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Vol. I

Volume I

Final Report

November 1975

Test Report

Titan IIIC Transtage/Stage II Separation Shock Bench Test

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A series of pyrotechnic shock tests were conducted to evaluate several concepts of attenuating the shock generated by the pyrotechnically actuated nuts during Transtage separation on the Titan IIIC launch vehicle. An orifice installed between the pyrotechnic device and the separation mechanism piston reduced shock levels by approximately 40%.

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MCR-75-425

Volume I	Final Report	November 1975

TEST REPORT

TITAN IIIC TRANSTAGE/STAGE II SEPARATION-SHOCK BENCH TEST

Approved

G. E. Reed
Project Engineer
Titan IIIC
Launch Vehicles

MARTIN MARIETTA CORPORATION
P.O. Box 179
Denver, Colorado 80201

FOREWORD

This report is submitted by the Martin Marietta Corporation, Denver Division, in accordance with Contract F04701-75-C-0166, CDRL Sequence Number A049. The document consists of three volumes:

Volume I - Test Report

Volume II - Analyses

Volume III - Test Data

CONTENTS

Table

I. Introduction and Summary

I. INTRODUCTION AND SUMMARY

A series of pyrotechnic shock tests were conducted to evaluate several concepts of shock attenuation. The investigation was occasioned by the results of full-scale pyrotechnic shock tests of a Titan IIIC Transtage (the fourth stage of a four-stage launch vehicle). The Transtage shock tests, reported in MCR-75-414,* investigated shock levels on truss structure supporting guidance and vehicle control equipment. The shock energy source was the pyrotechnically actuated nuts that separate Stage II from the Transtage. In general, based on data from a similar test some 10 years earlier, the test data showed shock levels on the trusses in the frequencies near 2000 Hz to be higher than anticipated.

It was decided to investigate shock attenuation concepts to provide a springboard for Titan IIIC hardware changes that would reduce shock levels on critical components. The result was achieved by demonstration of three means of shock attenuation. Although the effort was to support the solution of a particular problem, the test results are generally applicable in the industry. The various concepts of shock attenuation were chosen after consulation within the Denver Division of Martin Marietta, with the Air Force, Aerospace Corporation, and other related aerospace companies. The concepts tested are only those that would provide an economically acceptable means of solving the particular problem.

Concepts tested and generalizations of success are listed below:

1) Fire ordnance on one side of the separation plane only at a given time (sequenced firing)	No change in shock level
2) Vary the torque of the stud in the Stage II/Transtage joint	No change in shock level
3) Install an orifice in the separation nut between squib and piston	Significant shock reduction

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Titan IIIC Transtage/Stage II Separation Shock Test Final Report. Martin Marietta Corporation, Denver Division, November 1975.

4) Use of reduced charge, Viking Standard Initiator (VSI)	Significant shock reduction
5) Change the contact area and geometry of the washers in the Stage II/Transtage joint	No change in shock level
6) Shim or pad on end of stud of separation joint	No change in shock level
7) Shim at Station 133, mating plane of Transtage propulsion and control modules	No change in shock level
8) Shock isolate the truss from the control-module mounting attachment	Significant shock reduction

The 31 test runs are summarized in Table I-1.

This report comprises three volumes. Volume I describes the pyrotechnic tests. Volume II contains analyses related to shock isolation of both the trusses and component isolation and related effects on the Transtage. Truss structural modifications and separation nut and power cartridge variations are also discussed in Volume II. Volume III contains the shock response spectra for each of the 15 accelerometers for all 31 test runs described in Volume I.

The results of the tests and analyses show that significant reduction of the shock environment can be achieved by:

1) Use of an orificed separation nut (see Volume I, Chapters IIIA and IVA);

2) Full shock isolation of the equipment trusses (see Volume I, Chapters IIIC and IVA);

3) A combination of both approaches.

Martin Marietta Corporation's recommendations are to:

1) Incorporate the orificed separation nut to reduce the shock environment from Stage II/III separation;

2) Consider shock isolation of the equipment trusses if it is desirable to reduce the shock environment from all sources.

