzle closure can be estimated from the noise overpressure versus time trace by using an acoustic approximation. The energy density in an acoustic field is given by

$$\varepsilon = \frac{1}{2}\rho_1 \left[u^2 + \frac{p^2}{\rho_1^2 a_1^2} \right]$$

where ρ_1 and a_1 are undisturbed values of the density and sound speed, p is the acoustic pressure, and u is the particle velocity. Assuming spherical symmetry, the total energy in the acoustic field is

$$E_o = 4\pi \int_0^R \varepsilon(r)\, r^2\, dr$$

where R is the location of the initial wavefront. Furthermore, it may be assumed that the pressure and particle velocity are in phase and are related by, $\rho_1 a_1$, characteristic impedance of the medium -- $u = p/\rho_1 a_1$.

Thus

$$\varepsilon = \frac{p^2}{\rho_1 a_1^2}$$

and

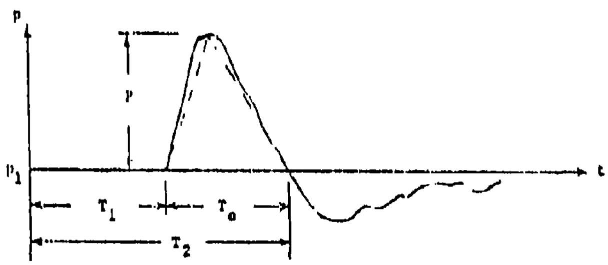
$$E_o = 4\pi \int_0^R \frac{p^2}{\rho_1 a_1^2}\, r^2\, dr$$

3.4 (Continued)

This integral can be changed to an integration over time at a fixed radial location R_0 by assuming that the wavefront is moving at the speed of sound, $dR = a_1\, dt$. Then

$$E_0 = 4\pi R_0^{\,2} \int_{T_1}^{T_2} \frac{p^2}{\rho_1 a_1}\, dt$$

Only the contribution of the initial pressure pulse was used to estimate the energy release and this was approximated by a triangular wave form as illustrated below.



Then

$$J = \int_{T_1}^{T_2} \frac{p^2}{\rho_1 a_1}\, dt \approx \frac{p^2 T_e}{3_1 a_1}$$

and

$$E_0 = 4\pi\, R_0^{\,2} J$$

3.4 (Continued)

This use of only the initial positive waveform obviously underestimates the energy flux since there is considerable energy contained in the field after the first zero crossing. However, the evaluation of this contribution would require numerical integration with a decision as to when to terminate the integral. This integral may contain a contribution from reflected waves.

The equations derived above have been used to calculate the energy of the blast E_o and the nondimensional distance $\overline{R}$ at gages A, B and C. Table 3-II shows these parameters with the corresponding peak noise pressure level for each heavyweight suppressor configuration given in Table 3-I. The concern is mainly for the protection of the gunner, that is the sound level at the location of gage A. Therefore, the conclusions are drawn based on the observations at gage A. As mentioned earlier, the spherical wave assumption does not fit the shock front at the gage A. This is also shown in the computed energy at A by this same method. The difference between E_{A_o} and E_{B_o} and E_{C_o} given in Table 3-II is one order of magnitude.

Correlation of the peak pressure with the characteristic (dimensionless) distance

$$\overline{R} = \frac{r}{r_o} = \frac{r\, p_1^{\,1/3}}{E_o^{\,1/3}}$$

was attempted. Figure 3-19 shows the noise level measured at each microphone, A, B and C, plotted against the dimensionless distance, $\overline{R}$. On Figure 3-19 all configurations of the 10" cylindrical suppressor are shown. Also shown is the correlation for spherically symmetric explosion data taken from Chapter 6 of "Explosions in Air," Reference 5. It is surprising to see the good agreement for the plotted values at gage A, while the sound pressure level at B and C seem to be usually higher

TABLE 3-II ENERGY LEVEL AT THE SOUND PRESSURE LEVEL GAGE POSITION

ROUND #	Eo_A	db_A	$\overline{R}_A$	Eo_B	db_B	$\overline{R}_B$	Eo_C	db_C	$\overline{R}_C$
1	250.12	177.19	2.36	7124.29	179.38	3.10	9299.02	175.56	5.67
2	240.50	177.19	2.40	3207.34	176.23	4.04	9299.02	175.56	5.67
3	188.83	176.51	2.60	6134.46	179.05	3.25	8154.11	174.61	5.92
4	253.39	177.60	2.35	5190.70	179.05	3.44	8876.40	175.36	5.75
5	413.46	179.38	2.00	3716.42	177.60	3.85	6282.45	174.27	6.46
6	358.33	178.13	2.10	5671.65	178.71	3.34	7694.18	175.15	6.04
8	9.23	164.00	7.10	4779.29	178.50	3.54	5013.67	173.29	6.96
9	12.72	165.40	6.38	9273.24	181.01	2.84	5472.71	173.67	6.76
10	19.66	166.87	5.52	7435.52	181.73	3.05	5789.90	173.92	6.64
11	11.08	164.00	6.68	2931.14	177.44	4.16	2487.85	169.83	8.79
12	3.27	164.73	10.03	5032.21	178.91	3.48	2271.62	169.44	9.06
13	11.54	164.00	6.59	6420.85	179.25	3.21	3071.42	170.75	8.20
14	27.79	167.65	4.92	3166.35	175.86	4.06	4132.90	172.04	7.42
15	64.58	172.04	3.71	2487.85	175.86	4.40	6547.03	174.04	6.37
16	88.06	172.04	3.35	5169.75	177.98	3.45	7148.03	174.83	6.19
17	19.08	165.40	5.57	1570.61	174.27	5.13	3322.04	171.09	7.99
18	17.45	164.73	5.74	2113.41	175.56	4.64	3137.31	171.26	8.14
19	27.92	168.81	4.91	2919.77	176.55	4.17	4648.00	173.42	7.14
20	7.68	162.79	7.55	1821.04	174.50	4.88	3137.31	171.26	8.14
21	23.52	167.65	5.20	6280.74	179.88	3.23	3991.61	171.89	7.51
22	10.99	166.31	6.70	10893.76	181.38	2.69	2652.59	170.75	8.61
23	10.91	164.73	6.72	9780.41	182.92	2.79	6621.98	174.50	6.35
24	20.72	164.73	5.42	7950.84	180.18	2.98	7694.18	175.15	6.04
25	23.09	169.24	5.23	12721.95	183.81	2.55	7148.03	174.83	6.19
26	113.48	175.36	3.08	10740.44	182.21	2.70	5951.85	174.04	6.57
27	14.14	166.31	6.16	9273.24	181.01	2.84	6282.45	174.27	6.46
28	28.27	169.83	4.89	8356.77	181.53	2.94	5472.71	173.67	6.76
29	30.65	169.44	4.76	10466.55	183.21	2.72	5680.89	173.42	6.68
30	39.27	170.75	4.38	11760.74	181.88	2.62	4432.89	172.76	7.25
31	51.03	171.89	4.02	11760.74	181.88	2.62	4432.89	172.76	7.25
32	42.41	169.83	4.27	9499.06	181.88	2.81	8463.60	175.15	5.85

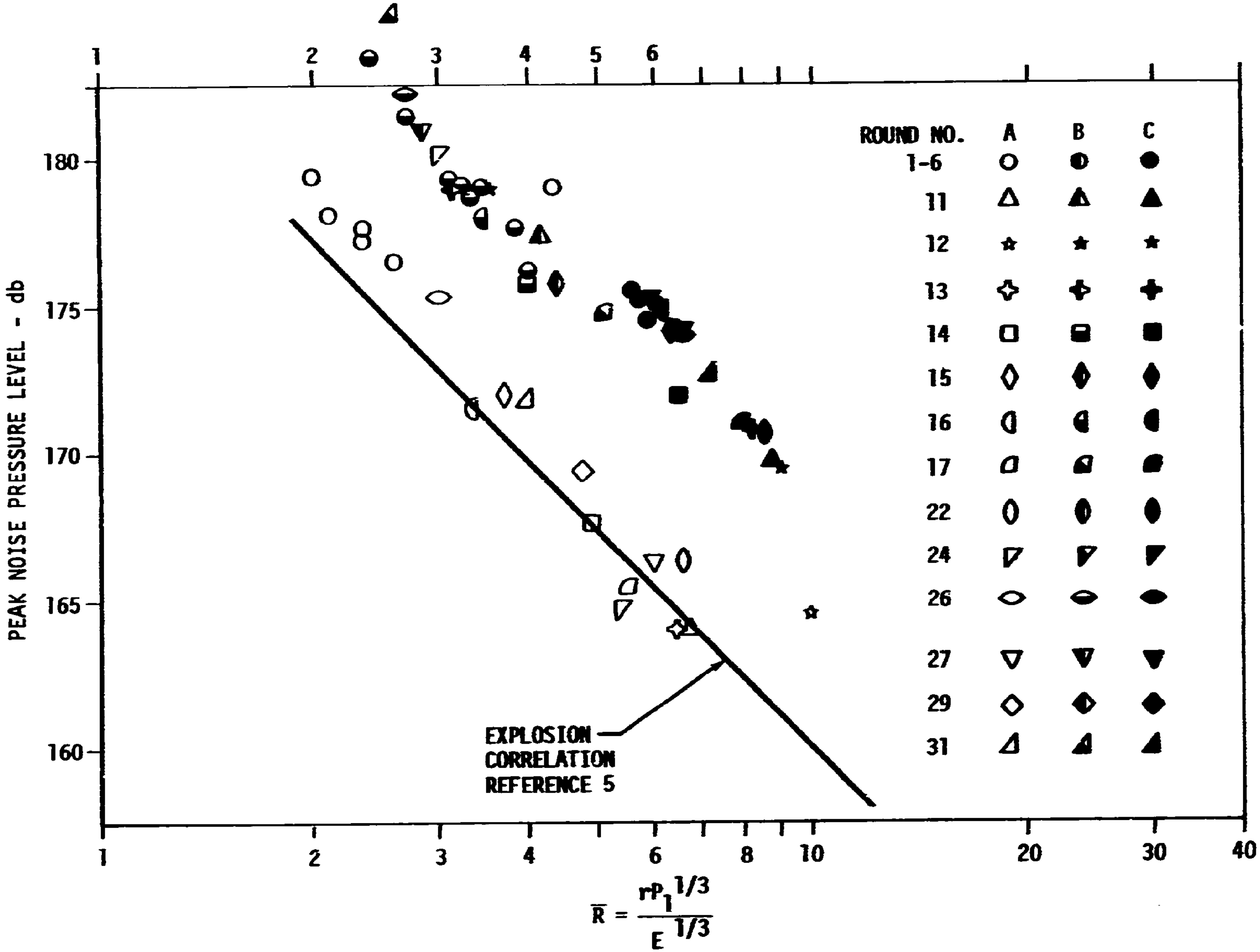


FIGURE 3-19 NOISE LEVEL MEASURED AT GAGE A, B, AND C WITH 10 INCH INSIDE DIAMETER SUPPRESSORS

3.4 (Continued)

than A measurements. The values measured at B and C show higher levels of sound energy. These lie on a line parallel to the explosion correlation but almost 5 db higher. This discrepancy was explained in the first part of Reference 1. It was discussed that the discrepancy may be due to underestimation of the energy released. A second possible source for this could be the lack of symmetry of the sound field produced by the blast. In the above evaluation of $\bar{R}$, the energy E_o at each point was used compared to using E_o from gage C (E_{o_C}).

It is believed that if we do use the E_{o_A} to calculate $\bar{R}_A$ it will be a reasonable approach. This is the case since, as discussed earlier, due to geometrical location of A with respect to the nozzle outlet, one spherical shock cannot define the phenomena at A, and B and C. This was concluded from the differences in energy calculated using the peak pressures measured at these points. Therefore, effectively, we are assuming that the shock at A is much weaker than the shock at B and C.

Therefore, due to the close agreement of the shock parameters at A and the spherical explosion correlation, the scaling problem is reduced to relating the energy level at A, i.e., E_{o_A} , to E_{o_B} or E_{o_C} . Figures 3-20 and 3-21 show plots of E_{o_B} and E_{o_C} against the sound pressure level, dbA, at gage A.

In Figures 3-20 and 3-21, selected data points, or data corresponding to the most effective sound suppressor, are plotted. The baseline data are also shown for comparison. The most effective configuration is selected based on the peak noise level at A, which corresponds to the gunner position.

3.4 (Continued)

The 10" cylindrical sound suppressor is very effective. The baffle spacing for this configuration is rather important. The baffle spacing used in rounds 11, 12 and 13 (6", 5" and 4" spacing) produce good suppression. Round 17 with flexible baffles at a 7" spacing is also an effective suppressor. For the 8" cylindrical suppressor, designs of rounds 18 and 20 are very effective.

The presence of baffles is necessary for the sound suppressor effectiveness. The physical mechanism of the shock motion through baffles was studied in Reference 1.

For the suppressed flow field, variations in E_{o_B} and E_{o_C} do not produce much change in the noise level at A; see Figures 3-20 and 3-21 Only the geometry of sound suppressor makes the difference of a few decibels. The average reduction in the noise level from Figure 3-20 and Figure 3-21 seem to be nearly 12 db. The final selection of the best geometry for the suppressor should be made with the recoil level consideration in mind.

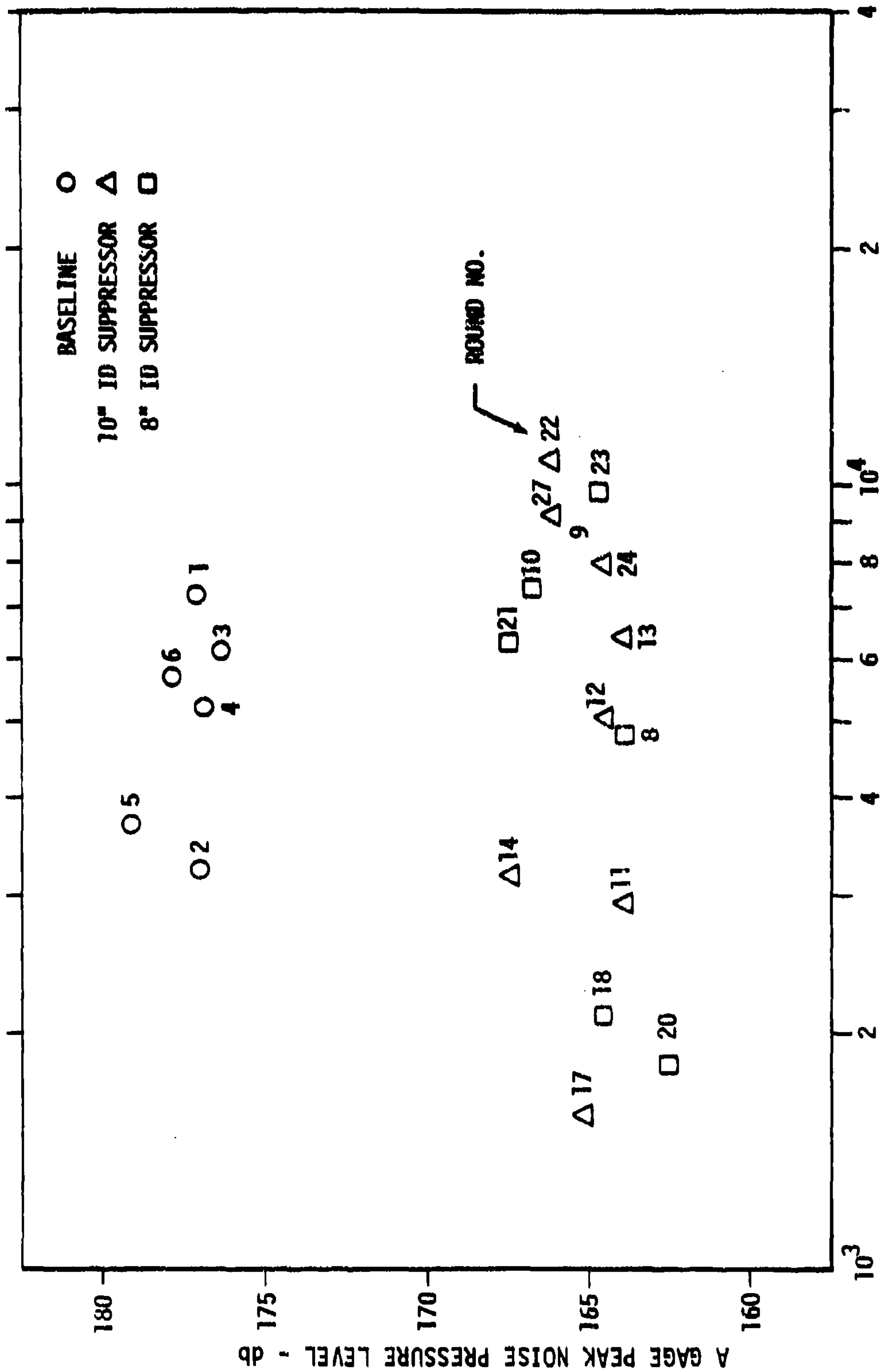


FIGURE 3-20 DEPENDENCE OF THE SOUND LEVEL AT GAGE A BASED ON THE ESTIMATED ENERGY AT GAGE B

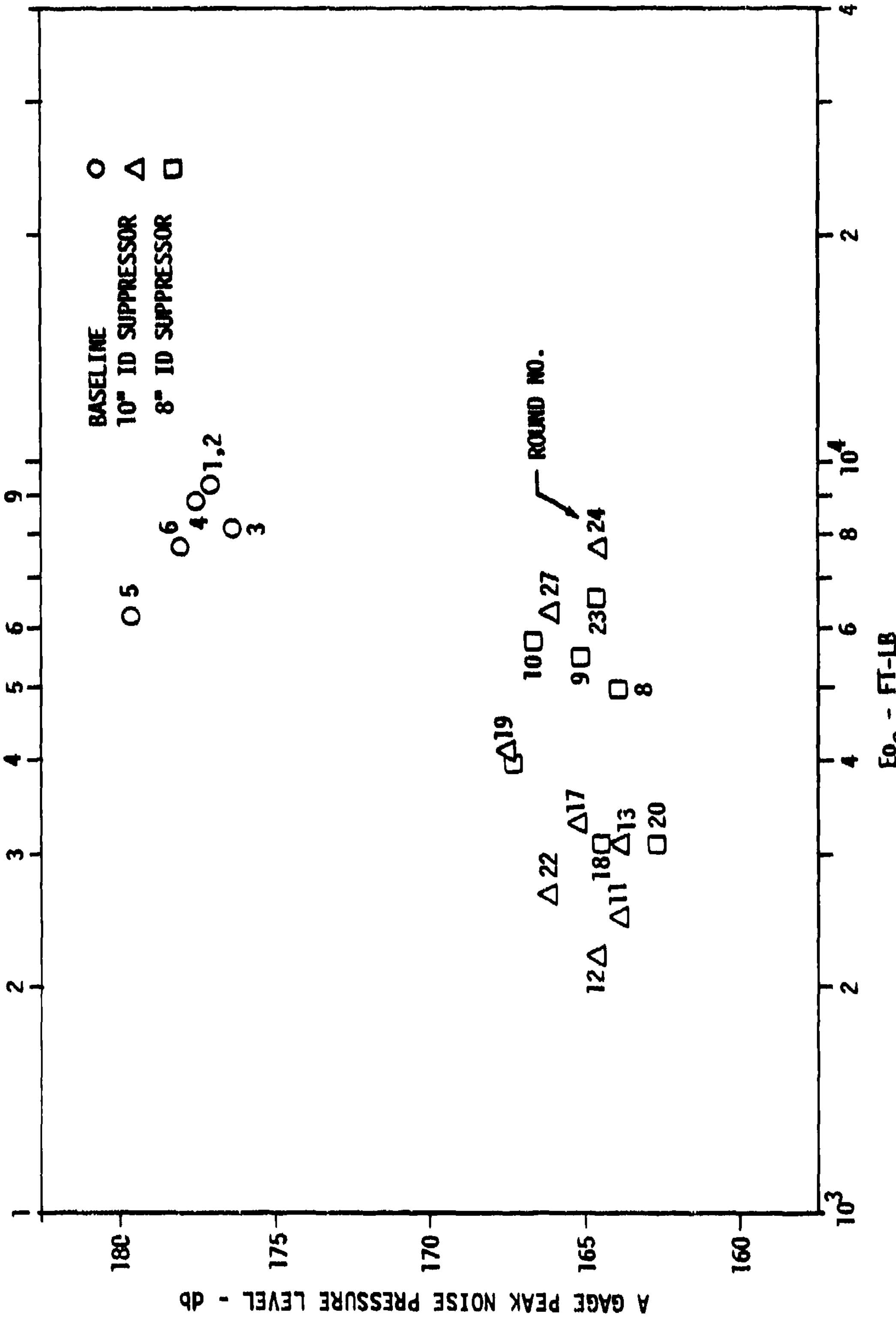


FIGURE 3-21 DEPENDENCE OF SOUND LEVEL AT GAGE A BASED ON ESTIMATED ENERGY AT GAGE C

Blank

4.0 ADVANCED SUPPRESSOR DESIGN AND EVALUATION

To extend the peak noise reduction program to include suppressor configurations other than baffled cylinders, several advanced suppressor designs were developed and tested. The advanced designs were based on the results of the heavyweight suppressor tests, Paragraph 3.0, and the results of the research reported in Reference 3. The advanced suppressors selected for design and test were the fabric bag suppressor, the fabric cylinder suppressor, the metal cylinder suppressor, the shielded cone/cylinder suppressor and a modified baffled cylinder suppressor that had a conical expansion forward chamber. The design of the suppressors was compatible with the test fixtures and instrumentation described in Paragraph 2.0 and with the test procedure in Paragraph 3.2.

The following paragraphs will discuss the design, test and performance analysis of the advanced suppressors. It will be shown that the total containment fabric bag suppressor and both the fabric and aluminum cylinder suppressors are effective lightweight peak noise suppressors. These suppressors reduced the peak noise overpressure at the gunners position by up to 75% with recoil levels varying from zero to 6.19 lb-sec. The performance data were lost on the shielded cone suppressor due to a structural failure in the fabrication welds during the test. The performance of the cone/cylinder suppressors are in general lower than the baffled cylinder suppressors and have internal pressure peaks as high as 215 psig. The best overall performance was obtained with an eight inch inside diameter cone/cylinder. This suppressor produced a 69% peak noise overpressure reduction at a launcher recoil level of 2.03 lb-sec. Internal pressure level in this suppressor was 150 psig, making it a poor candidate for a fieldweight suppressor configuration.

4.1 Advanced Suppressor Design

Based on the results and analysis given in Paragraph 3.3, Reference 1 and Reference 3, several advanced suppressor design concepts were developed for evaluation. The suppressor designs selected had two objectives. The first objective was to explore configurations other than the baffled cylinder and the second was to improve the performance of the baffled cylinder suppressor. Each of the advanced suppressor designs will be described in the following paragraphs.

4.1.1 Open Cylinder Suppressors

Test analysis results presented in Paragraph 3.3 were used to size the open cylinder suppressors. These data indicated that the configuration for minimum recoil and maximum peak noise suppression capabilities would be an open cylinder of six (6) inches inside diameter and twenty-four (24) inches long. Two materials, aluminum and a state-of-the-art Kevlar fabric, were selected for use in fabricating the open cylinder suppressors. The aluminum open cylinder suppressor is shown in Figure 4-1. As can be seen in Figure 4-1 the aluminum open cylinder suppressor is a cylinder and a forward end plate that can be attached directly to the reusable launch tube with the threaded connection. A detailed drawing of the aluminum cylinder suppressor is included in the Appendix.

Lined and unlined Kevlar fabric suppressors were selected as advanced suppressor configurations based on the results of testing fabric and acoustic foams reported in Reference 3. The unlined Kevlar fabric open cylinder suppressor is shown in Figure 4-2. The Kevlar fabric was sewn into a cylinder six (6) inches in diameter and thirty (30) inches long with a single side seam and the forward end was pleated to allow attachment to the reusable launch tube. A six (6) inch overlap was allowed in the length for this attachment. The lined Kevlar fabric open cylinder suppressor was designed with a liner of mylar film adhesive bonded to an acoustic foam that was adhesive bonded to the Kevlar fabric. This lined suppressor is shown in Figure 4-3.

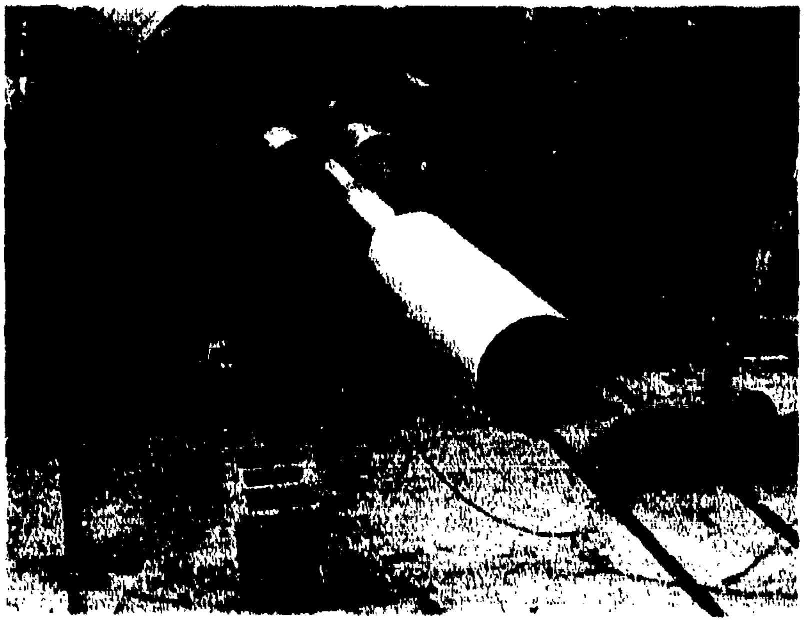


FIGURE 4-1 ALUMINUM OPEN CYLINDER SUPPRESSOR

FIGURE 4-2 KEVLAR FABRIC OPEN CYLINDER SUPPRESSOR

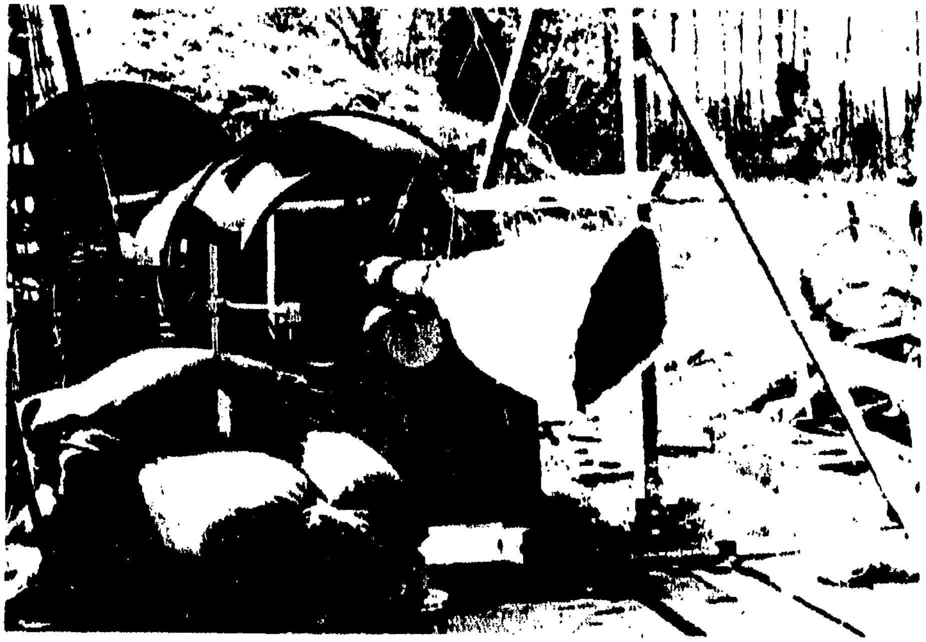


FIGURE 4-3 LINED KEVLAR OPEN CYLINDER SUPPRESSOR

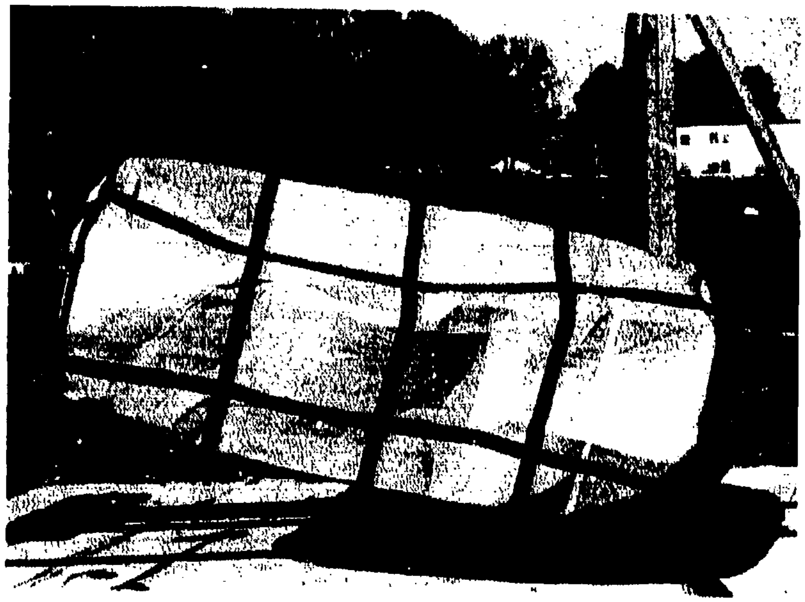
4.1.1 (Continued)

The lined Kevlar fabric was sewn into a cylinder six (6) inches in diameter and thirty (30) inches long with a single side seam and the forward end was pleated to allow attachment to the reusable launch tube. A six (6) inch overlap was allowed for this attachment. All seams made in the Kevlar used a 1800 denier Kevlar thread. A pattern for the Kevlar fabric open cylinder suppressor has been included in the Appendix.

4.1.2 Total Containment Bag Suppressors

The total containment bag suppressor concept was first reported in Reference 3. The data presented indicated that a bag with enough volume to contain, at a reasonable pressure, all the gas produced by the firing of a rocket motor could suppress the noise, smoke and flash normally associated with the motor firing. A bag suppressor of this type was sized to contain the M-72 rocket motor gas at 30 psia. To contain the exhaust gas at this pressure required 8.7 cubic feet of volume. This volume could be obtained with a bag twenty (20) inches in diameter and 48 inches long. Several fabrics were considered for fabricating the bag suppressor. The mylar film and acoustical foam used for the Kevlar fabric open cylinder suppressor liner was also considered for the bag suppressor. The two fabrics selected for fabrication of the bag suppressors were Nylon and Kevlar. Nylon fabric was selected for its strength and elongation properties. Kevlar fabric was selected because of its high strength to weight property. The web reinforced Nylon bag suppressor with the acoustic liner is shown in Figure 4-4. The one (1) inch nylon reinforcing web was sewn to the fabric prior to installation of the acoustic foam liner. Two nylon total containment bag suppressors were fabricated and both had the acoustic foam liner.

The Kevlar total containment bag suppressors are shown in Figure 4-5 and 4-6. The unlined configuration is shown in Figure 4-5 and the acoustic foam lined configuration is shown in Figure 4-6. The attachment webs for these suppressors are one (1) inch nylon webs. For these developmental tests the bags are shown



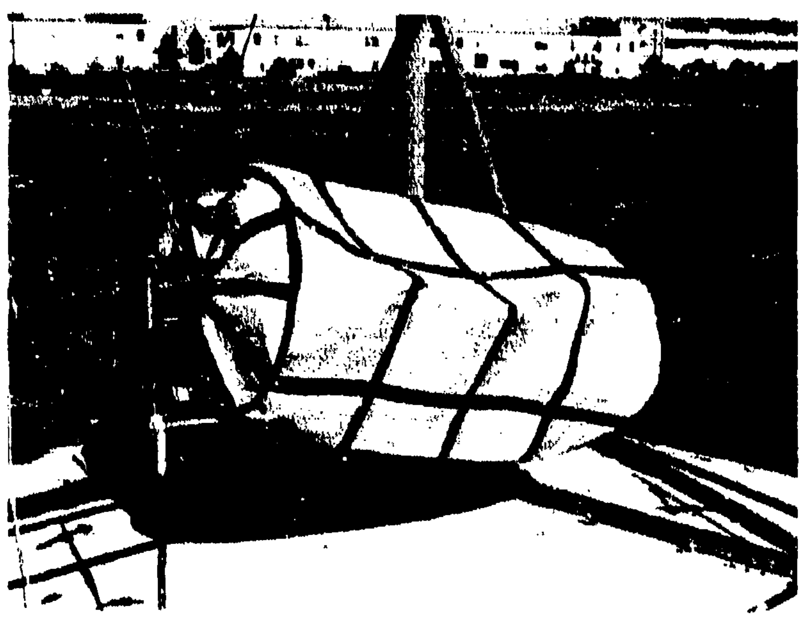


FIGURE 4-4 NYLON TOTAL CONTAINMENT BAG SUPPRESSOR WITH ACOUSTIC LINER

FIGURE 4-5 KEVLAR FABRIC TOTAL CONTAINMENT BAG SUPPRESSOR

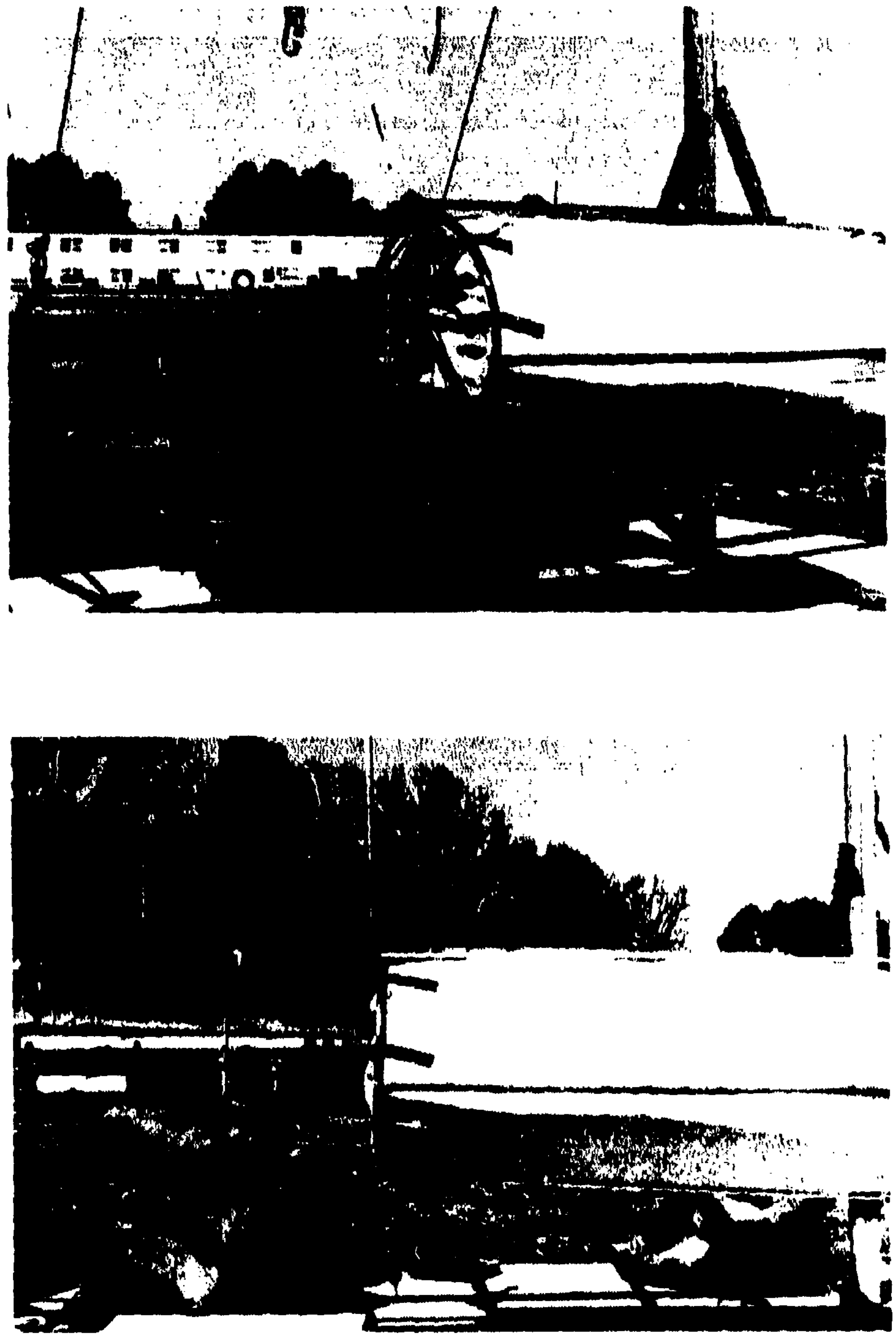


FIGURE 4-6 KEVLAR FABRIC TOTAL CONTAINMENT BAG SUPPRESSOR WITH ACOUSTIC LINER

4.1.2 (Continued)

attached to an aluminum frame that was used to maintain the cylindrical shape of the bag just prior to firing.

The pattern used for fabricating the Kevlar total containment bag is included in the Appendix.

4.1.3 Cone/Cylinder Suppressors

Results of the analyses reported in Reference 1 indicated that the baffled cylinder suppressor could be improved by the addition of a divergent chamber in the forward end of the suppressor. Conical divergent sections were designed for both the eight (8) and ten (10) inch inside diameter baffled cylinder suppressors described in Paragraph 3.1. These divergent sections are shown attached to their respective baffled cylinders which make up the cone/cylinder suppressors in Figure 4-7. Each of the divergent sections were designed so that baffles could be installed in the conical section. The divergent sections were also designed for use without the cylinder sections. A typical configuration of a baffled cone suppressor is shown in Figure 4-8. Detailed drawings of the conical divergent sections for the cone/cylinder suppressors are included in the Appendix.

The analyses presented in Reference 1 were used to design an improved performance cone/cylinder suppressor. The performance improvement was expected from a change in the design that would separate the motor exhaust gasses into two concentric flow passages. The inside flow passage has a configuration similar to the cone/cylinder described in Paragraph 4.1.2 with baffles in the cylindrical section. The outside flow passage has some minor baffling but the primary function of this passage is to

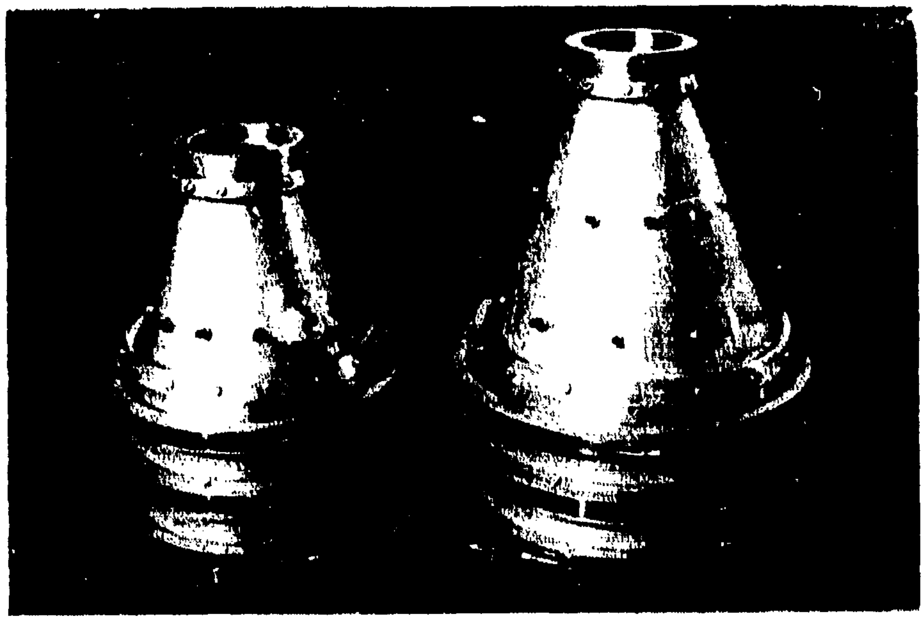


FIGURE 4-7 CONE/CYLINDER SUPPRESSOR

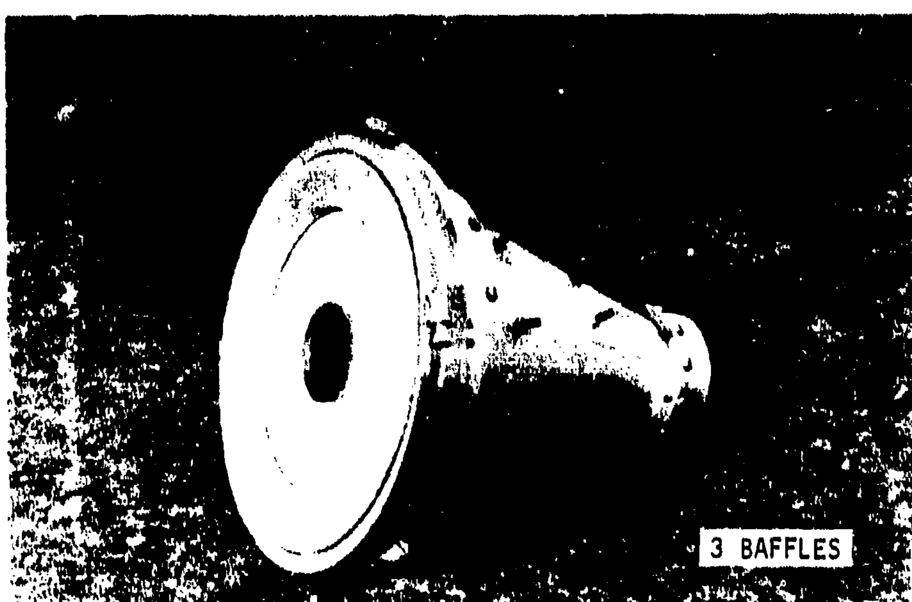


FIGURE 4-8 BAFFLED CONE SUPPRESSOR

4.1.3 (Continued)

provide a shield around the inside or core flow. An installed side and aft end view of the shielded cone/cylinder suppressor is shown in Figure 4-9. A detailed drawing of this suppressor configuration is included in the Appendix.

4.2 ADVANCED SUPPRESSOR TEST

Each of the advanced suppressor configurations described in Paragraph 4.1 were tested attached to the reusable launch tube mounted in the pendulum type test fixture described in Paragraph 2.0. The test procedures and instrumentation used during the Heavyweight Suppressor Test (Paragraph 3.2) were essentially repeated for these Advanced Suppressor Tests. The fabric suppressors were attached to the reusable launch tube with several band clamps rather than the threaded connection used for the aluminum suppressors. This band clamp connection is shown in use with the Kevlar Fabric Total Containment Bag Suppressor in Figure 4-5.

In addition to the instrumentation listed in Paragraph 2.0, high speed movies were taken during the tests of the Kevlar fabric suppressors. No movie data were obtained for the Nylon Total Containment Bag Suppressor. A photograph of a typical camera setup is shown in Figure 4-10.

4.3 ADVANCED SUPPRESSOR DATA ANALYSES

The data recorded during testing of the advanced suppressors were processed and analyzed in the same manner described for the heavyweight suppressors in Paragraph 3.3. The processed data from the test are given in Tables 4-I, 4-II and 4-III. Table 4-I contains the results of the open cylinder

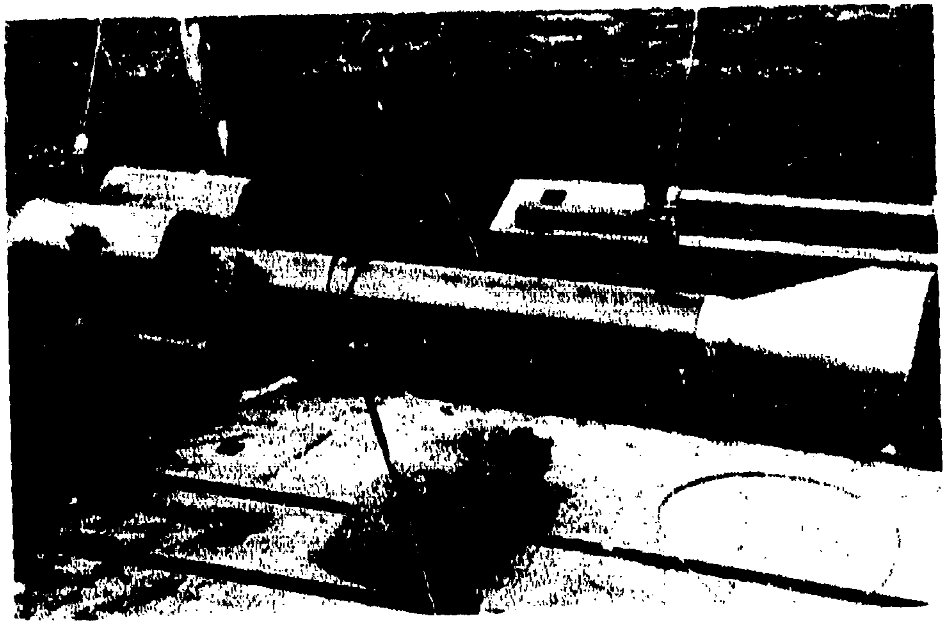


FIGURE 4-9   SHIELDED CONE/CYLINDER SUPPRESSOR

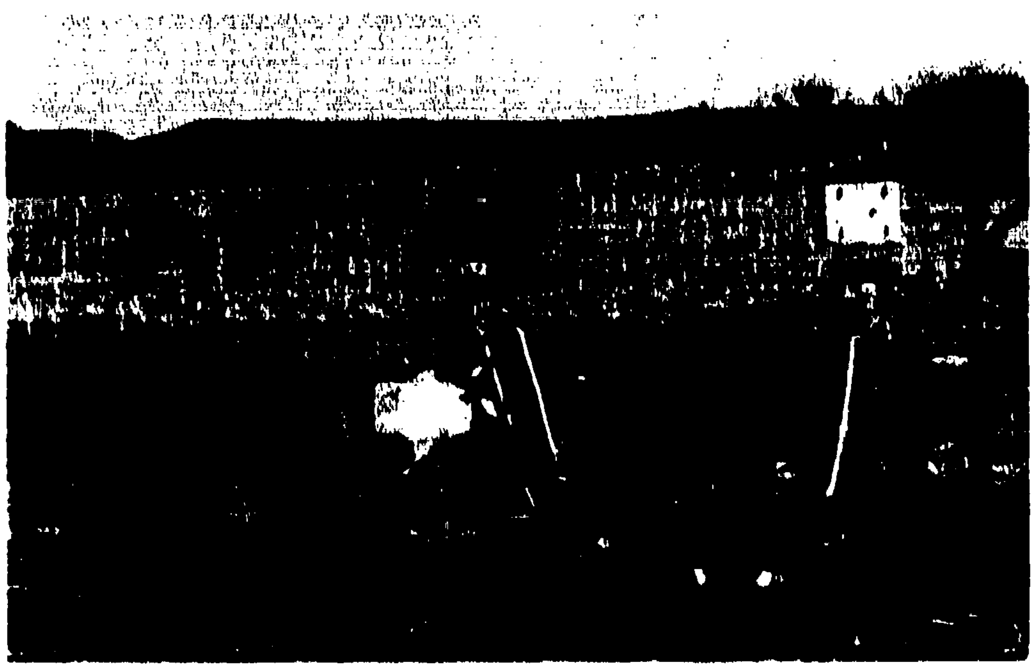


FIGURE 4-10   HIGH SPEED CAMERA INSTRUMENTATION

TABLE 4-I OPEN CYLINDER SUPPRESSOR TEST TABULATED DATA

ROUND #	OPEN CYLINDER SUPPRESSOR CONFIGURATION	GAGE POSITION PEAK NOISE PRESSURE LEVEL A		B		C		MISSILE MUZZLE VELOCITY FT/SEC (434.9)*	LAUNCHER RECOIL IMPULSE LB-SEC (.105)*
		db (177.5)*	PSID (2.14)*	db (178.8)*	PSID (2.53)*	db (175.2)*	PSID (1.66)*		
39	Aluminum 6 inches inside diameter 24 inches long	170	.94	181	3.44	178	2.36	454	1.31
68	Kevlar Fabric 6 inches inside diameter 24 inches long	166	.60	178	2.4	172	1.2	439	2.68
69	Kevlar Fabric Acoustic Foam Lined 6 inches inside diameter 24 inches long	168	.52	180	3.0	172	1.2	434	6.11

* BASELINE LEVELS FROM TABLE 2-II

TABLE 4-II TOTAL CONTAINMENT BAG SUPPRESSOR TEST TABULATED DATA

ROUND #	TOTAL CONTAINMENT BAG ** SUPPRESSOR CONFIGURATION	GAGE POSITION PEAK NOISE PRESSURE LEVEL*** A		B		C		MISSILE MUZZLE VELOCITY FT/SEC (434.9)*	LAUNCHER RECOIL IMPULSE LB-SEC (.105)*
		db (177.5)*	PSID (2.14)*	db (178.8)*	PSID (2.53)*	db (175.2)*	PSID (1.66)*		
44	Reinforced Nylon 20 inches inside diameter 48 inches long deflated	175	1.56	180	3.1	174	1.46	443	4.34
45	Reinforced Nylon 20 inches inside diameter 48 inches long inflated	169	.8	179	2.6	174	1.44	442	6.19
66	Kevlar Fabric 20 inches inside diameter 48 inches long inflated	168	.72	178	2.28	174	1.4	436	0
67	Kevlar Fabric Acoustic Foam Lined 20 inches inside diameter 48 inches long inflated	169	.80	181	3.2	178	2.4	418	.86

* BASELINE LEVELS FROM TABLE 3-II
** BAGS FAILED POSSIBLY DUE TO NOZZLE CLOSURE PENETRATION
*** VALUE OF FIRST PRESSURE PEAK

TABLE 4-III CONE/CYLINDER SUPPRESSOR TEST TABULATED DATA

ROUND #	CONE/CYLINDER SUPPRESSOR CONFIGURATION, ALL DIMENSIONS IN INCHES: CONICAL FORWARD CHAMBER (20°) LENGTH	ORIFICE DIAMETER	CENTER CHAMBER: TYPE	INSIDE DIAMETER	LENGTH	ORIFICE DIAMETER	AFT CHAMBER: TYPE	INSIDE DIAMETER	LENGTH	ORIFICE DIAMETER	CAGE POSITION PEAK NOISE PRESSURE LEVEL: dB (177.5)*	PSID (2.14)*	dB (170.8)*	PSID (2.53)*	dB (175.2)*	PSID (1.66)*	LAUNCHER RECOIL IMPULSE LB-SEC (.105)*	MISSILE MUZZLE VELOCITY FT/SEC (474.9)*	SUPPRESSOR INTERNAL CHAMBER PRESSURE PSIG: FORWARD	CENTER	AFT
40	[illegible] CONE (SEE DRAWING IN APPENDIX)										179	2.46	180	2.90	173	1.3	4.90	446	---	--	--
41	8	2.5	CYL	8	2	2.5	CYL	8	2	2.5	175	1.56	182	3.0	176	1.76	9.29	---	180	180	125
42	10	2.5	CYL	10	2	2.5	CYL	10	2	2.5	180	.7	177	2.2	176	1.8	0.56	428	130	75	---
43	3	7.5	NONE				20° CONE	8	3	2.5	173	1.3	180	3.76	170	1.92	8.82	450	110	---	--
48	8	3	CYL	12	2	3	CYL	8	2	3	167	.84	179	2.6	171	1.0	5.74	430	290	140	150
49	10	3	CYL	10	2	3	CYL	10	2	3	171	1.14	---	---	177	2.2	6.16	473	215	154	105
50	10	3	NONE				CYL	10	2	3	171	1.05	185	3.36	175	1.6	5.21	430	185	---	180
51	3	2.5	20° CONE	—	3	2.5	20° CONE	10	3	2.5	173	1.3	180	2.9	174	1.56	5.6	458	200	--	---
62	8	3	NONE				CYL	8	3	3	167	.66	176	1.8	174	1.5	2.03	425	180	--	150
63	3	2.5	20° CONE	8	3	3	CYL	8	3	4	173	1.26	179	2.46	175	1.6	1.20	460	50	--	-

* BASELINE LEVELS FROM TABLE 2-II

4.3 (Continued)

suppressor tests, Table 4-II contains the results of the total containment bag suppressor tests and Table 4-III contains the results of the cone/cylinder suppressor tests. Based on the missile muzzle velocity data tabulated in Tables 4-I, 4-II and 4-III, none of the advanced suppressors effect the missile performance in terms of muzzle velocity. The data analyses performed for each of the three basic types of advanced suppressors will be given in the following paragraphs.

4.3.1 Open Cylinder Suppressor Data Analysis

The peak noise reduction capability at the gunners position for the open cylinder suppressors is given in Figure 4-11. No significant trends are apparent in the data except that the rigid aluminum cylinder produces less recoil and less peak noise reduction capability than the Kevlar fabric suppressors. The high speed movies of the Kevlar open cylinder suppressors revealed that the unlined configuration broke in the side seam about two milliseconds after nozzle closure expulsion. Then about one millisecond later the suppressor separated from the reusable launch tube. In comparison, the lined configuration broke in the side seam about two milliseconds after nozzle closure expulsion but the suppressor remained attached to the reusable launch tube. A photograph taken after the firing of the acoustic foam lined Kevlar fabric open cylinder suppressor is shown in Figure 4-12. Since the lined suppressor remained attached it produced a greater recoil, shown in Figure 4-11, than the unlined suppressor that separated from the reusable launch tube. The higher recoil level may be the more realistic level for fabric open cylinder suppressors since there was enough force applied to the unlined configuration to separate it from the reusable launch tube. One general trend that can be developed from these data

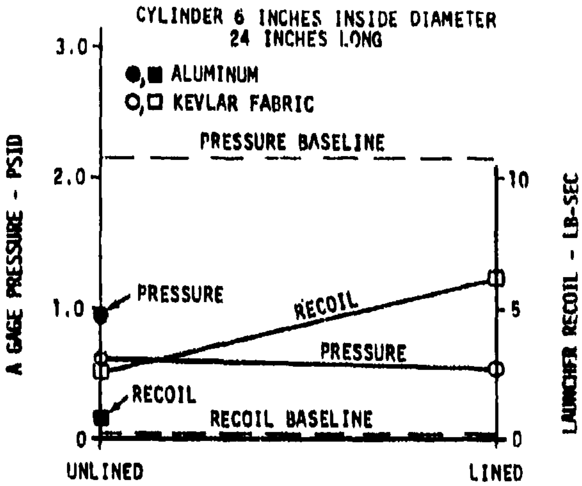


FIGURE 4-11 OPEN CYLINDER SUPPRESSOR PERFORMANCE

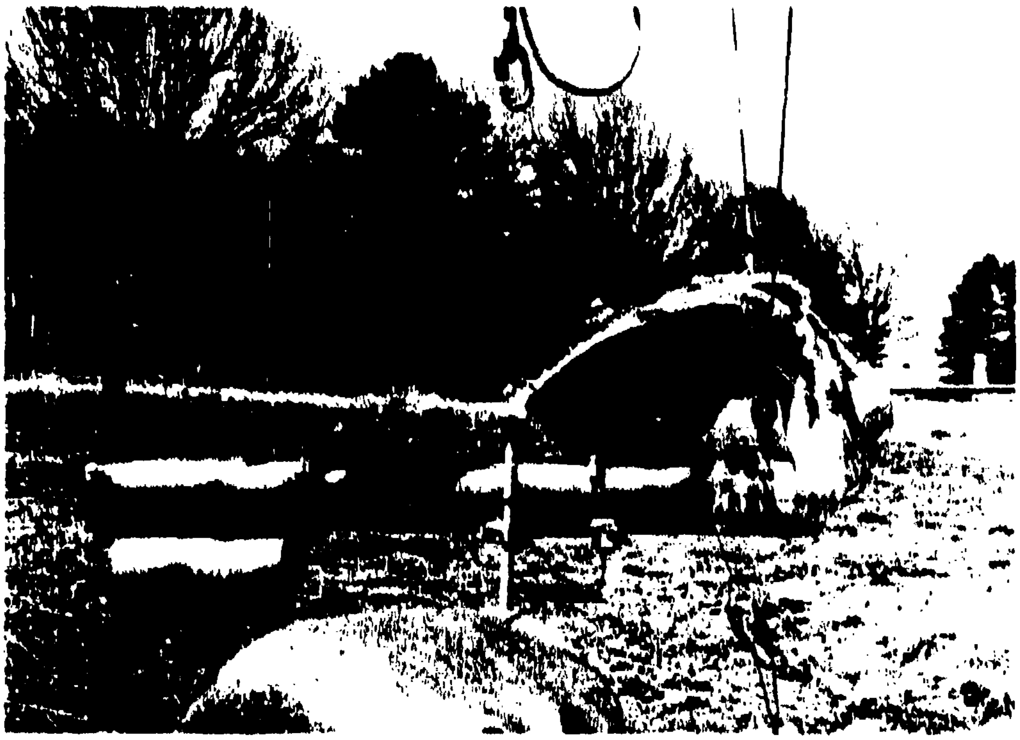


FIGURE 4-12 LINED KEVLAR FABRIC OPEN CYLINDER SUPPRESSOR AFTER FIRING

4.3.1 (Continued)

is that flexible fabric open cylinder suppressors are better peak noise suppressors and will have higher recoil than the rigid open cylinder suppressors.

4.3.2 Total Containment Bag Suppressor Data Analysis

The peak noise suppressing capability at the gunners position (gage A) for the total containment bag suppressors is shown in Figure 4-13. The data shown for the nylon bag are for a deflated and inflated deployed position. The inflated position is shown in Figure 4-4 and the deflated position shown in Figure 4-14 represents a configuration that a bag could have after it had just been released from a storage cannister in field use.

When comparing the peak noise pressure levels for the two initial bag configurations there is a strong indication that starting from an inflated bag configuration will produce better suppression capabilities. It should be noted that both nylon bag suppressors broke early in the firing causing the lower noise suppression performance. The high speed movies were not available for the nylon bag suppressor test therefore the time when the bags broke is not available.

The lined and unlined Kevlar bag suppressor peak noise reduction capability at the gunners position (gage A) is given in Figure 4-13. These data show that both configurations have essentially identical performance. The frame by frame analysis of the high speed movies of these tests revealed that the aft end of both suppressors failed at about two miliseconds into the firing. Since total containment was attained for at least two miliseconds, a peak noise reduction was achieved at a recoil level near zero. The probable cause for this low recoil can be attributed to the forward forces associated with the blowdown of the contained gasses through the aft end of the bag after it failed.

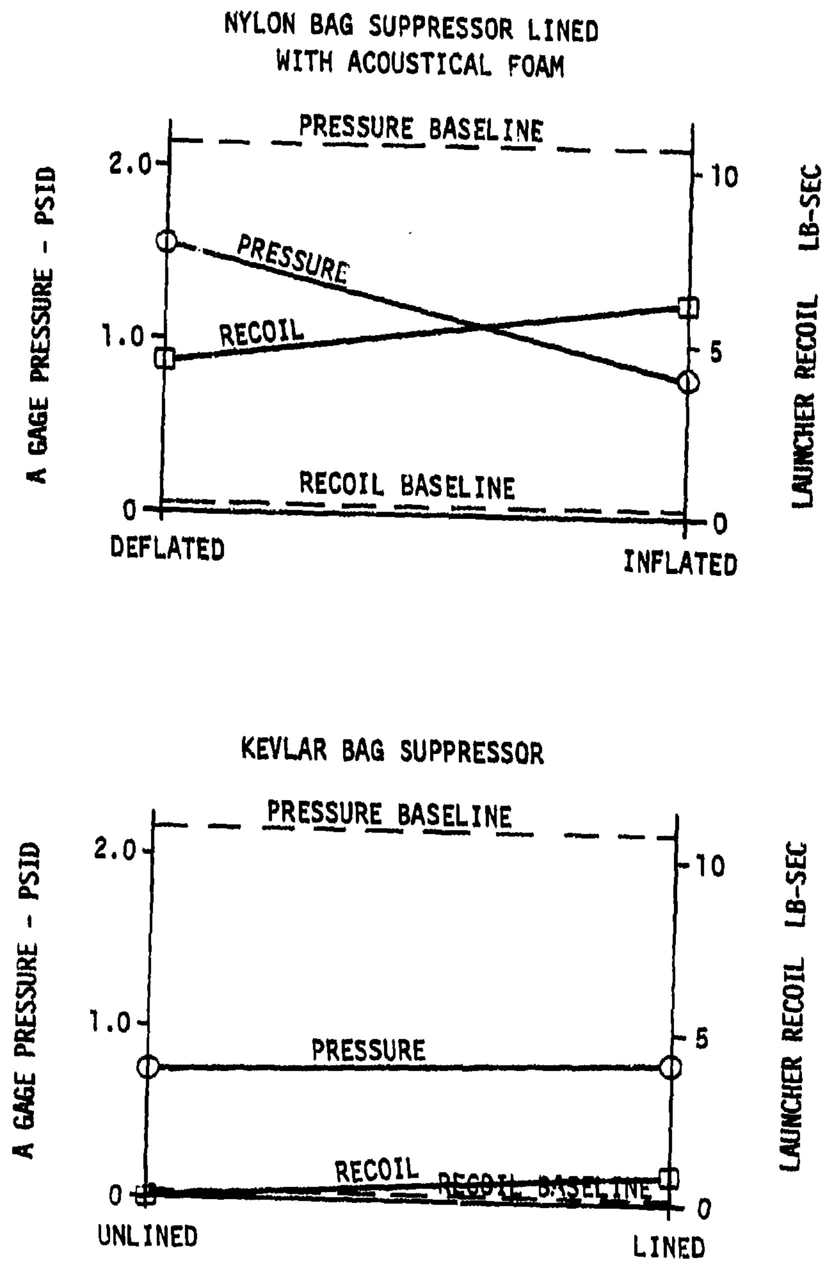


FIGURE 4-13 TOTAL CONTAINMENT BAG SUPPRESSOR PERFORMANCE

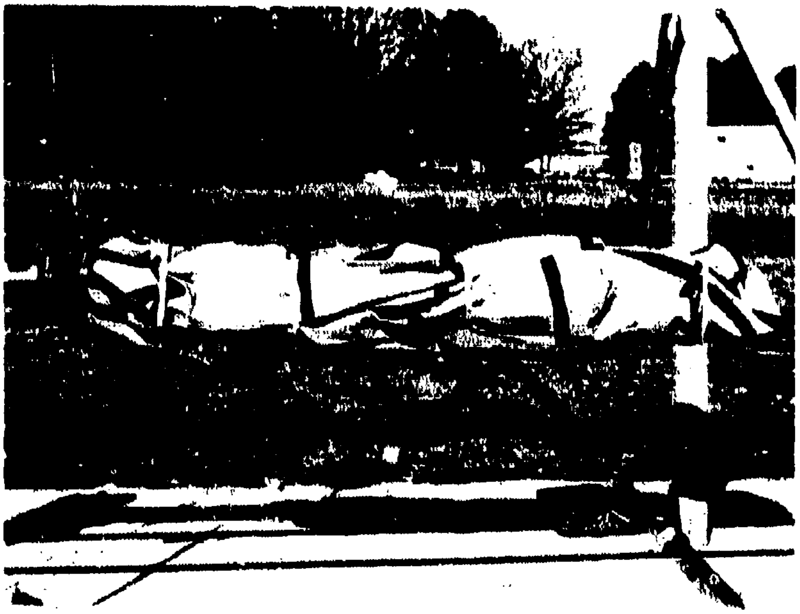


FIGURE 4-14   NYLON TOTAL CONTAINMENT BAG SUPPRESSOR IN DEFLATED CONFIGURATION

4.3.3 Cone/Cylinder Suppressor Data Analysis

The peak noise suppression capabilities of the cone/cylinder suppressors are shown in Figures 4-15 and 4-16 for the gunners position. The number of data points shown are few because hardware problems limited the number of tests that were conducted. The data for the shielded cone/cylinder suppressor is not shown because the suppressor separated during the test. Post test analysis of this suppressor revealed that poor penetration in the welds had caused the suppressor to fail under load. A similar problem was encountered with the heavyweight cone/cylinder suppressors that limited the testing performed with these suppressors. Two of the cone/cylinder suppressors with baffle orifice diameters of 2.5 inches separated at the band clamp joints during testing. Post test inspection of the hardware revealed that the welded joints in the divergent cones had some minor cracks. The cracks were repaired but a decision was made to minimize the number of tests conducted with the heavyweight cone/cylinder suppressor hardware.

The data for the ten (10) inch inside diameter cylinder with the divergent cone forward chamber are given in Figure 4-15. These data indicate that peak noise suppressing capability of this type of suppressor is not improved by increasing the number of baffles from two to three. If we compare the data for the cone/cylinder suppressor with the baffled cylinder suppressor in Figure 3-11, we see that the addition of the conical forward chamber decreases the peak noise reduction capability and increases the recoil of a suppressor with three baffles at three inch spacing and three inch orifices. An attempt was made to test a configuration with 2.5 inch orifice diameters but the cone/cylinder suppressor hardware separated at a band clamp during the test. The configuration was changed to an all conical suppressor that had three baffles with three inch spacing and 2.5 inch orifices shown in Figure 4.8. The test data given in Figure 4-15

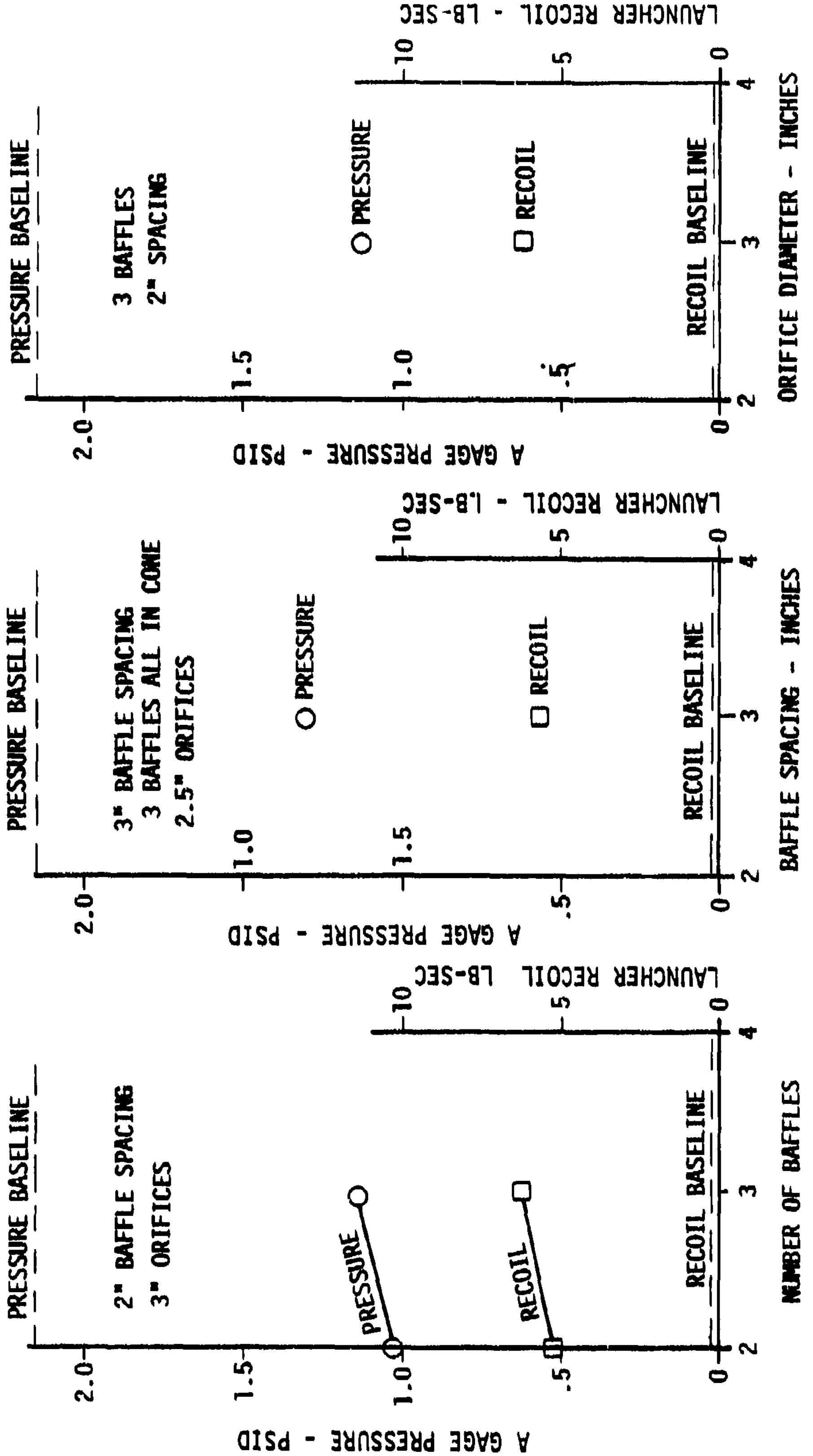


FIGURE 4-15 TEN INCH INSIDE DIAMETER CONE/CYLINDER SUPPRESSOR PERFORMANCE

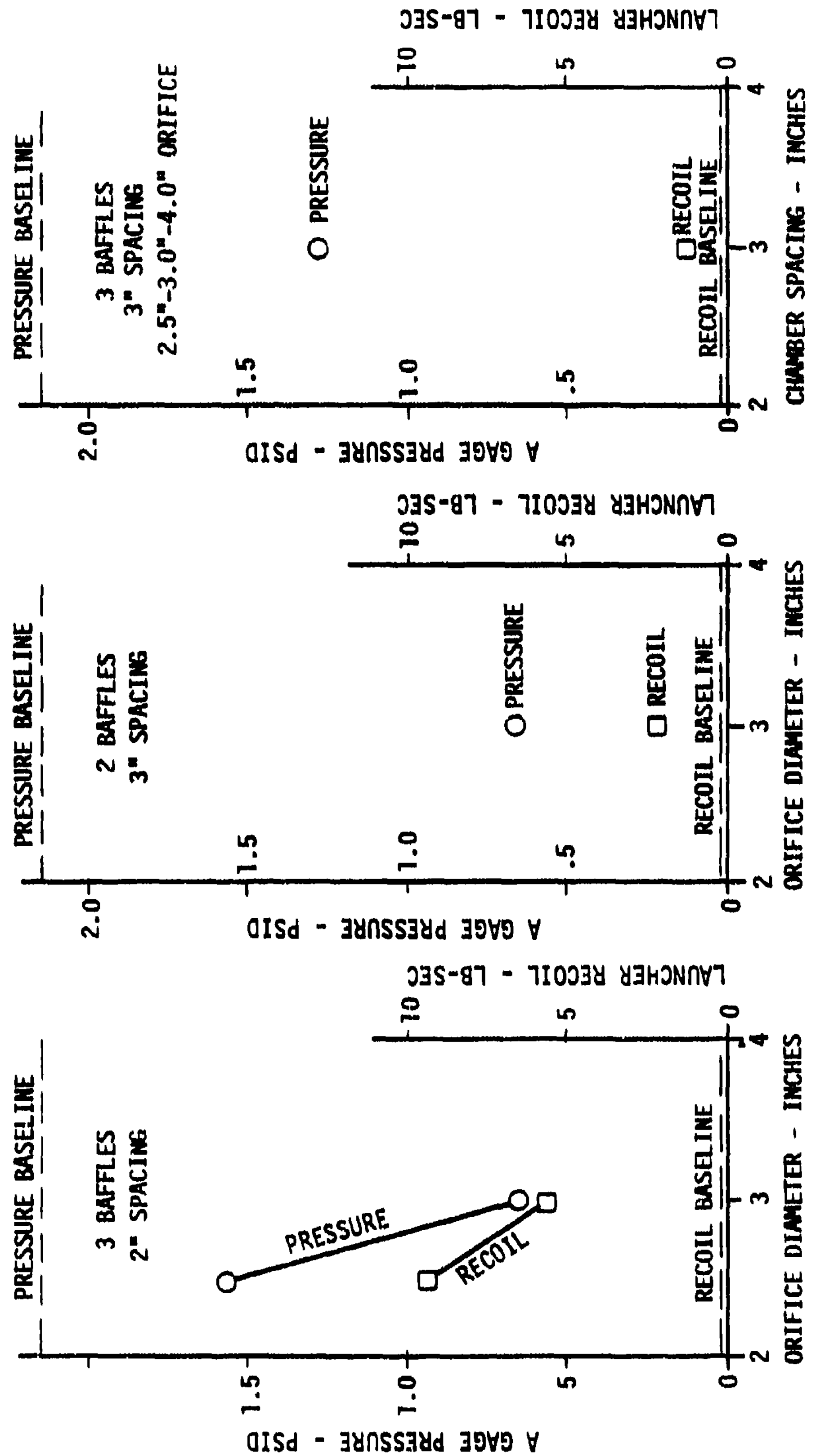


FIGURE 4-16 EIGHT INCH INSIDE DIAMETER CONE/CYLINDER SUPPRESSOR PERFORMANCE

4.3.3 (Continued)

shows a decrease in peak noise reduction capability and no change in recoil level.

The data for the eight (8) inch inside diameter cone/cylinder suppressors are given in Figure 4-16. The peak noise reduction capability of two of these suppressors was 1.5 psid/10.5 db at a recoil level of 5.74 and 2.03 lb-sec. The three (3) baffle configuration with the two (2) inch baffle spacing has a data trend that points to an orifice diameter larger than three (3) inches for higher peak noise reduction and lower recoil. This configuration was not tested because the conical section of the hardware developed some cracks in the weld and the measured pressure levels in the suppressor were above 200 psig. The data for a low recoil configuration using progressively increasing orifice diameters in each of the three baffles is shown in Figure 4-16. The recoil level is low, 1.2 lb-sec, but the peak noise reduction capability was only .78 psid/ 4.5 db.

The cone/cylinder suppressor shown in Figure 4-17 has two (2) baffles with three (3) inch spacing and three inch orifice diameters. This suppressor reduced the peak noise pressure at the gunner position by 1.5 psid/10.5 db at a recoil level of 2.03 lb-sec, making it one of the best performing suppressors tested. The measured peak internal chamber pressures were 100 and 150 psig in the two chambers. Pressures of this level are high for a fieldweight suppressor candidate.

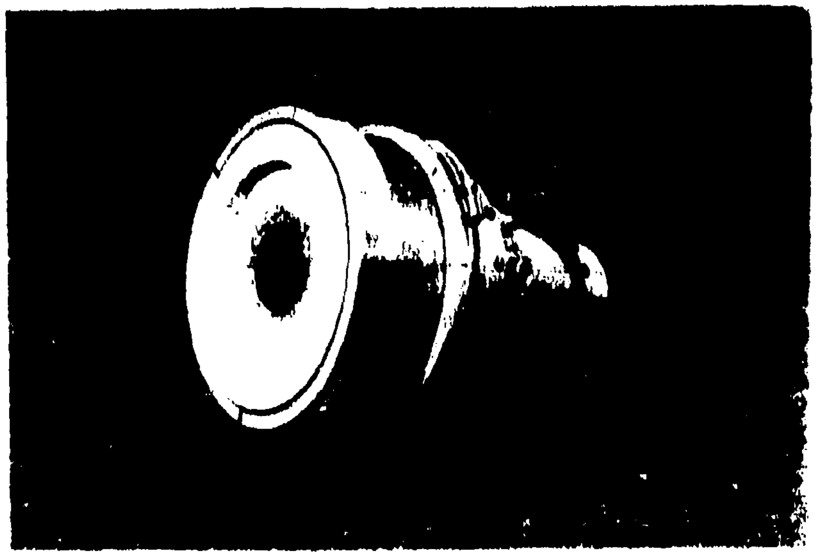


FIGURE 4-17 HIGH PERFORMANCE CONE/CYLINDER SUPPRESSOR

5.0 SOUND ABSORBING MATERIAL SUPPRESSOR DESIGN AND EVALUATION

The use of sound absorbing material to improve the performance of rocket motor peak noise suppressors was described in Reference 3. Several types of liner material were evaluated and from the liner materials tested, Tufcote Acoustical Foam was selected for use in the Sound Absorbing Material Suppressor Design and Evaluation. Tufcote Acoustical Foam is made up of a thick urethane foam with a tensilized mylar film bonded to the foam structure. This composite has a high resistance to airflow and absorbs airborne sound. Suppressor configurations already tested during the Heavyweight Suppressor Evaluation were selected for use in evaluating the Tufcote Acoustical Foam as a liner material. The Tufcote Acoustical Foam lined heavyweight suppressors were tested on the test fixture and with the same instrumentation described in Paragraph 2.0.

The following paragraphs will describe the design, test and performance evaluation of the Sound Absorbing Material Suppressors. It will be shown that Tufcote Acoustical Foam lined heavyweight suppressors have improved peak noise reduction capability with only minor increases in launcher recoil level. One lined baffled cylinder suppressor reduced the peak noise overpressure at the gunners position by 78.5% with a launcher recoil level of 2.86 lb-sec.

5.1 SOUND ABSORBING MATERIAL SUPPRESSOR DESIGN

The design of the sound absorbing material suppressors was similar to the several suppressor configurations tested in Reference 3. The basic design procedure was to select a suppressor tested during the Heavyweight and Advanced Suppressor test that had good peak noise suppression capability and low recoil and line the selected suppressor with Tufcote Acoustical Foam. Baffled cylinder suppressors of both eight (8) and ten (10) inches

5.1 (Continued)

inside diameter were selected from the heavyweight suppressor designs. The six (6) inch inside diameter and twenty-four (24) inch long rigid cylinder suppressor was selected from the advanced suppressor test. Only the rigid aluminum suppressors were selected for these tests because the adhesive backing used to hold the foam in place functioned better on metal. This backing was applied by the product manufacturer. Tufcote Acoustical Foam of one-half and one inch thickness was used to line the baffled cylinder suppressors as shown in Figure 5-1. As shown the inside baffles were lined only on the ten (10) inch inside diameter suppressors with four (4) inch spacing between the baffles. The lined six (6) inch diameter twenty four (24) inch long cylinder suppressor is shown in Figure 5-2.

5.2 SOUND ABSORBING MATERIAL TEST

Each of the Sound Absorbing Material Suppressor configurations described in Paragraph 5.1 were tested with the pendulum type test fixture and with the same instrumentation and test procedures described for the heavyweight suppressors in Paragraph 3.2.

5.3 SOUND ABSORBING MATERIAL SUPPRESSOR DATA ANALYSES

The data recorded during testing of the sound absorbing material suppressors were processed and analyzed in the same manner as described for the heavy-weight suppressor in Paragraph 3.3. The reduced data for the sound absorbing material suppressor tests are given in Table 5-I.

Since the sound absorbing material suppressors were Tufcote Acoustical Foam lined versions of the heavyweight and advanced suppressors, the performance data have been presented with the heavyweight and advanced suppressor as the zero material thickness in Figures 5-3, 5-4, 5-5 and 5-6. The peak noise

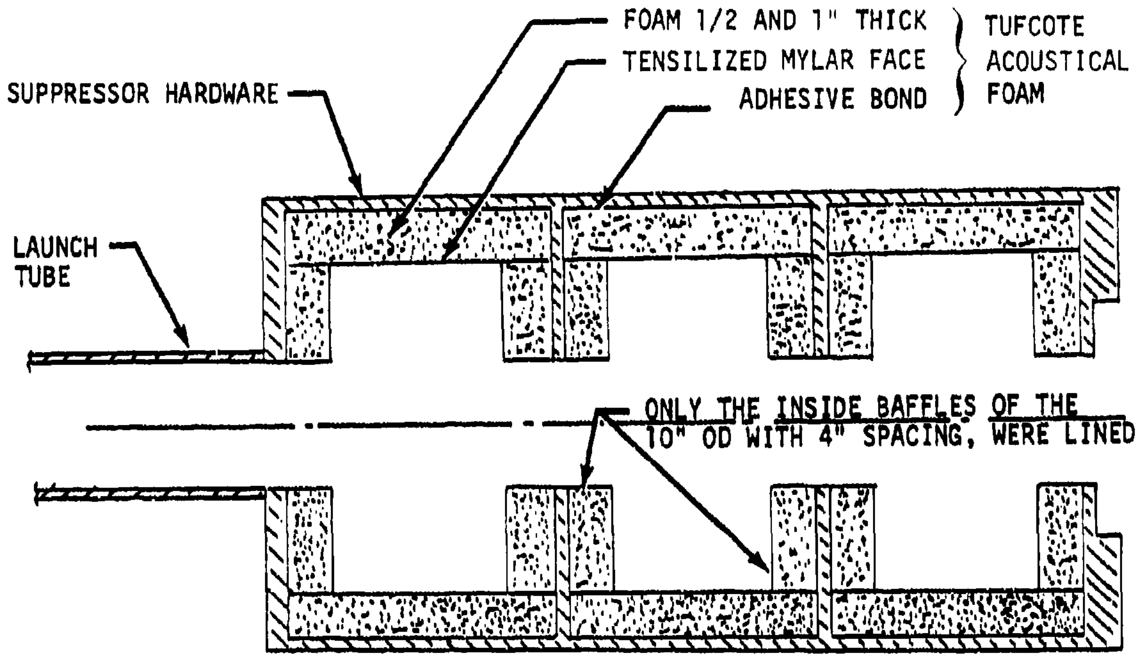


FIGURE 5-1 SOUND ABSORBING MATERIAL BAFFLED CYLINDER SUPPRESSOR DESIGN

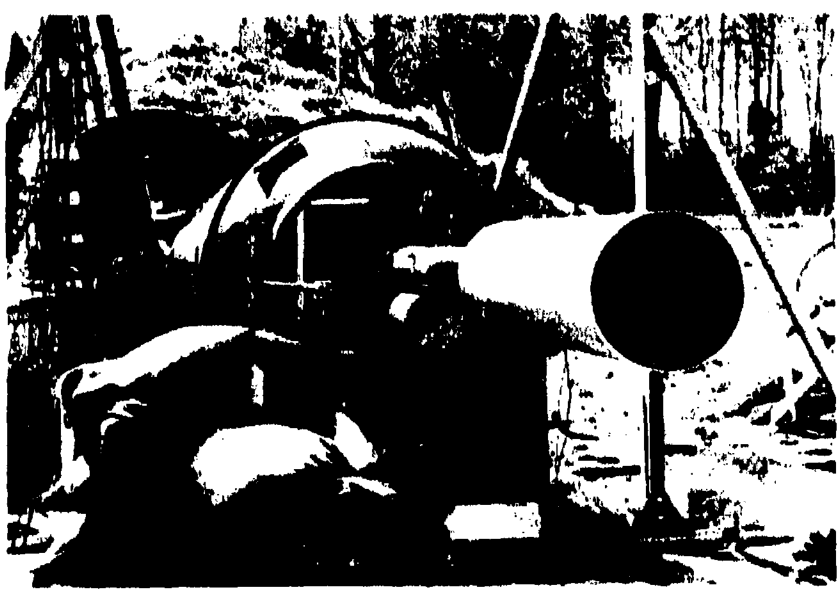


FIGURE 5-2 SOUND ABSORBING MATERIAL OPEN CYLINDER SUPPRESSOR DESIGN

TABLE 5-I SOUND ABSORBING MATERIAL TEST TABULATED DATA

RUN #	SUPPRESSOR ID (INCHES)	SUPPRESSOR CONFIGURATION CHAMBER LENGTH (INCHES) A	B	C	BAFFLE ORIFICE (INCHES) A	B	C	LINER MATERIAL CONFIGURATION	GAGE POSITION PEAK NOISE PRESSURE LEVEL A db (177.5)*	A PSID (2.14)*	B db (178.8)*	B PSID (2.53)*	C db (175.2)*	C PSID (1.65)*	LAUNCHER RECOIL IMPULSE LB-SEC (.105)*	MISSILE MUZZLE VELOCITY FT/SEC (434.9)*	SUPPRESSOR MATERIAL CHAMBER PRESSURE PSIG FORWARD	CENTER	AFT
52	10	2	2	2	2.5	2.5	2.5	1" [illegible] ON INSIDE BAFFLES	168	.7	---	---	176	1.5	3.38	490	100	50	120
53	8	2	2	2	2.5	2.5	2.5	1" [illegible] ON INSIDE BAFFLES	166	.76	180	2.9	176	1.78	3.16	498	160	70	150
54	10	2	2	2	2.5	2.5	2.5	1/2" [illegible] ON INSIDE BAFFLES	168	.74	---	---	176	1.78	3.92	430	---	75	160
55	8	2	2	2	2.5	2.5	2.5	1/2" [illegible] ON INSIDE BAFFLES	170	.90	178	2.3	175	1.7	2.95	442	---	85	245
56	10	3	3	3	3	3	3	1" [illegible] ON INSIDE BAFFLES	167	.66	---	---	176	1.8	2.40	434	---	110	102
57	8	3	3	3	3	3	3	1" [illegible] ON INSIDE BAFFLES	168	.7	178	2.16	174	1.56	2.90	451	75	---	110
58	10	3	3	3	3	3	3	1/2" [illegible] ON INSIDE BAFFLES	160	.8	---	---	174	1.54	2.87	437	---	85	135
59	8	3	3	3	3	3	3	1/2" [illegible] ON INSIDE BAFFLES	172	1.1	---	---	175	1.6	2.73	438	40	100	165
60	10	4	4	4	3	3	3	1" SIDES & ENDS 1/2" INSIDE BAFFLES	164	.96	178	2.3	175	1.66	2.06	446	50	60	100
61	10	4	4	4	4	4	4	1" SIDES & ENDS 1/2" INSIDE BAFFLES	168	.76	178	2.26	174	1.5	1.13	449	30	---	75
70	6	25	NONE	NONE	NONE	NONE	NONE	1" SIDES OF CYLINDER	166	.60	180	3.00	175	1.6	1.94	434	---	---	---

* BASELINE LEVELS FROM TABLE 2-II

5.3 (Continued)

suppression capability of the ten (10) inch inside diameter sound absorbing material suppressors is shown in Figure 5-3. The trend of the data indicates that addition of Tufcote Acoustical Foam liner improved the peak noise suppression capability of the suppressor at the gunners position. It should be noted that increasing the foam thickness increases the recoil produced by the suppressor.

The performance data for the lined ten (10) inch inside diameter suppressor with four (4) inch baffle spacing and three (3) and (4) inch orifices have been superimposed on similar data from the heavyweight suppressor test in Figure 5-4. These data show that the one (1) inch Tufcote Acoustical Foam Liner can increase the peak noise suppressing capability of both the three (3) and four (4) inch diameter orifice configurations up to .39 psid/4 db with an increase of 1 lb-sec recoil. The overall peak noise reduction capability of this lined suppressor when compared to the unsuppressed baseline is 1.68 psid/13.5 db at a recoil level of 1 lb-sec.

Summary performance data for the eight (8) inch inside diameter baffled cylinder suppressors that were lined with Tufcote Acoustical Foam are given in Figure 5-5. These data show that little or no improvement in peak noise suppression capability was achieved with the one-half inch liner material. Addition of the one (1) inch material improved the performance however the recoil levels were increased to about 3 lb-sec.

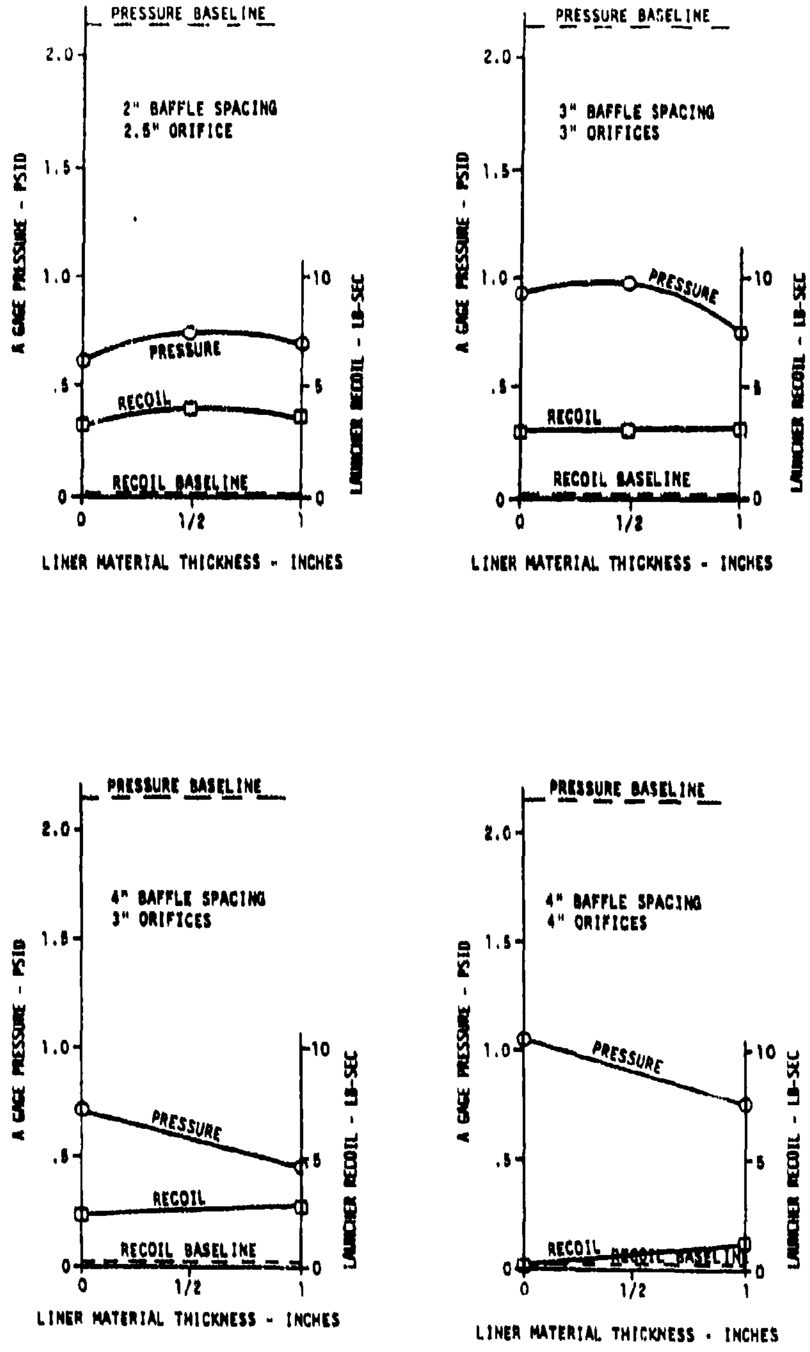


FIGURE 5-3 TEN INCH INSIDE DIAMETER SOUND ABSORBING MATERIAL SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY AND RECOIL LEVEL

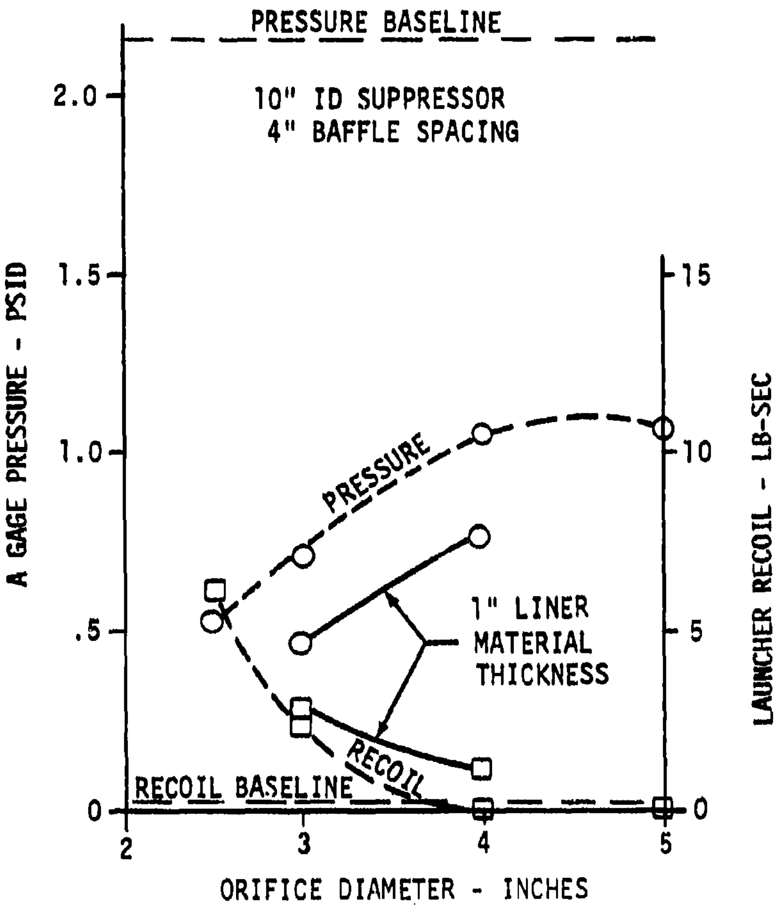


FIGURE 5-4 TEN INCH INSIDE DIAMETER BAFFLED CYLINDER SUPPRESSOR PERFORMANCE WITH ONE INCH LINER MATERIAL

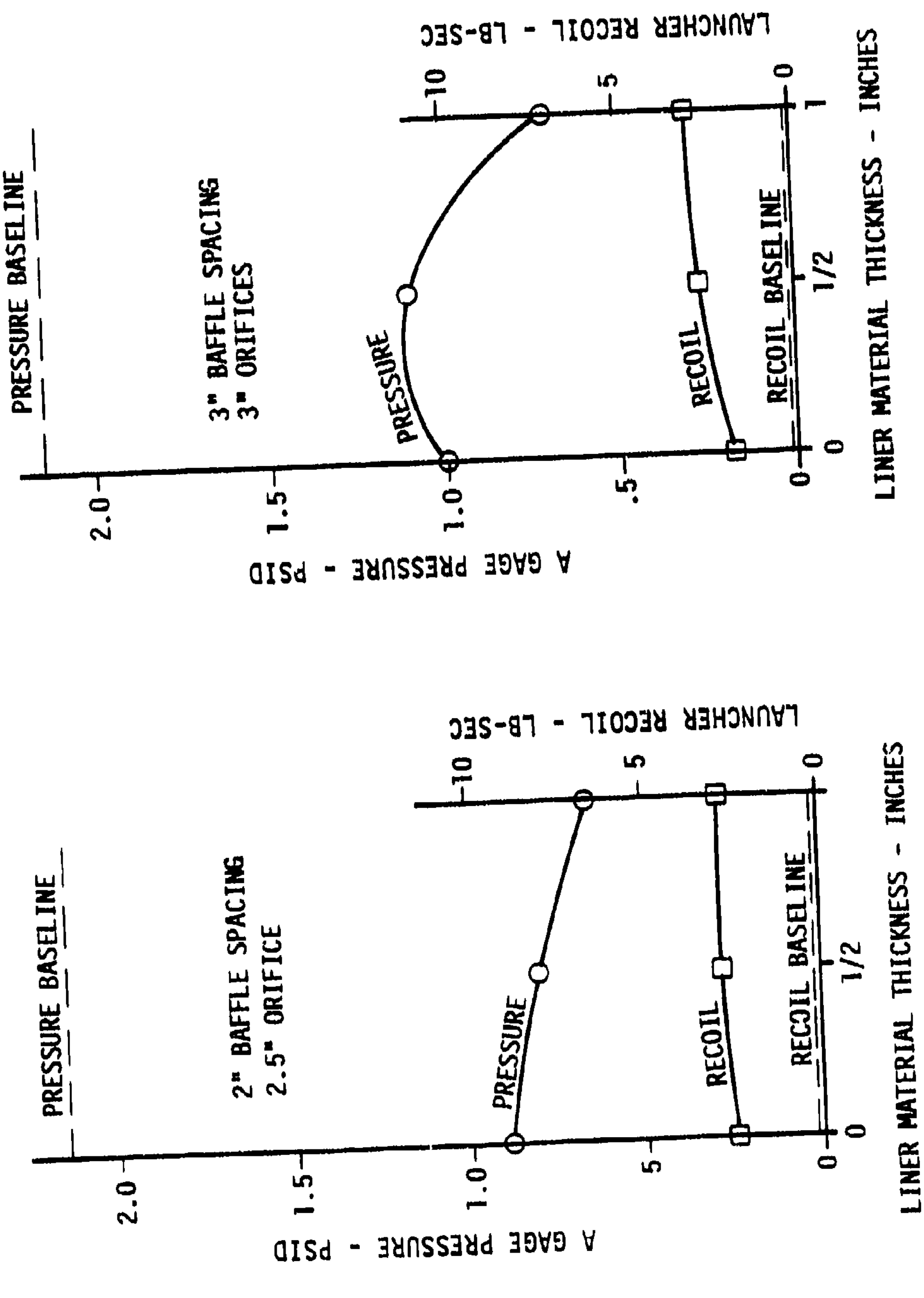


FIGURE 5-5 EIGHT INCH INSIDE DIAMETER SOUND ABSORBING MATERIAL SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY AND RECOIL LEVEL

5.3 (Continued)

A .34 psid/4 db improvement was gained with the six (6) inch inside diameter twenty four (24) inch long open cylinder suppressor by adding the one (1) inch Tufcote Acoustical Foam liner. These data are shown in Figure 5-6 along with the recoil data. It can be noted that the recoil increased only .44 lb-sec. The overall peak noise reduction capability of the lined open cylinder suppressor is 1.54 psid/11.5 db at the gunners position with a recoil level of 1.94 lb-sec.

In general the addition of one (1) inch Tufcote Acoustical Foam liner at least on the sides and ends of a particular suppressor configuration will improve the peak noise reduction capability by 4 db. No evidence is shown in the tabulated missile muzzle velocity data (Table 5-I). that the sound absorbing material suppressors effect missile performance in terms of muzzle velocity.

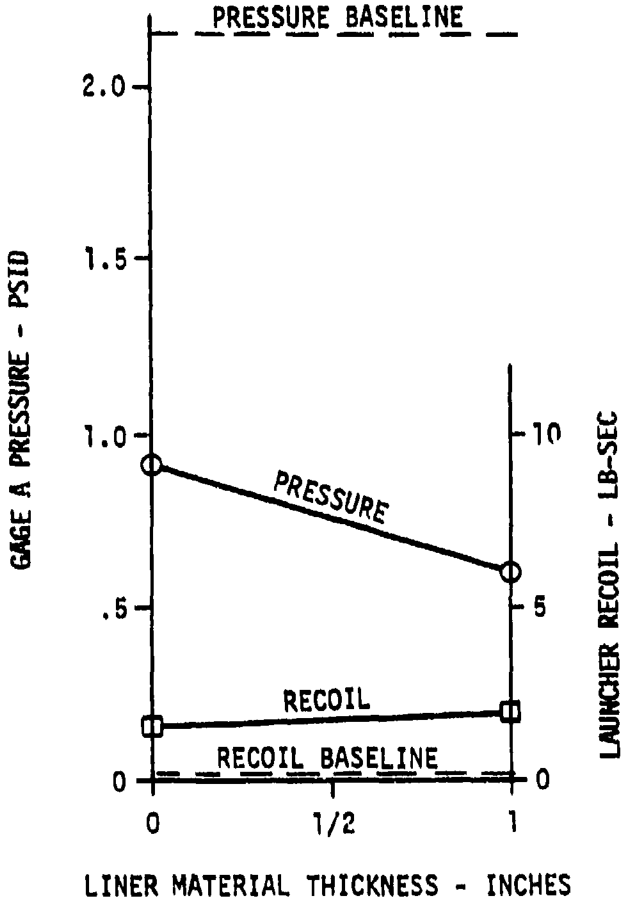


FIGURE 5-6 SIX INCH INSIDE DIAMETER, TWENTY-FOUR INCH LONG SOUND ABSORBING MATERIAL OPEN CYLINDER SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY AND RECOIL

6.0 SCALED AND FIELDWEIGHT SUPPRESSOR DESIGN AND EVALUATION

The peak noise suppression capabilities of Kevlar fabric open cylinder and total containment bag suppressors that were obtained during the Advanced Suppressor Test made this type of suppressor the primary candidate for the Scaled and Fieldweight Suppressor. A Kevlar fabric suppressor has the potential for being lightweight, storable and easily deployed. The size of the Kevlar fabric suppressor can be scaled for other shoulder launched rocket powered weapon applications without adversely effecting the carry weight or storage volume.

Other candidate suppressors as Scaled and Field Weight Suppressors, primarily the rigid open cylinder and baffled cylinders, have already undergone adequate testing to establish a data base for the design of a field weight suppressor. Test data and preliminary design studies have indicated that a fieldweight storable rigid baffled cylinder suppressor will require material and manufacturing techniques that are far too expensive to be used for fabricating a single test configuration. This design study was used to support the decision to limit further testing on rigid open cylinder and baffled cylinder suppressors in favor of Kevlar fabric suppressors. A seamless Kevlar tube was not readily available, therefore suppressors were fabricated by sewing Kevlar fabric into the desired shapes. A woven Nylon tube manufactured by Goodyear was used for some of the small diameter open cylinder suppressors.

The following paragraphs will describe the design, test and performance analysis of the Kevlar and Nylon fabric Scaled and Fieldweight Suppressors. It will be shown that the lightweight Kevlar fabric suppressors can be designed to withstand the rocket motor exhaust gas environment and that these suppressors have excellent peak noise reduction capability but have higher recoil than similar aluminum suppressors. Both performance parameters are configuration dependent. A typical nonvented Kevlar fabric open cylinder

6.0 (Continued)

suppressor reduced the peak noice overpressure at the gunners position by 80% with a launcher recoil level of 4.21 lb-sec. A similar suppressor with a braided aft vent reduced the overpressure by 71% but produced a recoil level of 9.10 lb-sec. The Kevlar fabric baffled cylinder suppressor will be shown to reduce the overpressure by 75% at a recoil level of 5.2 lb-sec. It will also be shown that the total containment bag suppressor can be designed to function where noise, flash and smoke suppression is a requirement. These bag suppressors will reduce the peak noise overpressure by 50% while containing the flash and smoke. The launcher recoil associated with the bag suppressor is 6 lb-sec.

6.1 SCALED AND FIELDWEIGHT SUPPRESSOR DESIGN

A frame by frame study was made of the high speed movies from tests of the Kevlar fabric open cylinder and full containment bag suppressors reported in Paragraph 4.0. This analysis indicated design variations that may offer significant improvements in suppressor functions. First, selective venting could be used in the designs to relieve internal pressure and improve the survivability of the suppressor. Second, the total containment bag suppressor concept could be improved if the nozzle closure mass could be reduced to a level incapable of destroying a reinforced bag aft end. Third, venting the full containment bag could lead to a more survivable partial containment bag suppressor design.

The following paragraphs will cover the design details of four types of fabric suppressors; total containment bags, partial containment bags, vented and nonvented open cyliner, and baffled cylinders.

6.1.1 Total Containment Kevlar Fabric Bag Suppressor Design

The total containment bag suppressors are minor modifications to the unlined total containment bag suppressors designed and tested as Advanced Suppressors (paragraph 4.0). Two modifications were made. One, the nylon attach webs on the forward end of the bag were replaced with a Kevlar web of the same strength. Two, the aft end of the bags were reinforced to withstand the impact of the nozzle closure debris. Two different aft end reinforcing designs were used. These were a layered fabric bottom and a web crossing grid pattern on the bottom. Each of these total containment bags is shown in Figure 6-1. The pattern used to fabricate the web reinforced total containment bag is included in the Appendix.