Table I-1 Bench Shock Test Summary

Run	Configuration	Results for 2000-Hz Range
1	Dual separation nuts, fixed longeron at Sta 77	Levels similar to system test
2	Dual separation nuts, free longeron at Sta 77	Levels exceeded system levels
3	Dual separation nuts, fixed longeron on this and all subsequent tests	Baseline
4	Dual separation nuts	Baseline, measurements on Accelerometers 10, 11, and 12 appeared abnormally low
5	Dual separation nuts	Baseline
6	Only Stage II nut fired	No reduction from baseline
7	Only Stage III nut fired	No reduction from baseline
8	Only Stage III nut fired	Measurements on Accelerometers 10, 11, and 12 appeared abnormally low
9	Stage III nut fired, 75 ft-lb torque	No reduction from baseline
10	Stage III nut fired, 300 ft-lb torque	No reduction from baseline
11	Stage III nut only, 0.063-in. orificed nut	≥ 6-dB reduction from baseline
12	Stage III nut only, 0.063-in. orificed nut	≥ 3-dB reduction from baseline
13	Stage III nut only, 0.063-in. orificed nut	≥ 3-dB reduction from baseline
14	Stage III nut only, castellated washer	No reduction from baseline
15	Dual nuts fired, 0.063-in. orificed nuts	≥ 3-dB reduction from baseline
16	Stage III nut only, reduced initiator charge	≥ 6-dB reduction from baseline
17	Stage III nut only, reduced initiator charge	≥ 5-dB reduction from baseline
18	Stage III nut only, padded stud	No reduction from baseline
19	Stage III nut only, reduced initiator charge	≥ 6-dB reduction from baseline
20	Stage III nut only, crushable washer	No reduction from baseline
21	Stage III nut only, isolation at Sta 133	Slight reduction from baseline
22	Stage III nut only, isolation at Sta 133	No reduction from baseline
23	Stage III nut only, 0.081-in. orificed nut	Similar to reduction with 0.063-in. orificed nut
24	Stage III nut only, 0.081-in. orificed nut	Similar to reduction with 0.063-in. orificed nut
25	Stage III nut only, 0.063-in. orificed nut with modified piston	Similar to reduction with 0.063-in. orificed nut
26	Stage III nut only, 0.063-in. orificed nut with modified piston	Similar to reduction with 0.063-in. orificed nut
27	Stage III nut only, 0.052-in. orificed nut	Greater reduction than with 0.063-in. orificed nut
28	Stage III nut only, 0.052-in orificed nut	Greater reduction than with 0.063-in. orificed nut
29	Stage III nut only, dual 0.052-in. orificed nut, internal nut cavity recessed	Levels slightly greater than other orificed-nut runs
30	Stage III nut only, dual 0.052-in. orificed nut, no internal recess	Similar to reductions obtained with single 0.052-in. orificed nut
31	Stage III nut only, single 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
32	Stage III nut only, dual 0.052-in orificed nut	Similar to other 0.052-in. orificed-nut runs
33	Stage III nut only, single 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
34	Stage III nut only, dual 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
35	Stage III nut only, isolator at truss bottom bracket	Reduction of levels at truss bottom, truss top similar to baseline
	Stage III nut only, isolator at truss bottom	Reduction only at truss bottom
37	Stage III nut only, isolator at truss bottom	Reduction only at truss bottom
38	Stage III nut only, dual 0.052-in. orificed nut, truss bottom-bracket isolation	Reduction at truss bottom greater than with orificed nuts alone
39	Stage III nut only, truss bottom bracket removed	Truss bottom level similar to that with isolation
40	Stage III nut only, truss bottom bracket isolated, top bracket removed	Truss level very low
41	Dual separation nuts, dual 0.052-in. orificed nuts	Similar to other 0.052-in. orificed-nut runs
42	Dual separation nuts, truss bottom isolation, dual 0.052-in. orificed nuts	Levels similar to orificed-nut run without isolation
43	Dual separation nuts, truss bottom isolation, dual 0.052-in. orificed nuts	≥ 6-dB reduction from orificed-nut run without isolation
44	Dual separation nuts, truss bottom isolation	Levels similar to baseline
45	Dual separation nuts, full truss isolation	≥ 6-dB reduction from baseline
46	Dual separation nuts, full truss isolation	Longeron levels very high, truss levels slightly lower than baseline
47	Dual separation nuts, full truss isolation	≥ 6-dB reduction from baseline
48	Dual separation nuts, full truss isolation, dual 0.052-in. orificed nuts	Levels slightly lower than with orificed nuts only
49	Dual separation nuts, full truss isolation, dual 0.052-in. orificed nuts	Levels slightly lower than with orificed nuts only
50	Dual separation nuts, full truss isolation, dual 0.052-in. orificed nuts	Levels slightly lower than with orificed nuts only (measurement on Accelerometer 13 appeared abnormally high
51	Dual separation nuts, full truss isolation	≥ 6-dB reduction from baseline