To improve the survivability of the total containment suppressors, MICOM Propulsion Directorate designed and fabricated a reduced debris igniter case-nozzle closure and electric squib to replace the standard polyurethane closure, igniter case and squib normally used for the M-72 weapon system during remote firing tests. The reduced debris igniter case-nozzle closure was molded from F-400 grade polystyrene beads by the two step expansion method. The density of igniter case-nozzle closure was 1-1/2 to 2 pounds per cubic foot. An M-105 electric squib was modified by replacing the standard wires with 32 gage formvar insulated wire. Rocket motors with these reduced debris were used during the testing of the full containment bag suppressors.

6.1.2 Partial Containment Kevlar Fabric Bag Suppressor Design

Two types of partial containment bag suppressors were designed to improve the survivability of the type of bags that were tested during the Advanced Suppressor Test. One bag suppressor design was a modified version of the unlined bag suppressor design described in paragraph 4.1.2. The aft end of the bag was replaced with a web grid as shown in Figure 6-2. The

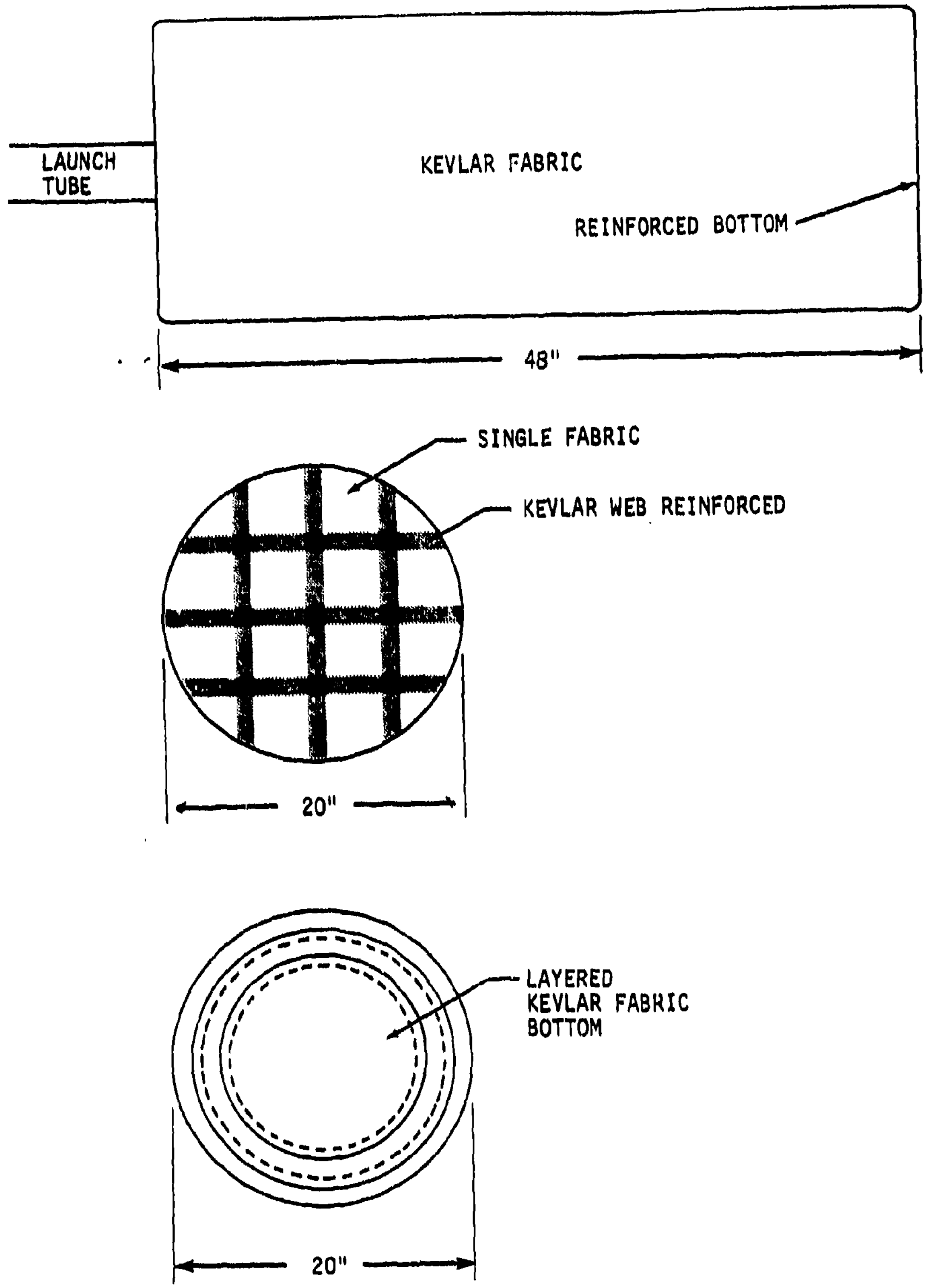


FIGURE 6-1 TOTAL CONTAINMENT BAG SUPPRESSORS

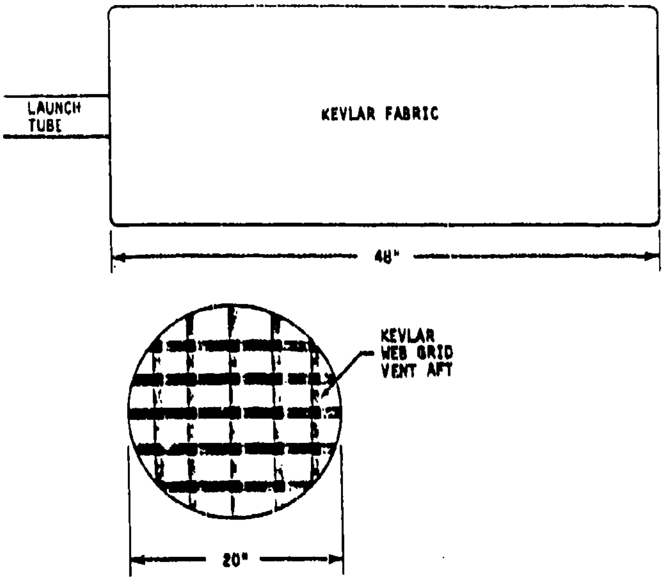


FIGURE 6-2 WEB GRID BOTTOM PARTIAL CONTAINMENT BAG SUPPRESSOR

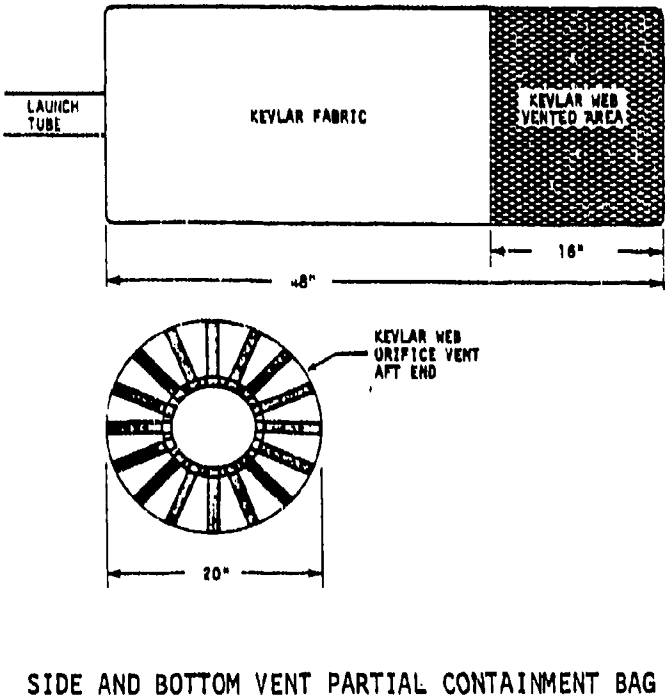


FIGURE 6-3 SIDE AND BOTTOM VENT PARTIAL CONTAINMENT BAG SUPPRESSOR

6.1.2 (Continued)

second bag design shown in Figure 6-3 utilizes a vent grid design made up of laced longitudinal and circumferential webs in the aft one-third of the bag. The longitudinal webs were extended to and used to partially close the aft end of the bag with an orifice type closure. The pattern used to fabricate the side and bottom vent partial containment bag suppressor is included in the Appendix.

6.1.3 Open Cylinder Kevlar Fabric and Woven Nylon Suppressor Design

Several open cylinder suppressor configurations were designed using Kevlar and Nylon fabric in conjunction with a Kevlar web. The non-vented open cylinder suppressors shown in Figure 6-4 were designed with Kevlar fabric and woven Nylon tube. Each of these configurations are listed in Table 6-I.

Four of the four (4) inch inside diameter woven Nylon tube open cylinder suppressors were fabricated for attachment to a six (6) inch launch tube aft extension. The reusable launch tube with the six (6) inch extension attached is shown in Figure 6-5. A typical pattern used to fabricate the non-vented open cylinder Kevlar fabric suppressor is included in the Appendix.

Each of the vented open cylinder suppressor configurations are shown in Figure 6-4. These are made up with several different Kevlar web vent designs. The braided vent concept was used in the forward half, the aft half and for the full cylindrical length of the suppressors. The configurations with the aft half and full length vent were tied at the aft end with a reinforced belt of Kevlar web or with a single seam of Kevlar thread. A typical pattern used for the fabrication of a vented open cylinder Kevlar fabric and web suppressor is included in the Appendix.

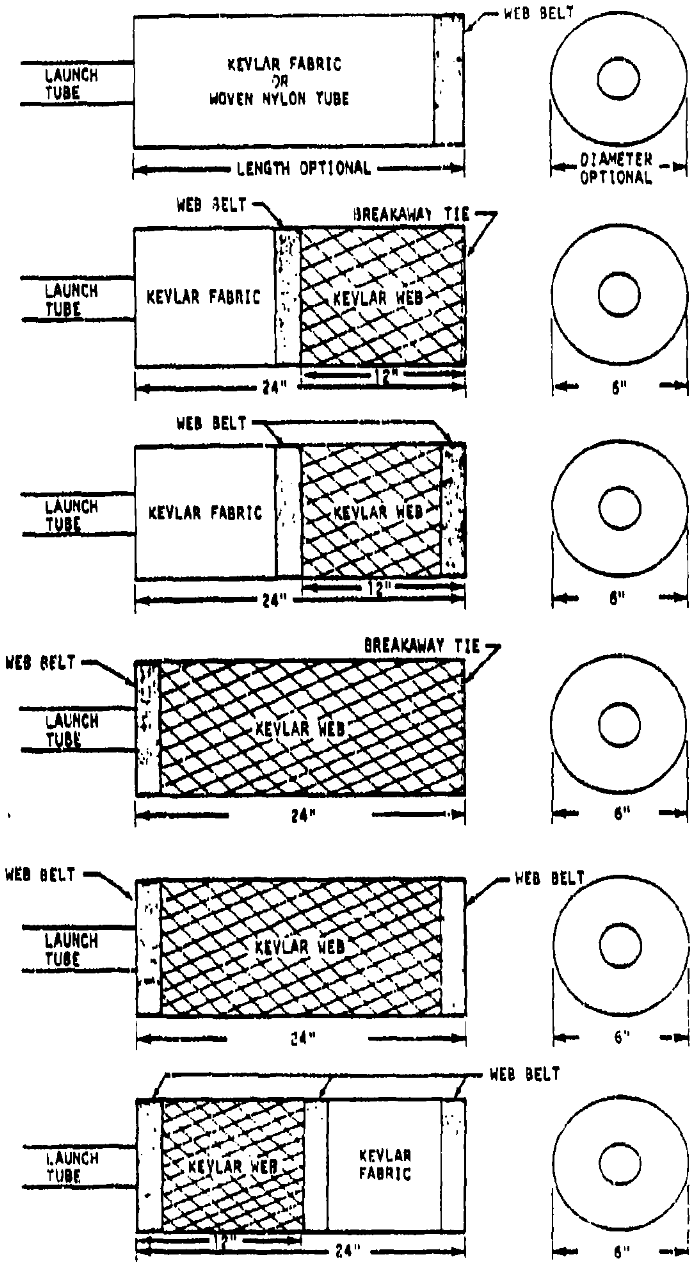


FIGURE 6-4 FABRIC OPEN CYLINDER SUPPRESSORS

TABLE 6-I OPEN CYLINDER SUPPRESSOR CONFIGURATIONS

FABRIC	CYLINDER DIAMETER inches	CYLINDER LENGTH inches
Woven Nylon Tube	4	12*
Woven Nylon Tube	4	24*
Woven Nylon Tube	4	36*
Woven Nylon Tube	4	48*
Kevlar	4	24
Kevlar	6	24
Kevlar	6	36
Kevlar	6	48
Kevlar	8	24
Kevlar	10	24

* Duplicated for 6" launch tube extension

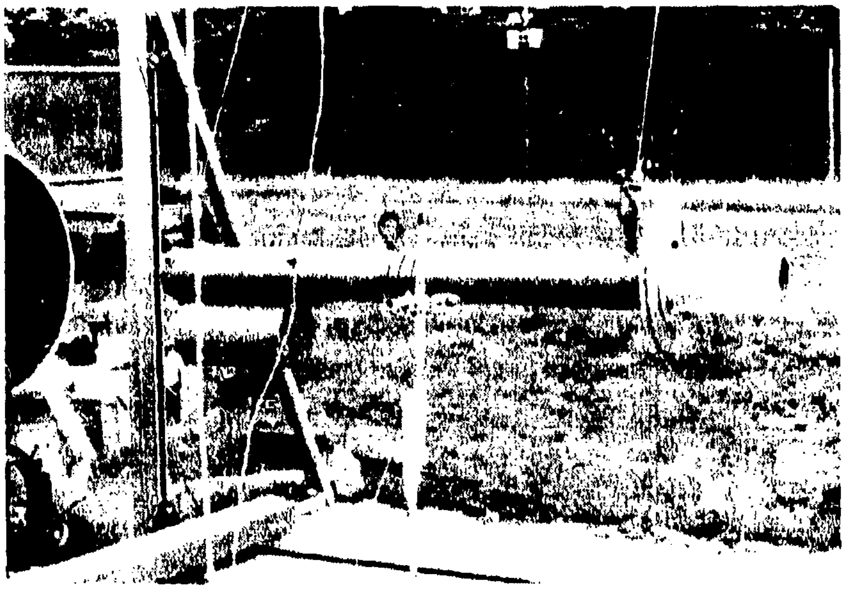


FIGURE 6-5   REUSABLE LAUNCH TUBE WITH SIX INCH AFT EXTENSION ATTACHED

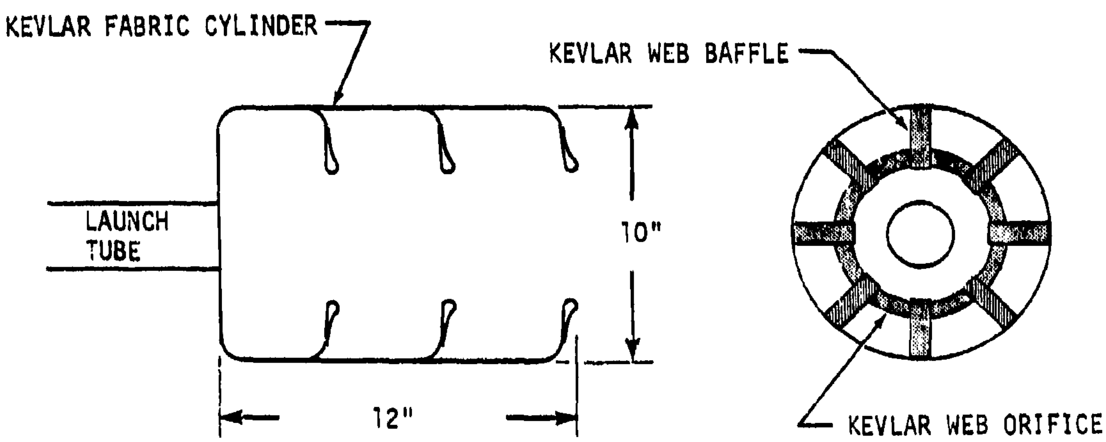


FIGURE 6-6   KEVLAR FABRIC BAFFLED CYLINDER SUPPRESSOR

6.1.4 Baffled Cylinder Kevlar Fabric Suppressor Design

Based on the peak noise suppression capability and low recoil of the ten (10) inch inside diameter baffled cylinder suppressor discussed in Paragraph 3.3, a similar configuration was designed for fabrication with Kevlar fabric. The cylinder part of the suppressor was designed the same as the fabric open cylinder suppressors. The baffles were made up of eight (8) longitudinal Kevlar webs equally spaced around the cylinder. These webs were also used to attach the suppressor to the reusable launch tube. Loops were attached to each web in the location required for the baffle. The baffle was completed with a Kevlar web tied through each of the loops to form the orifice. A sketch of this baffled cylinder Kevlar fabric suppressor is given in Figure 6-6. The pattern used to fabricate the baffled cylinder Kevlar fabric suppressor has been included in the Appendix.

6.2 SCALED AND FIELDWEIGHT SUPPRESSOR TEST

Each of the Scaled and Fieldweight Suppressor configurations described in Paragraph 6.1 were tested with the pendulum type test fixture and with the same test procedures and instrumentation described for the Advanced Suppressor Test in Paragraph 4.2.

6.3 SCALED AND FIELDWEIGHT SUPPRESSOR DATA ANALYSIS

The data recorded during the testing of the Scaled and Fieldweight Suppressors were processed and analyzed in the same manner as described for the Heavyweight Suppressor Data Analyses in Paragraph 3.3. The data that were reduced by this process are given in Table 6-II. It showed that due to the unique characteristics of the fabric suppressors there are some secondary peak noise pressures that exceed the initial peak noise pressure peaks. These secondary pressure peaks are not listed in Table 6-II but they will be pointed out where they occur as a part of the detailed data analysis for each suppressor configuration. The

TABLE 6-II SCALED AND FIELDWEIGHT SUPPRESSOR TEST TABULATED DATA

ROUND #	SUPPRESSOR CONFIGURATION	GAGE POSITION PEAK NOISE PRESSURE LEVEL: A dB (177.0)	A PSID (2.14)*	B dB (178.8)*	B PSID (2.93)*	C dB (175.2)*	C PSID (1.68)*	MISSILE MUZZLE VELOCITY FT/SEC (434.9)*	LAUNCHER RECOIL IMPULSE LB-SEC (.105)*
72	KEVLAR FABRIC OPEN CYLINDER 6" DIAMETER - 24" LONG	161	.32	181.0	1.6	172.3	1.2	439	5.5
73	KEVLAR FABRIC OPEN CYLINDER 6" DIAMETER - 36" LONG	162.8	.4	179.7	2.8	173.2	1.32	457	4.21
74	KEVLAR FABRIC OPEN CYLINDER 6" DIAMETER - 48" LONG	168.8	.4	183.2	4.2	176.8	2.0	463.8	5.5
75	KEVLAR FABRIC OPEN CYLINDER 8" DIAMETER - 24" LONG	160.9	.32	180.9	3.2	174.9	1.6	438.6	5.82
76	KEVLAR FABRIC OPEN CYLINDER 10" DIAMETER - 24" LONG	162.8	.4	184.4	4.8	176.8	2.0	434	4.21
77	KEVLAR FABRIC OPEN CYLINDER 4" DIAMETER - 24" LONG	162.8	.4	180.2	1.2	172.3	1.2	444	5.01
78	WOVEN NYLON OPEN CYLINDER 4" DIAMETER - 12" LONG	160.8	.4	180	3.9	172.3	1.2	438	3.80
79	WOVEN NYLON OPEN CYLINDER 4" DIAMETER - 24" LONG	163.8	.4	176.8	2.0	164.3	.6	451	5.07
80	WOVEN NYLON OPEN CYLINDER 4" DIAMETER - 36" LONG	164.4	.40	186.3	6.0	176.8	2.0	435	2.91
81	WOVEN NYLON OPEN CYLINDER 4" DIAMETER - 48" LONG	162.9	.4	184.3	4.72	173.2	1.32	400	4.10
82	WOVEN FABRIC BRAIDED AFT VENT CYLINDER WITH REINFORCED END 6" DIAMETER - 24" LONG	165.1	.52	181.9	3.6	170.8	1.0	475	3.93
83	KEVLAR FABRIC BRAIDED AFT VENT CYLINDER WITH BREAKAWAY END 6" DIAMETER - 24" LONG	168.3	.6	181.9	3.6	173.7	1.4	472	9.10
84	KEVLAR FABRIC BRAIDED FWD VENT CYLINDER 6" DIAMETER - 24" LONG	173.7	1.4	181.9	3.6	174.9	1.6	464	4.88
87	KEVLAR FABRIC FULL BRAIDED VENT CYLINDER WITH REINFORCED END 6" DIAMETER - 24" LONG	173	1.3	182.6	4.0	172.3	1.2	457	8.14
88	KEVLAR FABRIC FULL BRAIDED VENT CYLINDER WITH BREAKAWAY END 6" DIAMETER - 24" LONG	174.9	1.6	181.9	3.6	178.0	2.3	454	4.88
89	WOVEN NYLON CYLINDER MOUNTED ON 6" TUBE EXTENSION 4" DIAMETER - 12" LONG	168.8	.8	179.7	2.8	173.2	1.32	447	4.53
90	WOVEN NYLON CYLINDER MOUNTED ON 6" TUBE EXTENSION 4" DIAMETER - 24" LONG	166.8	.2	176.8	2.0	167.4	.68	444	4.32
91	WOVEN NYLON CYLINDER MOUNTED ON 6" TUBE EXTENSION 4" DIAMETER - 36" LONG	166.8	.2	179.1	2.6	170.1	.92	469	4.0
92	WOVEN NYLON CYLINDER MOUNTED ON 6" TUBE EXTENSION 4" DIAMETER - 40" LONG	156.8	.2	172.3	1.2	166.3	.6	492	3.86
93	KEVLAR FABRIC TOTAL CONTAINMENT BAG WITH LAYERED BOTTOM 20" DIAMETER - 48" LONG	167.0	.65	170.7	2.5	168.3	.75	192	5.99
94	KEVLAR FABRIC TOTAL CONTAINMENT BAG WITH REINFORCED BOTTOM 20" DIAMETER - 48" LONG	168.3	.6	179.9	2.75	168.3	.75	303	5.99
95	KEVLAR FABRIC PARTIAL CONTAINMENT BAG WITH WEB GRID BOTTOM 20" DIAMETER - 48" LONG	170.8	2.0	176.8	2.0	176.3	1.9	481	2.81
96	KEVLAR FABRIC PARTIAL CONTAINMENT BAG WITH VENTED SIDE AND BOTTOM 20" DIAMETER - 48" LONG	172.7	1.25	181.3	3.35	174.3	1.5	466	5.20
97	REDUCED DEBRIS NOZZLE CLOSURE BASELINE	176.1	1.88	182.8	4.0	172.7	1.25	281	.32
98	REDUCED DEBRIS NOZZLE CLOSURE BASELINE	175.1	1.68	181.9	3.6	174.3	1.5	367	.32
99	KEVLAR FABRIC BAFFLED CYLINDER 3 BAFFLES - 4" SPACING 10" DIAMETER - 12" LONG	174.3	1.5	179.6	2.75	170.5	.97	479	4.4
100	KEVLAR FABRIC BAFFLED CYLINDER 3 BAFFLES - 4" SPACING 10" DIAMETER - 12" LONG FIRED WET	164.7	.5	176.8	2.0	167.7	.7	485	5.2
101	6" LAUNCH TUBE AFT EXTENSION WITH NO SUPPRESSOR	160.1	.75	181.9	3.6	171.7	1.1	479	.98

* BASELINE LEVELS FROM TABLE 2-II

6.3 (Continued)

sound pressure level versus time data used to locate these secondary pressure peaks were recorded in real time during each firing of the Scaled and Fieldweight Suppressor Test. These recorded data were played back at a slower speed to obtain the traces used in these analyses. The baseline pressure versus time trace from Round 71 used for comparison is typical of an unsuppressed firing of the M-72 weapon system but it was not one of the firings used to establish the baseline data given in Table 2-II. In order to compare these pressure versus time traces for different configurations it was necessary to determine if the pressure wave arrival time at gage A varied with configuration. Since actual firing time could not be determined from the available data, it was decided to use the muzzle velocity timed gate 1 as a reference. The time differential between the pressure wave arrival at gage A and the timed gate 1 has been plotted for several suppressor configurations in Figure 6-7. The mean time differential for time differentials given in Figure 6-7 is 9.996 miliseconds with a standard deviation of ± .317 miliseconds. Based on this small deviation, the pressure versus time traces compared in the following analyses assume that the pressure wave arrival time at gage A is the same for each configuration. This relationship was also used in the frame by frame analyses of the high speed movie data. This analysis was made to relate noise pressure level versus time traces with events that could be determined optically. Results of the film data analyses will also be pointed out where they were used.

The projectile muzzle velocity for each scaled and fieldweight suppressor configuration tested are tabulated in Table 6-II. These data show that the presence of these suppressors do not effect missile performance in terms of muzzle velocity. The performance results of each of the four basic types of Scaled and Fieldweight Suppressors will be discussed in the following paragraphs.

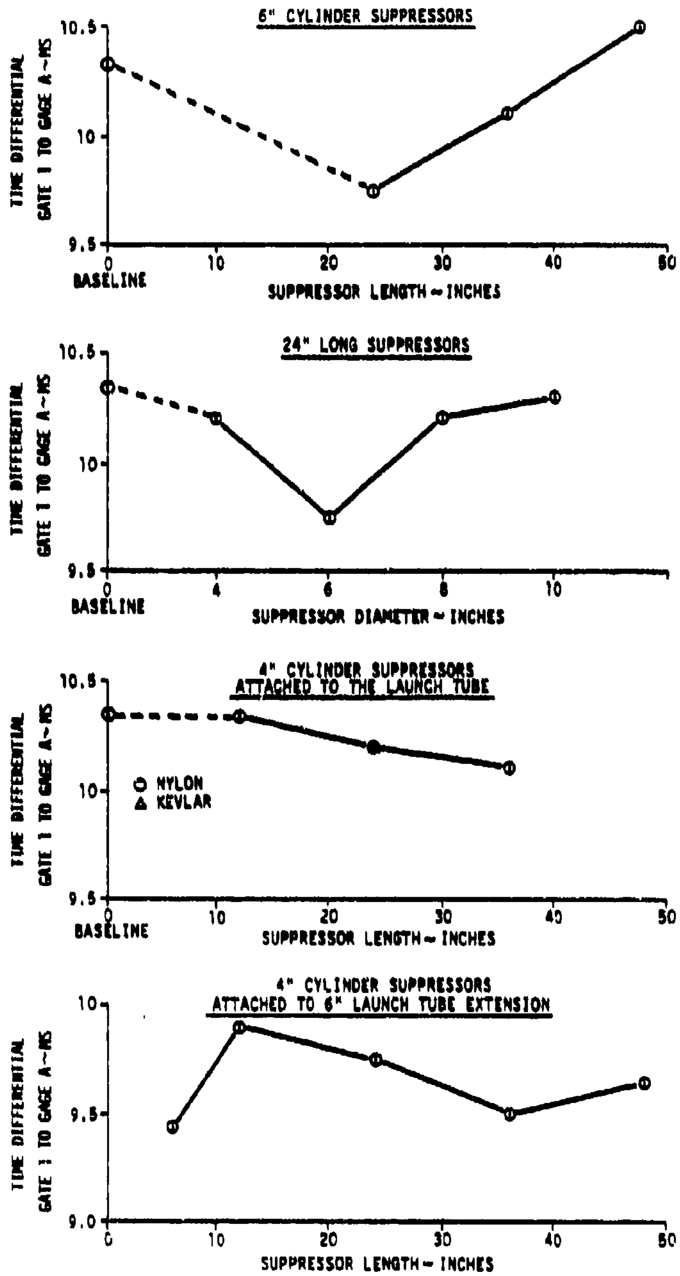


FIGURE 6-7 PRESSURE WAVE ARRIVAL TIME AT GAGE A VERIFICATION

6.3.1 Total Containment Kevlar Fabric Bag Suppressor Data Analysis

The full containment Kevlar fabric bag suppressors were tested with the M-72 weapon system rocket motor that used the reduced debris nozzle closure and igniter case described in Paragraph 6.1.1. Two firings were made with this modified nozzle closure to establish a baseline. The peak noise at the gunners position using these modified nozzle closures averaged 1.75 psid/175.6 db compared ro 2.14 psid/177.5 db for the standard M-72 baseline established in Paragraph 2.0. The sound pressure level versus time trace for a firing of the modified closure is given in Figure 6.8. The time scale for these data has been established as the time when the initial peak pressure wave arrived at gage A position. The data are shown for at least ten (10) miliseconds following the initial peak noise pressure rise. Gage A (gunners position) noise pressure data are shown in Figure 6-8 for the layered and reinforced bottom total containment Kevlar fabric bags. The initial peak pressure for each of these bags occurs almost a milisecond after the initial noise pressure rise sensed by gage A. The total containment bag peak noise reduction capability based on this initial pressure peak 1.15 psid/9.3 db when compared to the baseline for the reduced debris nozzle closure motor firings. Analysis of the movie data provided some rationale for the secondary peak pressures occuring at about 4, 5 and 9 miliseconds into the recorded data for gage A in Figure 6-8. The first secondary pressure peak late in the third milisecond apparently occurred when the bag was completely filled and began to pressurize above ambient pressure. The pressure peak at about five (5) miliseconds was caused when the forward end of the bag began to break near the launch tube/bag joint and allow some of the contained gasses to escape. At about nine (9) miliseconds, the pressurized bag began separating from the reusable launch tube. As the bag began to break the gasses contained in the bag began flowing forward through the opening in the forward end of the bag. These forward flowing gasses impacted the aft flowing blowdown gasses from the launch tube creating an impact area of severe turbulence near the aft end of the launch tube. The turbulence was the likely cause of the noise and/or

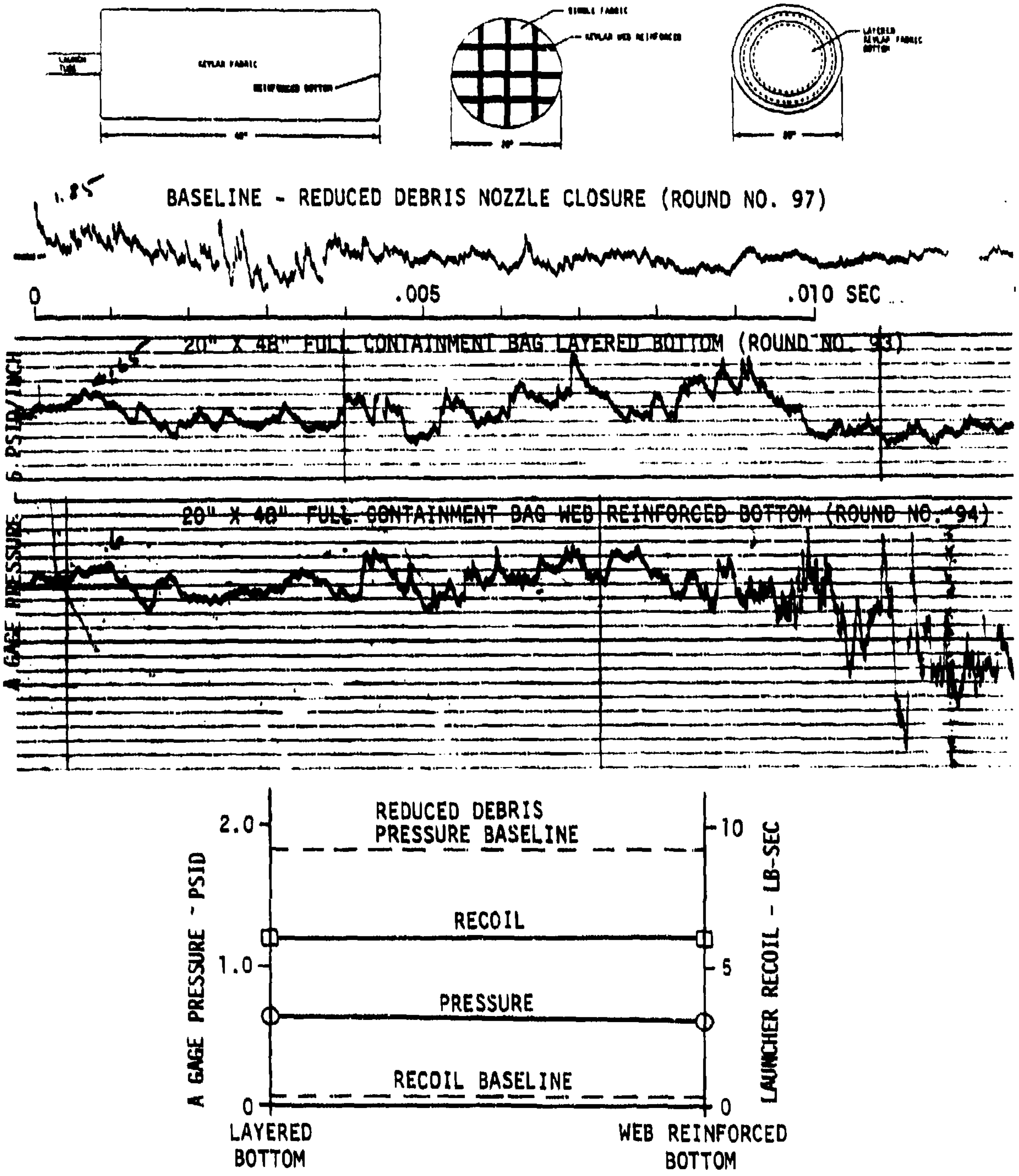


FIGURE 6-8 TOTAL CONTAINMENT KEVLAR FABRIC BAG SUPPRESSOR PERFORMANCE

6.3.1 (Continued)

acceleration which began at about nine (9) miliseconds into the recorded data for gage A.

The recoil level for the total containment bags was measured at six lb-sec. It should be noted that both bags separated from the reusable launch tube late in the missile firing. The reduced debris nozzle apparently caused a slow burn to occur in the M-72 rocket motor. This low performance is apparent in the data for Rounds 93, 94, 97 and 98 which show the low projectile muzzle velocity (Table 6-II) both in the baseline and the suppressor tests. This apparent ignition problem can be corrected by a redesign of the igniter without sacrificing it's debrisless nature.

6.3.2 Partial Containment Kevlar Fabric Bag Suppressor Data Analysis

The partial containment Kevlar fabric bag suppressors were tested with the standard M-72 rocket motor. The baseline noise sound pressure level versus time at the gunners position (gage A) for the standard M-72 is shown in Figure 6-9. Similar data for the partial containment bag suppressors are also shown in Figure 6-9. The data show that the initial pressure that penetrates the web bottom bag is attenuated by .2 psid. No significant secondary pressure peaks occur with the web bottom partial containment bag. The gunners position noise pressure level versus time data for the side and bottom vent partial containment bag show that the initial pressure wave that penetrated the bag was attenuated by .95 psid. No significant secondary pressure peaks occurred with the side and bottom vent bag suppressor.

Comparing recoil levels of the two partial containment bag suppressors reveal that the addition of side venting increased the launcher recoil by 2 lb-sec.

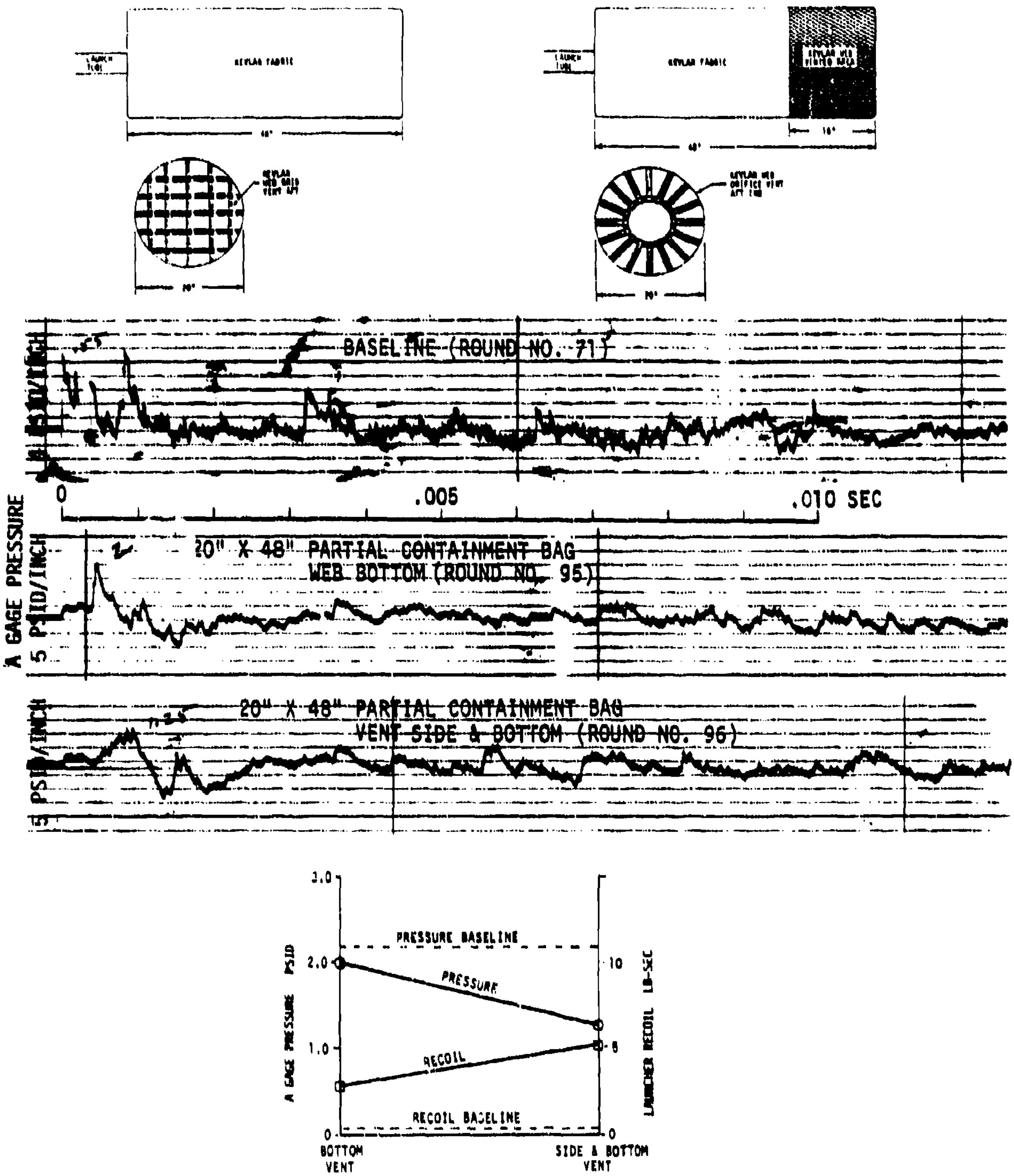


FIGURE 6-9 PARTIAL CONTAINMENT KEVLAR FABRIC BAG SUPPRESSOR PERFORMANCE

6.3.3 Open Cylinder Kevlar Fabric and Woven Nylon Suppressor Data Analyses

The gunners position peak noise reduction capability and launcher recoil level of twenty different Kevlar fabric and woven Nylon open cylinder suppressors are summarized in Figures 6-10 through Figure 6-15. These summary data include both vented and non-vented configurations. The following paragraphs will include comments on particular groupings of the open cylinder suppressor configurations.

6.3.3.1 Six Inch Diameter Kevlar Fabric Open Cylinder Suppressors

The data for the six (6) inch inside diameter Kevlar fabric open cylinder suppressors are presented in Figure 6-10. Data are given for 24, 36 and 48 inch long suppressors that includes tne gunners position (gage A) noise pressure level versus time and launcher recoil impulse.

Each configuration has similar capability for reducing the initial noise pressure wave produced during the first milisecond of the baseline firing. The film study revealed that the secondary pressure peak in the data for the 24 inch long suppressor was caused by a break occurring in the side seam of the suppressor. No film data were available for the 36 inch long suppressor but it did break in the side seam. This break could have caused the secondary pressure peak at three (3) miliseconds into the recorded data. The 48 inch long suppressor also failed in the side seam. The film showed that the side seam failed in a progressive manner beginning near the forward end and progressing to the aft. The break occurred over a two (2) milisecond period accounting for the several pressure peaks during the second and third miliseconds of the recorded data.

The recoil data do not show recoil to be a strong function of suppressor length. This may not be realistic since each of the suppressors broke in the side seam two to three miliseconds into the recorded data. A break of this type allows gas to divert off the launch tube centerline causing the suppressor to produce recoil. These similar side seam breaks

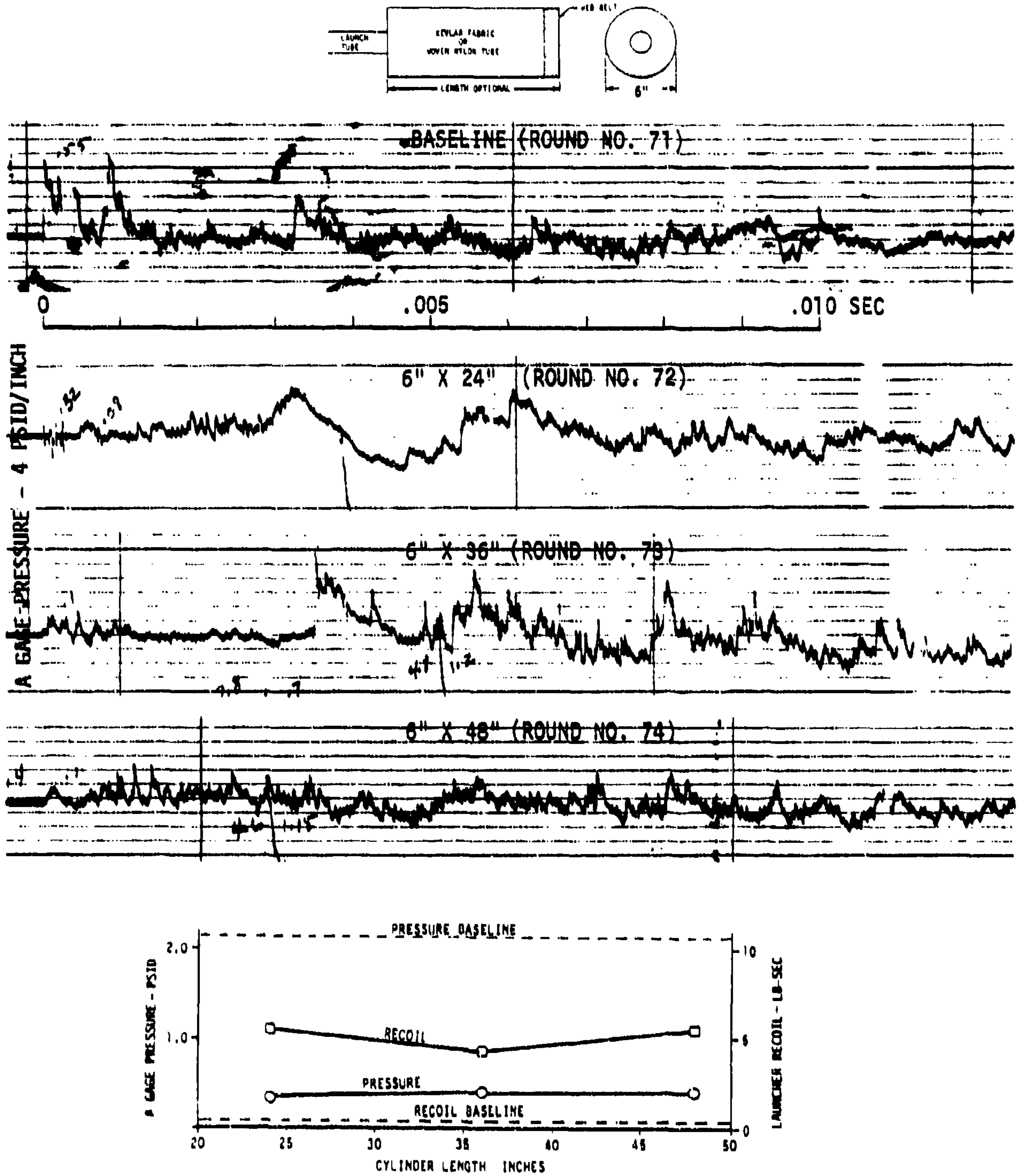


FIGURE 6-10 SIX INCH INSIDE DIAMETER KEVLAR FABRIC OPEN CYLINDER SUPPRESSOR PERFORMANCE

6.3.3.1 (Continued)

produce recoil levels from 4.2 to 5.5 lbs-sec. The rigid open cylinder suppressor six (6) inches diameter and twenty four (24) inches long (Figure 4-11) produced only 1.1 lb-sec recoil. When compared to the rigid open cylinder suppressor, the fabric suppressor also has more internal surface roughness, it has a tendency to balloon and ripple and it does not have a rigid forward closure for reaction of pressure forced. Each of these can be considered contributors to the higher recoil levels which can be reduced by minor redesign of the suppressors.

6.3.3.2 Twenty Four Inch Long Kevlar Fabric Open Cylinder Suppressor

The data for the 24 inch long Kevlar fabric open cylinder suppressors of 4, 6, 8 and 10 inch inside diameters are given in Figure 6-11. These data include the gunners position (gage A) noise pressure level versus time and the launcher recoil impulse. Each of the suppressors reduced the peak noise pressure level produced by the baseline M-72 rocket motor firing. A frame by frame study of the high speed movies recorded during the test of each suppressor revealed that the secondary pressure peaks are associated with breaks in the side seam of each suppressor. The four (4) inch inside diameter suppressor reduced the initial peak noise pressure level to .4 psid but when the side seam failed, at about two (2) miliseconds into the recorded data, a secondary pressure peak of 2.4 psid occurred.

The performance of the six (6) inch inside diameter and 24 inch long Kevlar fabric suppressor was discussed in Paragraph 6.3.3.1.

The eight (8) inch inside diameter suppressor reduced the initial peak noise pressure level to .32 psid. The side seam began to break at two (2) miliseconds into the recorded data and was open the entire length of the suppressor at four (4) miliseconds. Secondary pressure peaks associated with the progressive side seam break can be seen in the data from 2 to

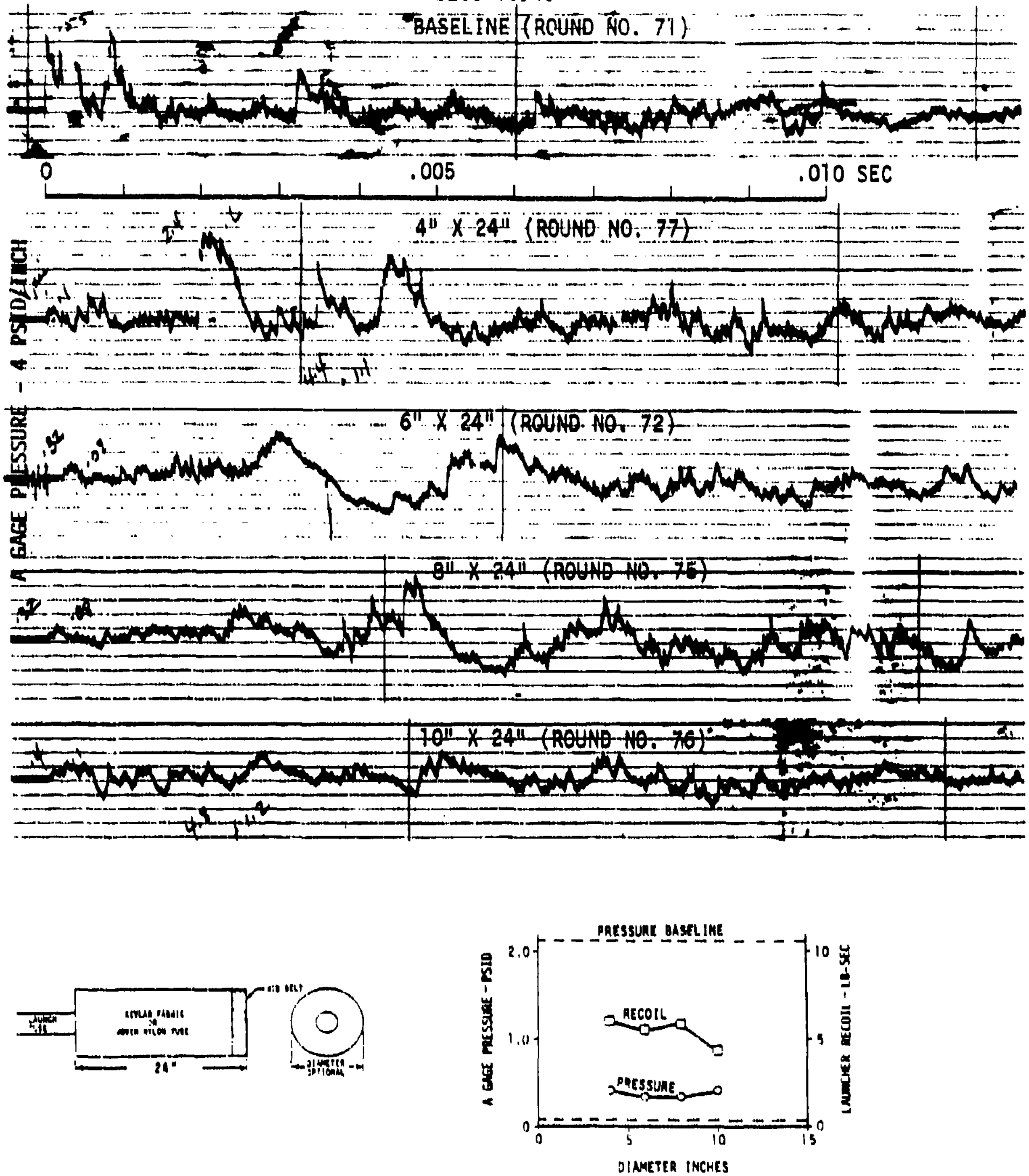


FIGURE 6-11 TWENTY FOUR INCH LONG KEVLAR FABRIC OPEN CYLINDER SUPPRESSOR PERFORMANCE

6.3.3.2 (Continued

4.5 miliseconds into the recorded data.

The ten (10) inch inside diameter suppressor reduced the initial peak noise pressure level produced by the baseline firing to .4 psid and has no appreciable secondary pressure peaks. The ten (10) inch inside diameter suppressor had only a small break in the side seam after the test. The absence of a significant noise pulse for this suppressor is further indication that the strong secondary pressure peaks seen in the 4, 6 and 8 inch inside diameter suppressor data were caused when the side seams broke.

The recoil level of the 4, 6 and 8 inch inside diameter open cylinder Kevlar fabric suppressors was between 5.5 and 6 lb-sec while the ten (10) inch inside diameter suppressor produced only 4.2 lbs-sec recoil. This lower recoil indicates that if the side seam breaks, allowing the exhaust gasses to turn away from the launcher centerline and impinge on the suppressor, higher recoil can be expected from the suppressor.