II. Test Configuration

II. TEST CONFIGURATION

A. TEST SETUP

The test setup was designed to simulate one longeron and the Transtage guidance truss, as shown in Figure II-1. For convenience of installations at the separation plane, the setup was inverted from the normal position. The pulley, cable, and counterweight assembly ensured separation of the Stage II longeron after separation-nut firing. Figures II-2 and II-3 show the test setup in detail.

The longeron extended from Station 77 to approximately 4 ft below the separation plane, including the control-module section, propulsion-module section, and Stage II section. Because of material availability, the longeron was fabricated from 2219 aluminum instead of 7178. Grain direction was longitudinal. The cross-sectional area of the longeron along the shock transmission path was the same as in flight hardware. However, protuberances for frame splices and other structural details not considered relevant to shock characteristics were omitted. The joints at Stations 133 and 155 were made in the same manner as in flight hardware, except as modified to test shock reduction techniques.

A Titan IIIB truss of early vintage supported the longeron at representative locations. The truss in turn was supported by a structural steel fixture specifically fabricated for that purpose. The truss used had basically the same shock transmission path to the corners as trusses used in current flight hardware. Minor modifications to the truss, fittings required for the joint, and attachments are shown in Figure II-4. To enhance dynamic simulation, masses of grossly representative weight were added to the truss at major equipment mountings (Fig. II-1).