6.3.3.3 Four Inch Diameter Open Cylinder Suppressors Mounted on the Launch Tube

The data for the four (4) inch inside diameter Kevlar Fabric and woven Nylon open cylinder suppressors mounted on the reusable launch tube are given in Figure 6-12. These data include the gunners position (gage A) noise pressure level versus time and the launcher recoil. Each configuration reduced the peak noise pressure level produced by the firing of the M-72 weapon system. The high speed movie data was used to explain the cause of the secondary pressure peaks that occurred in the data for each of the configurations. The woven Nylon open cylinder suppressors retained structural integrity for about one milisecond and then began to separate from the launch tube due to melting of the fabric about one diameter aft of the launch tube. As this melting and separation occurred, secondary noise pressure peaks occurred in the recorded data. The thirty six (36) inch long suppressor broke in less than one milisecond causing the high

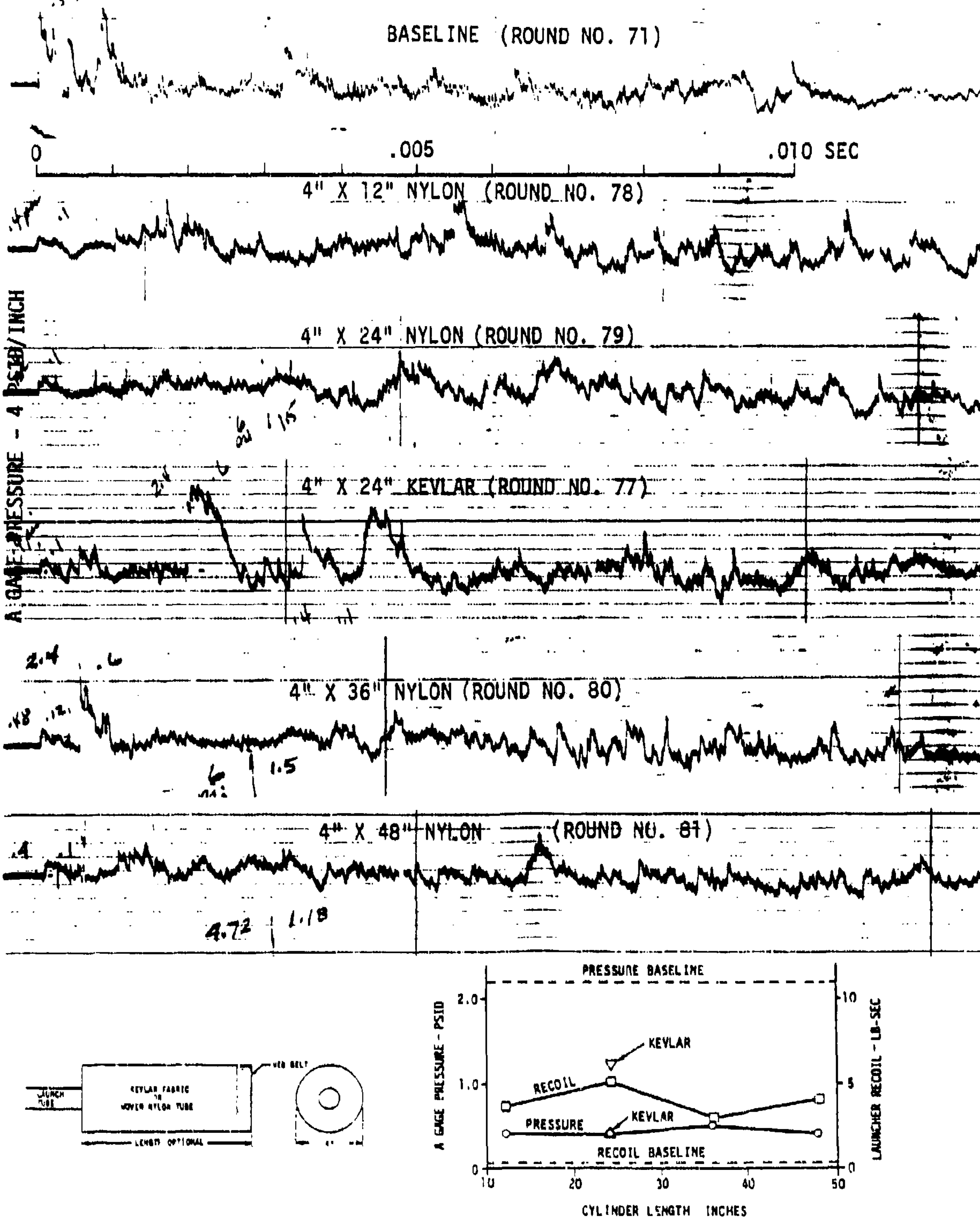


FIGURE 6-12 FOUR INCH DIAMETER OPEN CYLINDER SUPPRESSOR PERFORMANCE WHEN MOUNTED ON THE LAUNCH TUBE

6.3.3.3 (Continued)

secondary pressure peak at about .5 milisecond into the recorded data.

The twenty four (24) inch long Kevlar fabric suppressor began to fail and vent through the side seam during the first milisecond of the recorded data and the entire side seam had failed at about two miliseconds. This failure in the side seam caused the high secondary pressure peak at two miliseconds into the recorded data.

The recoil impulse produced by the woven Nylon open cylinder suppressors appear to be a function of the time required for the suppressor to separate from the reusable launch tube. The thirty six (36) inch long woven Nylon suppressor broke free in .5 miliseconds and produced only 2.91 lb-sec recoil. The Kevlar fabric twenty four (24) inch long suppressor which broke free of the launcher in almost two miliseconds produced 6.01 lb-sec recoil impulse.

6.3.3.4 Four Inch Diameter Open Cylinder Suppressors Mounted on a Six Inch Launch Tube Aft Extension

The data for the four (4) inch inside diameter woven Nylon open cylinder suppressors mounted on a six (6) inch launch tube extension are given in Figure 6-13. These data include the gunners position (gage A) noise pressure level versus time and the launcher recoil. Each configuration including the launch tube extension reduced the initial peak noise pressure produced by the baseline firing of the M-72 weapon system. The six inch launch tube extension was not very effective in reducing the peak noise overpressure until the fabric suppressor was added, however the increase in recoil level remained low. Addition of the fabric suppressor not only improved the noise reduction capability but caused a large increase in recoil level. This abrupt change in the recoil level can be attributed to the

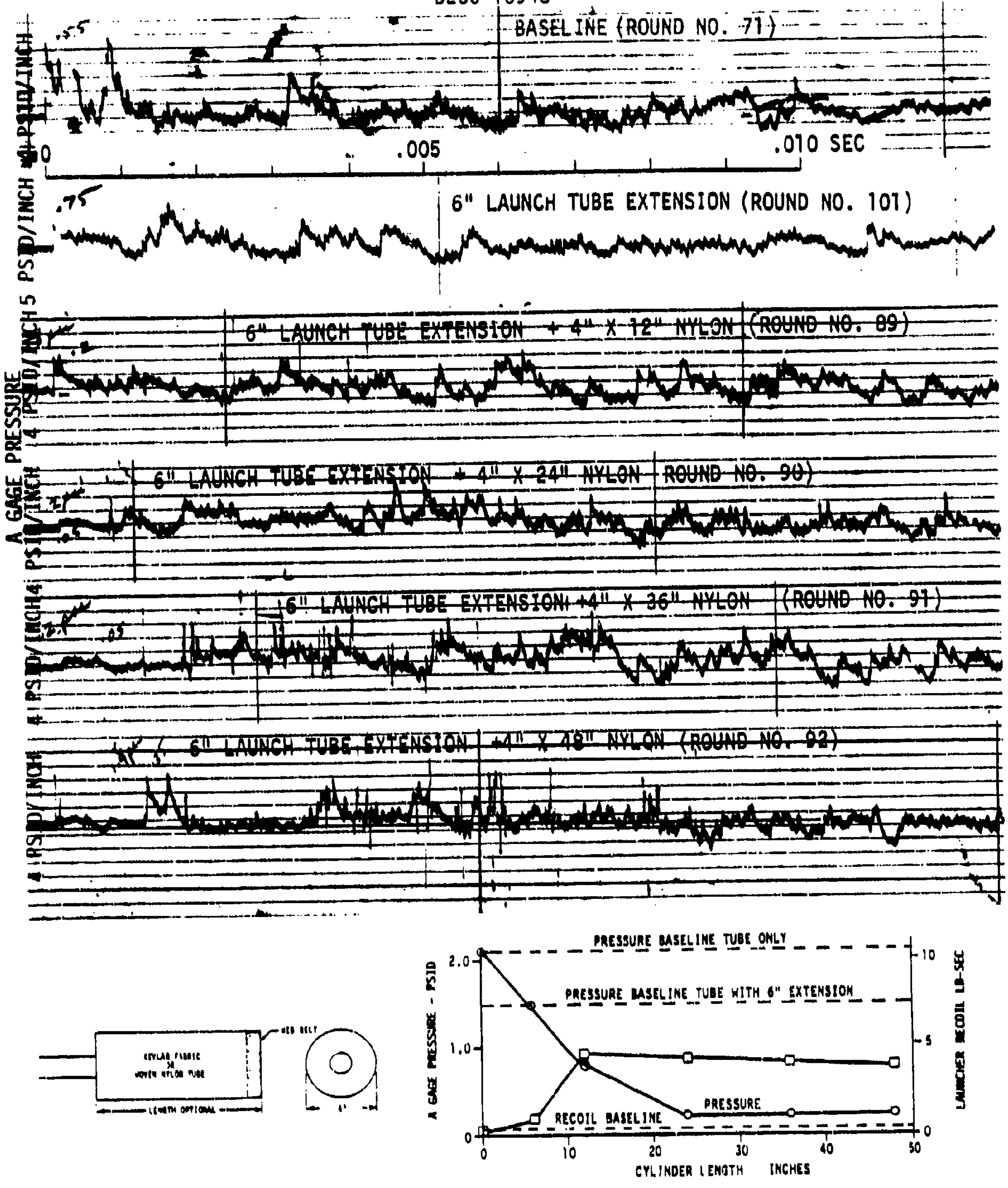


FIGURE 6-13 FOUR INCH DIAMETER OPEN CYLINDER SUPPRESSOR PERFORMANCE WHEN MOUNTED ON A SIX INCH LAUNCH TUBE EXTENSION

6.3.3.4 (Continued)

internal surface roughness, ballooning and rippling associated with a functioning fabric suppressor. The initial peak pressure is reduced to .2 psid by suppressor lengths of 24, 36 and 48 inches. Increasing suppressor lengths above 24 inches has no apparent effect on the noise reduction capability at the gunners position for these suppressors.

The movie data revealed that the first secondary peak in the 12 and 24 inch long suppressor data is associated with the noise pressure wave that is emitted from the aft end of the suppressor. Each of the woven Nylon suppressors melted and separated from the launch tube extension in the same manner as similar configurations separated from the launch tube as described in Paragraph 6.3.2.3. The 12 inch long suppressor began to fail just after three miliseconds and the 24 inch long suppressor began to fail at about 1.5 miliseconds. A second secondary pressure peak can be seen in the data where the suppressors began to fail and allow exhaust gasses to escape through the side of the suppressor.

The 36 inch long suppressor began to fail before the initial pressure wave was emitted from the suppressor aft end. The strong secondary pressure peaks beginning at 1.5 miliseconds are associated with the gasses escaping through the side of the suppressor near the end of the six inch launch tube extension.

The first secondary pressure peak in the data for the 48 inch long suppressor occurred when the suppressor separated from the six inch launch extension.

The recoil impulse measured during this series of tests show that recoil increases for open cylinder lengths up to twelve inches. Suppressor lengths above twelve inches have essentially the same recoil impulse. This is an indication that the 24, 36 and 48 inch long suppressors separated from the suppressor at near the same time after the motor fired. Secondary peak pressures associated with the break are evident

6.3.3.4 (Continued)

in the second milisecond of the recorded data for each of these configurations.

6.3.3.5 Six Inch Inside Diameter, Twenty-Four Inches Long Vented Cylinder Suppressors

The data for the six inch inside diameter by 24 inches long vented cylinder suppressors are shown in Figures 6-14 and 6-15. These data include the gunners position (A gage) noise pressure level versus time and the launcher recoil. As shown in Figure 6-14, the initial peak noise pressure was reduced by each configuration well below that of the baseline M-72 peak noise pressure levels. It can also be seen that the aft vent configurations reduce the peak noise more effectively than the forward or full vent configurations. The gunners position (A gage) noise pressure level versus time data given in Figure 6-15 show that the secondary pressure peaks in the data for each configuration. A study of the movies revealed that the secondary pressure peaks during the second milisecond in the data for the aft vent configurations were caused by the pressure wave penetrating the vent area and then exiting the aft end of the suppressor. The third secondary pressure peak at almost four miliseconds occurred when these suppressors separated from the launch tube.

The forward vent cylinder suppressor has a series of secondary pressure peaks caused by first the pressure wave reaching the forward end of the aft non-vented cylinder, second the pressure wave exiting the aft end of the suppressor and third when the suppressor separated from the launcher. The full braided vent suppressors have two secondary pressure peaks. The first is associated with the pressure wave exiting from the aft end of the suppressor and the second is associated with the suppressor breaking away from the launch tube or the breakaway tie breaking.

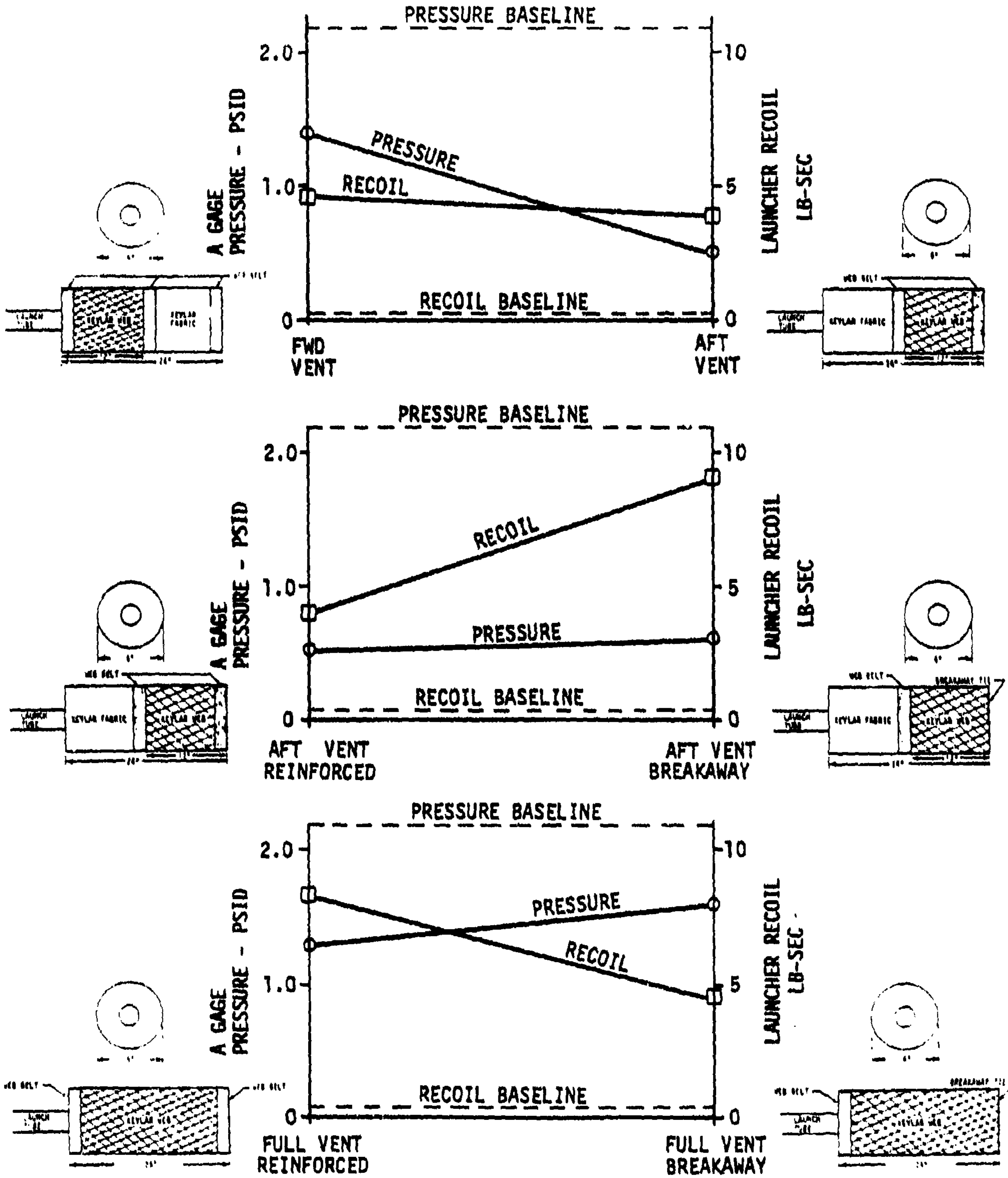


FIGURE 6-14 SIX INCH VENTED CYLINDER SUPPRESSOR PERFORMANCE

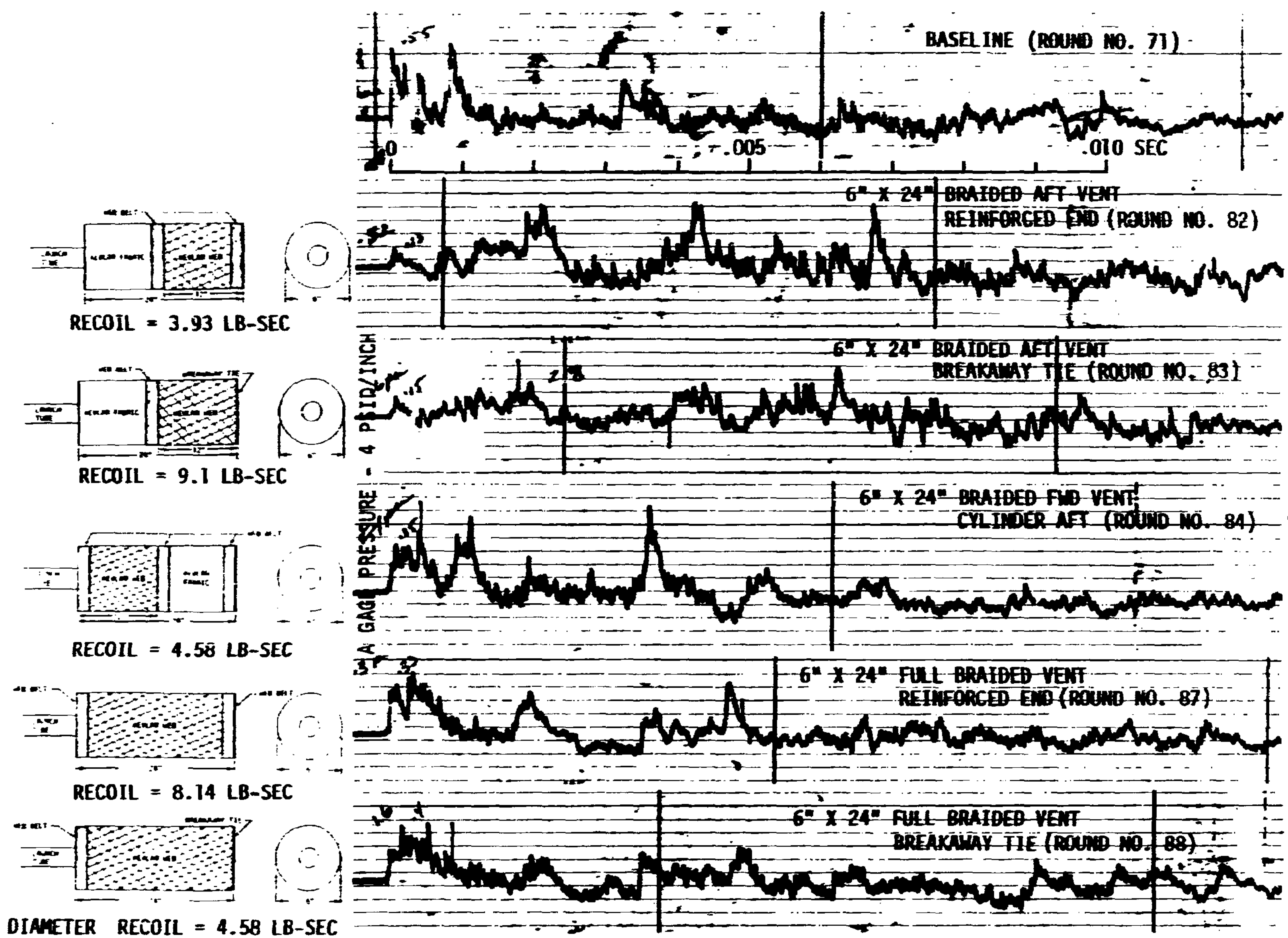


FIGURE 6-15 SIX INCH VENTED CYLINDER SUPPRESSOR GUNNER POSITION NOISE PRESSURE LEVEL

6.3.3.5 (Continued)

The full vented suppressor with the breakaway tie did not separate from the launch tube. Forward and full vent suppressors show very little effect on peak noise suppression indicating that the non venting portion of the partial vent cylinder suppressors is functioning as the suppressor.

6.3.4 Kevlar Fabric Baffled Cylinder Suppressor Test Data Analysis

The peak noise reduction capability for the Kevlar fabric baffled cylinder suppressor at the gunners position (gage A) is given in Figure 6-16. Both configurations tested were the same configuration with only the test conditions different. One suppressor was tested dry and the other was saturated with water just prior to the firing. The data presented in Figure 6-16 show that both suppressors reduced the initial peak noise produced by the baseline firing of the M-72 weapon system. The dry suppressor reduced the initial peak pressure by .64 psid/3.2 db but had several secondary pressure peaks that occurred during the firing. A frame by frame study of the high speed film taken during the test revealed that the secondary pressure peaks occurring during the second milisecond were associated with the pressure wave exiting the suppressor aft end. The pressure peak that occurred at about 3.5 miliseconds was associated with the suppressor separating from the reusable launch tube.

The saturated Kevlar fabric baffled cylinder suppressor reduced the initial peak noise pressure by 1.64 psid/12 db. The noise pressure versus time data contain two weak secondary pressure peaks that were identified in the film study as being caused by the pressure wave exiting the aft end of the suppressor (1.6 miliseconds) and when the suppressor separated from the reusable launch tube (3.8 miliseconds).

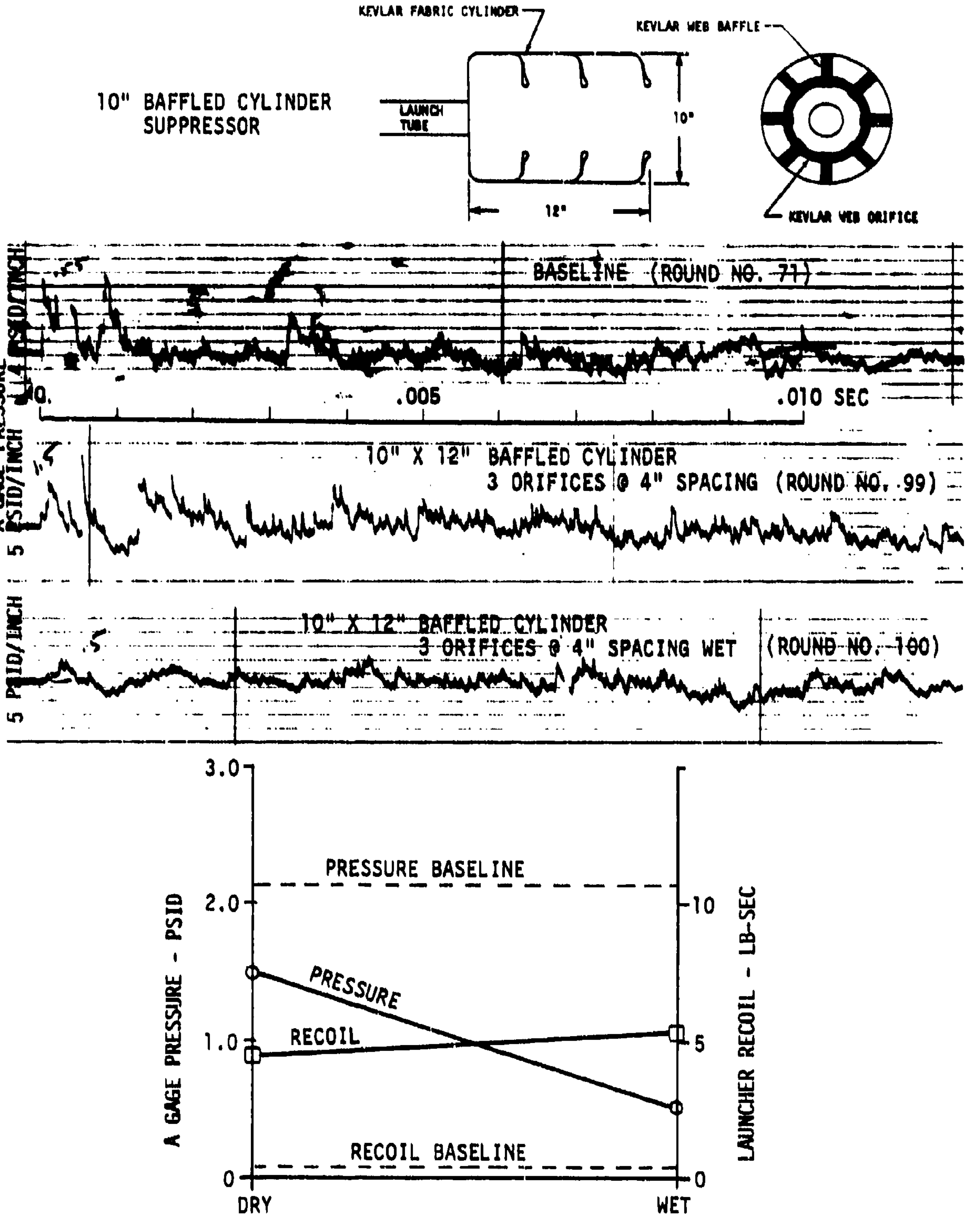


FIGURE 6-16 KEVLAR FABRIC BAFFLED CYLINDER SUPPRESSOR PERFORMANCE

6.3.4 (Continued)

The recoil level (4.4 and 5.2 lb-sec) of both the dry and wet Kevlar fabric baffled cylinder suppressors was slightly lower than the 5.97 lb-sec recoil produced by the 10 inch inside diameter heavyweight suppressor with flexible baffles at four inch spacing and 2.5 inch orifices. This fabric suppressor did not approach the zero recoil level measured for this heavyweight suppressor with yielding baffles.

7.0 ANALYSIS AND PREDICTION MODEL

When the pressure in the combustion chamber has increased to a sufficient level, after a rocket motor ignition, the nozzle closure is suddenly discharged. The resultant flow field generated is difficult to analyze as a result of the large number of variables related to the closure discharge. Assuming an instantaneous closure discharge, a planer shock wave would be formed in the ambient air within the nozzle and it would travel down the nozzle. This planar shock then diffracts around the launcher aft end and becomes the spherical lead shock. Immediately following the lead shock, the contact surface between the quiescent ambient air and the high temperature/pressure rropellant exhaust gases would be discharged from the nozzle exit plane. The lead shock can be considered spherical with its center located on the launch tube center line downstream of the nozzle exit plane. The distance downstream can be determined by momentum considerations consistent with the motor properties such as thrust, nozzle exit velocity and propellant flow rates. It should be noted that when the nozzle closure is discharged, double shocks could be evidenced. This may be the result of momentary chamber pressure decay and subsequent build-up until stable combustion has been obtained. Because individual motor burn rate, combustion chamber pressure, etc., are different, this phenomena may not be necessarily repeatable for all firings. The energy released from the closure discharge is relatively small compared to the motor propellant energy release therefore the initial closure shock will be overtaken and coalesced with the exhaust gas contact surface at some location near the launcher aft end.

The following paragraphs will describe the unsteady inviscid and adiabatic fluid flow equations along with the assumptions and approach to solving these equations for evaluating the flow field response to the firing of

7.0 (Continued)

the M-72 rocket motor. Conservation of mass, energy and momentum for the elemental control volumes are evaluated in relation to the upstream flow conditions and the elemental boundary constraints. The solution is brought about by using an electric resistance network analog technique suitable for a phenomena where transported flux is proportional to a driving flux or a potential gradient is developed.

The model has been used to predict the overpressure associated with the shock generated by firing the M-72 weapon system with no suppressor. This prediction produced a shock overpressure at the gunners position of 2.19 PSID compared to the average baseline peak noise overpressure of 2.14 PSID. Recommendations for future model development have also been included.

7.1 ASSUMPTIONS

The assumptions that are considered the most dominant in the formulation of blast wave numerical solutions are listed below.

- When the nozzle is underexpanded there are no shock waves in the nozzle, and the operation is frictionless.

- The process is considered adiabatic for boundary conditions along the suppressor longitudinal axis.

- When the motor closure is discharged a compressive lead shock wave is instantaneously formed at the nozzle exit plane. This lead shock (and a trailing contact surface wave) are considered spherically symmetric at numerical integration initiations.

7.1 (Continued)

- The total energy (including kinetic) from the discharge of the expanding propellant gas is thermally dissipated in the control volume.
- When the planar shock is ejected from the nozzle, it is diffracted spherically around the aft end of the launcher.
- The burned propellant is considered a single component.
- For both the cylindrical coordinates and the spherical coordinates there are no conductive thermal flux in the radial component direction. There is however, a fluid flow conductive flux in the launcher longitudinal direction.
- There are no secondary or tertiary pressure pulses in the control volume resulting from the burning of particulate propellant.
- The physical presence of the nozzle closure in the effective control volume has no influence on the flow field.

7.2 MODEL DEVELOPMENT

The equations defined in this paragraph are the basic equations used in the numerical integration techniques. They are intended to give some insight into the qualitative and quantitative requirements for defining the shock wave phenomena. The following is a list of the nomenclature used in developing the equations.

a_1	local speed of sound
C_s	lead shock velocity
C_v	specific heat at constant volume
K_{i_j}	fluid flow conductance

7.2 (Continued)

K'_{ij}	fluid flow conductance after displacement
M_1	shock Mach number
N	number of iterations
n_i	elemental lumped parameters for the control volume
n_j	elemental lumped parameter for the motor
n'_i	displaced elemental lumped parameter for the control volume
n'_j	displaced elemental lumped parameter for the motor
P_1	ambient pressure
P_2	contact surface pressure
P'_2	pressure behind the contact surface
Q_1	motor nozzle total energy source
Q_2	energy loss/gain from total density change
Q_3	energy loss/gain from suppressor volume change
Q_4	energy loss/gain from blast wave volume change
Q_5	energy loss/gain from launcher volume change
Q_{in}	heat flow into a control volume
Q_{out}	heat flow out of a control volume
r_{1C}	cylindrical control radius in launch tube
r_{2C}	cylindrical control radius in suppressor
r_{3S}	spherical control radius
$\dot{r}_c$	radial velocity in cylindrical coordinates
$\dot{r}_s$	radial velocity in spherical coordinates
Δr_1	spherical control volume displacement distance
S_n	energy source
T	temperature
U	internal energy (WC_vT)
U_s	contact surface velocity
U'	particle velocity behind the contact surface
V	projectile velocity
V_1	control volume in the launch tube
V_2	control volume in the suppressor
V_3	spherical control volume

7.2 (Continued)

V_T	total volume control
V'_3	displaced spherical control volume
W	mass in lumped element
x	axial distance
$\dot{x}$	axial velocity
$-X_B$	body inertial coordinate in X direction
ΔX_1	projectile displacement distance in launch tube
ΔX_2	contact surface displacement distance in the suppressor
$\Delta X'$	center of explosion dislocation resulting from momentum effects
y'	pressure ratio P_2/P_1
$-Z_B$	body inertial coordinate in Z direction
V_1	specific heat ratio for motor exhaust gasses
ρ_T	total control volume density

7.2.1 Elemental Control Volume

The effective control volume for tube launched weapon system suppressor attached and unattached mode are depicted in Figures 7-1 and 7-2 respectively. Looking at Figure 7-1 the control volume for V_1 is contingent on the distance (ΔX_1) the rocket traverses along the launcher axial center line in the negative body coordinate direction. The swept volume is applicable when the suppressor is attached or unattached. The swept volume displaced in the attached suppressor cylinder V_2 is a function of the contact surface velocity displacement (ΔX_2) along the center line (assuming a planar wave pattern) until it is emitted from the suppressor aft interface. The spherical control volume is estimated by the radial displacement (Δr_1) originating from the center of explosion.

The control volumes for the no suppressor mode are similar to the attach suppressor concept except the intermediate control volume for the suppressor cylinder is omitted.

The summated volume for the cylindrical and spherical coordinates in differential form is:

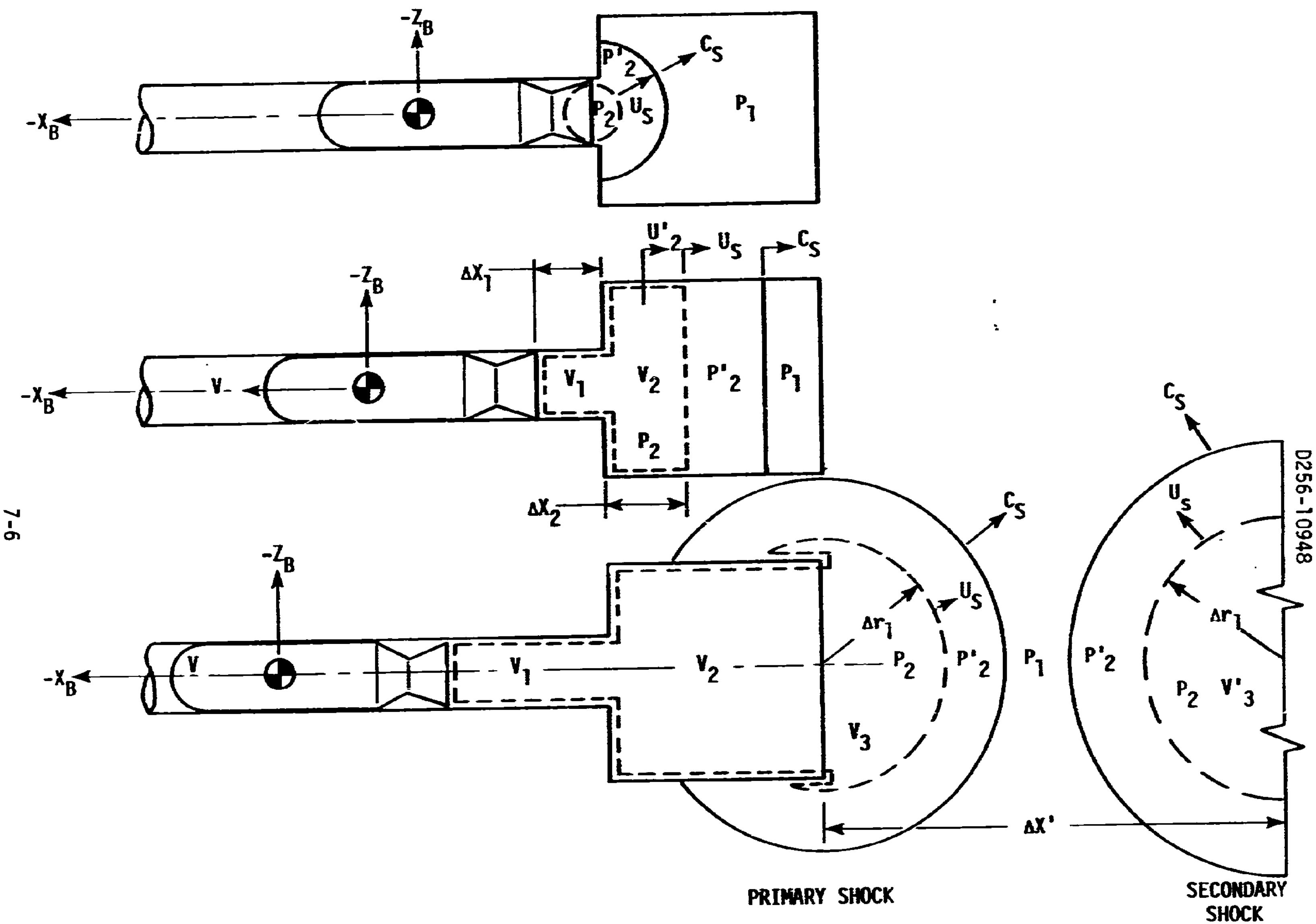


FIGURE 7-1 EFFECTIVE CONTROL VOLUME WITH SUPPRESSOR ATTACHED

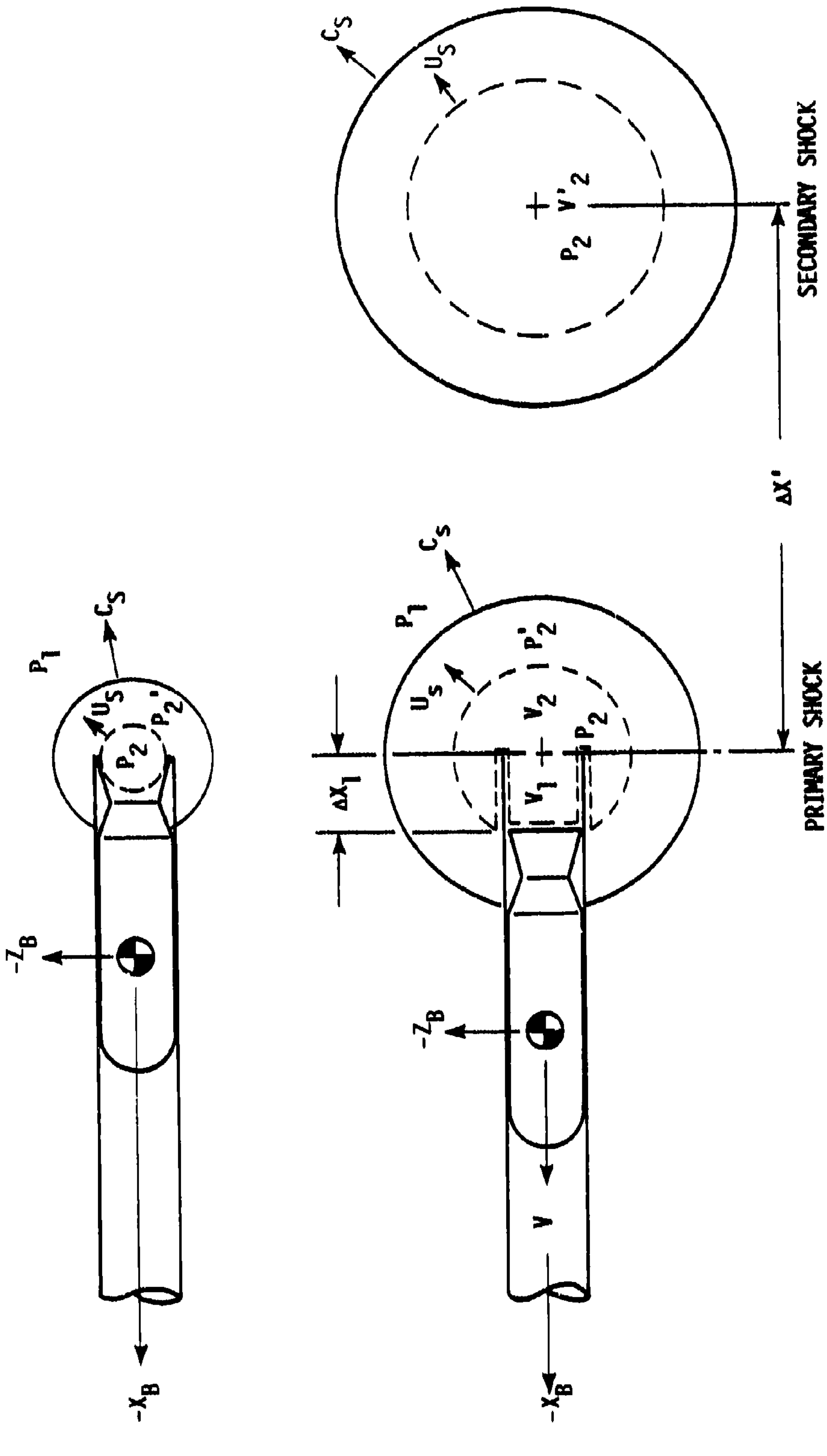


FIGURE 7-2 EFFECTIVE CONTROL VOLUME WITHOUT SUPPRESSOR

7.2.1 (Continued)

$$\frac{dV_{TOT}}{dt} = \left(\frac{\partial V_1}{\partial r_c} + \frac{\partial V_2}{\partial r_c}\right) \dot{r}_c + \frac{\partial V_3}{\partial r_s} \dot{r}_s + \left(\frac{\partial V_1}{\partial x} + \frac{\partial V_2}{\partial x}\right) \dot{x}$$

7.2.2 Shock Velocity

For plane wave motion it is noted that on either side of the contact surface the instantaneous temperature and densities have different values, but the pressure and particle velocities behind the surface have the same magnitudes:

$$U' = U_s$$

and

$$P'_2 = P_2.$$

Using the pressure ratio P_2/P_1 contact surface velocity (see Figures 7-1 and 7-2) can be evaluated for both plane and spherical surfaces:

$$U_s = a_1 \, (y' - 1) \left[\frac{2/\gamma_1}{(\gamma_1+1) \, y' + (\gamma_1-1)} \right]^{1/2}$$

7.2.2 (Continued)

The lead shock velocity is evaluated using the Rankine-Hugoneot relations:

$$C_s = M_1 a_1 = a_1 \left(\frac{\gamma_1 - 1}{2\gamma_1} + \frac{\gamma_1 + 1}{2\gamma_1} y'\right)^{1/2}$$

7.2.3 Electric Analog Network

The electric circuit analog of tube launched weapon systems (with and without a suppressor) are diagrammatically shown in Figures 7-3 and 7-4 respectively. The elemental (lumped parameter) locations utilized in the network are identified as n_j for the motor element and n_i for the control volume element. The circuit consists of two capacitive elements, one fluid flow conductor and an energy source to element n_j. It is noted that the fluid flow conductor matrix K_{i_j} and element n_i are displaced by an axial distance $\Delta X'$. This displacement results from the motor thrust, propellant flow and exit velocity transient and steady state variations that are consistent with the momentum conservation requirements.

7.2.4 Energy Balance

The method for computing the thermal dissipation within the system requires that the differential equations represents time dependent systems. This system is established by an energy balance on the element

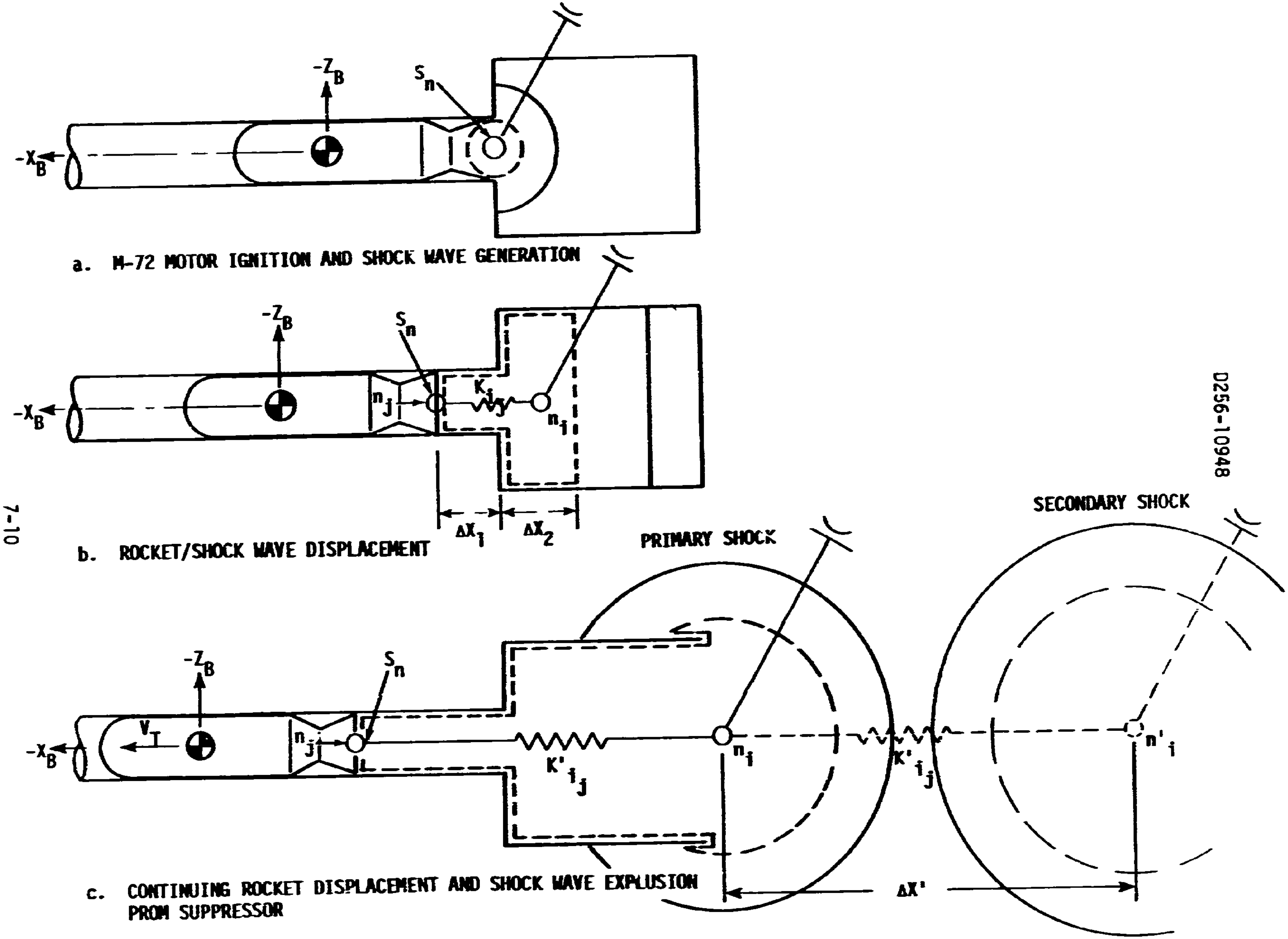


FIGURE 7-3 ELECTRIC CIRCUIT ANALOG WITH SUPPRESSOR ATTACHED

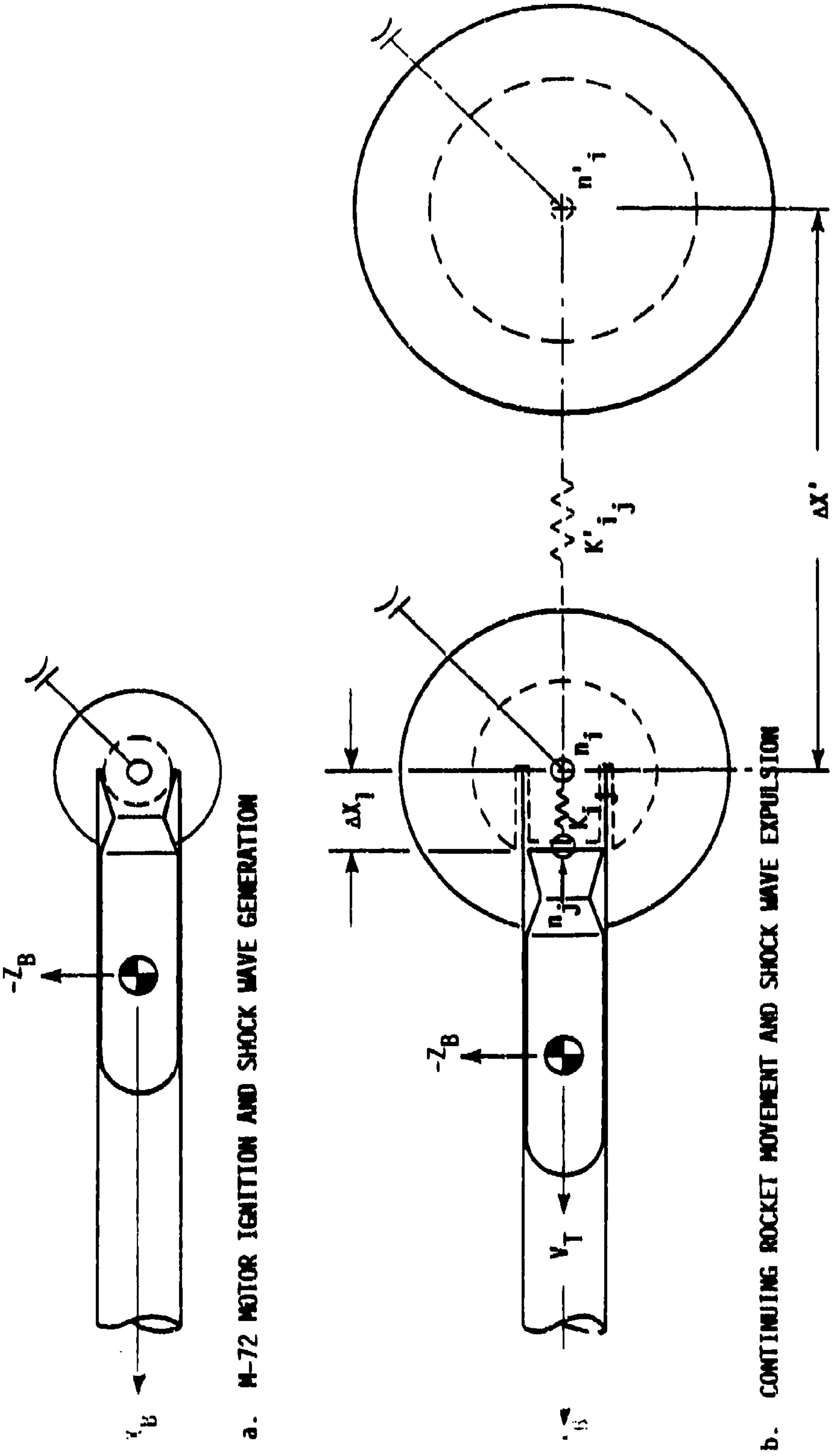


FIGURE 7-4 ELECTRIC CIRCUIT ANALOG WITHOUT SUPPRESSOR

7.2.4 (Continued)

control volumes:

Heat stored = Heat flow in - Heat flow out

In differential form:

$$\frac{dU}{dt} = Q_{in} - Q_{out}$$

The total differential temperature change for element n_i or n_i' is:

$$\frac{dT}{dt} = \frac{Q_{in}}{WC_V} - \left[\frac{\partial \rho_T}{\partial \rho}\frac{d\rho}{dt} + \frac{\partial \rho_T}{\partial T}\frac{dT}{dt}\right]\frac{T^{N-1}}{\rho^{N-1}}$$

$$- \left(\frac{\partial V_T}{\partial r}\frac{dr}{dt} + \frac{\partial V_T}{\partial x}\frac{dx}{dt} - \frac{\partial V_T}{\partial r}\frac{dr}{dt} - \frac{\partial V_T}{\partial x}\frac{dx}{dt}\right)\frac{T^{N-1}}{\Delta V^{N-1}}$$

Figure 7-5 depicts the simple energy balance diagram for the suppressor attached concept. It is noted that the various energy losses/gains are not chronologically sequenced and should not be construed as such. They do however, show the pertinent energy transport over the span of the

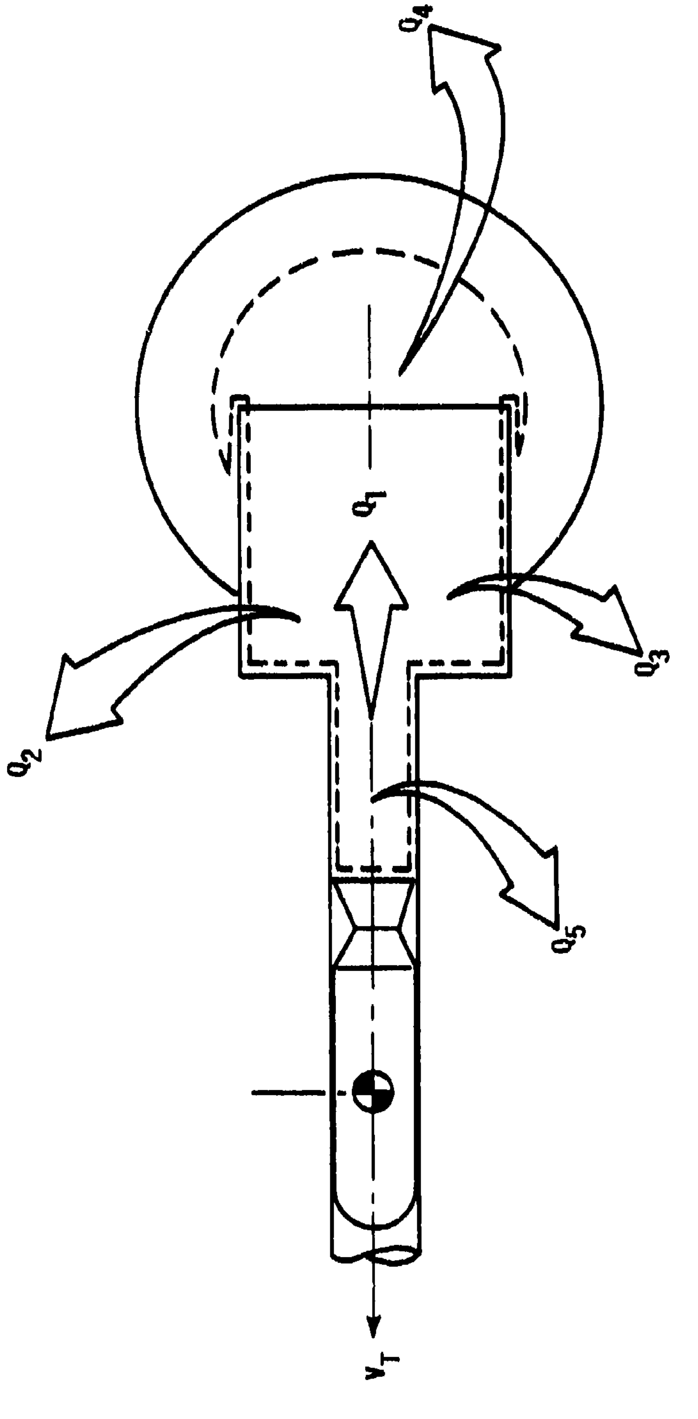


FIGURE 7-5 PICTORIAL ENERGY BALANCE WITH SUPPRESSOR

7.2.4 (Continued)

weapon firing duration up to the last stage where the blast wave is emitted into the atmosphere. The possibility of the energy losses as a consequence of a porous suppressor material are included in energy term Q_3.

7.3 PROJECTED MODEL CAPABILITIES

The equations described in Paragraph 7.2 were assembled into a model and solved using numerical integration techniques. Input data for this solution included the M-72 launcher geometry and rocket motor characteristics. The input data did not include a suppressor. Once completed, the solution constituted a prediction of the shock field characteristics versus time for a firing of the M-72 weapon system. The results of the prediction included time variations of pressure and temperature in the control volume and the lead shock velocity. By selecting pressures and time when the lead shock passed the instrumentation positions given in Figure 2-4 a comparison can be made to data recorded during an actual firing as shown in Table 7-I. Comparison data were selected from Round 71 which was used extensively as representative of the baseline in Paragraph 6.3. The predicted shock overpressure shows excellent correlation at all three instrumentation locations. The relative incremental time was selected for comparison because it does not require an absolute motor start time as a reference. The predicted incremental times between gages A and B response indicate a lead response of .8 miliseconds and a delayed response of .6 miliseconds for gages B and C relative to test data. The qualitative results reflect excellent correlation for all incremental time responses between applicable sensors.

7.3 (Continued)

These correlation results indicate that this approach to modeling the flow field response to a rocket motor firing should be developed for use in predicting shock wave overpressures for rocket powered weapon systems other than the M-72. The areas requiring further development are as follows.

(1) The number of model elements should be optimized to improve accuracy.

(2) Further analytical investigation should be made into the concept of the explosion center location as a function of momentum effects.

(3) The model software should be made more efficient, stable, accurate and documented into a User's Manual.

TABLE 7-I CORRELATION OF MODEL AND TEST RESULTS (ROUND 71)

PRESSURE WAVE PROPERTIES

PARAMETER	GAGE A PEAK NOISE PRESSURE LEVEL			GAGE B PEAK NOISE PRESSURE LEVEL			GAGE C PEAK NOISE PRESSURE LEVEL		
	TEST	PRED.	DIFF.	TEST	PRED.	DIFF.	TEST	PRED.	DIFF.
Pp (psid)	2.2	2.19	-.01	3.6	3.42	-.18	1.8	1.43	-.37
PPL (db)	177.598	177.559	-.039	181.87	181.43	-.44	175.86	173.85	-2.01
$\overline{T}$ (Temp in Control Volume, ^oF)	---	431	---	---	406	---	---	417.3	---
$\overline{P}$ (Press. in Control Volume, psia)	---	16.89	---	---	18.12	---	---	16.13	---
$\overline{V}$ (Lead Shock Velocity, Ft/Sec/M)	---	1218.7/ 1.079	---	---	1259/ 1.12	---	---	1193/ 1.056	---

PRESSURE WAVE INCREMENTAL TIMES

	TIME GAGE A TO B			TIME GAGE B TO C		
	TEST	PRED.	DIFF.	TEST	PRED.	DIFF.
Δt (Shock Time Between Gage Responses, Sec)	.0021	.0012	+.0008	.0036	.0030	-.0006

8.0 PROJECTED CAPABILITIES OF FIELDWEIGHT SUPPRESSORS

The tests conducted during the Propulsion Noise Reduction Technology Program covered a broad range of peak noise reduction suppressors for the M-72 weapon system. These included both heavyweight and fieldweight suppressors. In some cases configurations were tested with similar shapes but were drastically different in weight. The available data have been used to project the capability of a fieldweight suppressor for the M-72 weapon system and for weapon systems similar to the M-72 but requiring scaling of the available suppressor performance data.

8.1 PROJECTED CAPABILITIES OF THE M-72 FIELDWEIGHT SUPPRESSOR

The ten (10) inch inside diameter baffled cylinder suppressor was tested on the M-72 weapon system in both the heavyweight and fieldweight configuration. One heavyweight configuration with yielding baffles was similar to the suppressor shown in Figure 3-1. The cylinder segments of this configuration were designed as reusable test articles and the suppressor weighed approximately thirty (30) pounds. A fieldable version of the baffled cylinder suppressor that can be stored as a canister shown in Figure 8-1 is predicted to weigh 2.5 pounds. The fieldweight baffled cylinder suppressor shown in Figure 6-6 was fabricated from Kevlar fabric, Kevlar web and using Kevlar thread in all the seams. This configuration weighs one-half pound. A fieldable version of the fieldweight baffled cylinder suppressor can be stored in a rigid or flexible container as shwon in Figure 8-2. A comparison of the peak noise reduction capability at gunners position for the heavyweight and fieldweight baffled cylinder suppressors in the test configuration is shown in Figure 8-3. These data show excellent noise reduction capability for both the heavyweight and fieldweight baffled cylinder suppressors however recoil level tends to increase above the baseline level for the fieldweight suppressor tested.

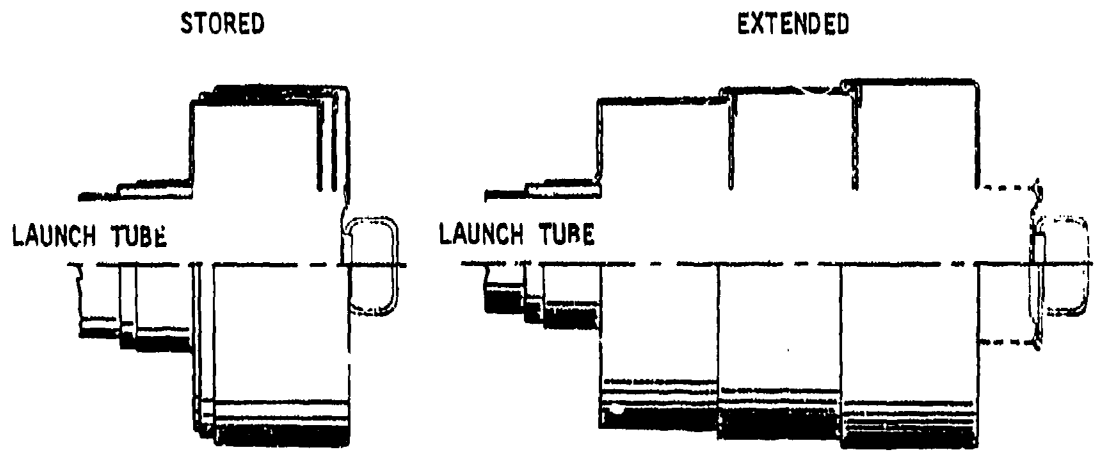


FIGURE 8-1 FIELDWEIGHT BAFFLED CYLINDER SUPPRESSOR

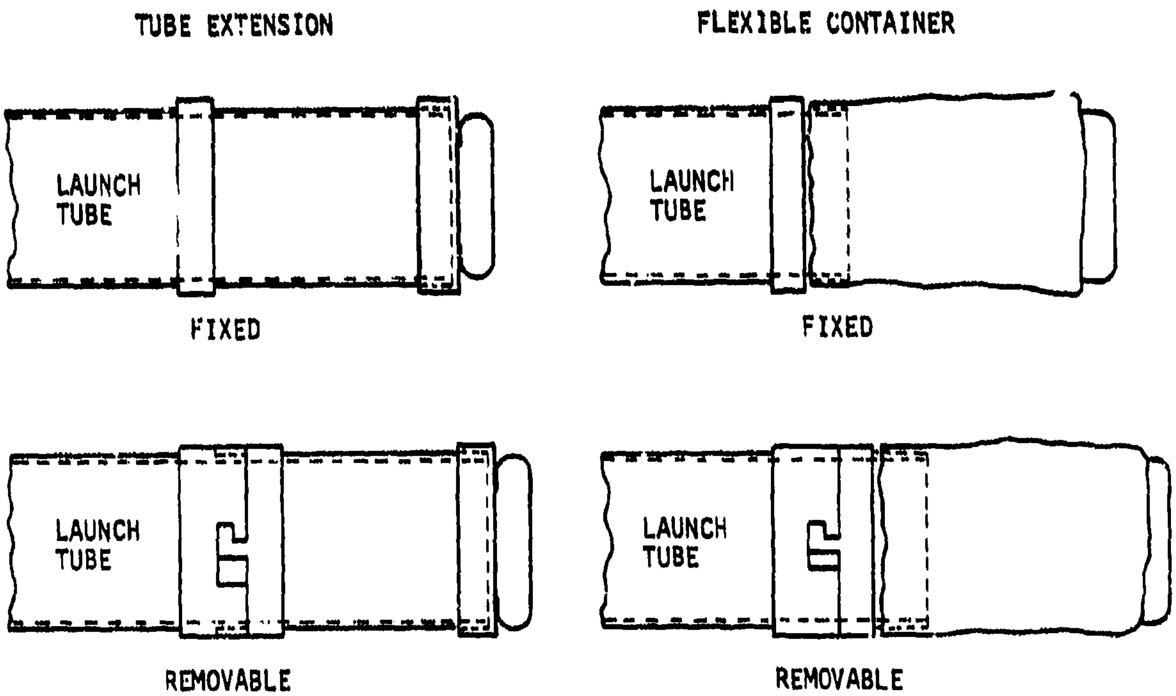


FIGURE 8-2 STORAGE CONCEPTS FOR THE KEVLAR FABRIC BAFFLED CYLINDER SUPPRESSOR

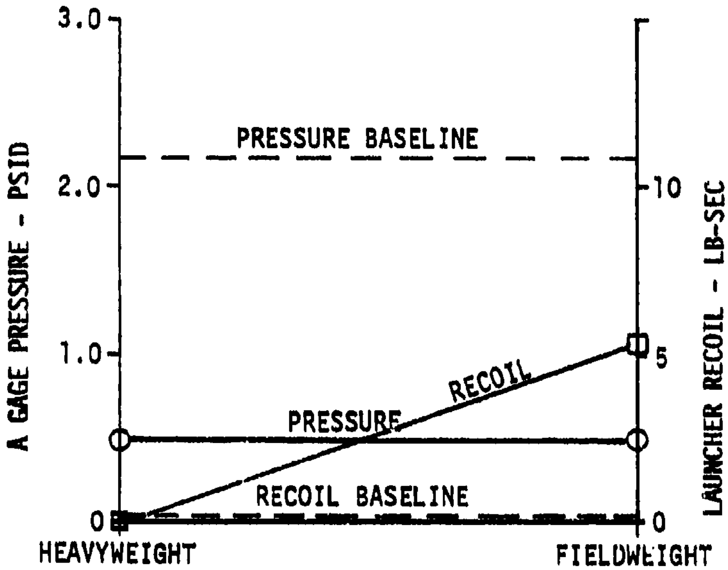


FIGURE 8-3   HEAVYWEIGHT AND FIELDWEIGHT BAFFLED CYLINDER SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY

8.1 (Continued)

A second comparison of similar suppressors can be made with the Aluminum and Kevlar fabric open cylinder suppressors. Both of these suppressors were six (6) inches in diameter and twenty four (24) inches long. The test configuration of the aluminum open cylinder suppressor weighs 5.43 pounds compared to only 0.3 pounds for the Kevlar fabric open cylinder suppressor. These open cylinder suppressors are shown in Figures 4-1 and 4-2 respectively as they were tested. The test results for the two open cylinder suppressors, given in Figure 8-4, show that the peak noise reduction capability at the gunners position will not be significantly affected by going to lower mass suppressors. The cylinder suppressor data also show a tendency toward higher recoil for fieldweight suppressors.

The Kevlar fabric open cylinder suppressors of 4, 6, 8 and 10 inches inside diameter were tested to determine peak noise reduction capability and the survivability of a fabric suppressor in the M-72 exhaust gas environment. Each suppressor design was fabricated for minimum weight. The test results of these Kevlar fabric open cylinder suppressors was discussed in Paragraph 6.0 and further illustrates the noise reduction capability that can be expected from a fieldweight suppressor. All but one of these extremely lightweight Kevlar fabric suppressors failed in the sideseam during the M-72 rocket motor firing. Prior to the failure, each configuration was very effective in reducing the peak noise produced by the M-72 weapon system at the gunners position. Improving the design of the Kevlar fabric suppressor to prevent the failure in the sideseam should produce a noise reduction capability equivalent to the ten (10) inch inside diameter Kevlar fabric open cylinder suppressor that survived the total duration of the M-72 firing. The noise pressure level versus time at the gunners position for each of these suppressors compared to the M-72 baseline is given in Figure 6-10.

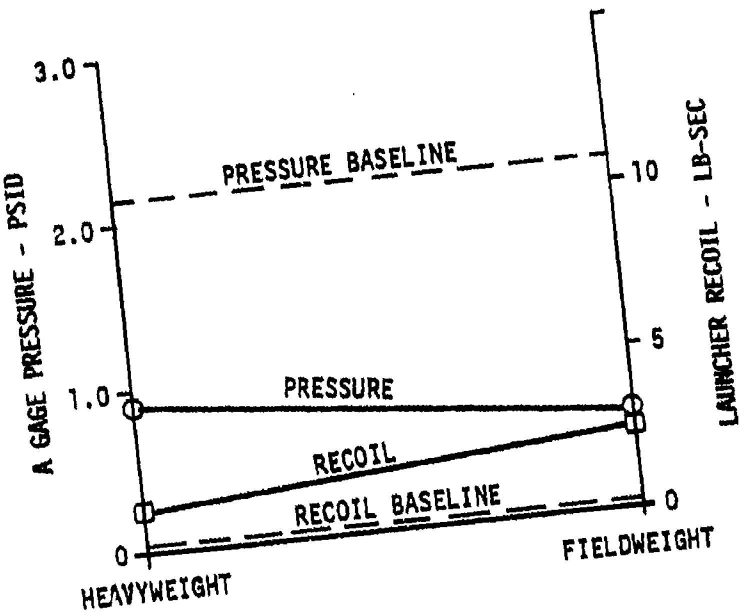


FIGURE 8-4 HEAVYWEIGHT AND FIELDWEIGHT OPEN CYLINDER SUPPRESSOR PEAK NOISE REDUCTION CAPABILITY

8.1 (Continued)

The suppressor performance comparisons given for the open cylinder and baffled cylinder suppressors in Figures 8-3, 8-4 and 6-10 show excellent peak noise reduction capability for both the heavyweight and fieldweight configurations, however recoil has a tendency to increase above the baseline level with the fieldweight suppressors. The reason for this recoil level increase has not been established and should be the objective of a future program. Minor design changes that (1) reduce the surface roughness of the Kevlar fabric, (2) eliminate side seam failures, (3) stiffen the forward closure to take advantage of internal pressure forces and (4) reduce billowing and rippling should produce a lightweight Kevlar fabric suppressor with lower recoil. A design modification to a controlled release of the suppressor from the launch tube could also be used to control the recoil to a desired level.

Use of the peak noise reduction technology developed during this program and the test results of the design modifications described above will provide a basis for designing a lightweight peak noise suppressor for the M-72 that has both excellent peak noise reduction capability and low recoil. Fabricating this suppressor with Kevlar fabric will produce a storable fieldweight suppressor that can be easily deployed by the gunner.

8.2 PROJECTED CAPABILITY OF A SCALED FIELDWEIGHT SUPPRESSOR

The series of tests that were conducted with the 4, 6, 8 and 10 inch inside diameter open cylinder Kevlar fabric suppressors can be used to illustrate the scaleability of the open cylinder suppressor for use on weapon systems other than the M-72 weapon system. If we express the suppressor size in terms of a volume and the rocket motor size in terms of exhaust gas volume, a plot of suppressor capability versus the volume ratio of the suppressor to exhaust gas can be developed. An example of

8.2 (Continued)

this type of data is presented in Figure 8-5 where the M-72 exhaust gas volume was calculated at 16 psia and the suppressor volumes are those of each of the open cylinder suppressors tested during this program. These include aluminum, Kevlar and woven Nylon both launch tube and extension mounted open cylinder suppressors. The data show that volume ratios above .0116 are not necessary for the M-72 weapon system so long as the suppressor survives the exhaust gas environment. If we have a suppressor requirement for a weapon system similar to the M-72 but with a different size motor, these data can be used to develop a scaled suppressor volume for the different weapon system. Typically, an open cylinder suppressor for a motor with 3.5 times the exhaust gas volume as the M-72 would be 13.5 inches inside diameter and 24 inches long if we used a volume ratio of .0375. This scaled open cylinder Kevlar fabric suppressor should have a peak noise reduction capability at the gunners position equivalent to the six (6) inch inside diameter and twenty four (24) inches long suppressor tested on the M-72 weapon system. The weight of this suppressor, if fabricated with Kevlar fabric, would be about one (1) pound. This weight and performance estimate make the Kevlar fabric open cylinder suppressors good candidates for the high energy man portable weapon systems that require a gunner at or nearby the launcher when the missile is fired.

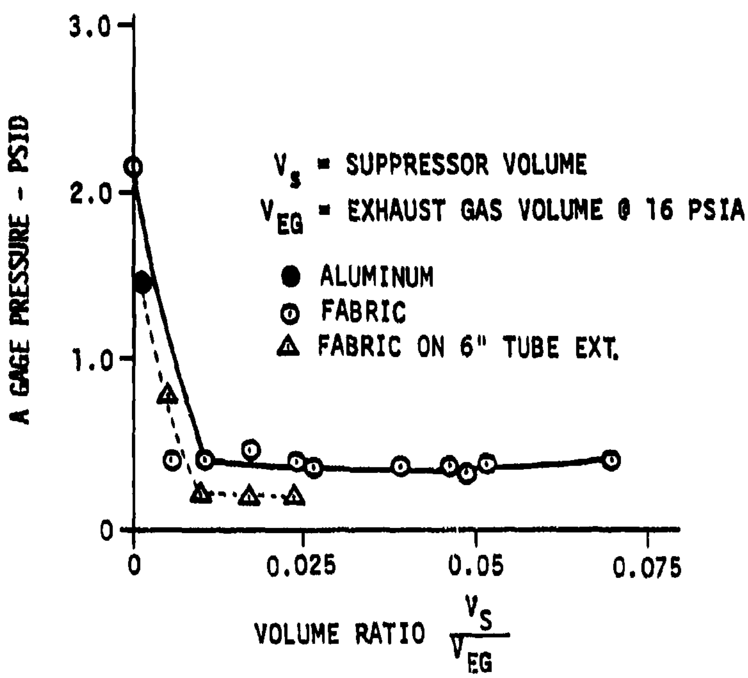


FIGURE 8-5 OPEN CYLINDER SUPPRESSOR SCALING PARAMETER

9.0 RECOMMENDATIONS

The peak noise suppressors that were designed and tested during the Propulsion Noise Reduction Technology Program were heavyweight aluminum or extremely lightweight fabric laboratory test articles. The test articles were designed to test peak noise suppressor concepts in an open field environment. The data presented in this report have verified that the peak noise produced by the M-72 weapon system firing can be reduced at the gunners position with a suppressor that attaches to the launch tube. Further, peak noise reduction was accomplished with no effect on projectile velocity and little effect on launcher recoil. Based on these findings it is recommended that these heavyweight and extremely lightweight peak noise suppressors be tested in simulated battlefield environments other than an open field. Specifically, tests should be conducted in simulated urban areas, fighting vehicles and bunkers to determine the effects of these environments on the gunner position peak noise reduction capability of the suppressor.

It is further recommended that selected peak noise reduction suppressor configurations be developed to a fieldable system for the M-72 or similar weapon system. This development should be done by selecting a baseline suppressor configuration and two alternate configurations to be fabricated from lightweight material. The design should allow the suppressor to be packaged in a compact size and be easily deployed by the G.I. in the field. This development should involve all aspects of a development cycle including, configuration selection, material studies and selection, fabrication techniques and manufacturing processes, packaging studies, environmental testing, deployment studies involving the G.I. and performance testing.

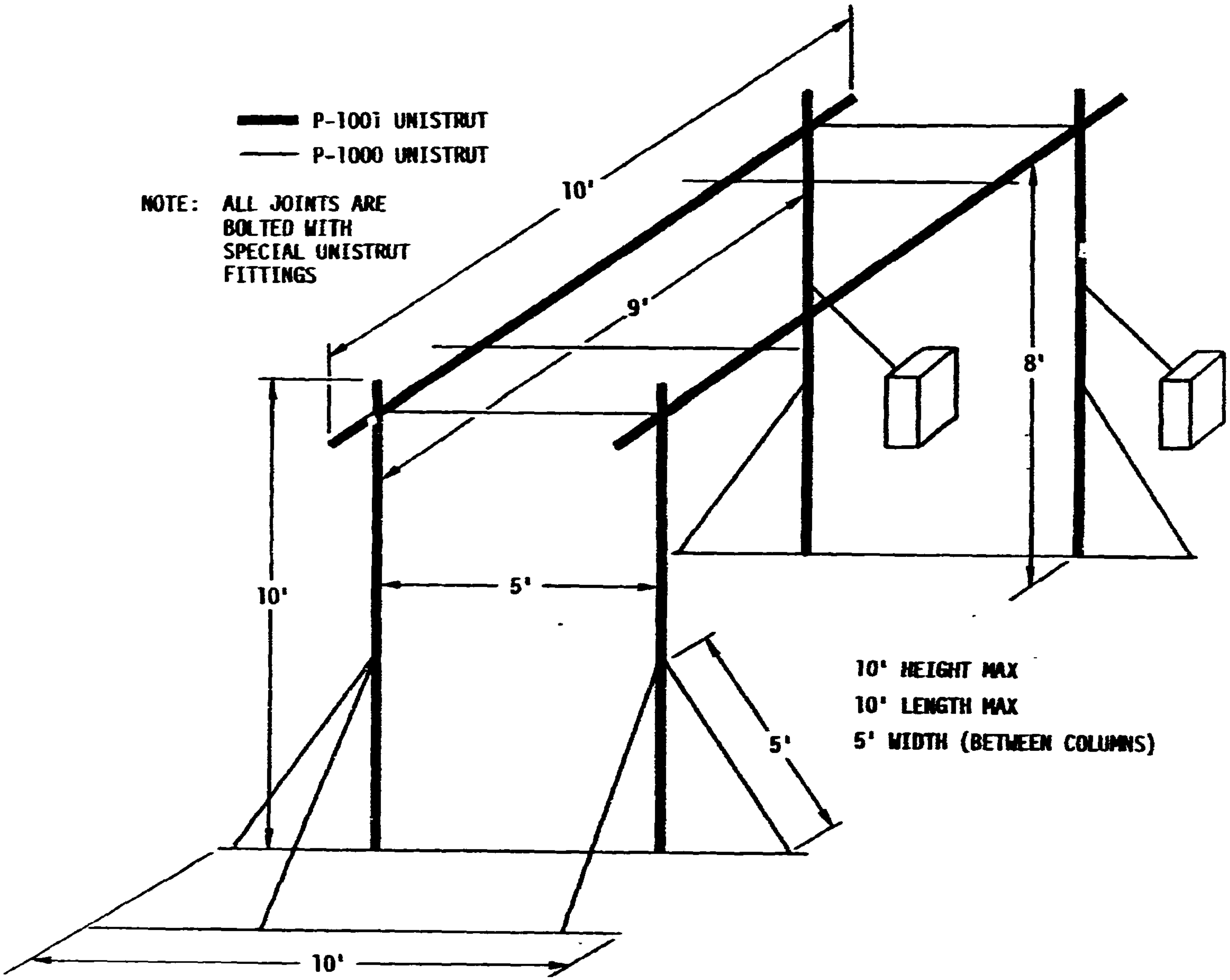
The Propulsion Noise Reduction Technology and peak noise reduction capability should be extended to include weapon systems other than the shoulder fired

9.0 (Continued)

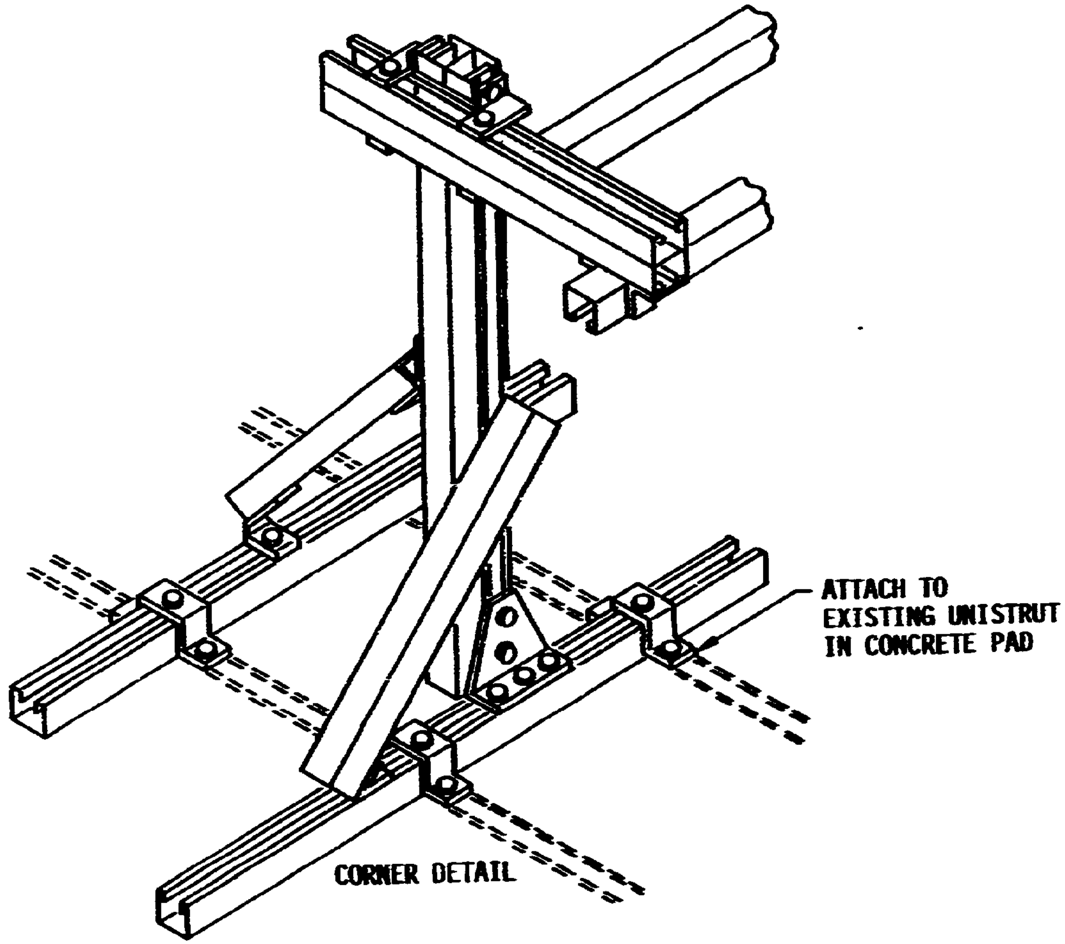
type. Peak noise suppressors should be designed and tested on all current weapon systems that require a gunner at or nearby the launcher when the missile is fired. Suppressor applications should be started early in the program development phase of new weapon systems such as the IMAAWS and Tank Breaker. Using the available Propulsion Noise Reduction Technology during the development phase of these programs will produce a system with maximum performance and minimum peak noise at the gunners position.

The Propulsion Noise Reduction Technology Program should be continued with the specific purpose of developing advanced suppressors and continuing analytical investigations of the pressure field surrounding a rocket motor firing. The instrumentation should be increased to include more sound pressure level gages and to include optical measurements. This instrumentation will produce more of the data required for better understanding of the sound pressure waves produced by a high energy rocket firing. If an optical system cannot be used effectively with the live rocket firing, cold flow tests should be conducted with simulated rockets using a Shadowgraph or Schlerin system to record the visual data generated by the pressure wave development and decay. This expanded data base should be used to develop a computer simulation program that will simulate the near-field characteristics of the pressure wave generated by a fast burning high energy solid rocket motor in both the unsuppressed and suppressed cases.

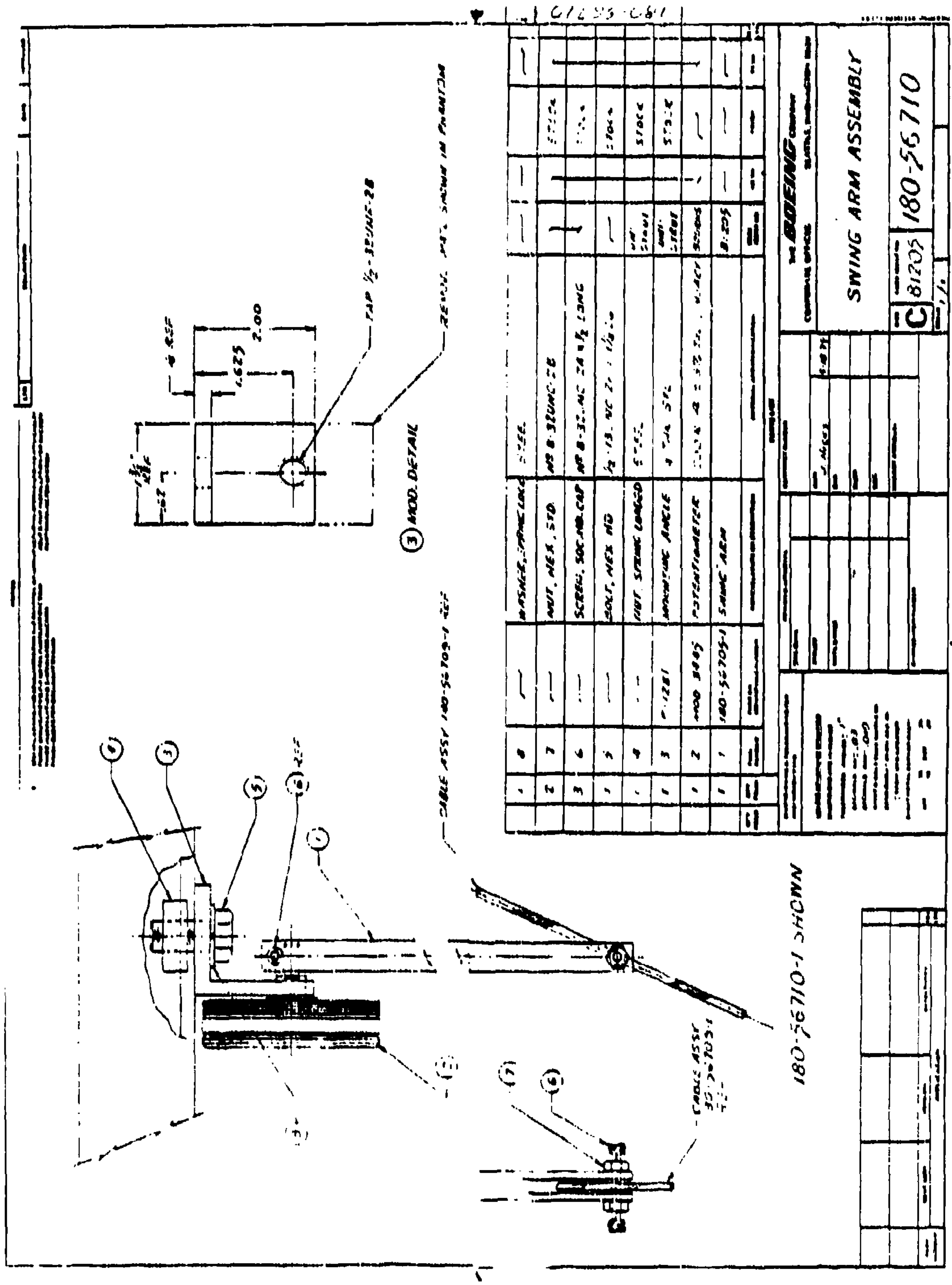
APPENDIX

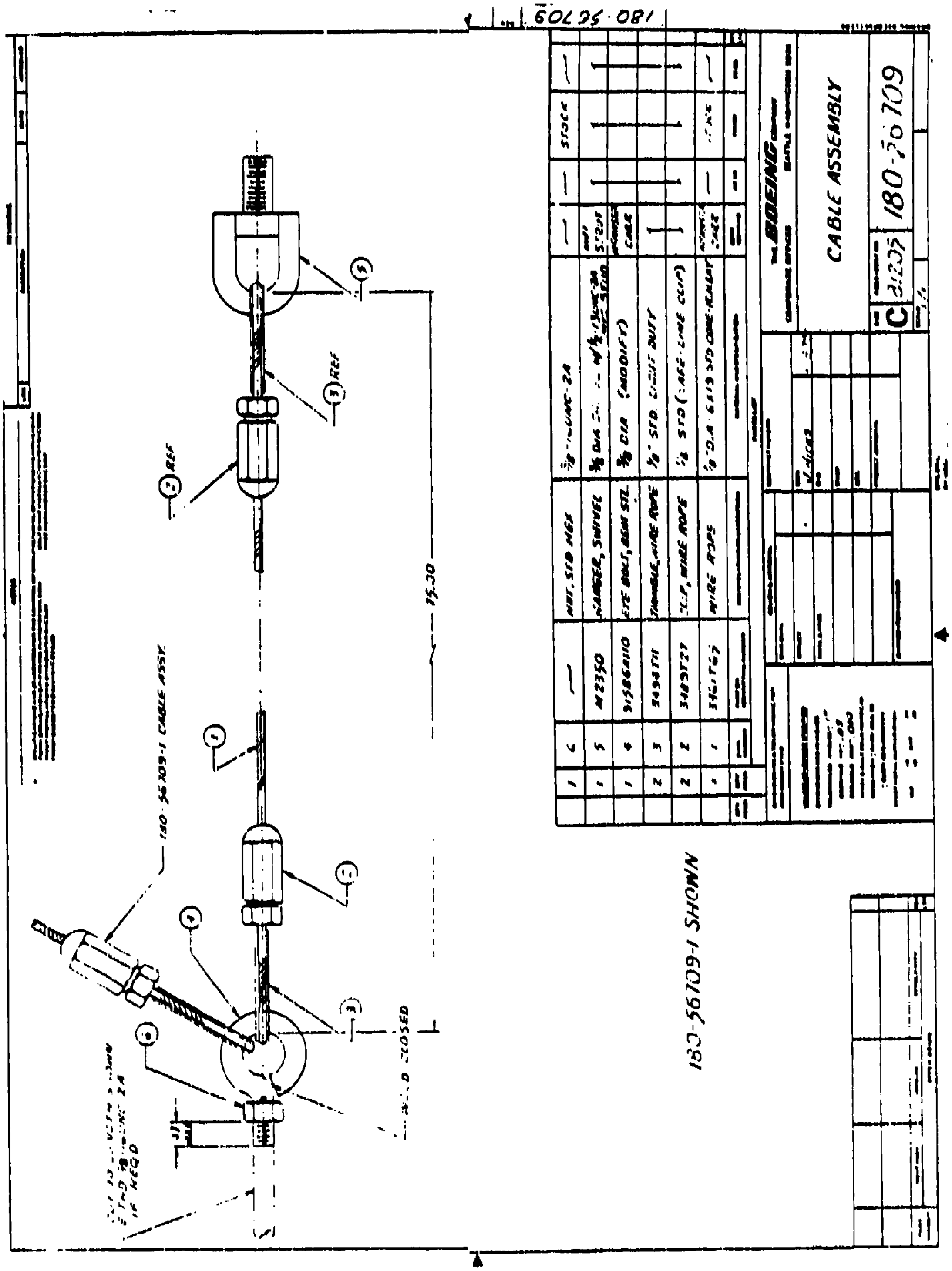


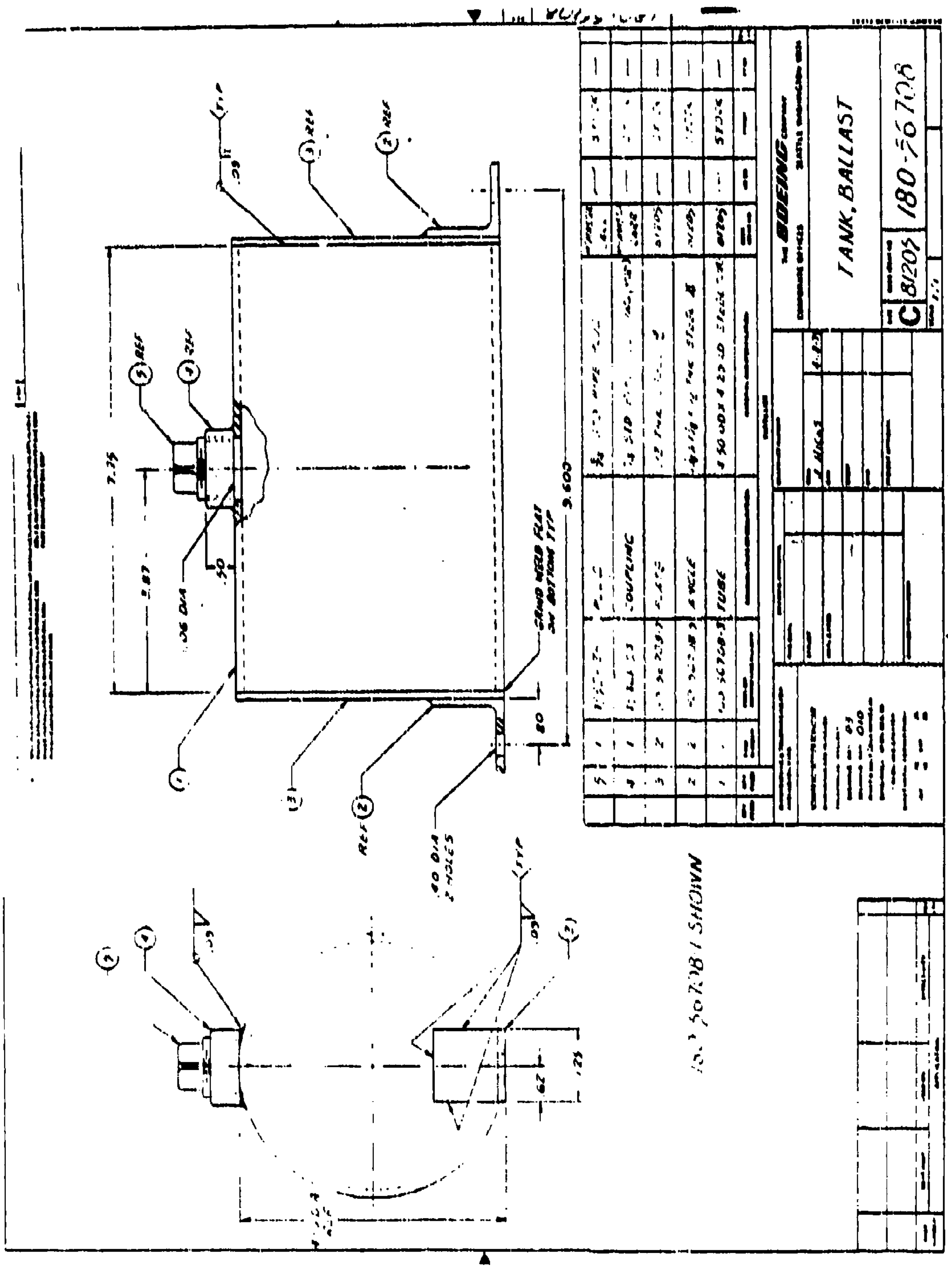
UNISTRUT FRAME

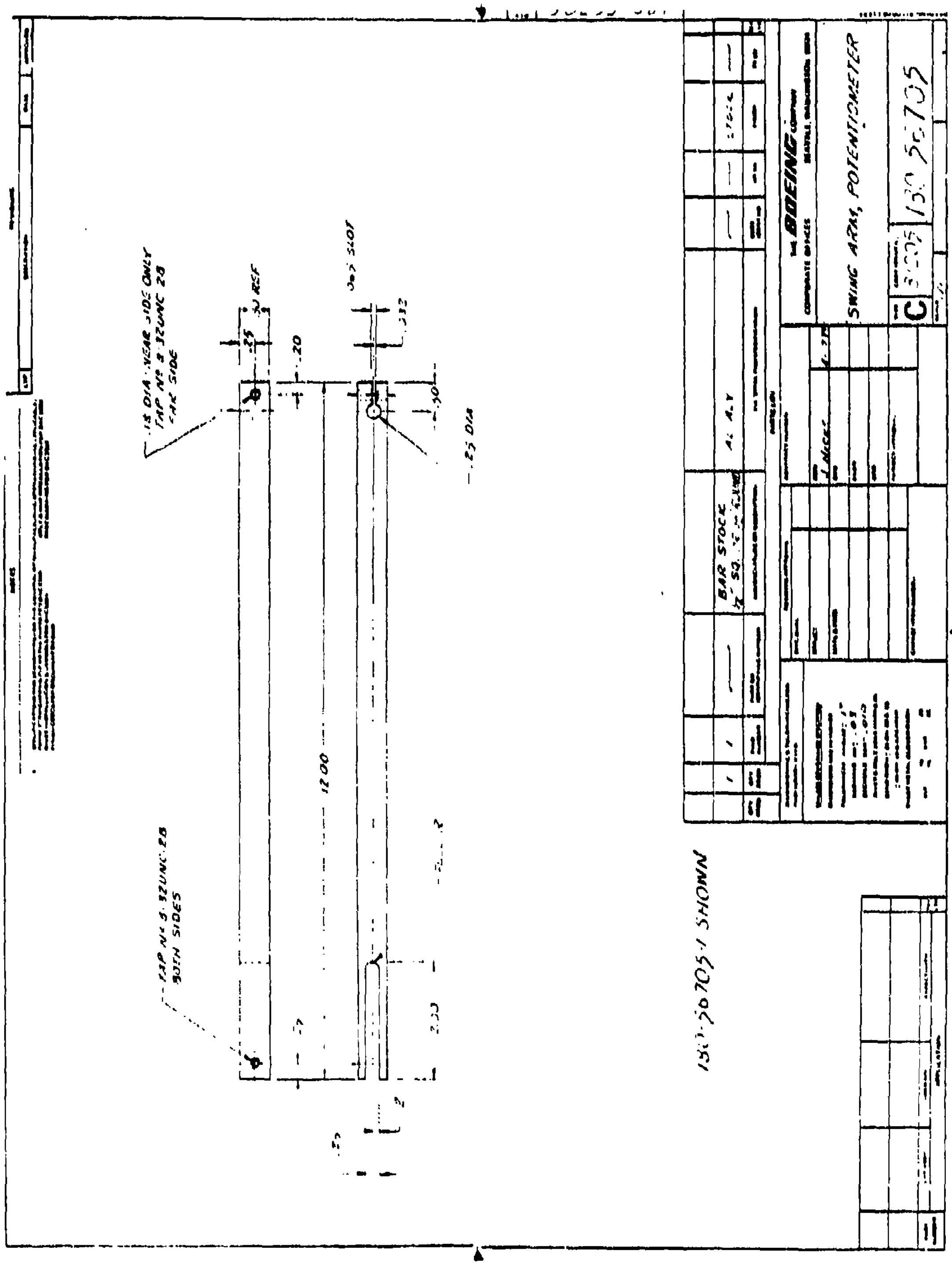


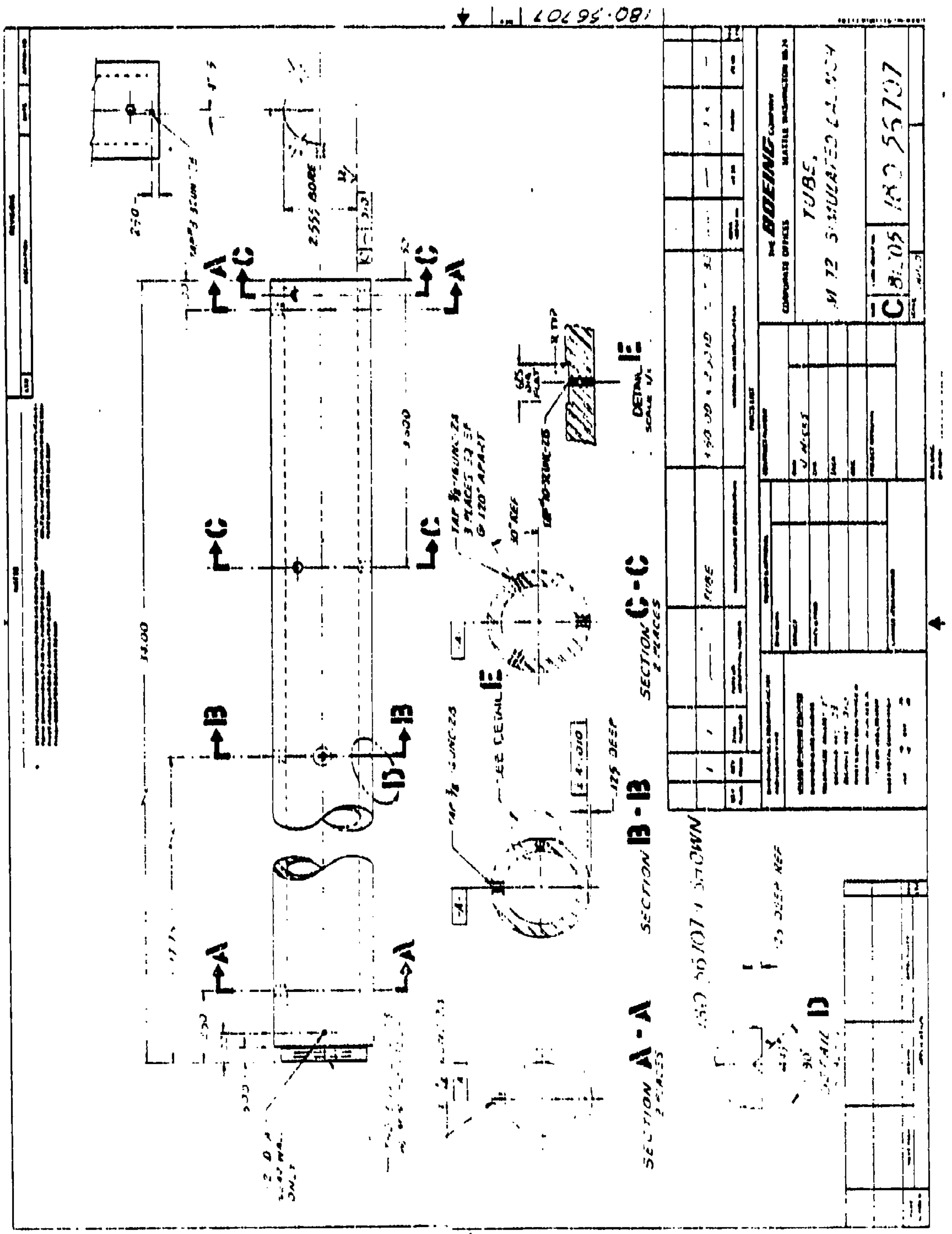
UNISTRUT FRAME CORNER DETAIL


SWING ARM ASSEMBLY
180-56710
180-56710-1 SHOWN
BOEING
MOD. DETAIL
2.00
.625
WASHER, SPRING LOCK
NUT, HEX, STD
SCREW, SOC HD CAP
BOLT, HEX HD
MOUNTING ANGLE
POTENTIOMETER
SWING ARM
C 81205