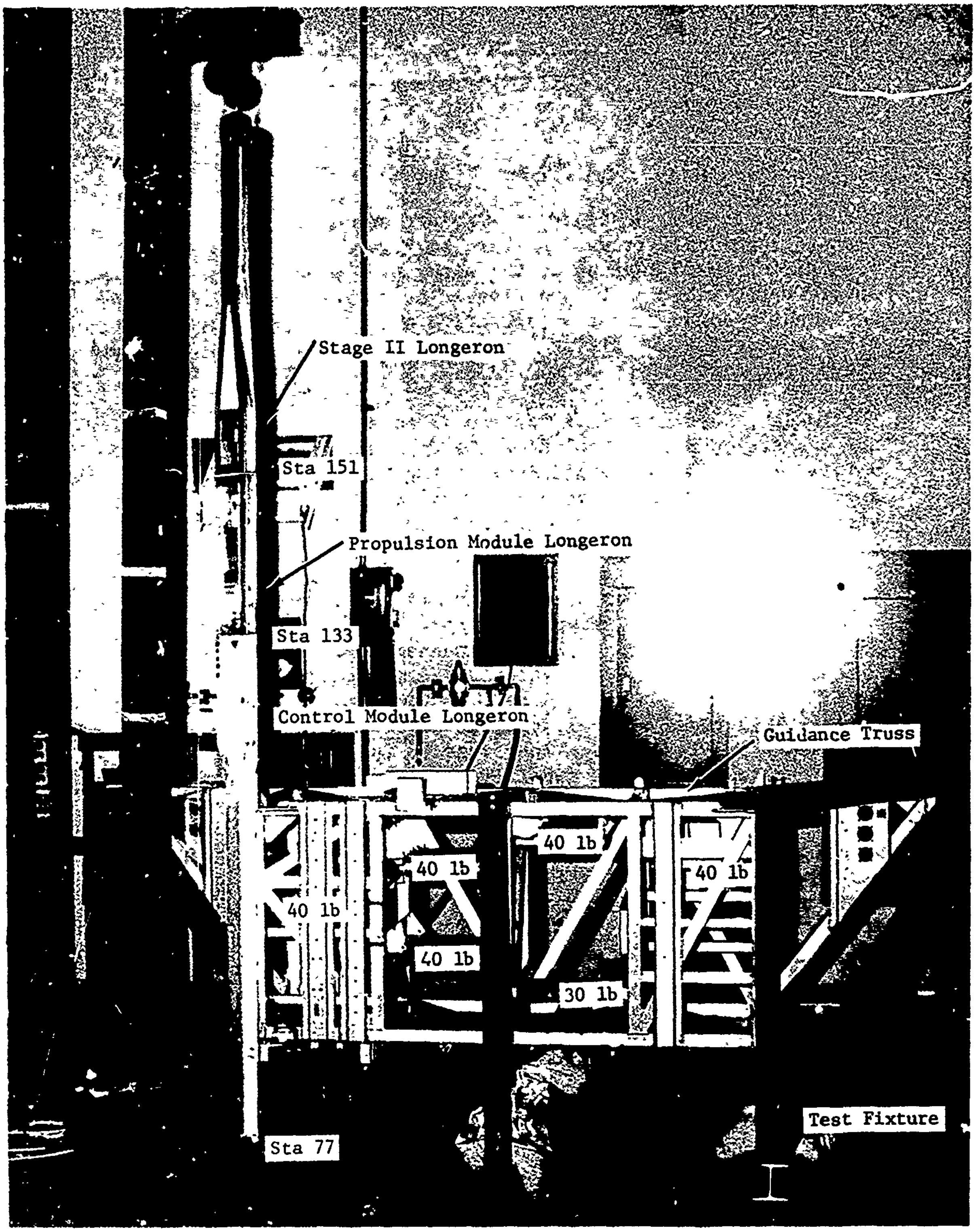
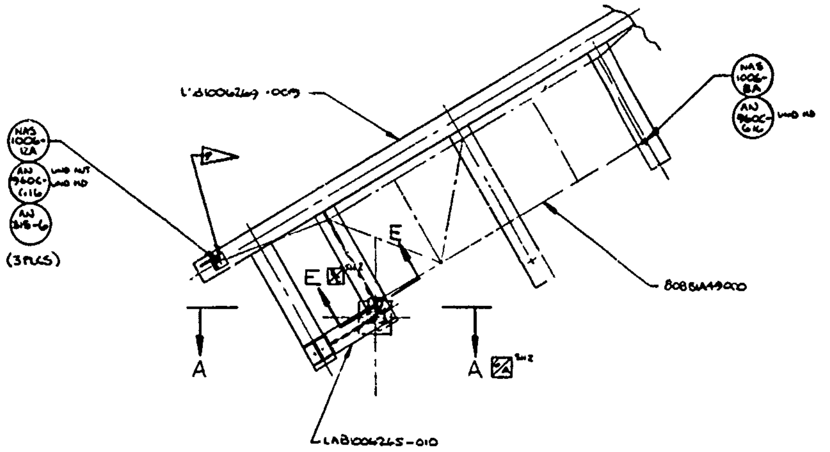
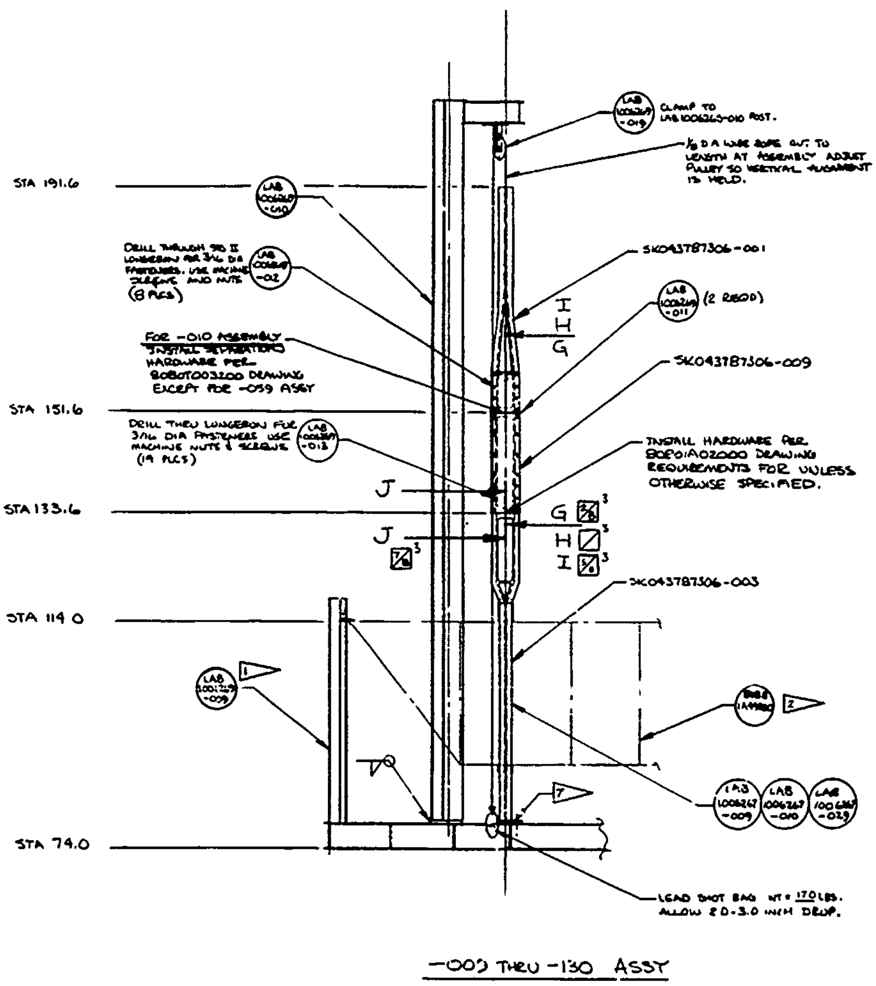