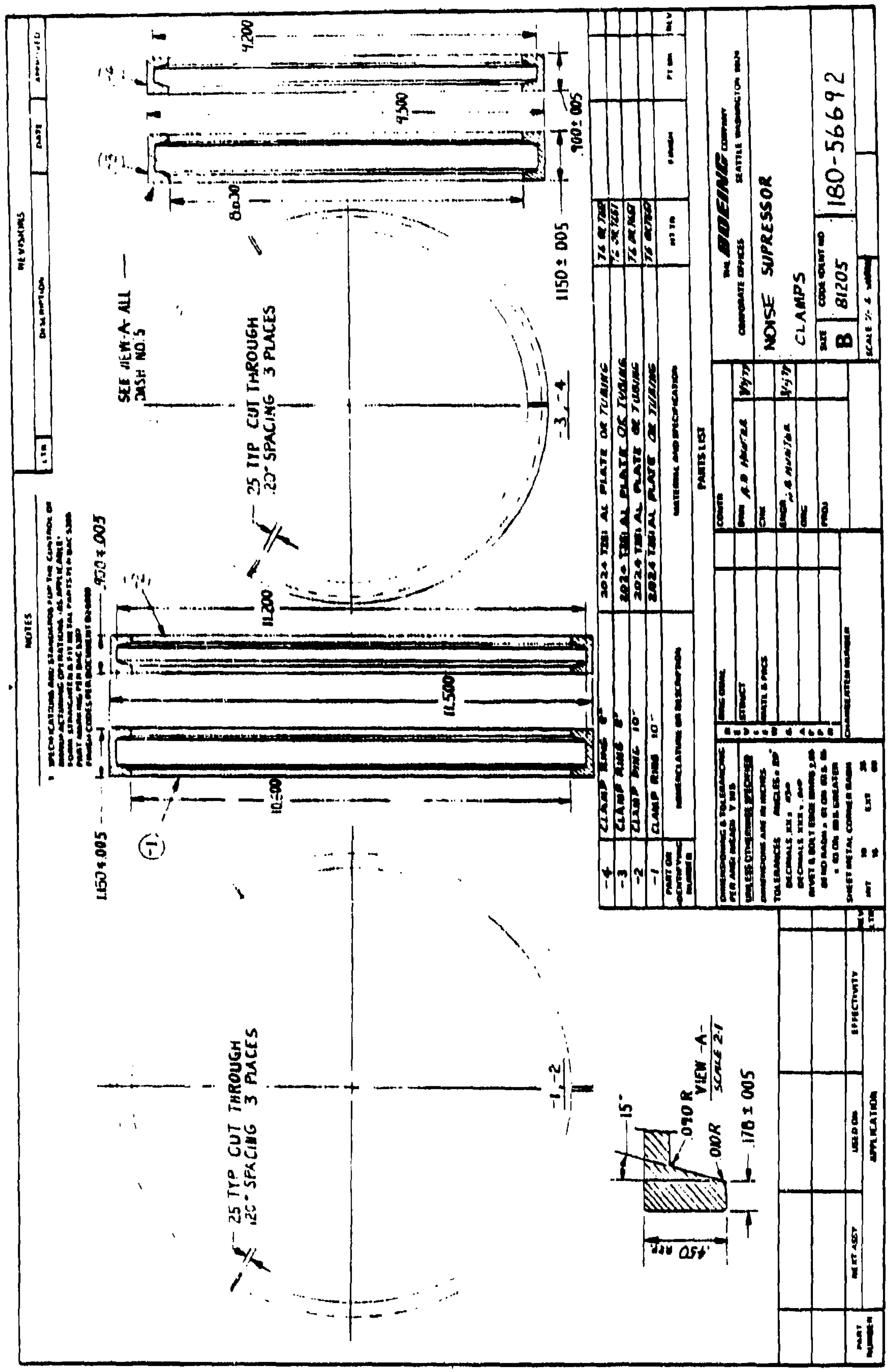

180-56709-1 SHOWN
180-56709-1 CABLE ASSY
15.30
REF
CABLE ASSEMBLY
BOEING
180-56709

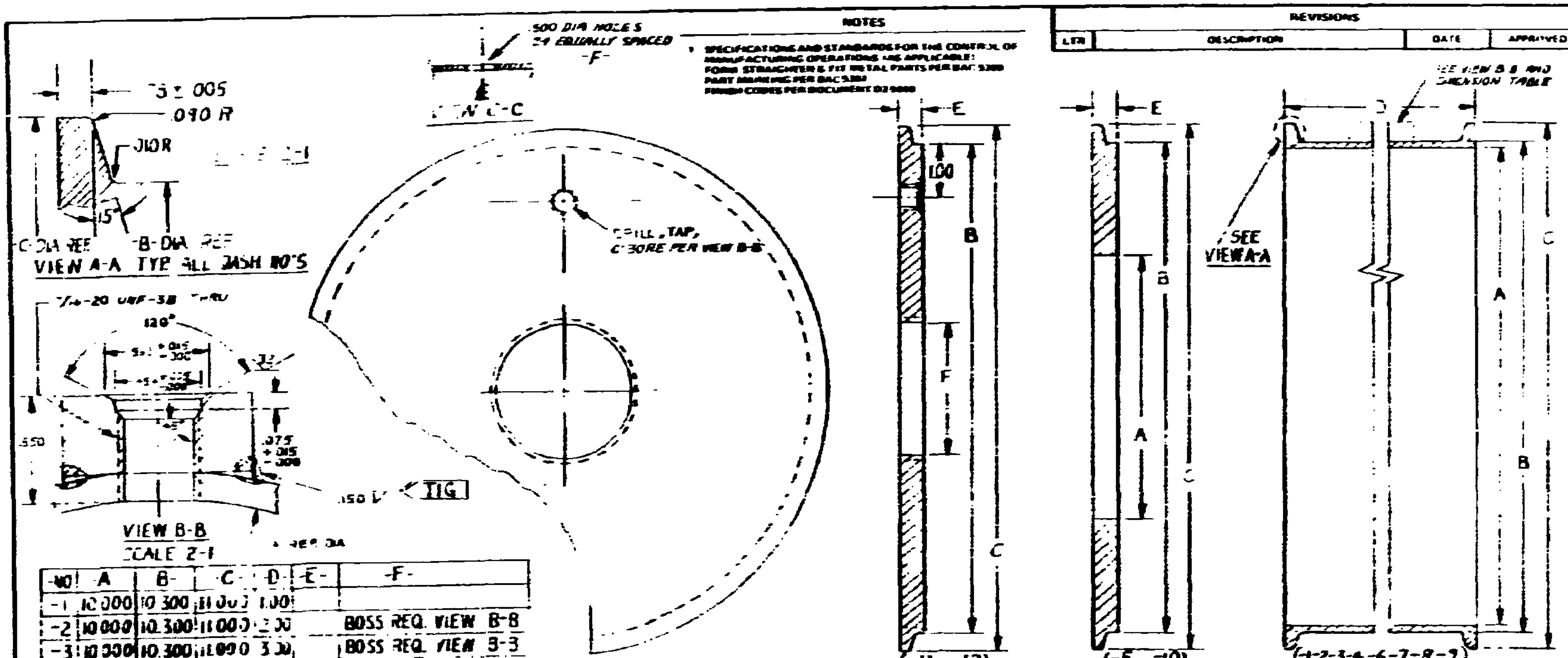

THE BOEING COMPANY
TANK, BALLAST
C 81205
180-56708


SWING ARM, POTENTIOMETER
BOEING
BAR STOCK
12.00
.25 DIA
.20
SLOT
BOTH SIDES



180-56707
SECTION A-A
SECTION B-B
SECTION C-C
DETAIL E
DETAIL D
TUBE
BOEING


NOISE SUPPRESSOR
CLAMPS
180-56692
81205
B
THE BOEING COMPANY
SEATTLE WASHINGTON
CLAMP RING 8"
CLAMP RING 10"
2024 T351 AL PLATE OR TUBING
PARTS LIST
25 TYP CUT THROUGH
120° SPACING 3 PLACES
SEE VIEW-A- ALL
DASH NO. 5
VIEW -A-
SCALE 2:1
1150 ± 005
950 ± 005
900 ± 005
178 ± 005
11.500
11.200
10.000
9.500
9.200
8.000
.450
.090 R
.010 R
15°
NOTES
REVISIONS



NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS ARE APPLICABLE:
   FORM STRAIGHTEN & FIT METAL PARTS PER BAC 5300
   PART MARKING PER BAC 5307
   FINISH CODES PER DOCUMENT D2-5000

-NO	A	B	C	D	E	F
-1	10.000	10.300	11.000	1.00		
-2	10.000	10.300	11.000	2.00		BOSS REQ. VIEW B-B
-3	10.000	10.300	11.000	3.00		BOSS REQ. VIEW B-B
-4	10.000	10.300	11.000	2.00		PERFORATE-VIEW C-C
-5	[illegible]	10.300	11.000		.500	
-6	8.000	8.300	9.000	1.00		
-7	8.000	8.300	9.000	2.00		BOSS REQ. VIEW B-B
-8	8.000	8.300	9.000	3.00		BOSS REQ. VIEW B-B
-9	8.000	8.300	9.000	2.00		PERFORATE VIEW C-C
-10	[illegible]	8.300	9.000		.500	
-11		10.300	11.000		.500	.50-12 UNF-2B THD
-12		8.300	9.000		.500	.50-12 UNF-2B THD

PARTS LIST

PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION
-11 -12	FORWARD END PLATES	2024 T351 AL PLATE
-5 -10	AFT END PLATES	2024 T351 AL PLATE
-1-6-4-9	TUBE SECTIONS WITHOUT BOSS	6061 T6 AL PLATE OR TUBE OR 2024 T351
-2-3-7-8	TUBE SECTIONS WITH BOSS	6061 T6 AL PLATE OR TUBE OR 2024 T351

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE WASHINGTON

NOISE SUPRESSOR

END PLATES AND TUBE SECTIONS

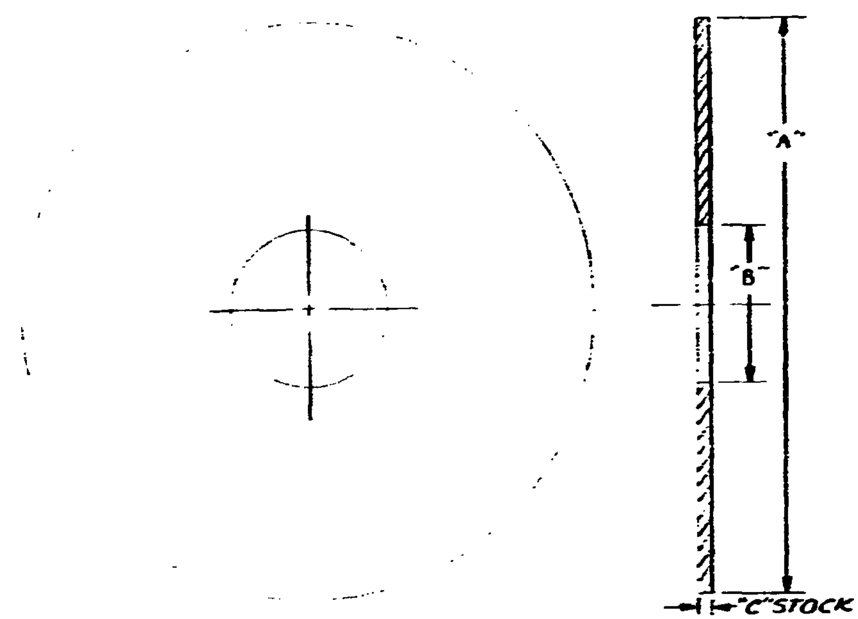
SIZE B CODE IDENT NO 81205 180-56693

NOTES

• SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE): FORM, STRAIGHTEN & FIT METAL PARTS PER BAC5300; PART MARKING PER BAC5307; FINISH CODES PER DOCUMENT [illegible]

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED



-NO.	-A-	-B-	-C-	
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-3	11.000	4.00	.250	
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-6	9.000	3.00	.250	
-7	9.000	4.00	.250	
-8	9.000	2.55	.063	
-9	11.000	10.00	.090	
-10	9.000	8.00	.090	
-11	11.000	5.00	.250	
-12	11.000	3.00	.063	
-13	11.000	4.00	.063	
-14	11.000	5.00	.063	
-15	9.000	3.00	.063	
-16	9.000	4.00	.063	

PARTS LIST

PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION
-4-8-9-10 -12 thru -16	BAFFLES & SPACERS	6061 T6 AL SHEET OR 2024 T3 AL
-1-2-3-5 -6-7-11	BAFFLES	6061 T6 AL PLATE

THE BOEING COMPANY, CORPORATE OFFICES, SEATTLE WASHINGTON

NOISE SUPRESSOR

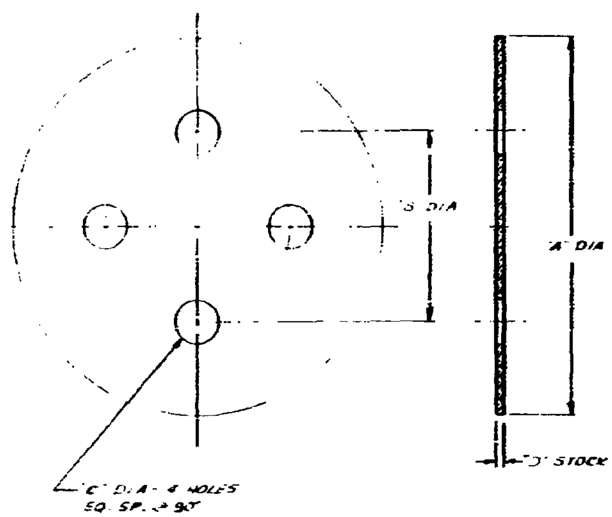
BAFFLES

SIZE: B | CODE IDENT NO: 81205 | 30-56694

SCALE 1/2

DIMENSIONING & TOLERANCING PER ANSI Y14.5; UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

NEXT ASSY | USED ON | EFFECTIVITY | APPLICATION



TABULATION					
PT. NO.	"A" DIA	"B" DIA	"C" DIA	"D" STOCK	
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-3	9.00	4.000	1.275	.250	
-4	9.00	4.000	1.275	.063	
-5	11.00	5.000	2.500	.250	
-6	11.00	5.000	2.000	.250	
-7	11.00	5.000	1.500	.250	
-8	9.00	4.000	2.000	.250	
-9	9.00	4.000	1.500	.250	
-10	9.00	4.000	1.500	.063	
-11	9.00	4.000	2.000	.063	
-12	11.00	5.000	2.500	.063	
-13	11.00	5.000	2.000	.063	
-14	11.00	5.000	1.500	.063	

TABULATED DETAIL DRAWING

1 EA	—	-2, -4, -10 THRU -14	BAFFLE	AL ALY 6061-T6 OR 2024-T3	81205	—	STOCK	—
1 EA	—	-1, -3, -5, -6, -7, -8, -9	BAFFLE	AL ALY 6061-T6	81205	—	STOCK	—

J. Hicks

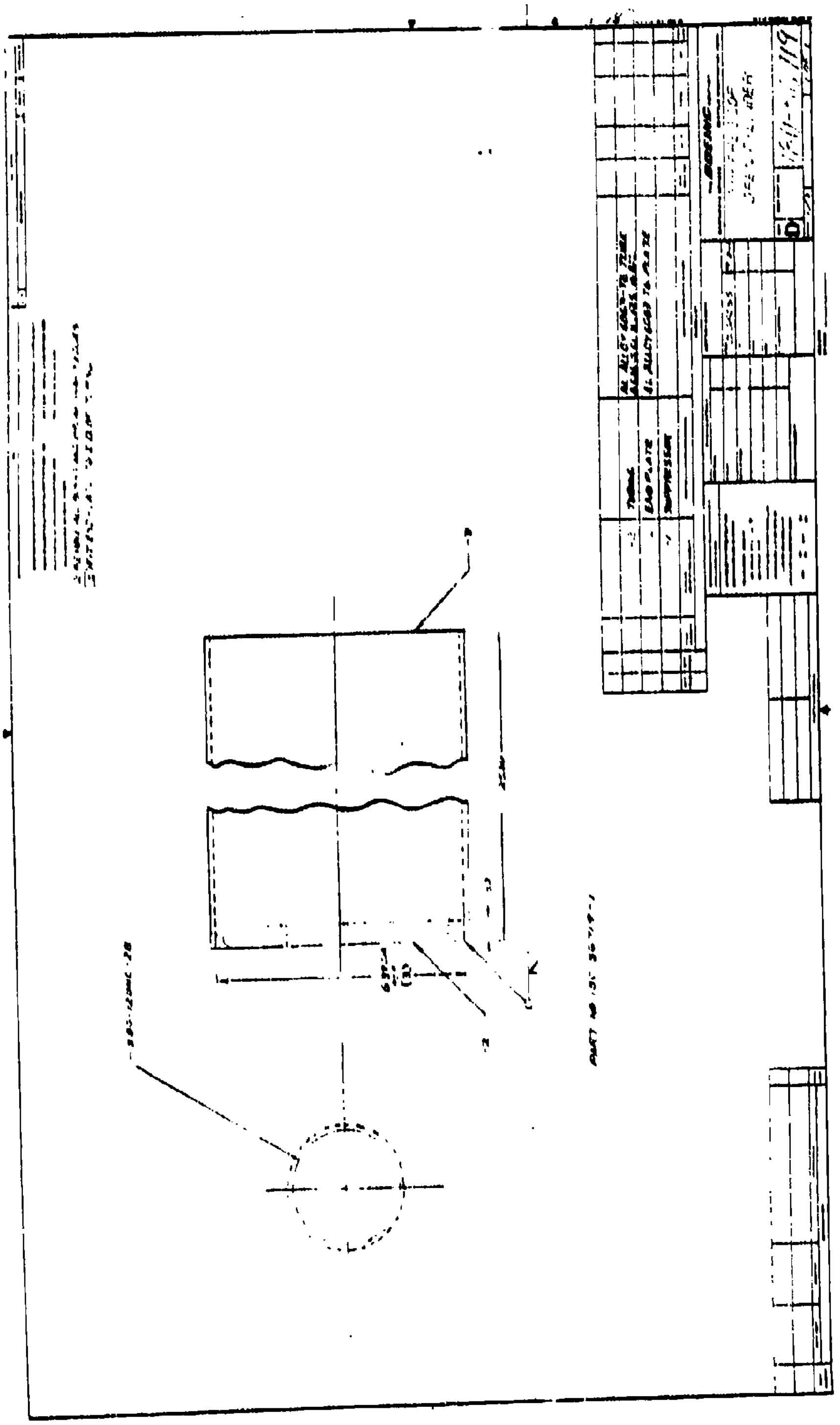
THE BOEING COMPANY

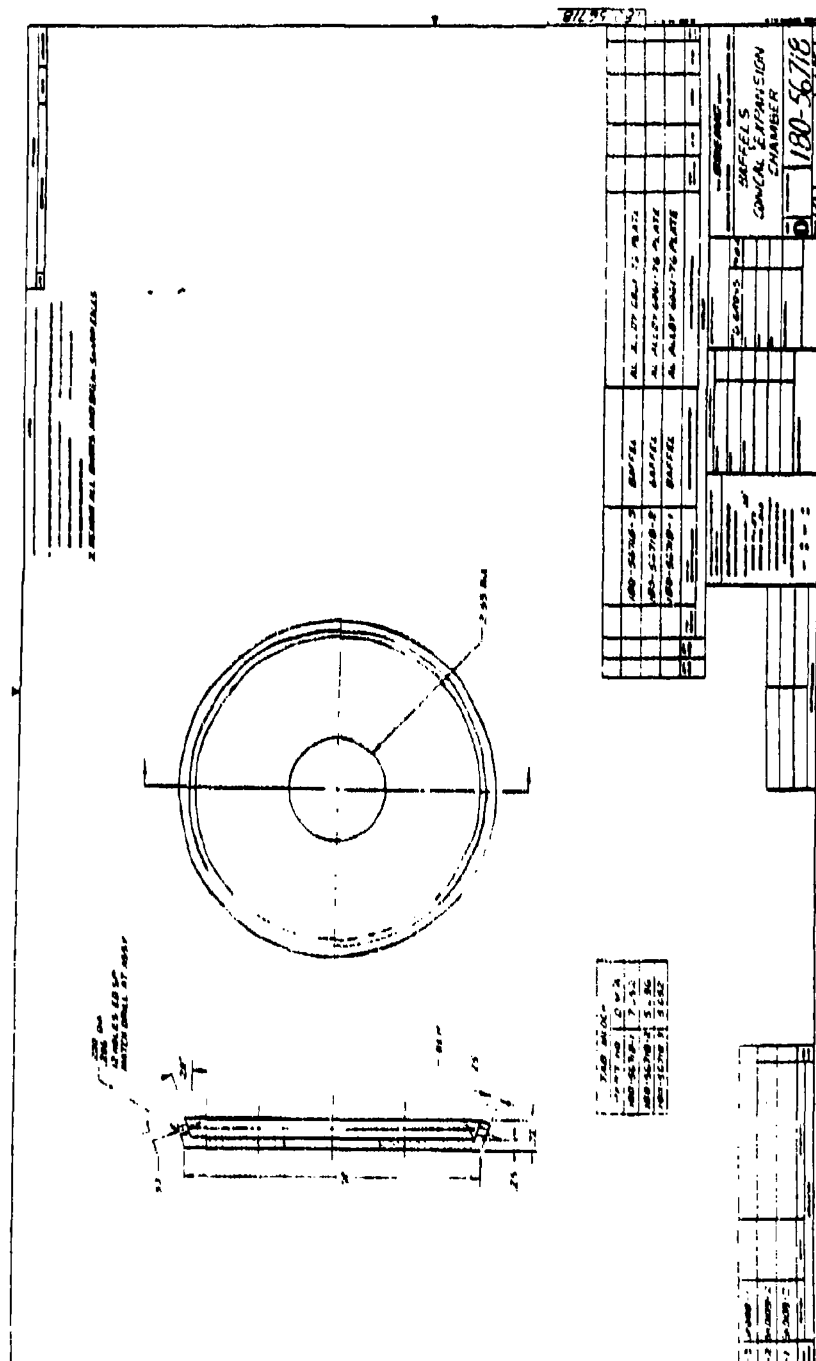
BAFFLE,
NOISE SUPRESSOR

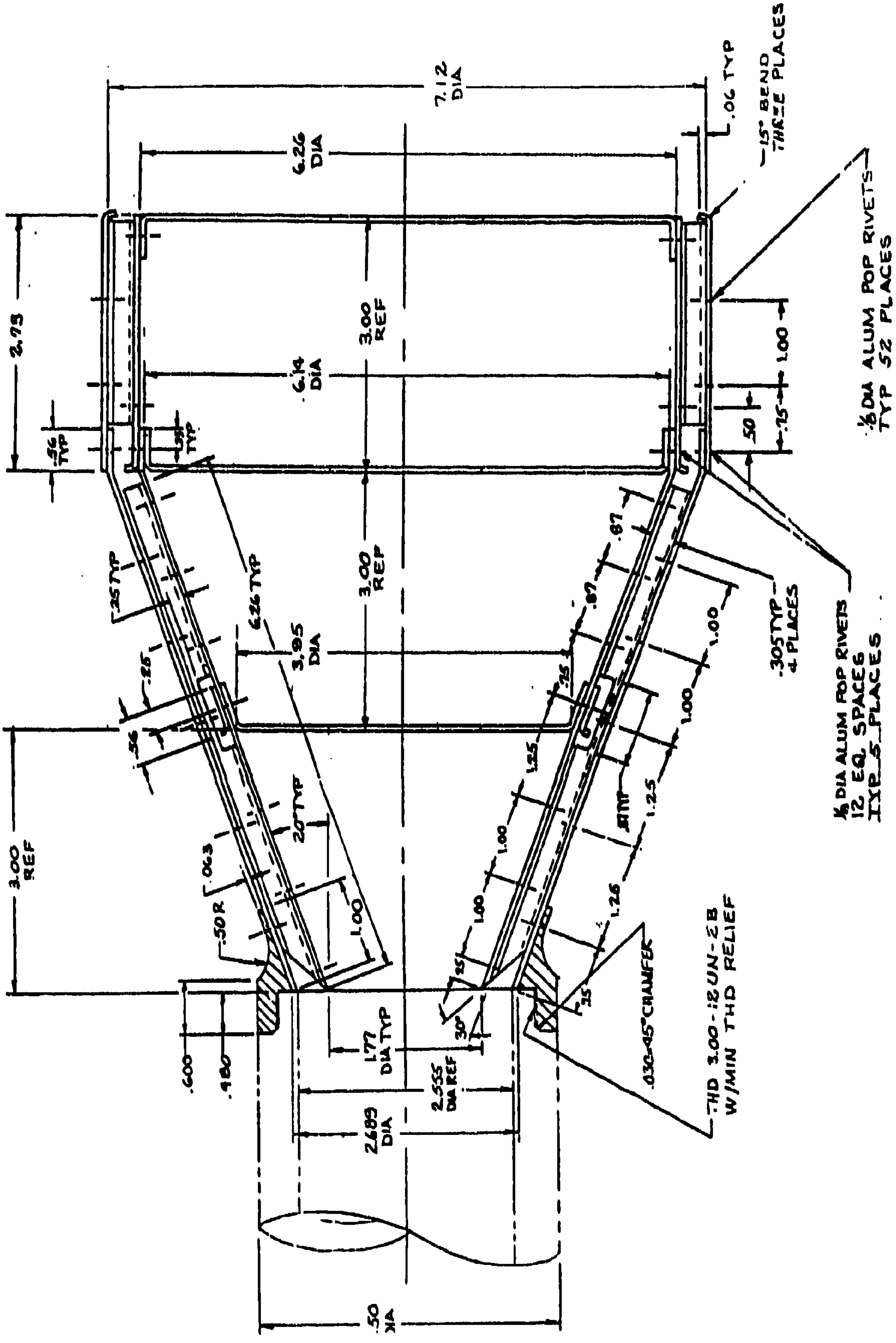
C 81205 180-56711

SCALE NONE

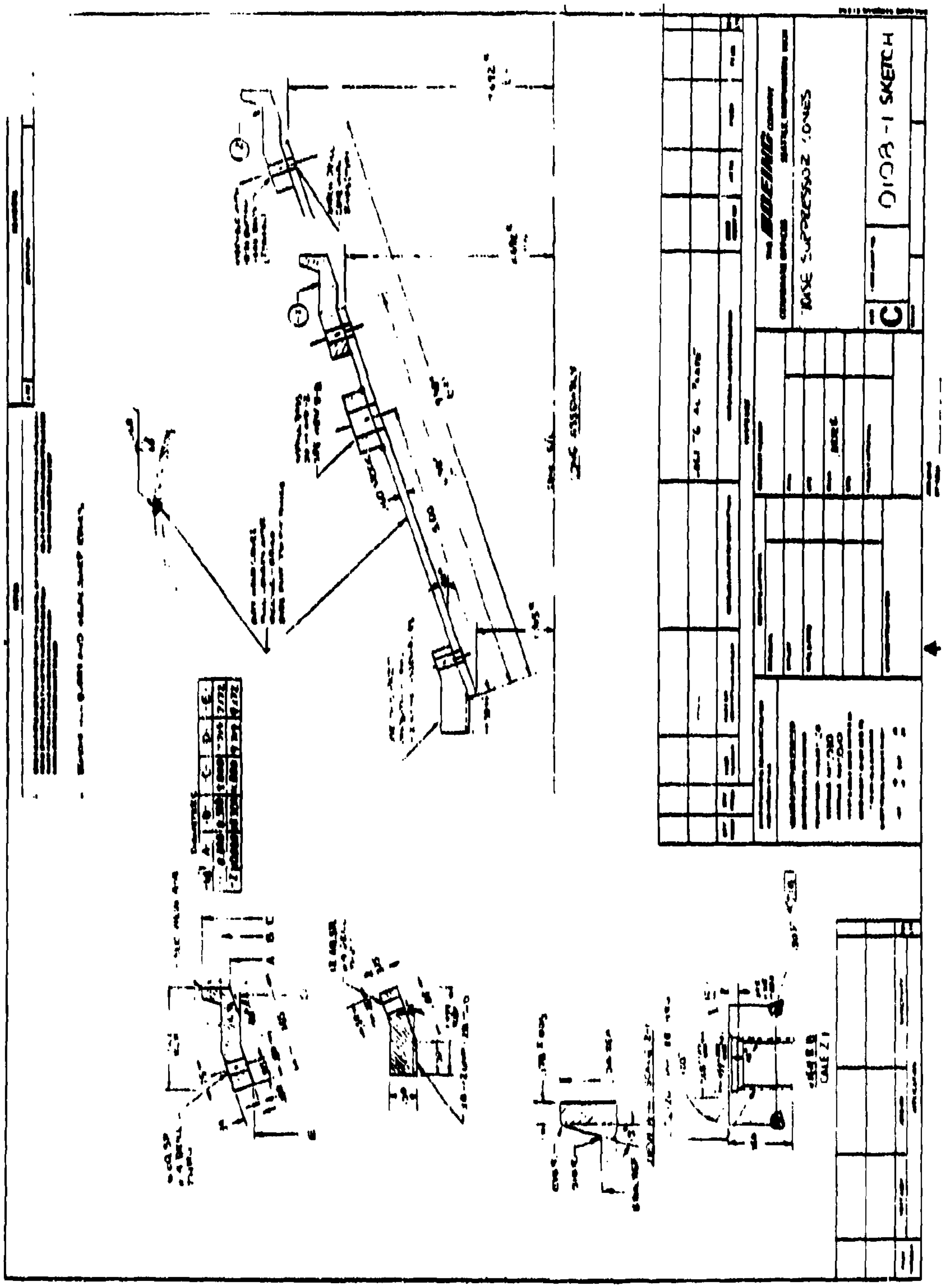
180-56711




BAFFELS
CONICAL EXPANSION
CHAMBER
180-56718

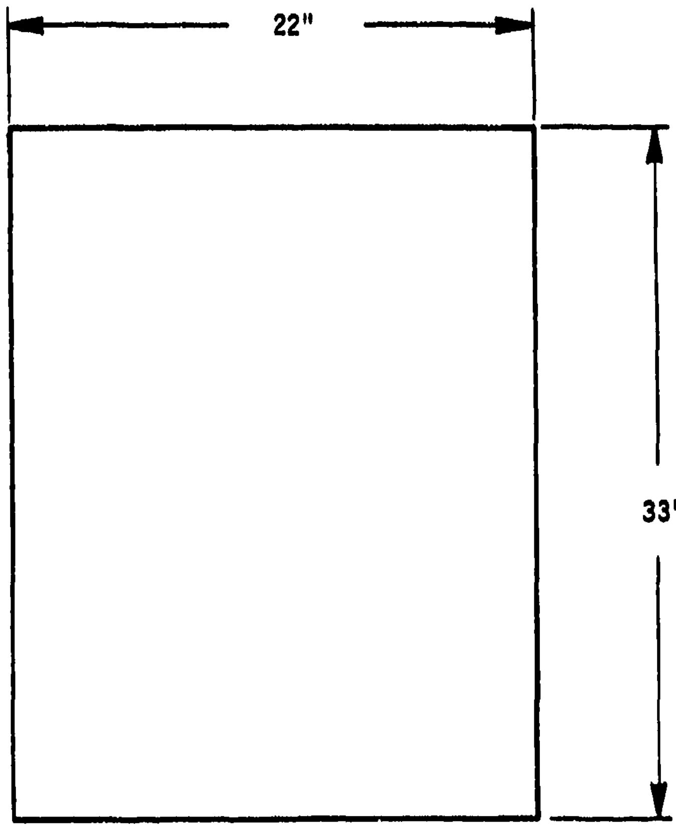


SHIELDED CORE BAFFLED CYLINDER SUPPRESSOR

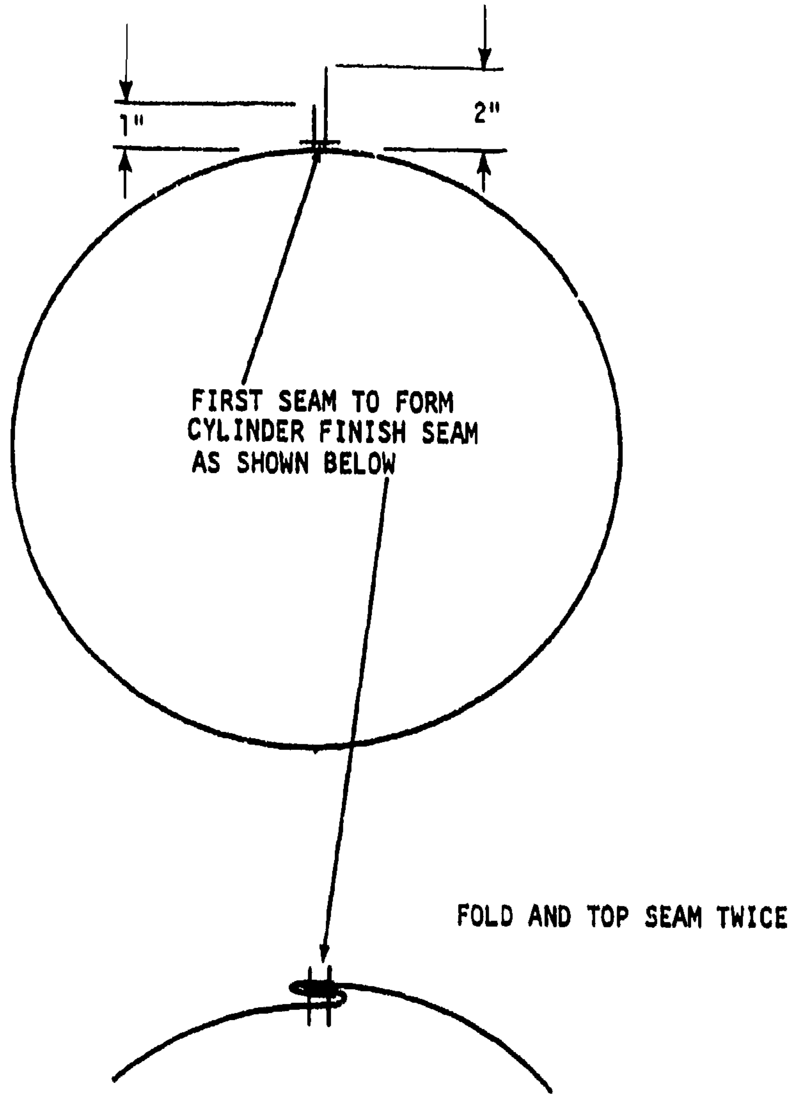

BOEING
NOISE SUPPRESSOR ZONES
0108-1 SKETCH

KEVLAR CYLINDER PATTERN AND ASSEMBLY

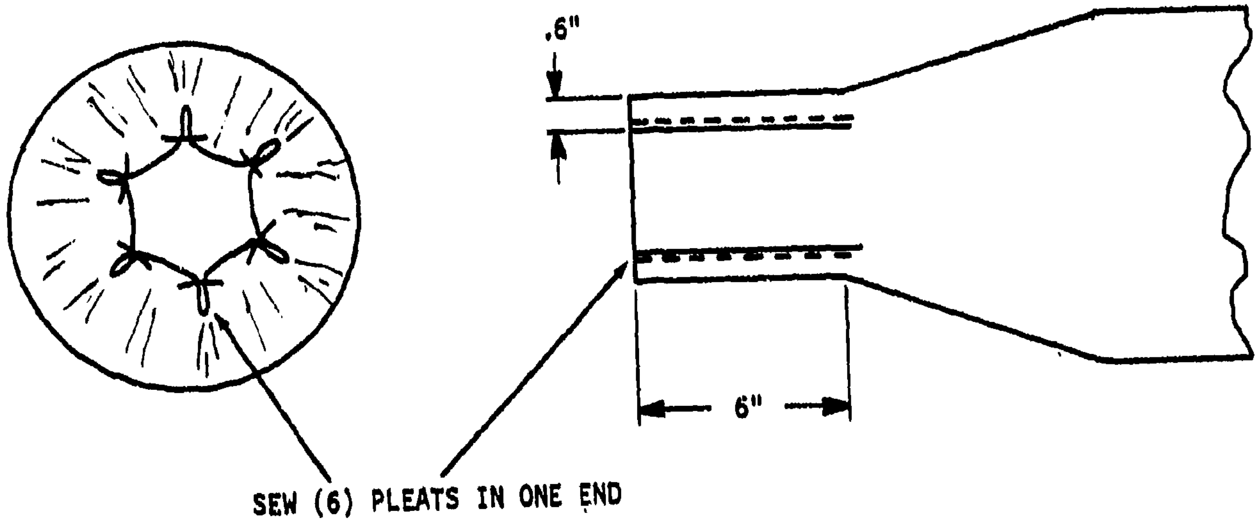
SIDE PATTERN

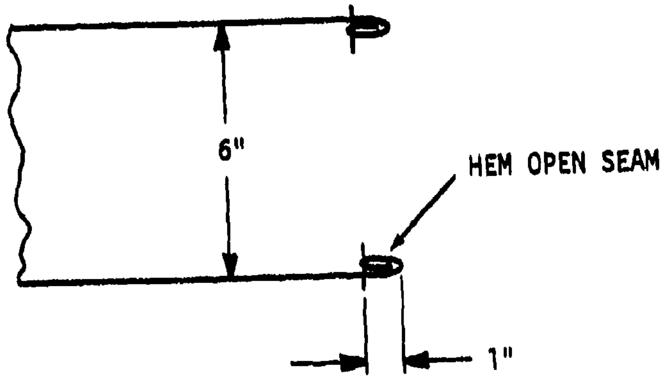


SIDE ASSEMBLY

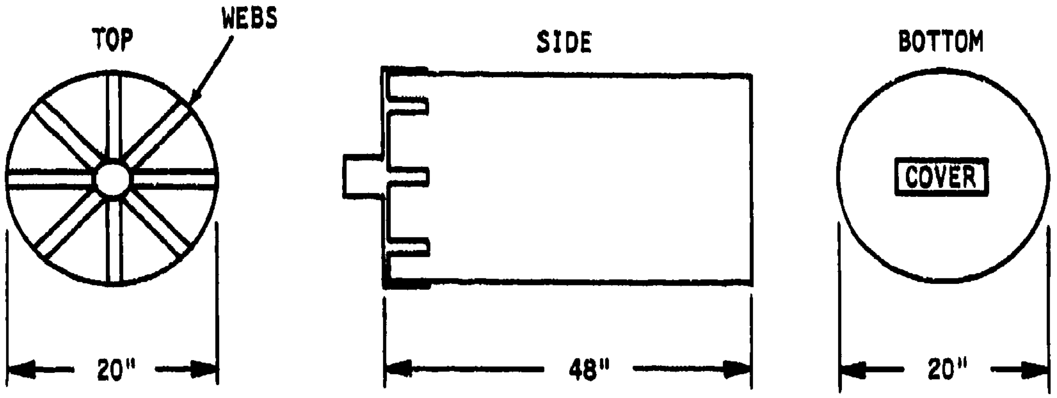


KEVLAR CYLINDER PATTERN AND ASSEMBLY (Continued)

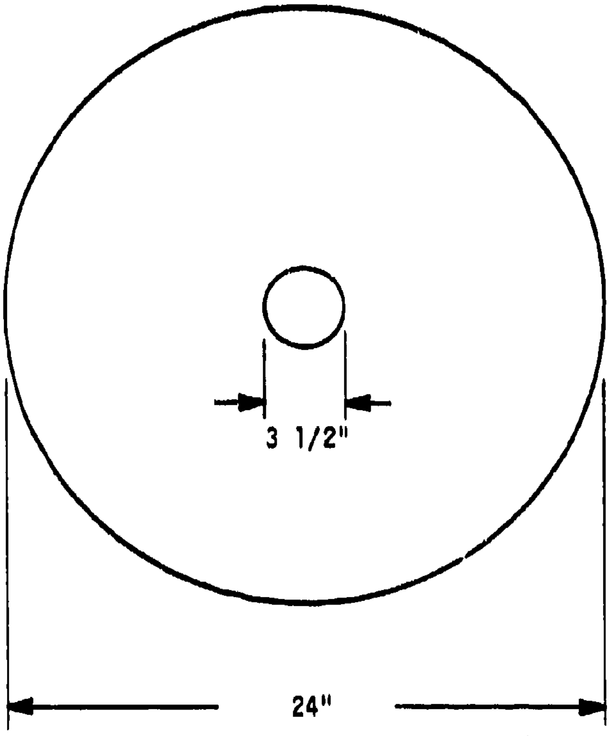




KEVLAR TOTAL CONTAINMENT BAG PATTERN AND ASSEMBLY

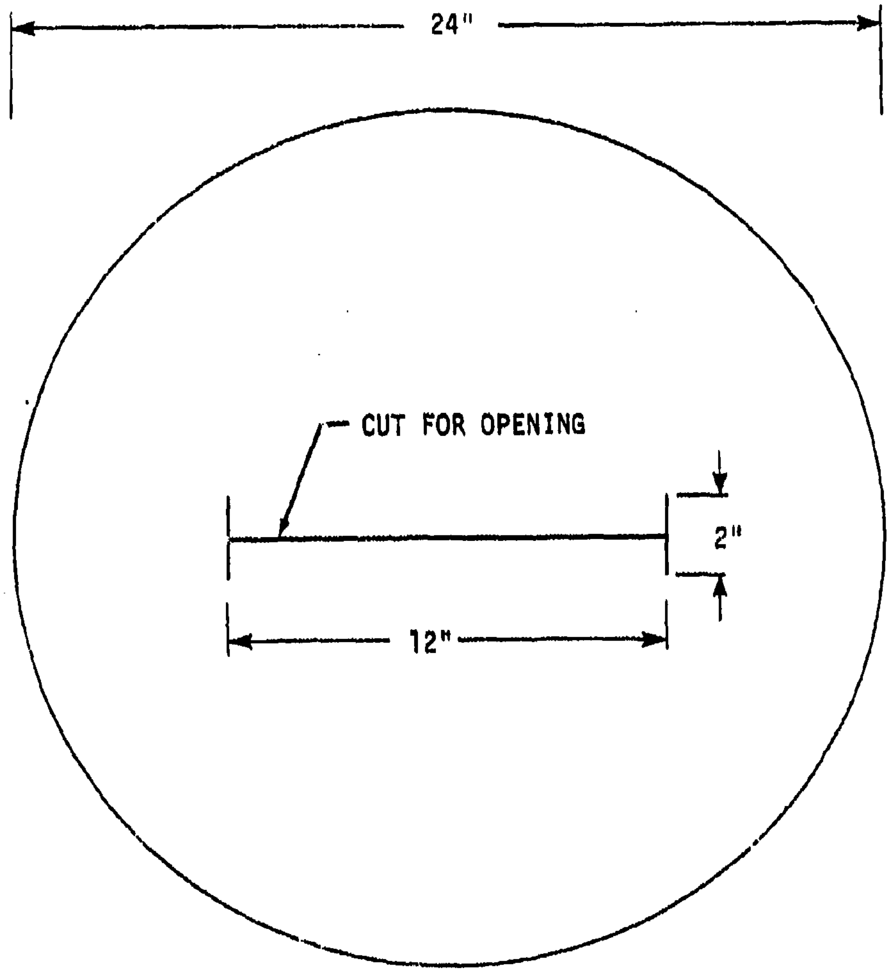


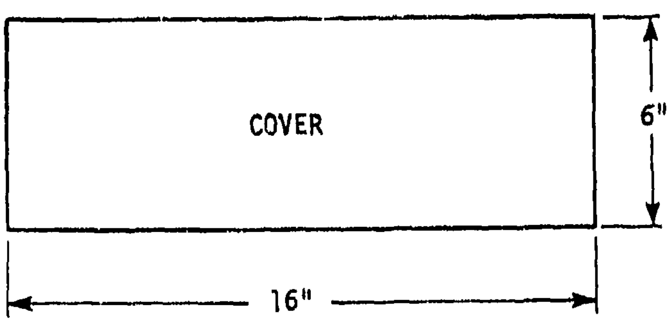
TOP PATTERN



KEVLAR TOTAL CONTAINMENT BAG PATTERN AND ASSEMBLY (Continued)

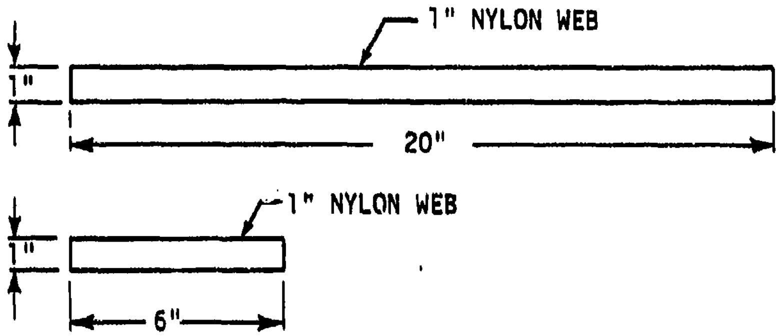
BOTTOM PATTERN



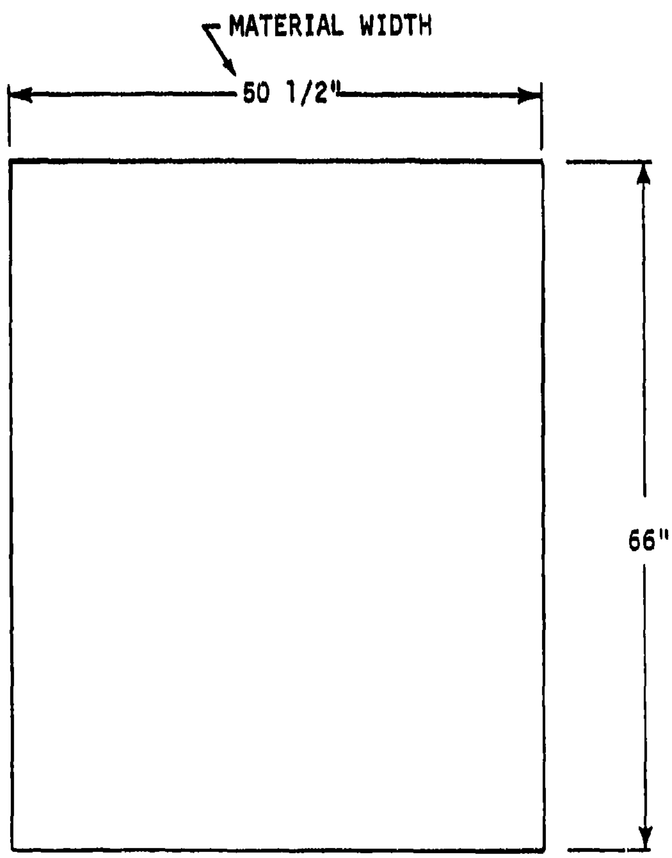


KEVLAR TOTAL CONTAINMENT BAG PATTERN AND ASSEMBLY (Continued)

WEB PATTERN (8 EACH REQD)

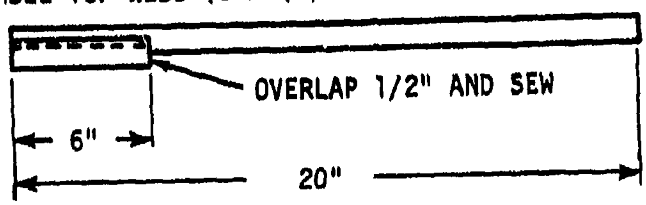


SIDE PATTERN

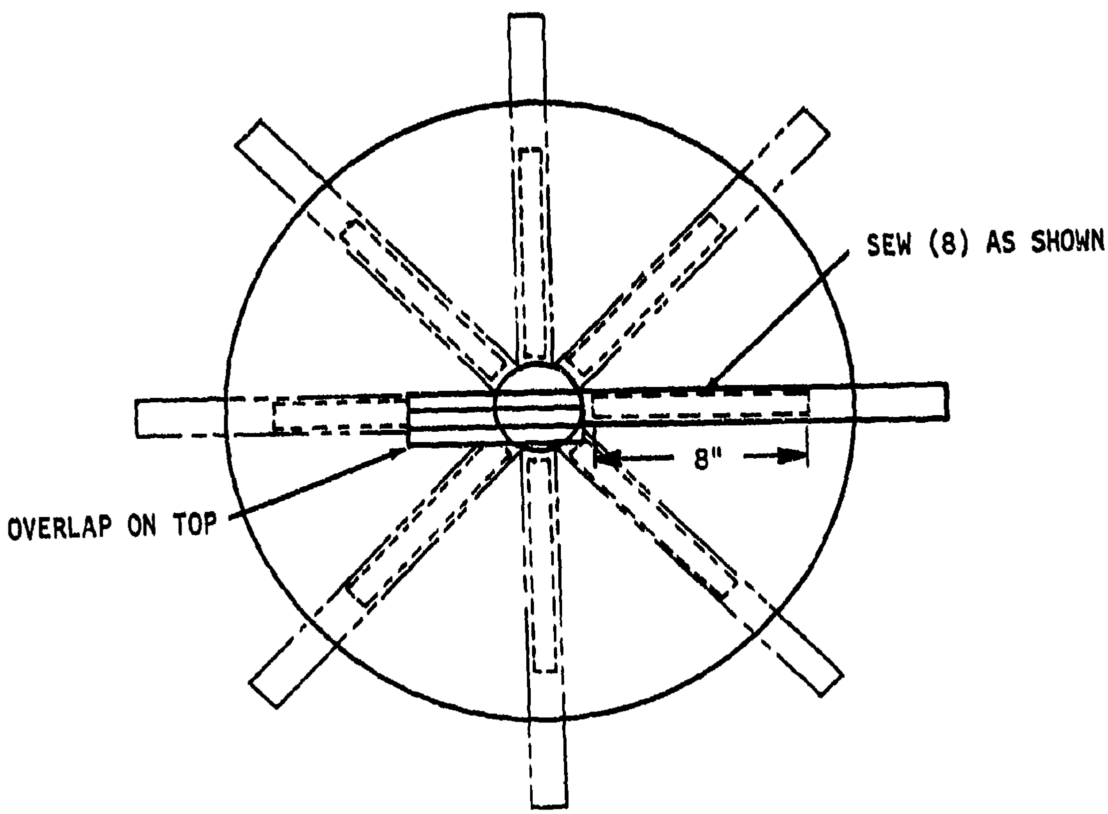


TOP ASSEMBLY

① ASSEMBLE TOP WEBS (8 REQD)

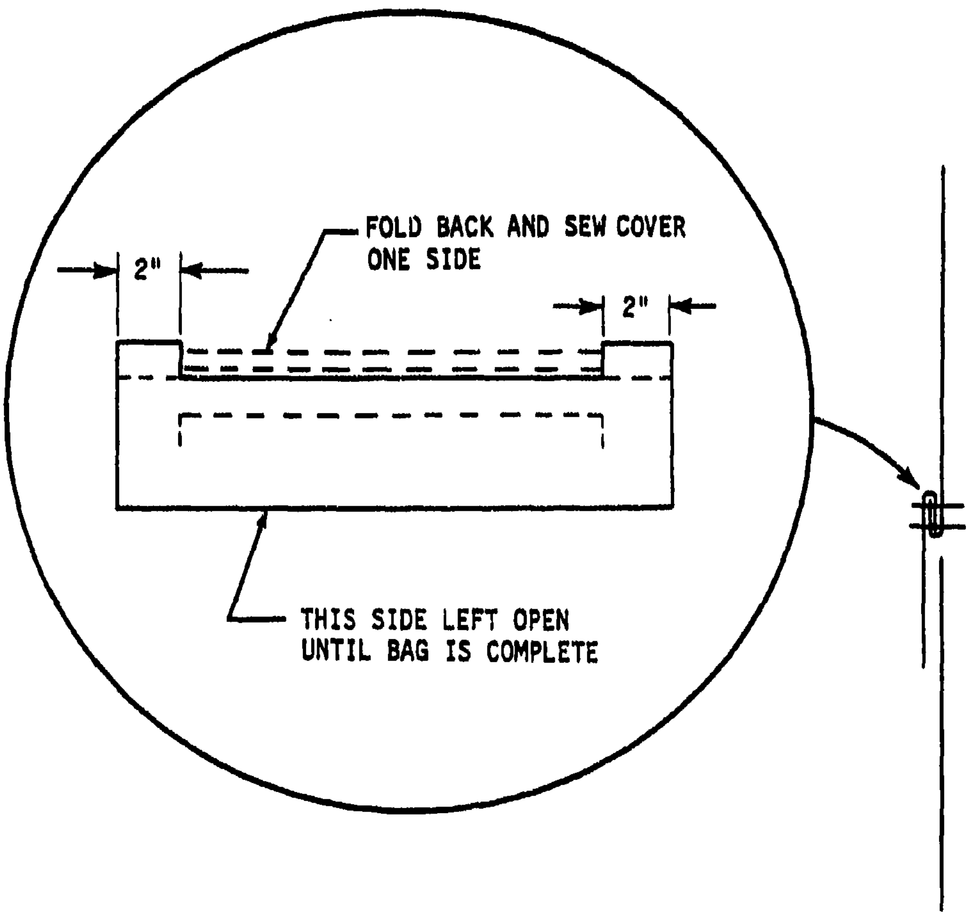


② SEW TOP WEBS TO TOP



BOTTOM ASSEMBLY

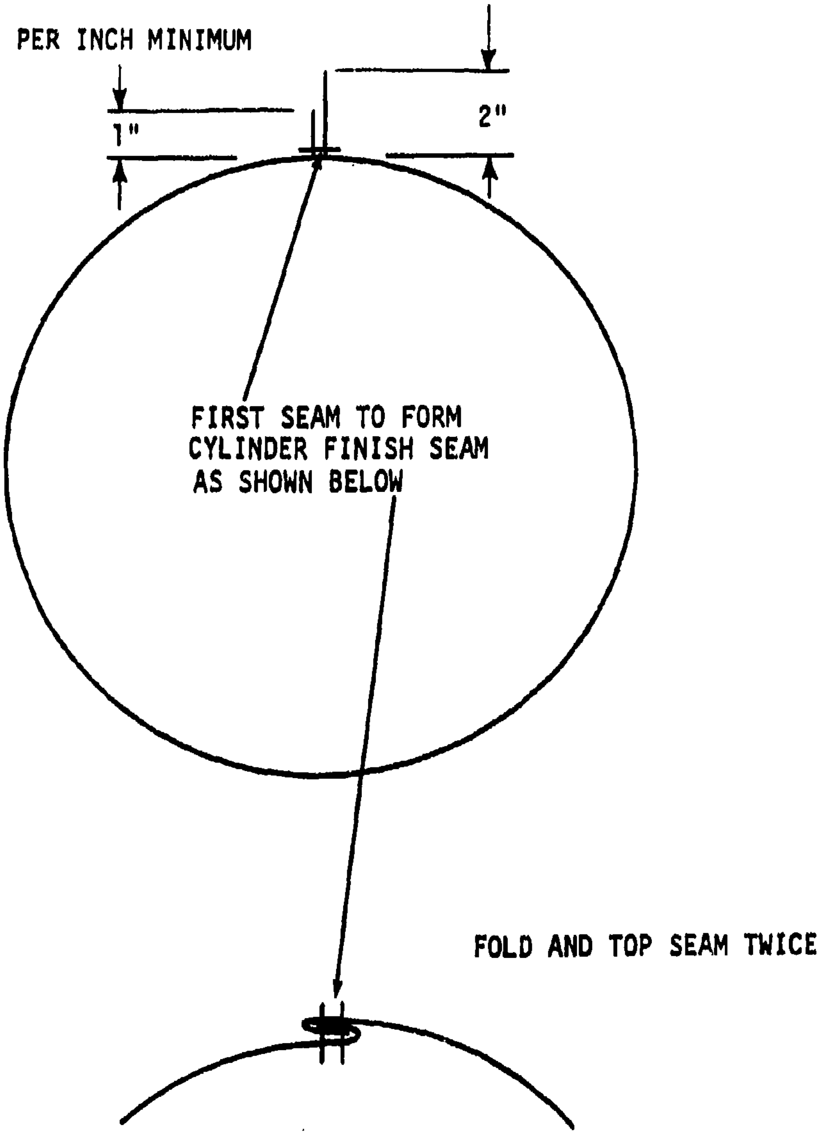
NOTE: 8 STITCHES PER INCH MINIMUM



KEVLAR TOTAL CONTAINMENT BAG PATTERN AND ASSEMBLY (Continued)