Figure II-1 Test Setup

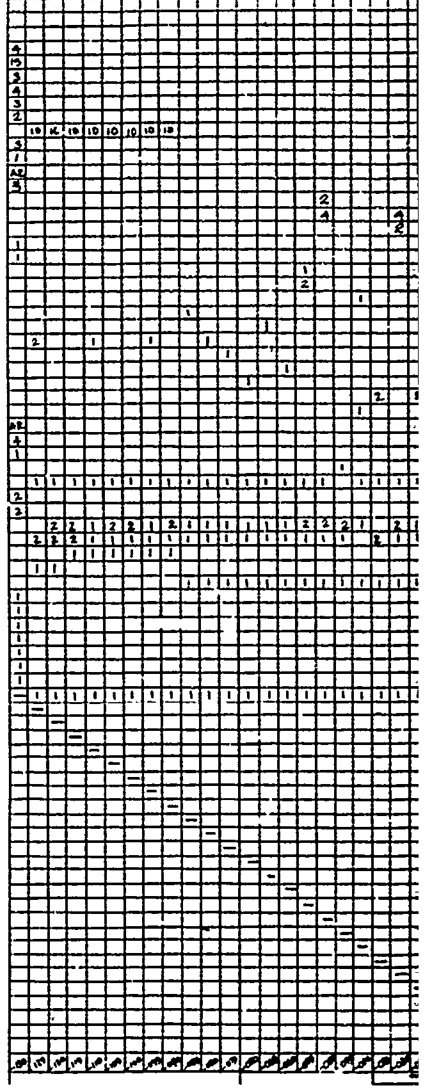


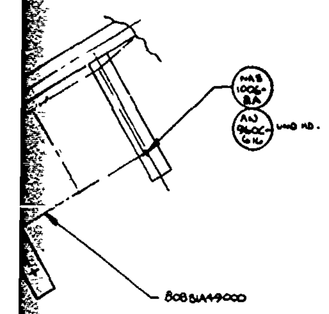
NOTES

1. [1] STIFFEN BASE FIXTURE (LAB10... 2x2x1/4 STRUCTURAL ANGLE T...
2. [2] STEEL MASS SIMULATORS TO...
3. [3] TORQUE VARIATIONS OF 75 FT-L...
4. [4] STATION 114 STRUCTURAL JOINT...
5. [5] TRUSS UPPER BRACKET JOINT...
6. [6] TORQUE SEPARATION NUT:...
7. [7] STATION 77 END OF LONGER... DRILLING TWO 1/2 DIA HOLES... IN BASE FIXTURE AND US...
8. [8] LONGERON FORWARD END...
9. [9] FOR -090 THROUGH -129 ASSE... EACH TRUSS BOLT TO PROV... IS LOCATED BETWEEN BOLT... BETWEEN THE BRACKET AN... ON EACH BOLT SHANK.