SIDE ASSEMBLY

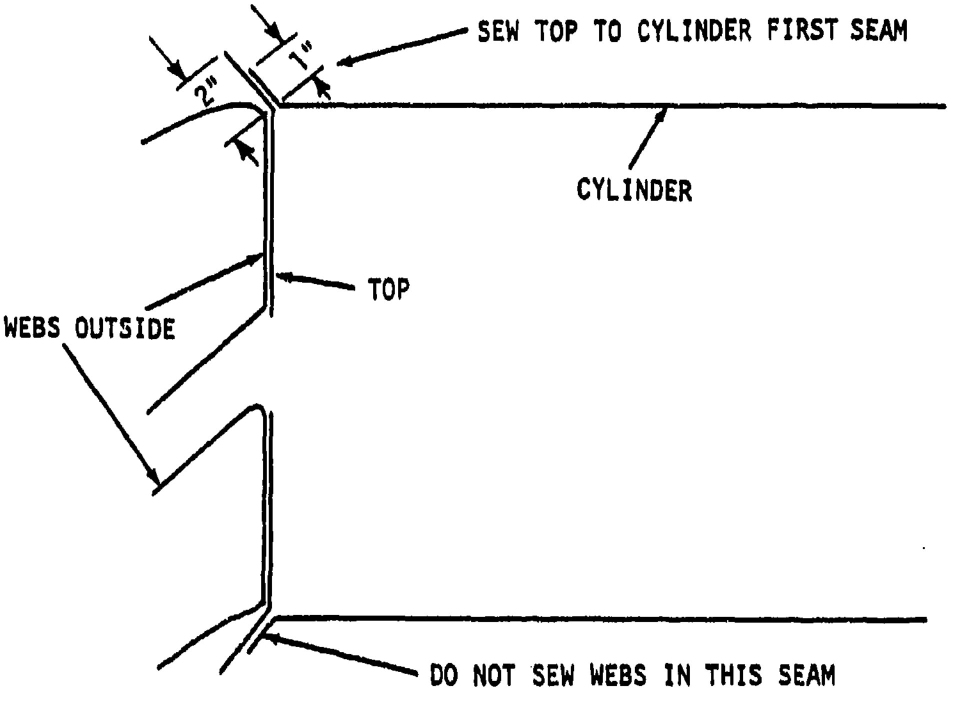
NOTE: 8 STITCHES PER INCH MINIMUM

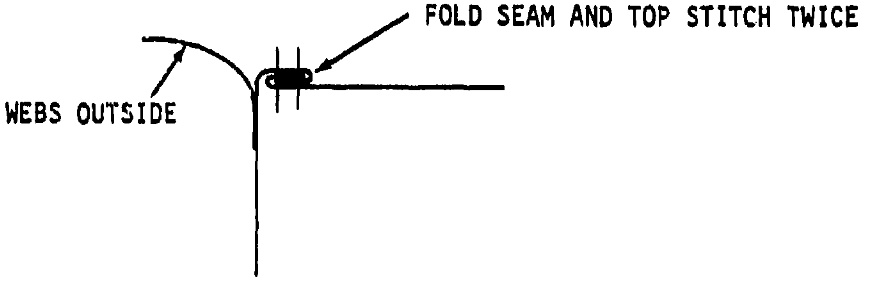


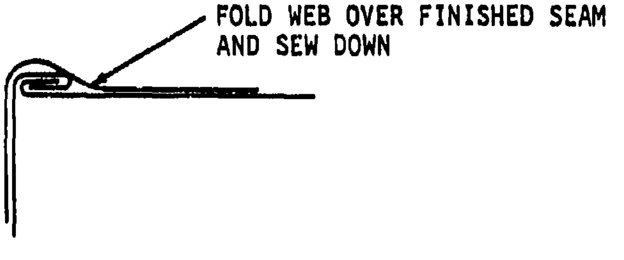
KEVLAR TOTAL CONTAINMENT BAG PATTERN AND ASSEMBLY (Continued)

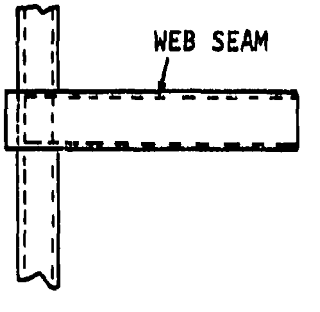
INSTALL TOP OF BAG

NOTE: 8 STITCHES PER INCH MINIMUM



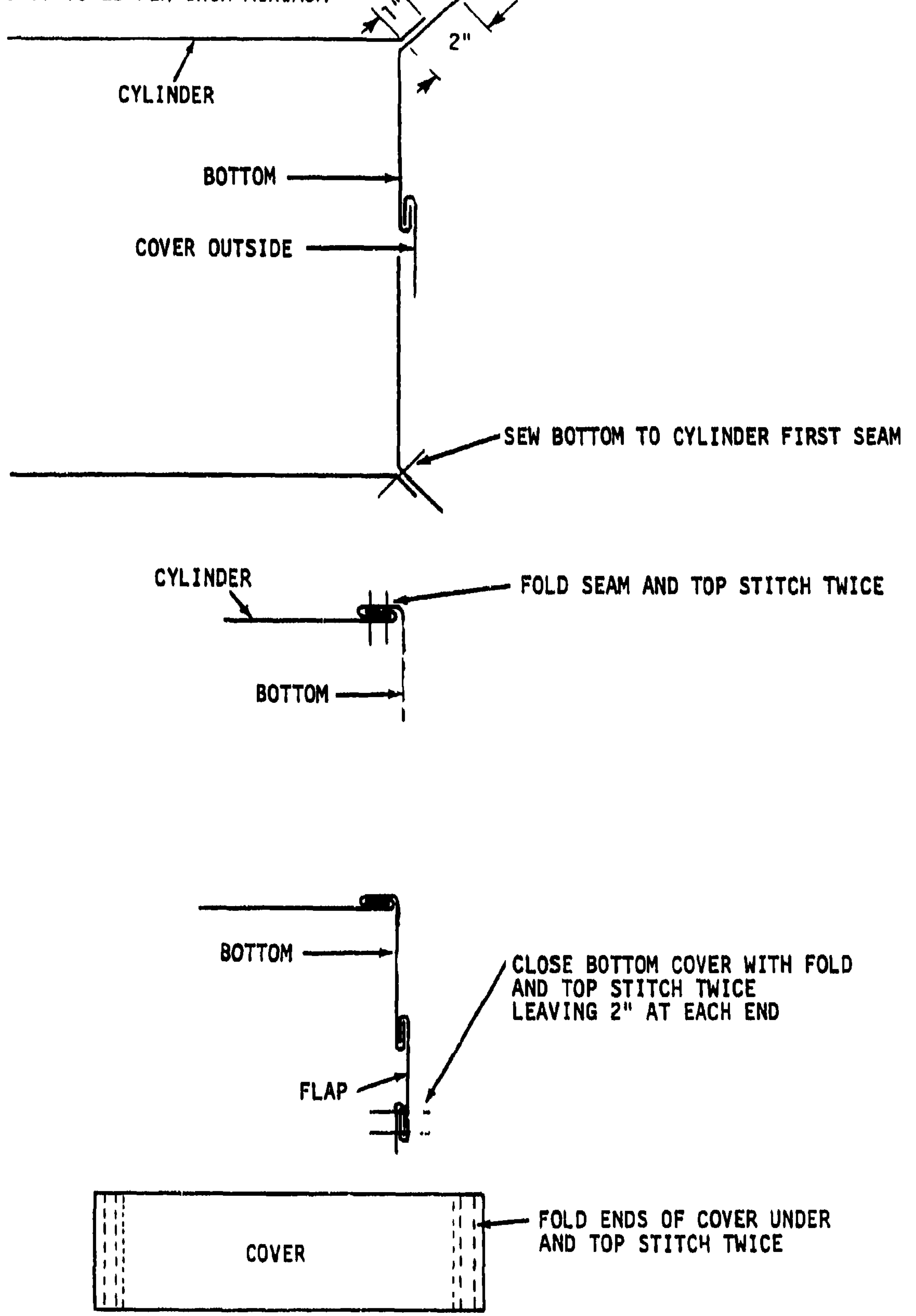




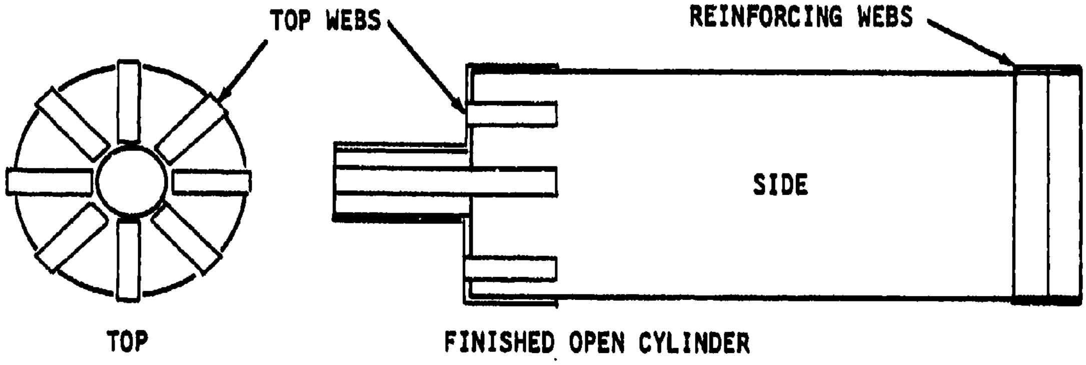


INSTALL BOTTOM OF BAG

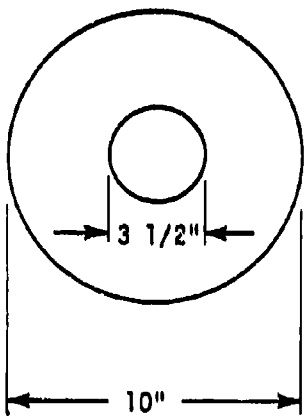
NOTE: 8 STITCHES PER INCH MINIMUM



OPEN CYLINDER PATTERN & ASSEMBLY
6" DIAMETER 24" LONG

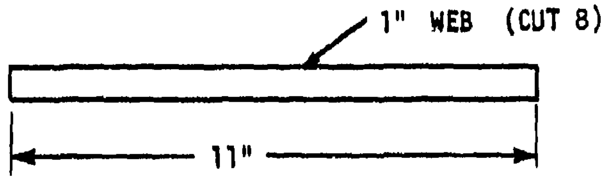


TOP PATTERN

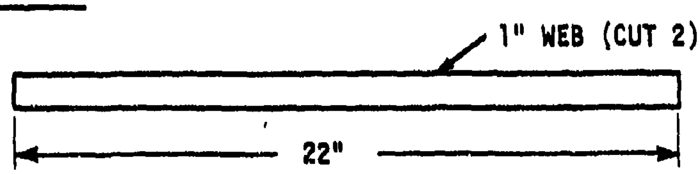


OPEN CYLINDER PATTERN & ASSEMBLY (Continued)

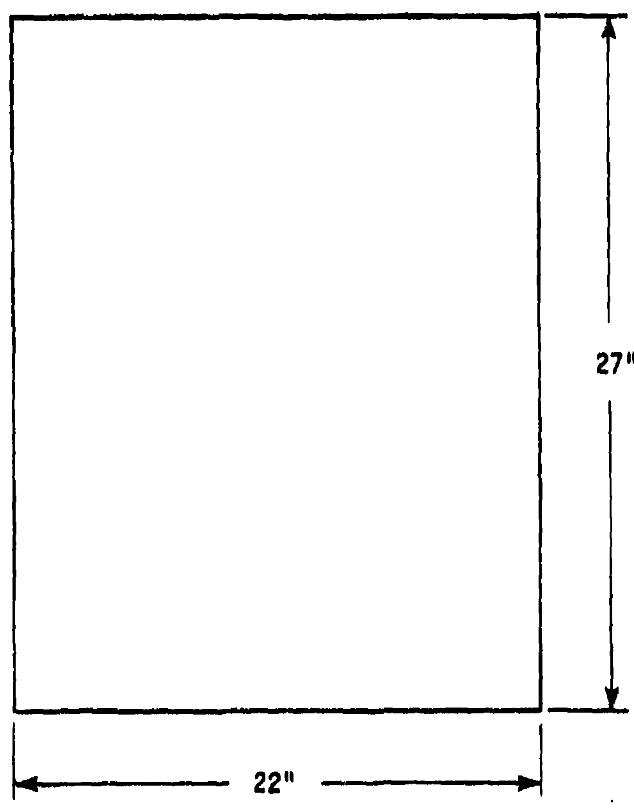
TOP WEB PATTERN



REINFORCING WEB PATTERN

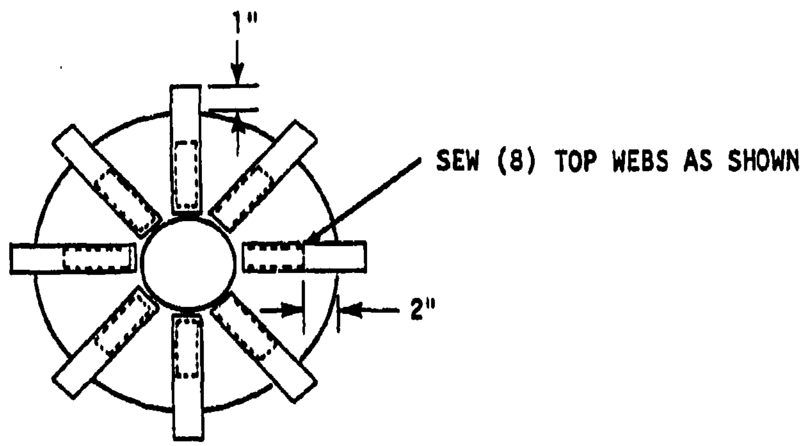


SIDE PATTERN



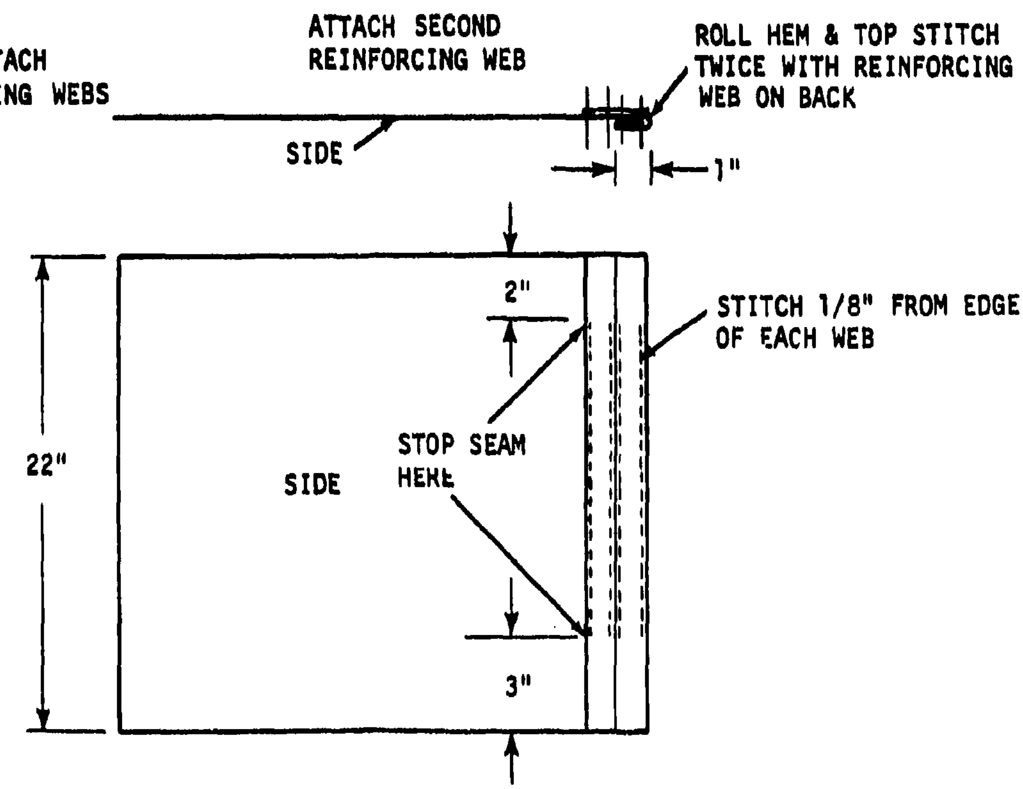
TOP ASSEMBLY

① ATTACH TOP WEBS



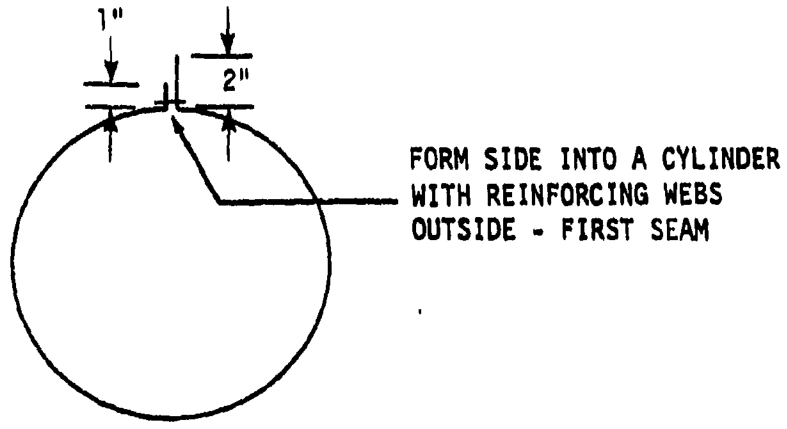
SIDE ASSEMBLY

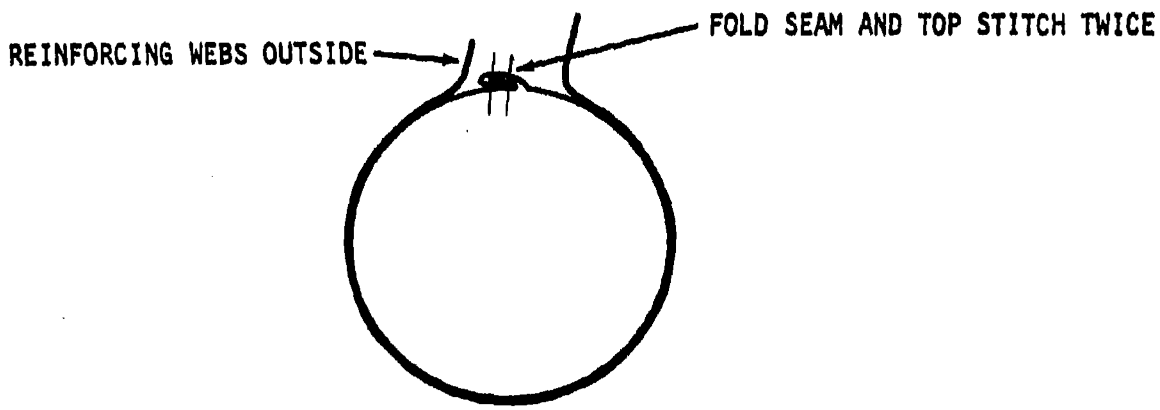
①
HEM & ATTACH REINFORCING WEBS

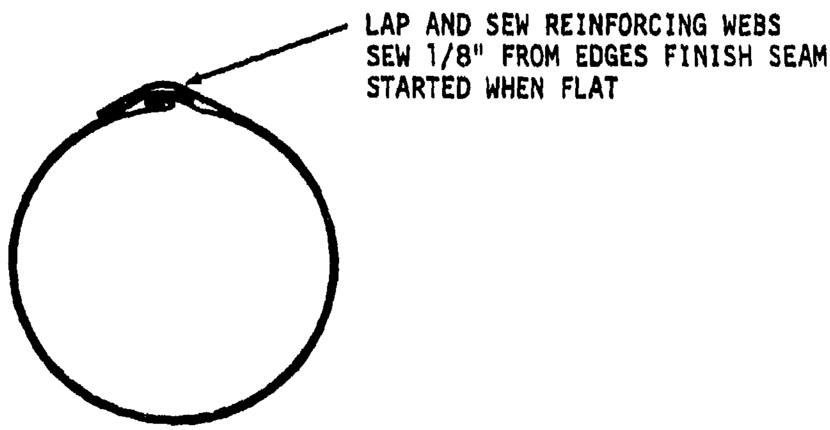


OPEN CYLINDER PATTERN AND ASSEMBLY (Continued)

(2) SEW SIDE INTO A CYLINDER

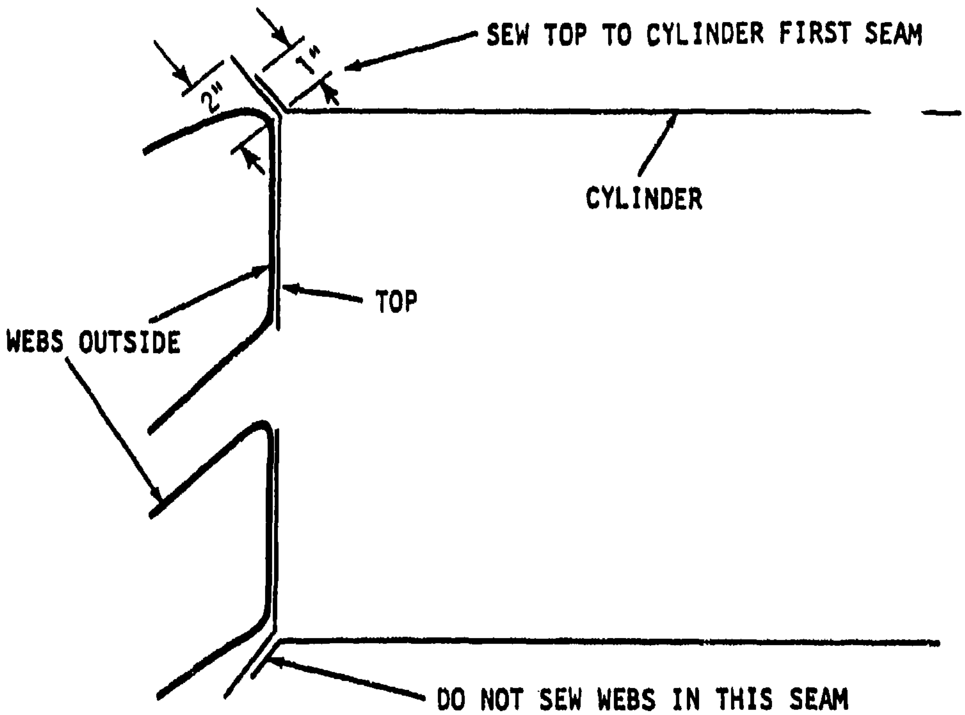


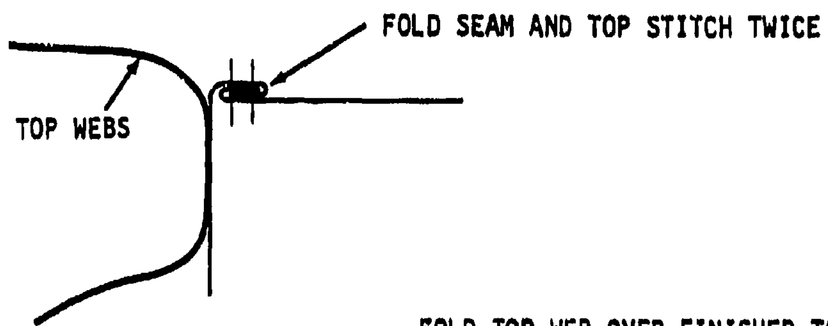


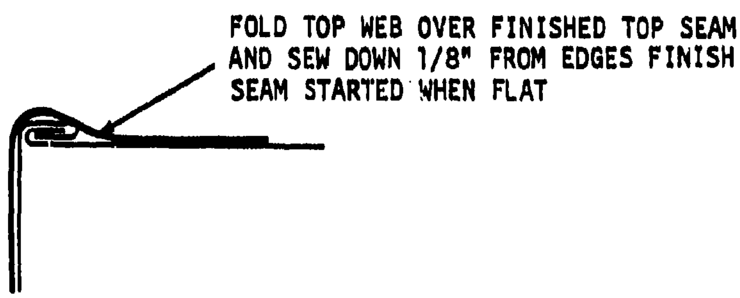


OPEN CYLINDER PATTERN AND ASSEMBLY (Continued)

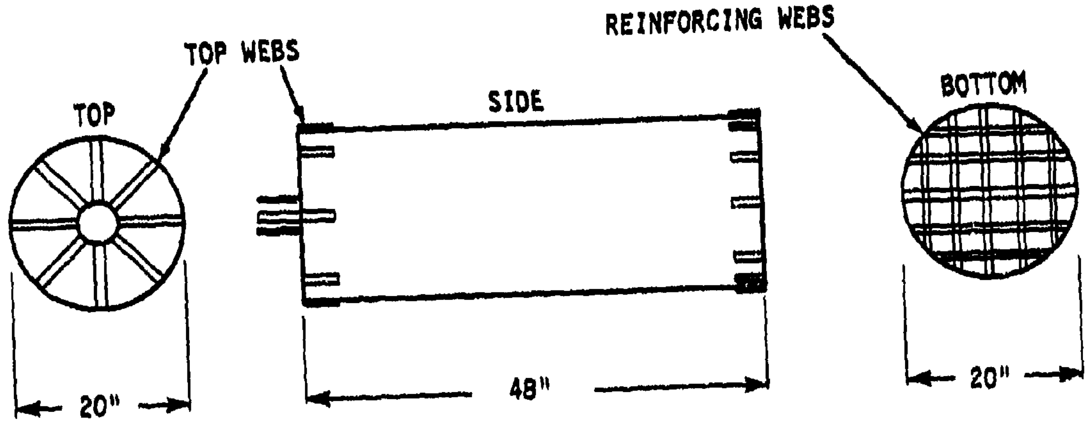
ASSEMBLE TOP AND CYLINDER



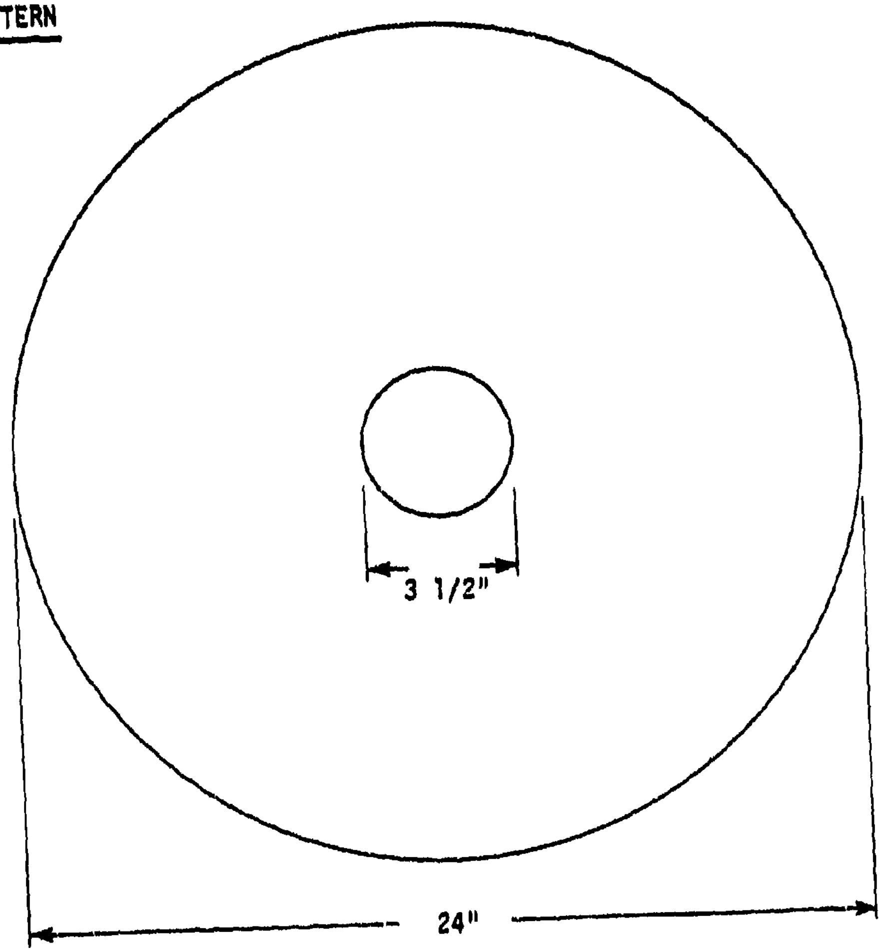




KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY

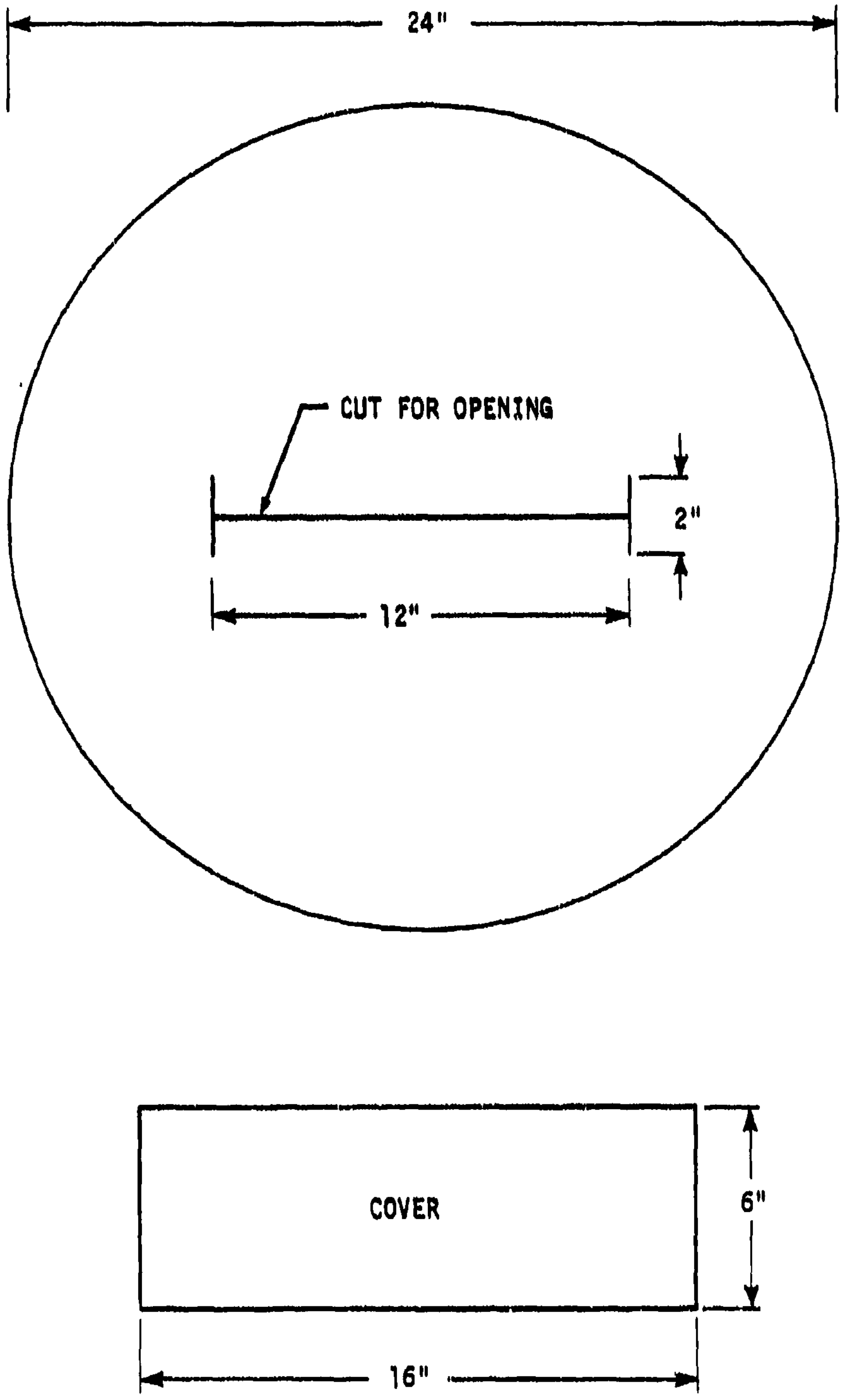


TOP PATTERN

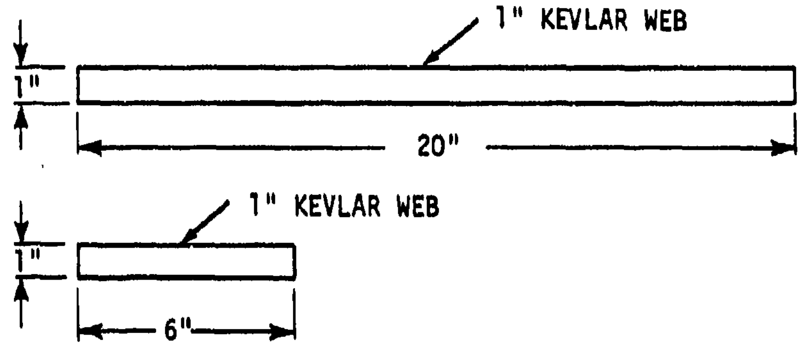


KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

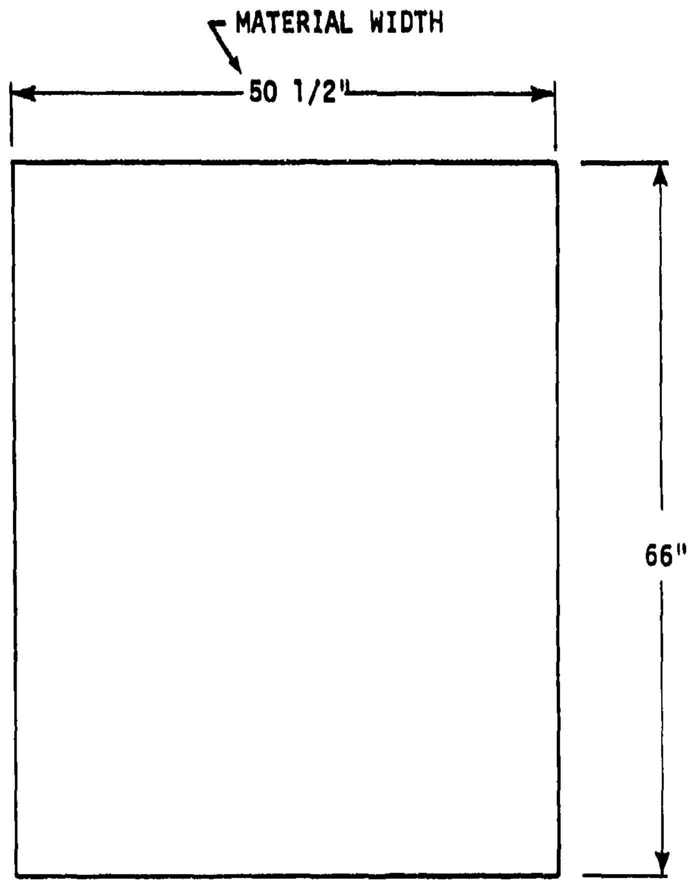
BOTTOM PATTERN



TOP WEB PATTERN (8 EACH REQD)

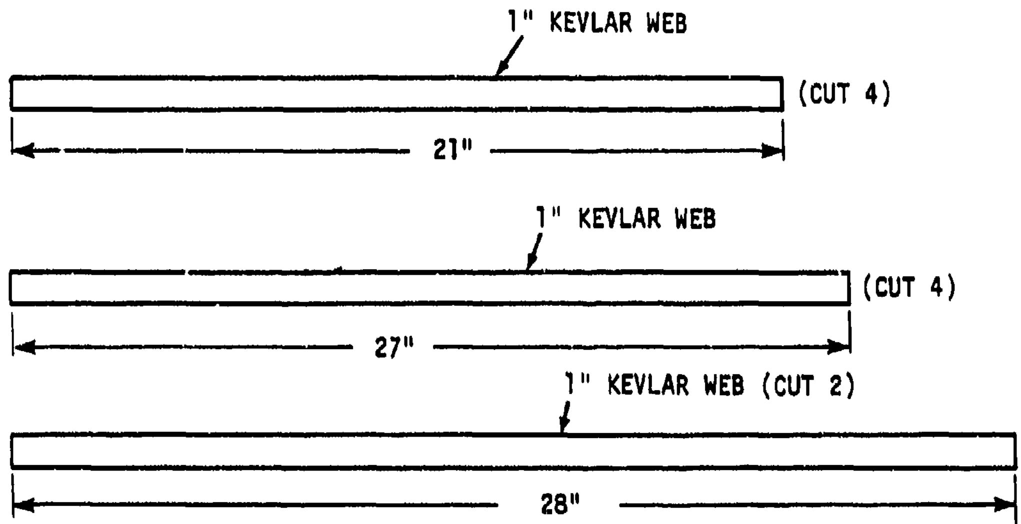


SIDE PATTERN



KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

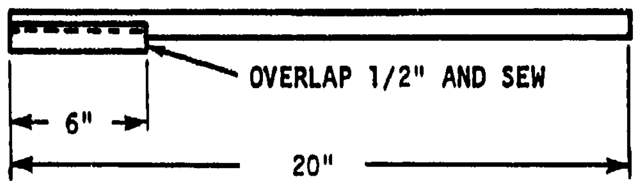
BOTTOM WEB REINFORCING PATTERNS



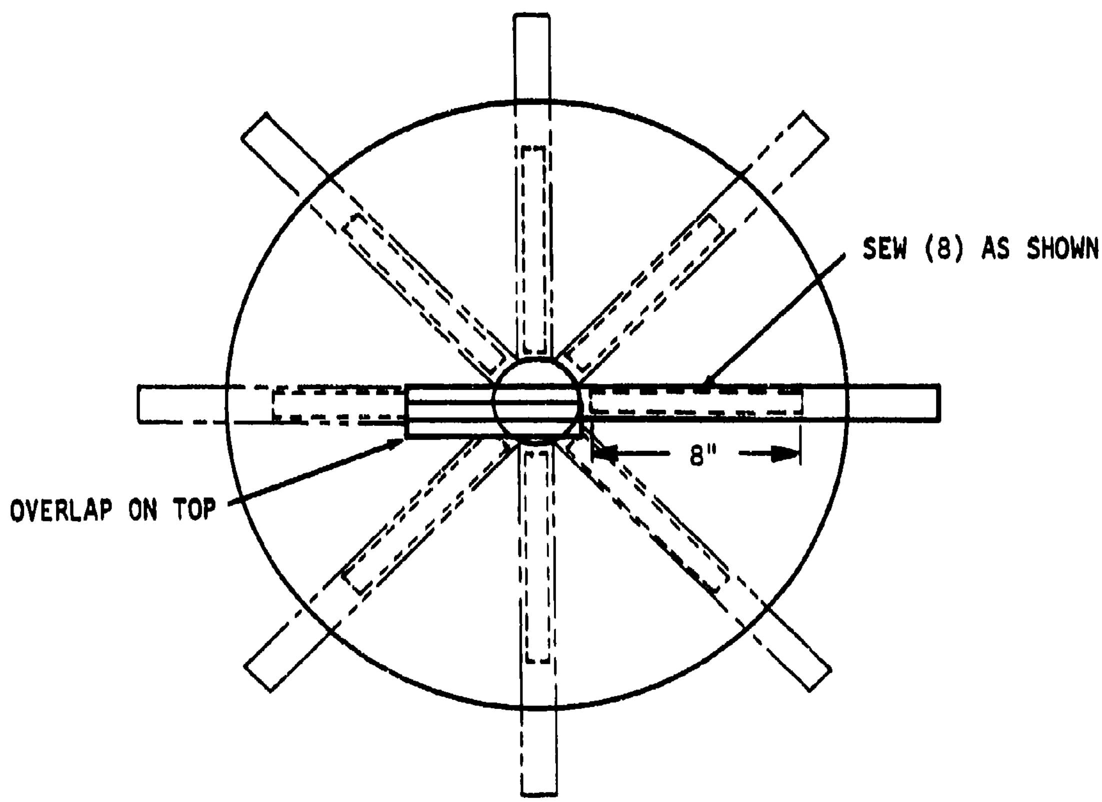
KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

TOP ASSEMBLY

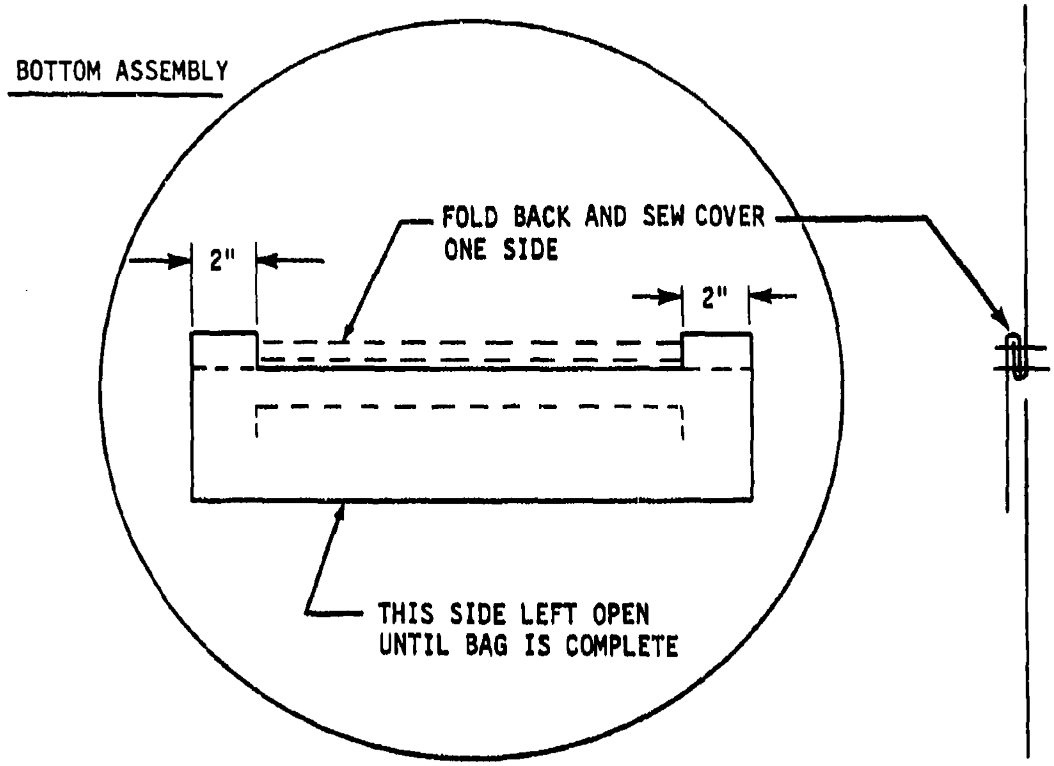
(1) ASSEMBLE TOP WEBS (8 REQD)



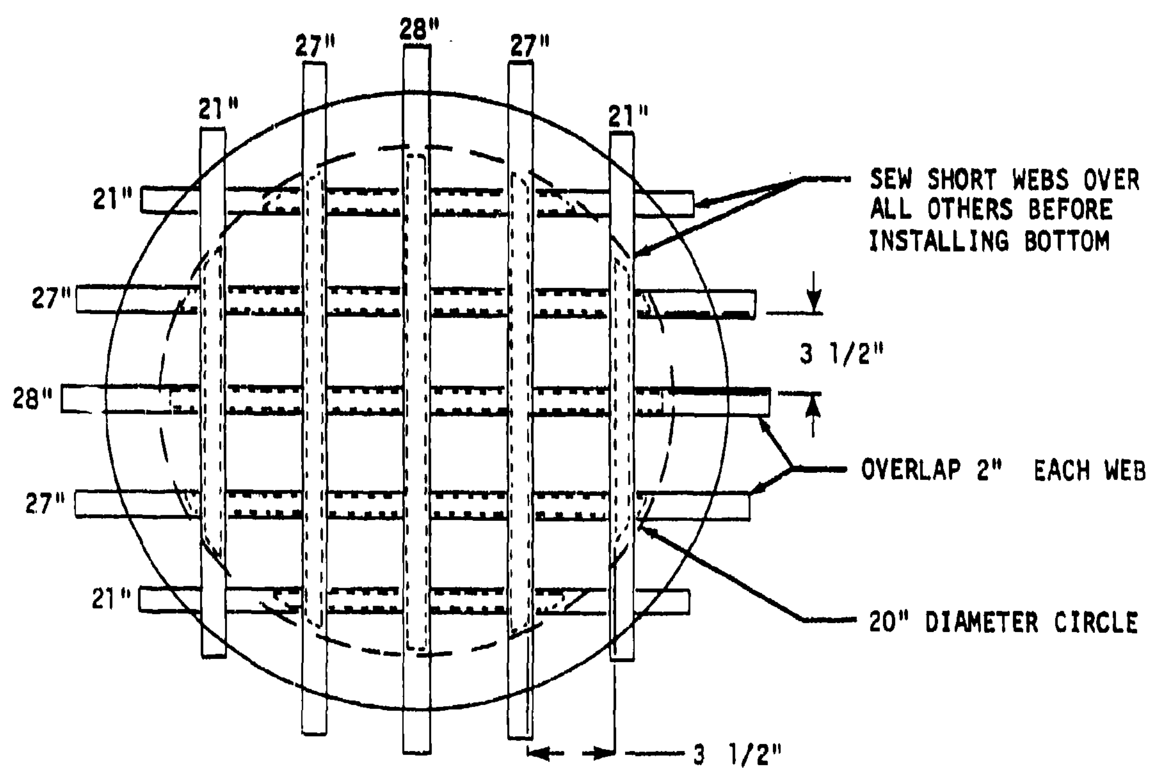
(2) SEW TOP WEBS TO TOP



KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

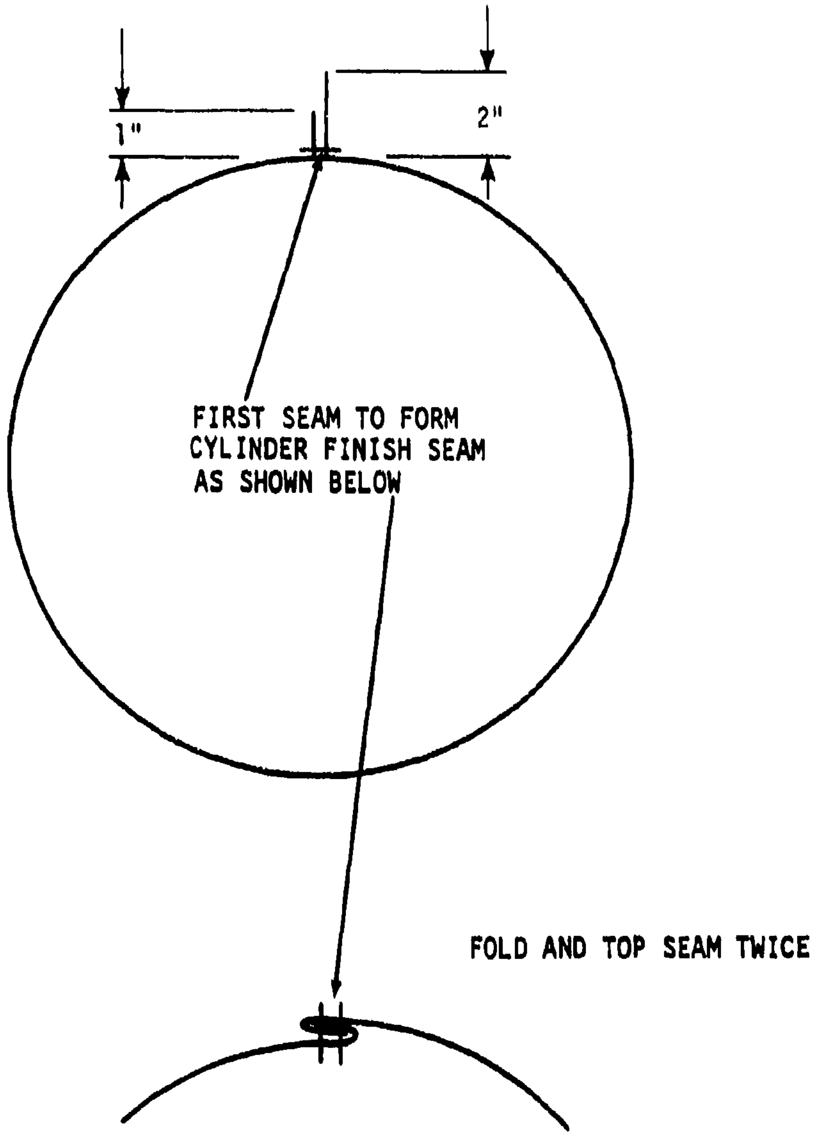


POSITION REINFORCING WEBS AND SEW ONLY THE 4 SHORT WEBS. USE 4 STITCHES/INCH. THIS WILL RETAIN ALL WEBS IN POSITION.



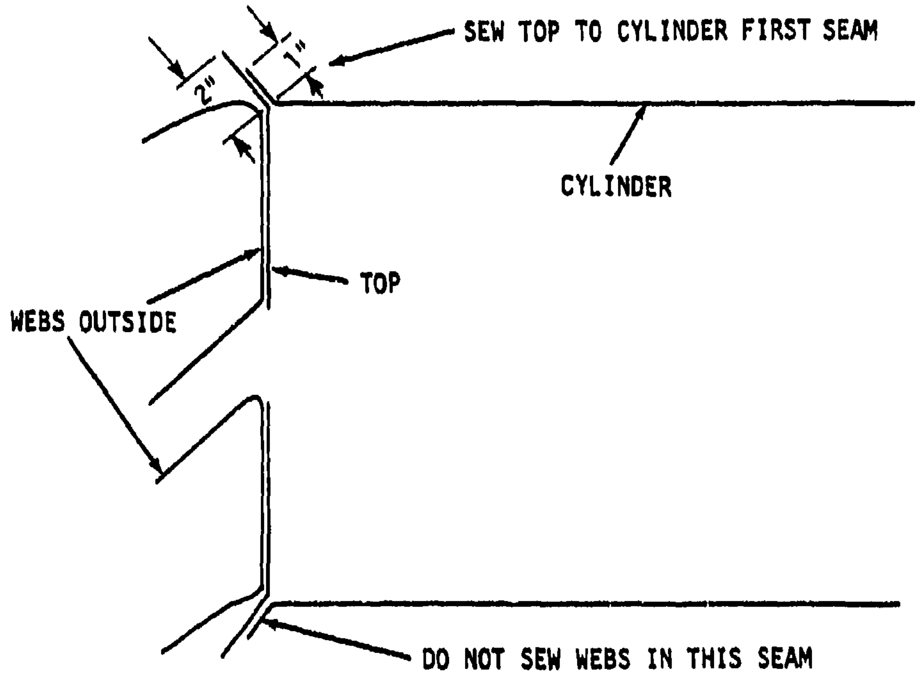
KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

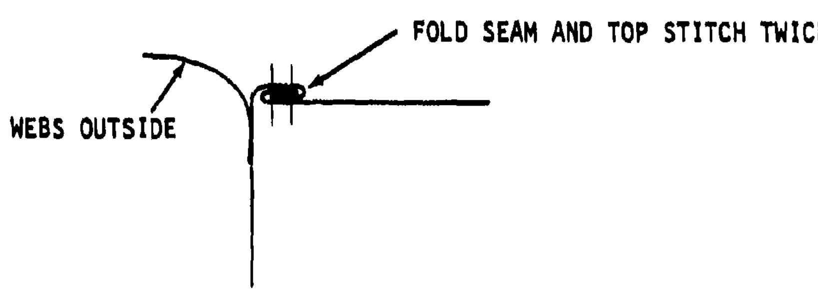
SIDE ASSEMBLY

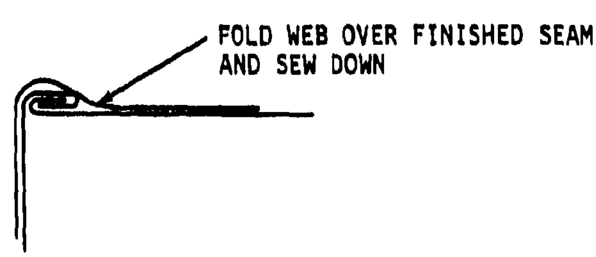


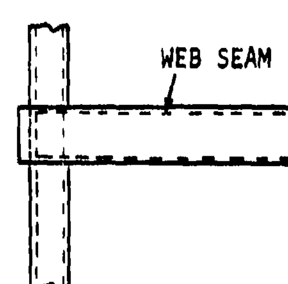
KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

INSTALL TOP OF BAG



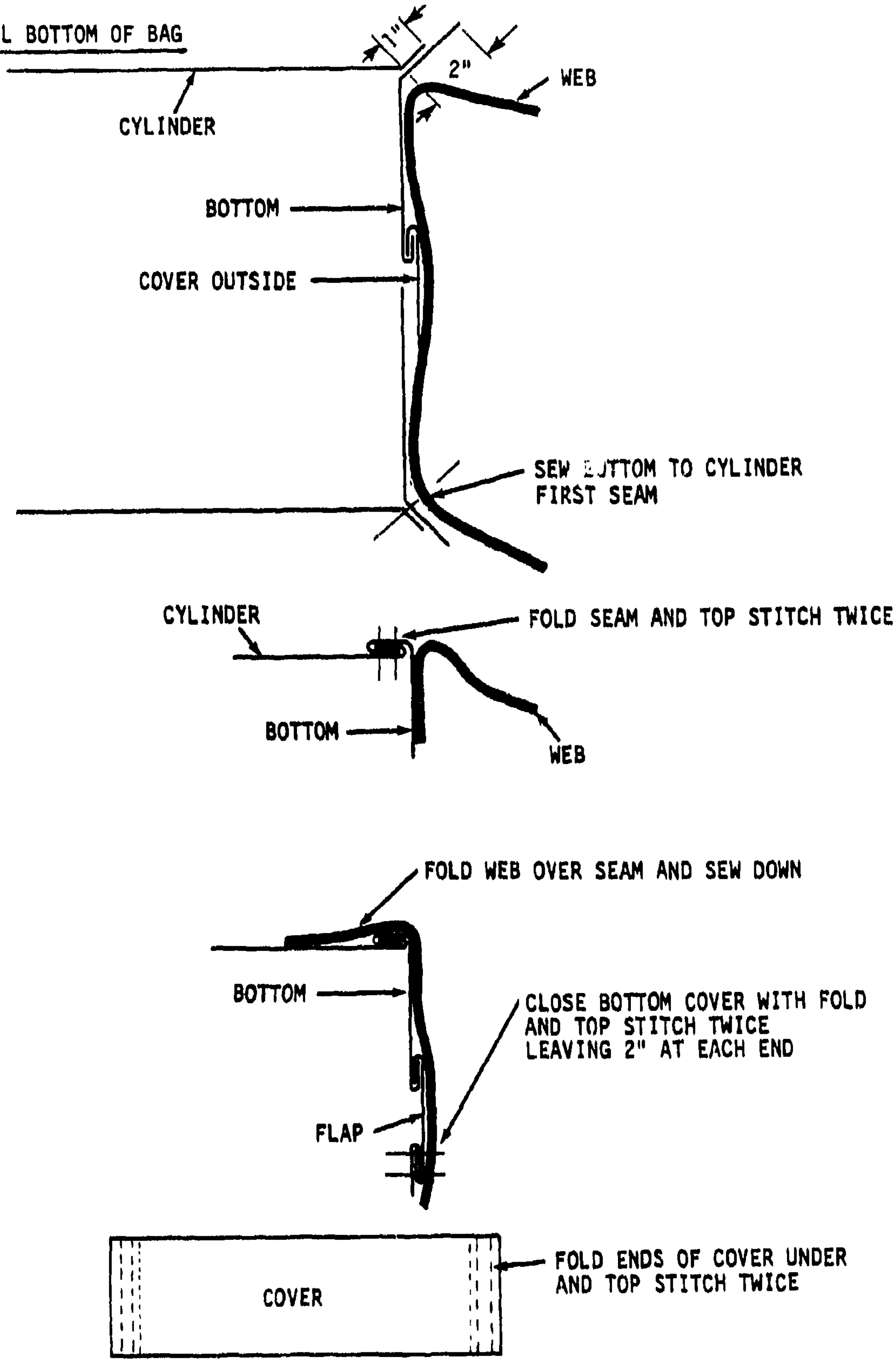




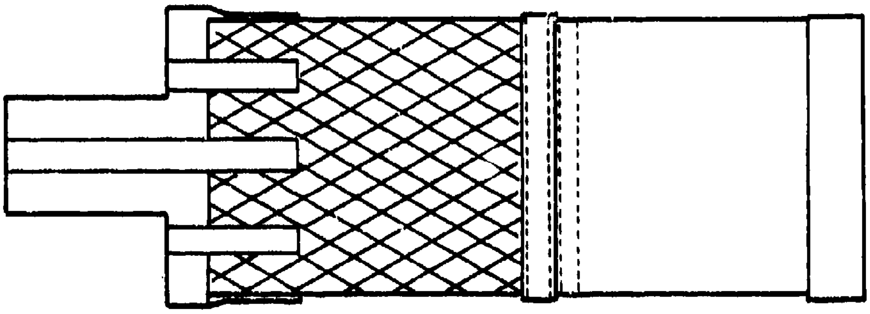


KEVLAR TOTAL CONTAINMENT BAG WITH WEB REINFORCED BOTTOM PATTERN AND ASSEMBLY (Continued)

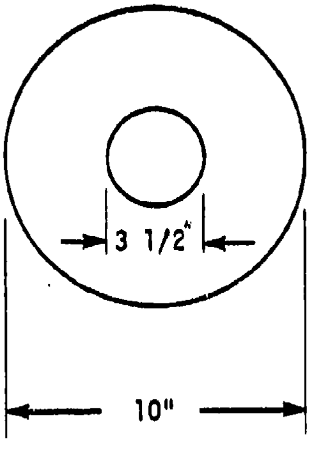
INSTALL BOTTOM OF BAG



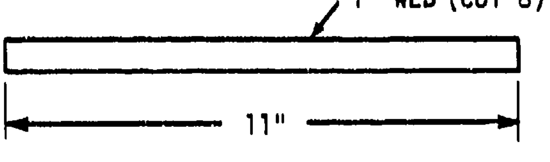
FORWARD BRAIDED VENT OPEN CYLINDER PATTERN AND ASSEMBLY



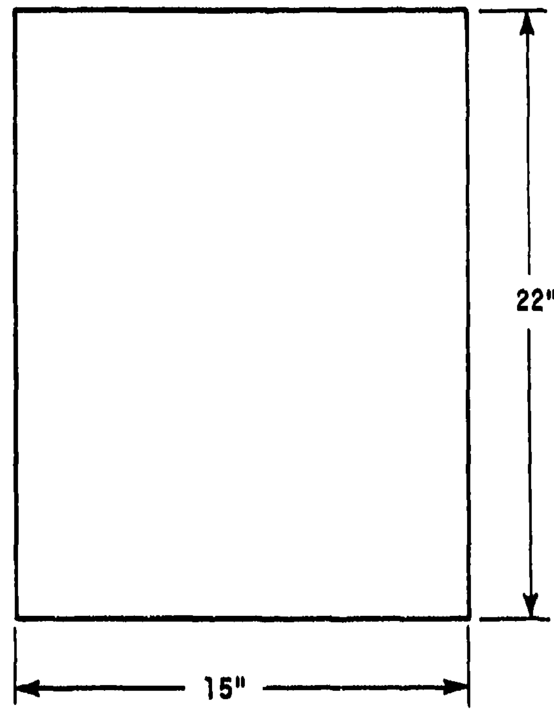
TOP PATTERN



TOP WEB PATTERN

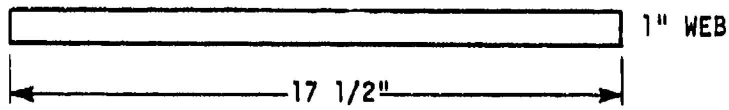


SIDE PATTERN

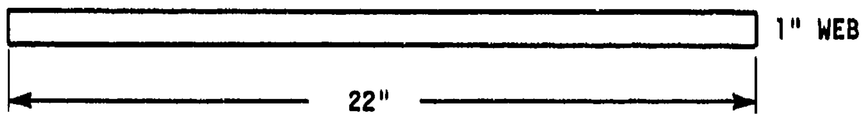


FORWARD BRAIDED VENT OPEN CYLINDER PATTERN AND ASSEMBLY (Continued)

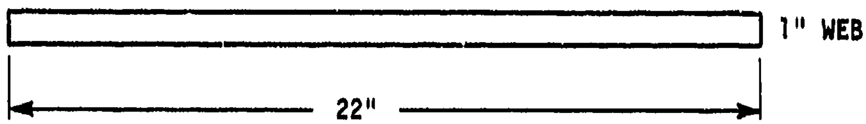
VENT WEB PATTERN (CUT 32)



RADIAL WEB PATTERN (CUT 1)

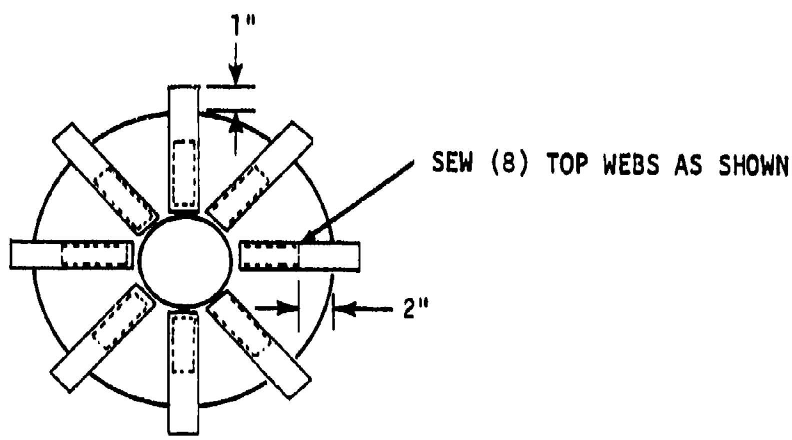


REINFORCING WEB PATTERN (CUT 3)



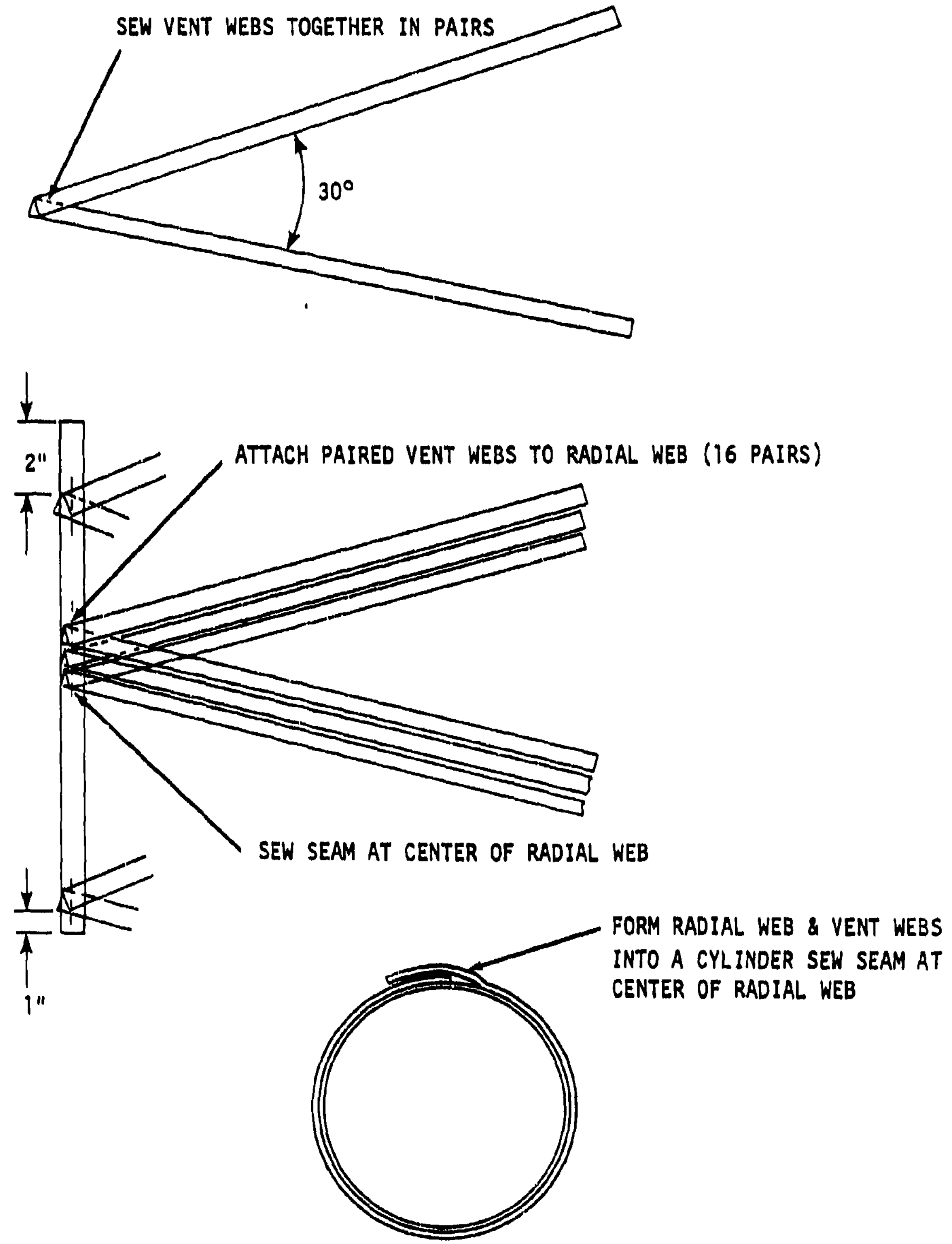
TOP ASSEMBLY

ATTACH TOP WEBS

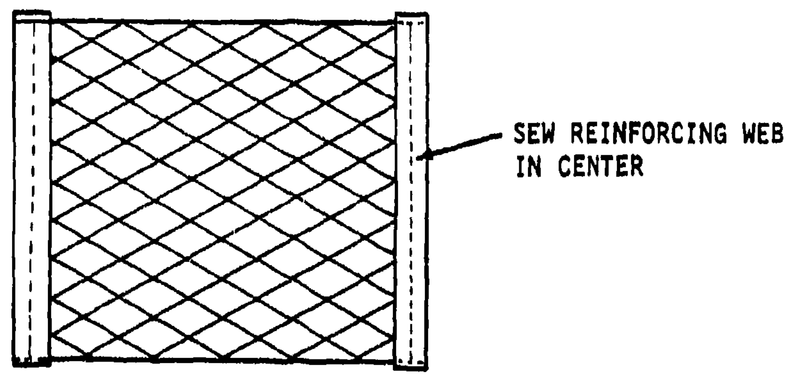


FORWARD BRAIDED VENT OPEN CYLINDER PATTERN AND ASSEMBLY (Continued)

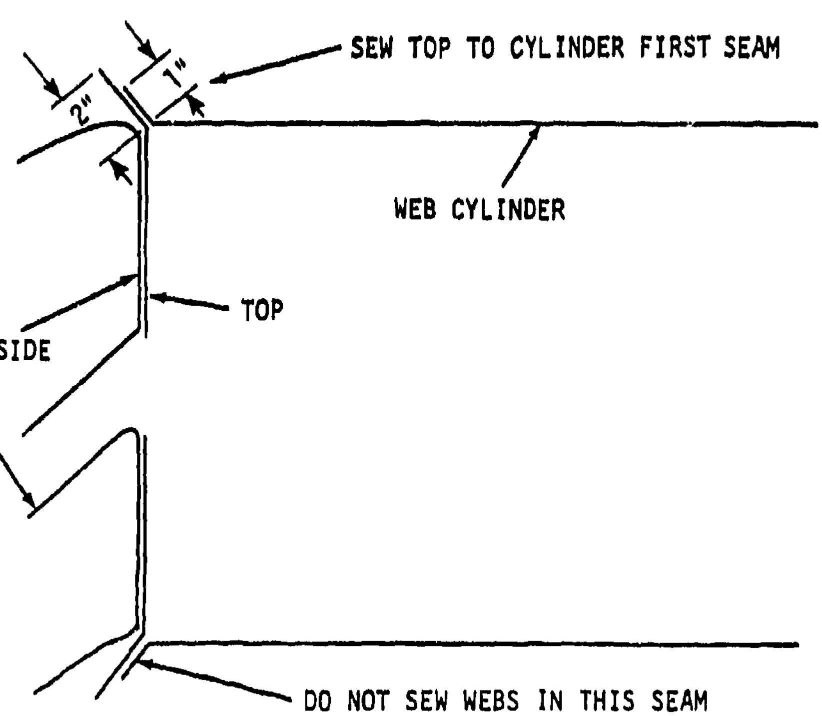
ASSEMBLE WEB VENT



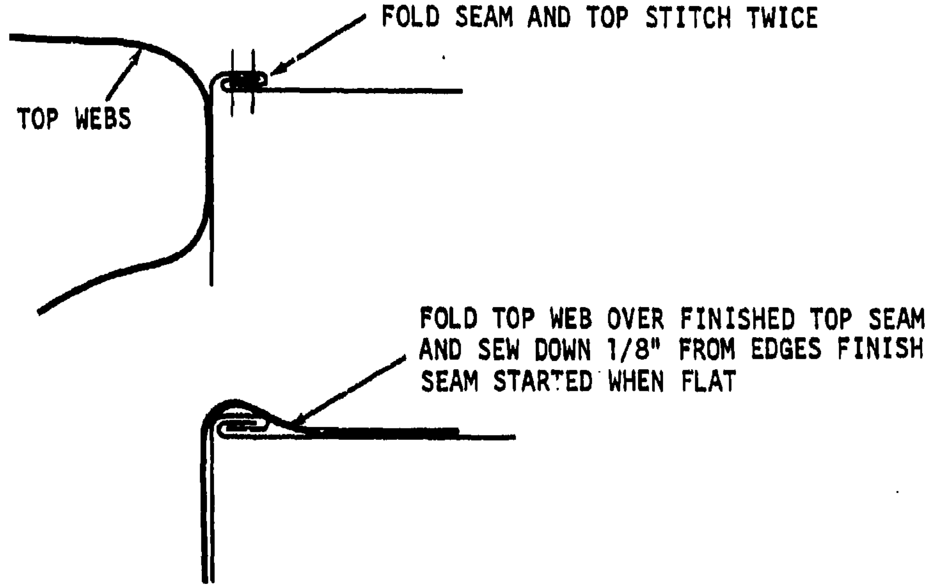
BRAID VENT WEBS TO END AND SEW REINFORCING WEB



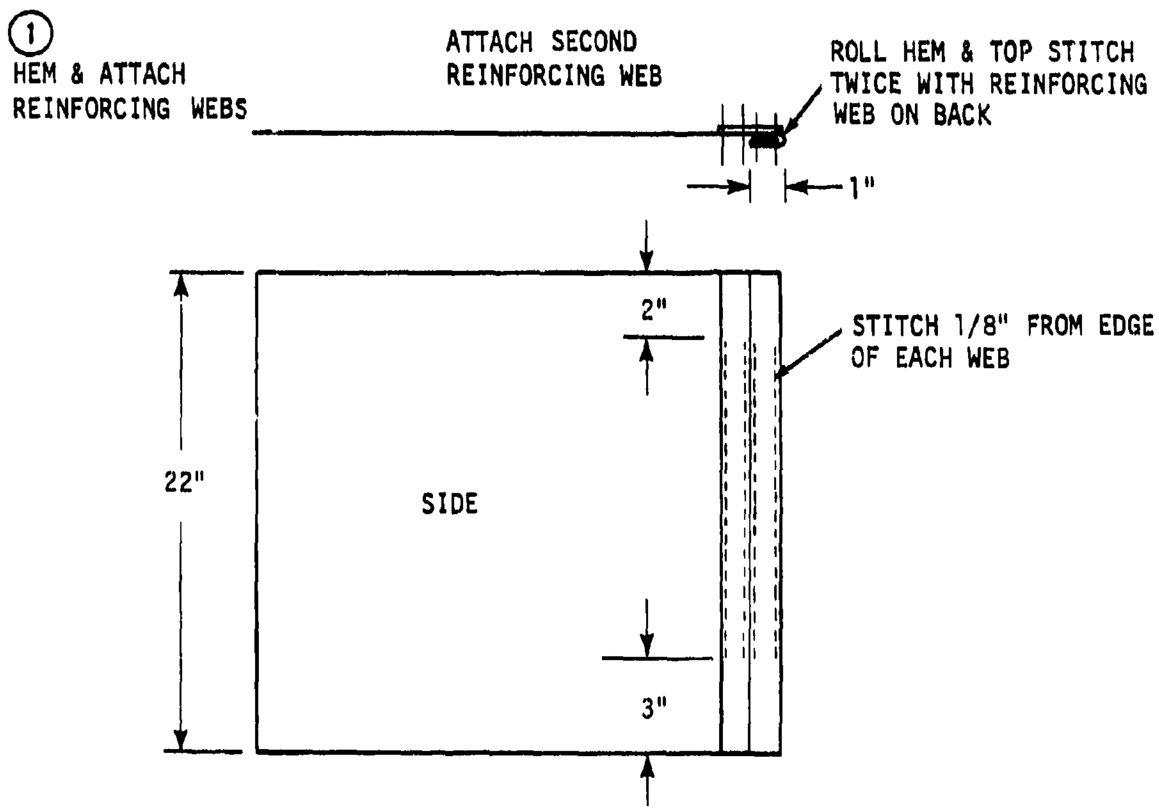
ASSEMBLE TOP AND WEB VENT CYLINDER



ASSEMBLE TOP AND VENT WEB CYLINDER COND.

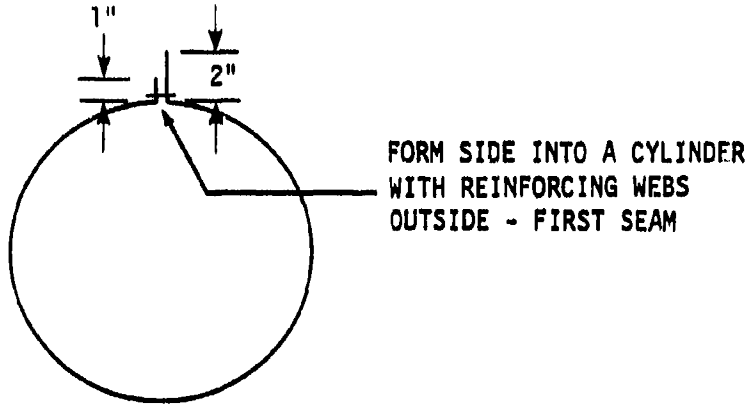


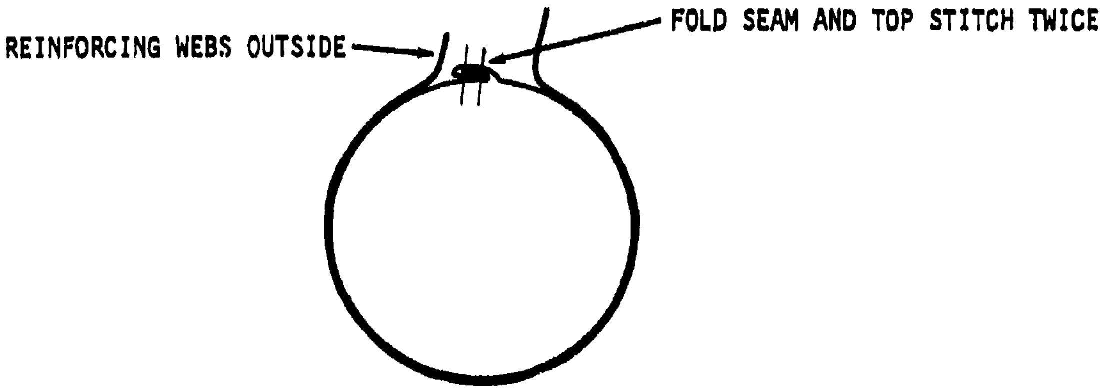
SIDE ASSEMBLY

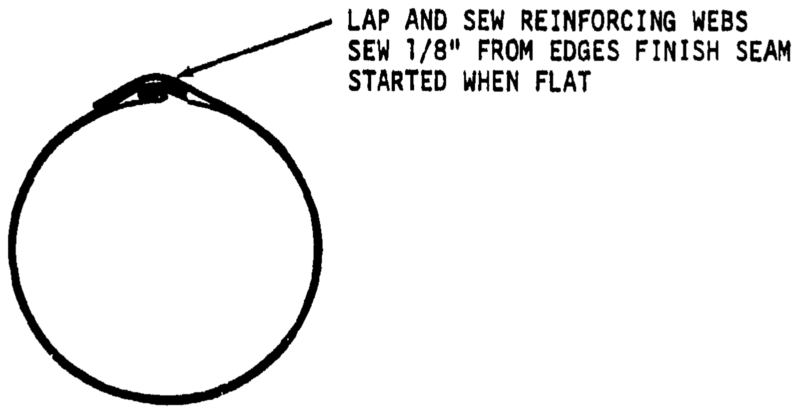


FORWARD BRAIDED VENT OPEN CYLINDER PATTERN AND ASSEMBLY (Continued)

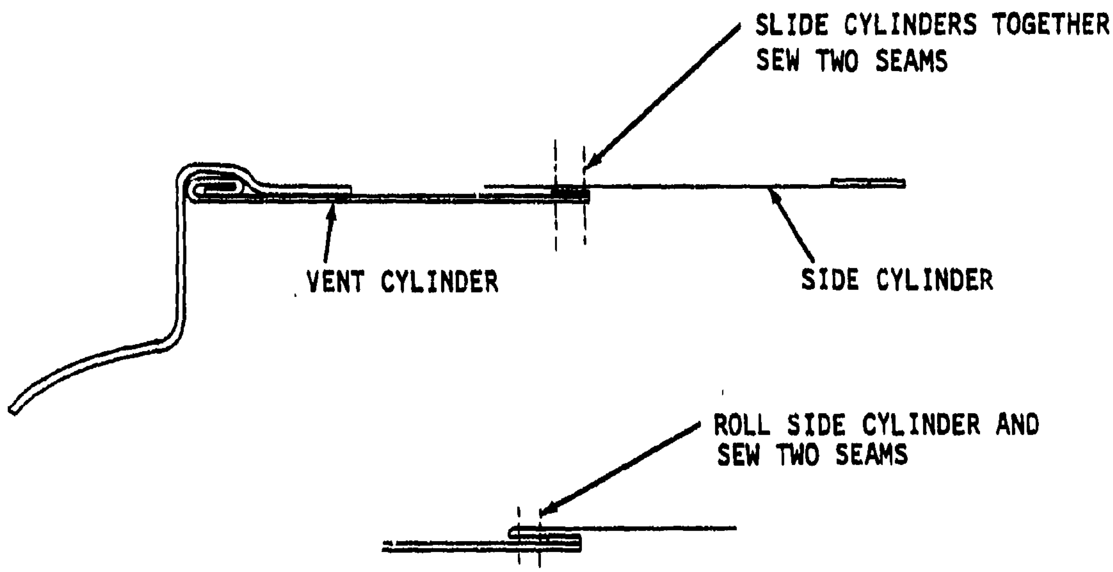
(2) SEW SIDE INTO A CYLINDER



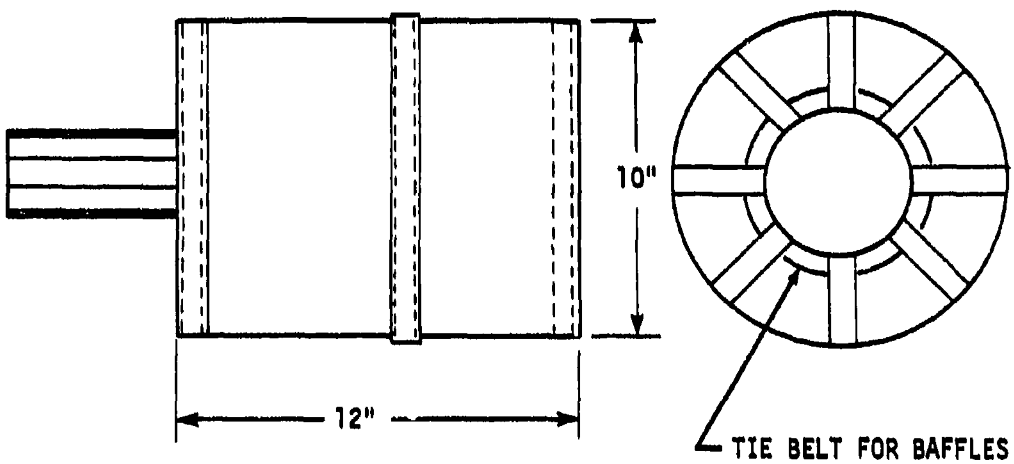


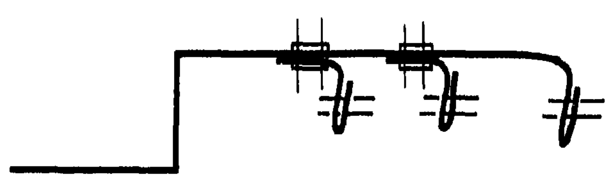


ASSEMBLE VENT CYLINDER AND SIDE CYLINDER



BAFFLED CYLINDER PATTERN & ASSEMBLY

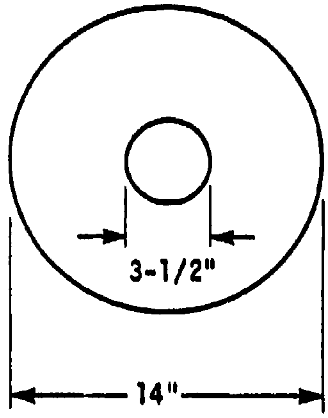




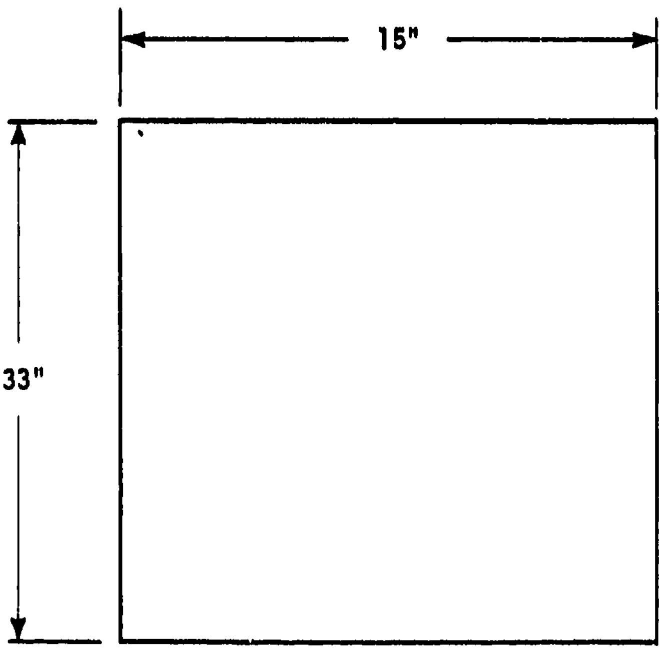
WEB DESIGN

FINISHED BAFFLED CYLINDER

FORWARD END PATTERN

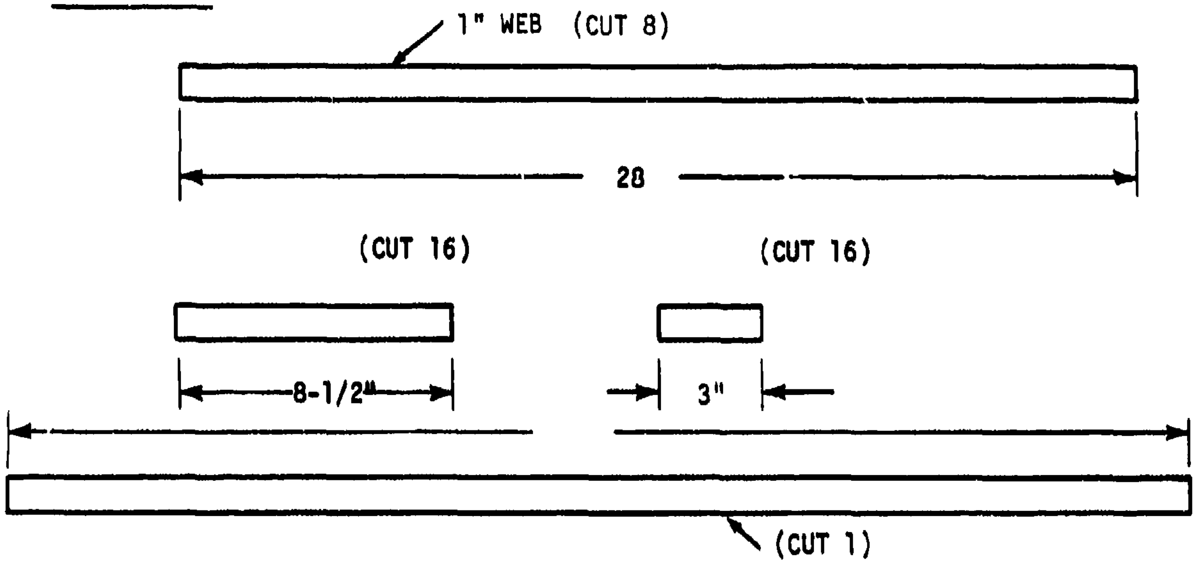


SIDE PATTERN

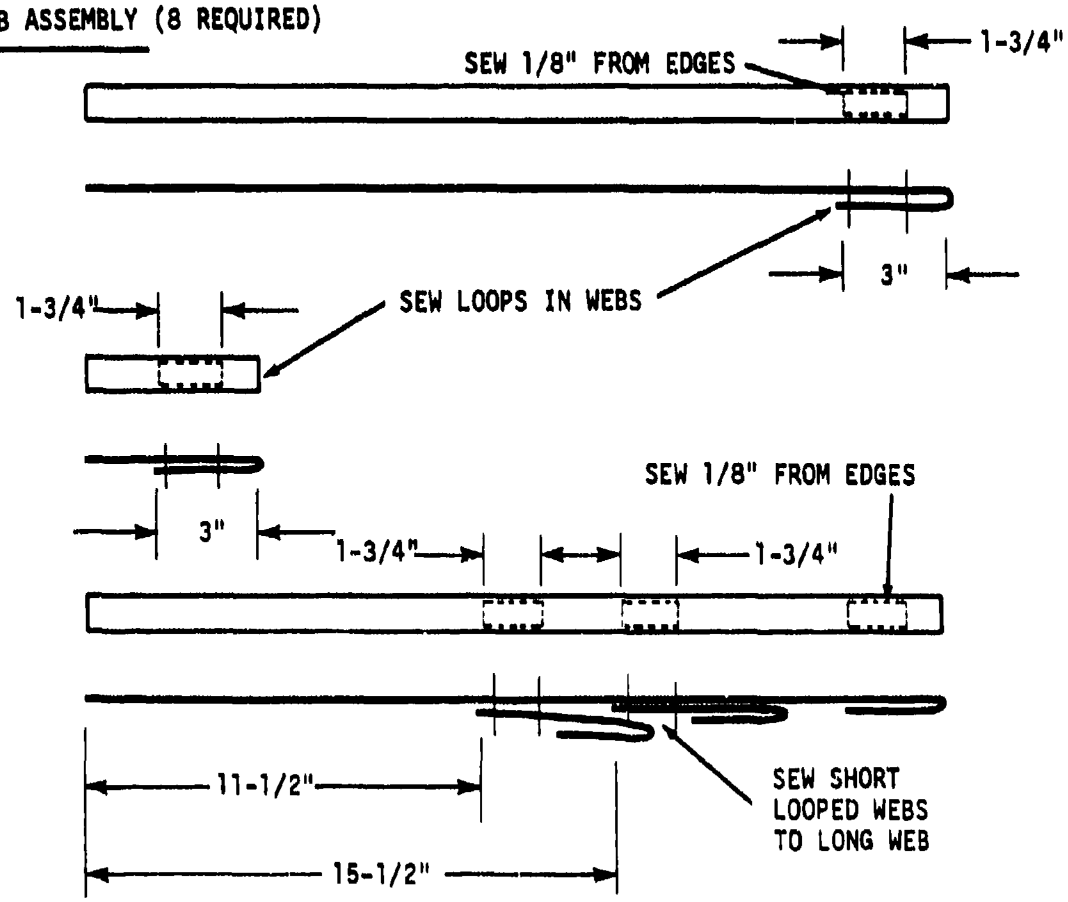


BAFFLED CYLINDER PATTERN AND ASSEMBLY (Continued)

WEB PATTERN

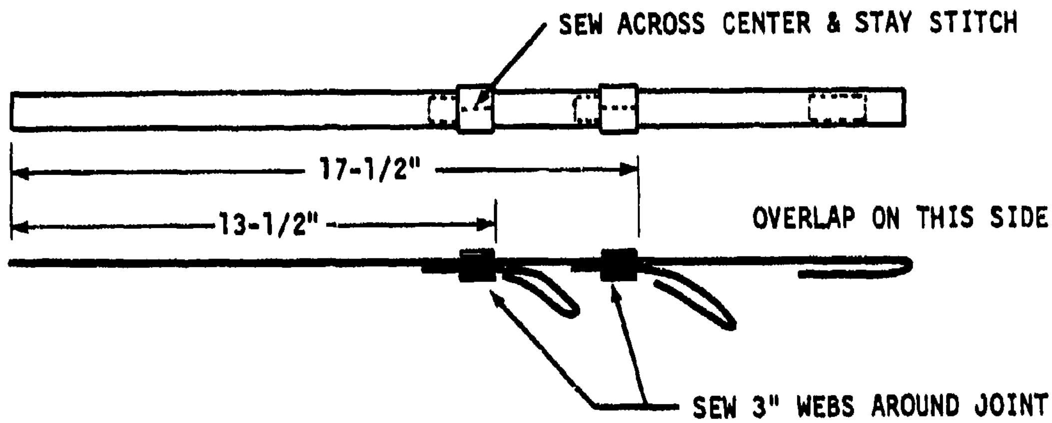


WEB ASSEMBLY (8 REQUIRED)

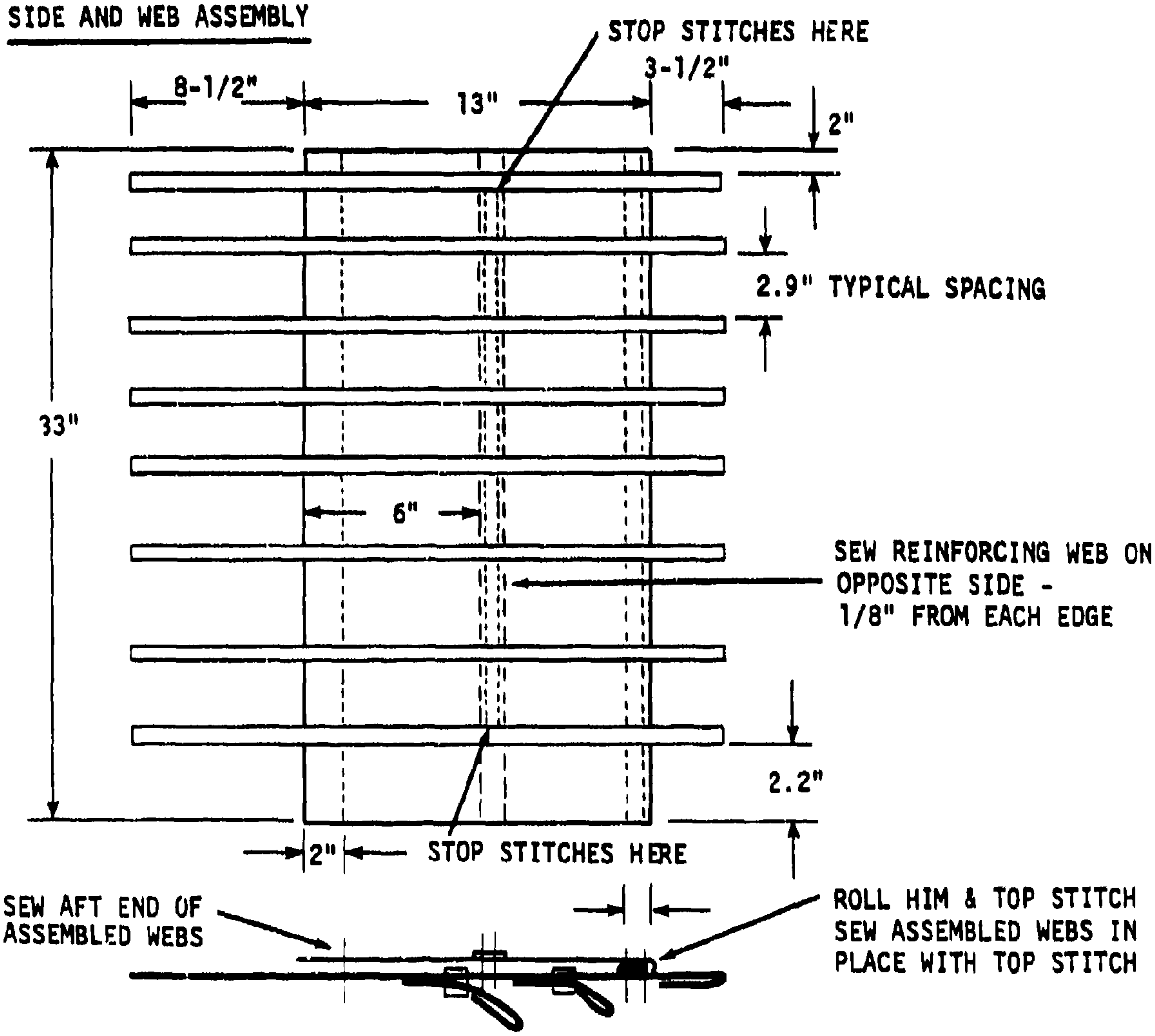


BAFFLED CYLINDER PATTERN AND ASSEMBLY (Continued)

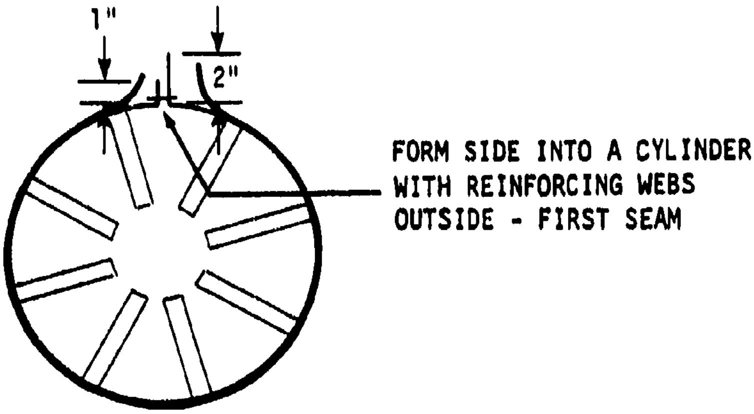
WEB ASSEMBLY (Continued)

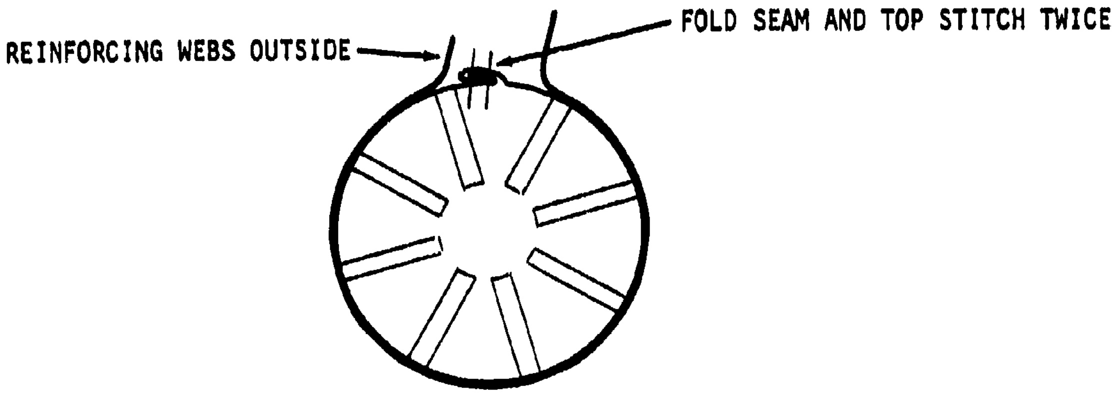


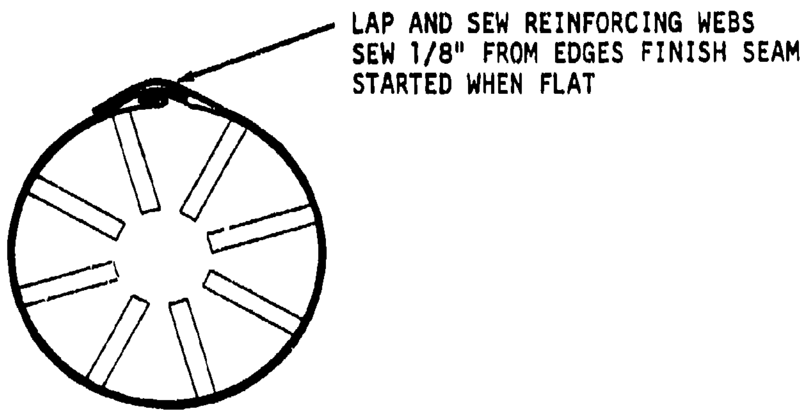
SIDE AND WEB ASSEMBLY



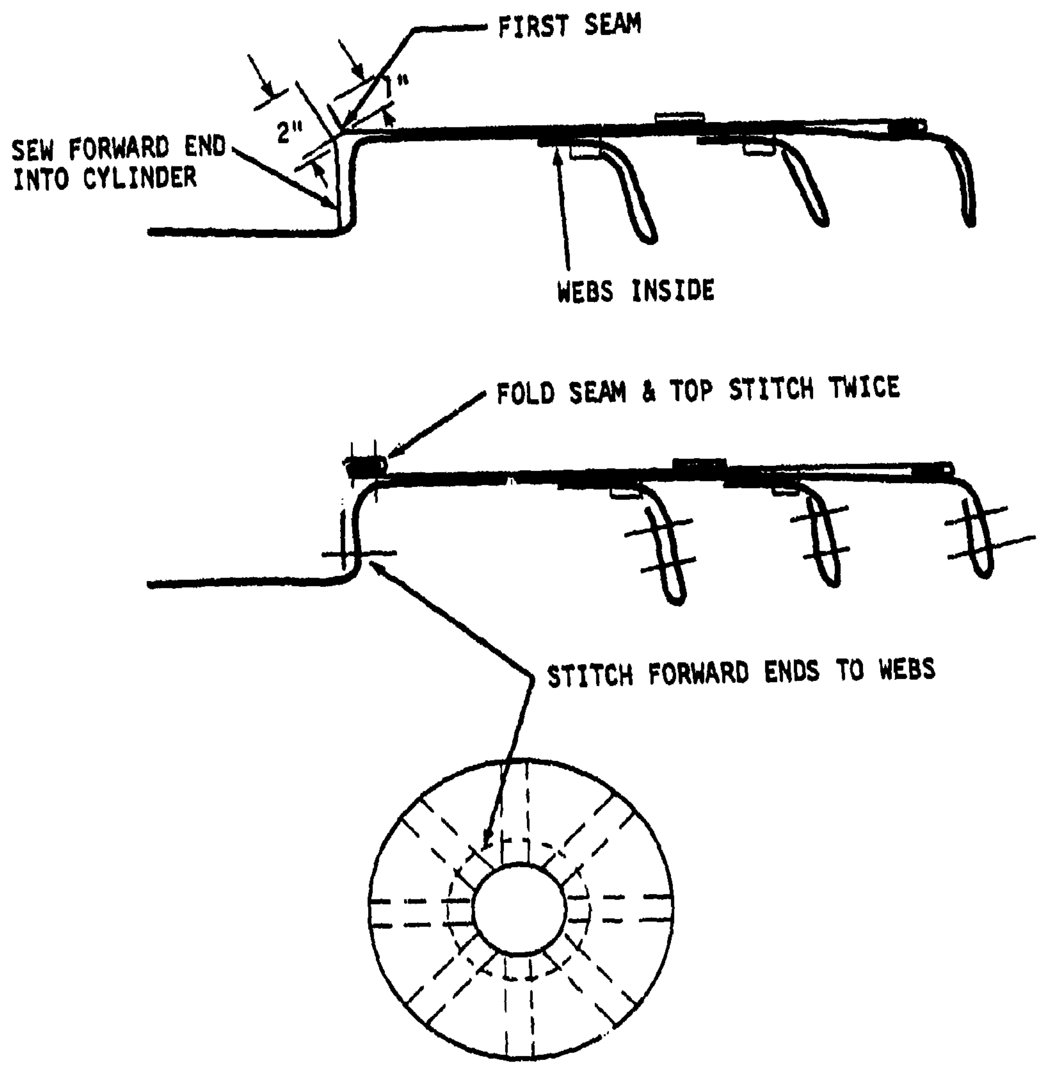
SIDE AND WEB ASSEMBLY CONTINUED







FORWARD END ASSEMBLY



BAFFLED CYLINDER PATTERN AND ASSEMBLY (Continued)

WEB TIES (3 REQUIRED)