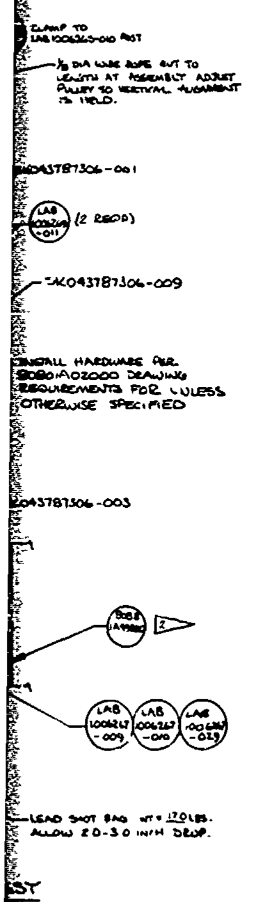
-009 THRU -130 ASSY





Notes

1. STIFFEN BASE FIXTURE (LAB1006269-009) STRUCTURE AS REQUIRED USING 2x2x1/4 STRUCTURAL ANGLE TACK WELDED IN PLACE.
2. STEEL MASS SIMULATORS TOTALING 230 POUNDS DISTRIBUTED ON TRUSS.
3. TORQUE VARIATIONS OF 75 FT-LB, 200 FT LB AND 300 FT-LB USED FOR -020 ASSEMBLY.
4. STATION 114 STRUCTURAL JOINT REMOVED FOR -100 AND -110 ASSEMBLIES.
5. TRUSS UPPER BRACKET JOINT REMOVED FOR -109 ASSEMBLY
6. TORQUE SEPARATION NUT TO 200-215 FT-LB.
7. STATION 77 END OF LONGERON FIXED FOR APPLICABLE ASSEMBLIES BY DRILLING TWO 1/2 DIA HOLES THROUGH 6x6x1/2 END PAD AND W4x13 IN 3POE FIXTURE AND USING 1/2 DIA. STRUCTURAL HARDWARE AND SHIMS.
8. LONGERON FORWARD END FIXED, STAGE III SIDE SEPARATION NUT ONLY FIRED
9. FOR -090 THROUGH -129 ASSEMBLIES USE TWO LAB1006270-034 ISOLATORS AT EACH TRUSS BOLT TO PROVIDE ISOLATION FROM TEST FIXTURE. ONE ISOLATOR IS LOCATED BETWEEN BOLT HEAD WASHER AND BRACKET WHILE THE OTHER IS BETWEEN THE BRACKET AND TRUSS END PAD USE HEAT SHRINK TUBE ON EACH BOLT SHANK.



Part No.	Zone	Qty	Description
33266-1032-2	1/c	2	BLIND NUT
ENDEVCO ACCEL	–	2	ACCELEROMETER / HIGH FREQUENCY
LAB1006266-020	–	2	SCREEN ASSY
LAB1006266-019	–	2	SCREEN ASSY
LAB1006266-003	–	2	LONGERON ACCELEROMETER BLOCK
LAB1006266-002	–	2	TRUSS ACCELEROMETER BLOCK
LAB1006270-034	–	1	ISOLATOR
AN 315-6	7/B	3	NUT
NAS1006-8A	3/H	3	BOLT
AN960C-616	7/B	3	WASHER
NAS1006-12A	7/H	3	BOLT
SK808-02327-001	–	3	WASHER - REDUCED CONTACT AREA
SK808-02327-002	–	3	WASHER - FLAT
-003	–	3	CRUSHABLE WASHER M/F HENDRICK TUBE NO. 111B1242X-2
8080A02000	–	1	STA 133.6 HARDWARE INSTALLATION
8080T003200	–	1	STA 151.6 HARDWARE INSTALLATION
-002	7/C	3	RUBBER SHIM 29x3.2x.063 70 DUROMETER SILICONE RUBBER
-001	7/D	3	PHENOLIC WASHER 1.500X .5070X.126 THICK
SK808-02332-040	4/C	3	MODIFIED SEPARATION NUT/
SK808-02332-039	7/B	3	MODIFIED SEPARATION NUT/
SK808-02332-030	7/B	3	MODIFIED SEPARATION NUT/
SK808-02332-029	4/C	3	MODIFIED
SK808-02332-020	4/C	3	
SK808-02332-019	7/B	3	
SK808-02332-010	4/B	3	
SK808-02332-009	–	3	
PD5000006-001	7/B	3	VIKING STANDARD INITIATOR
AN960D416L	–	3	WASHER
NAS1004-3A	–	3	BOLT
8080183034-010	–	3	NUT CATCHER
SK808-02336-009	3/D	3	STUD
8080183040-024	–	3	STUD
50ATC12V6A	–	3	SPHERICAL WASHER
50ATC1216B	–	3	SPHERICAL WASHER
PD338007-005	–	3	SEPARATION NUT
PD6030129-307	–	3	PRESSURE CARTRIDGE
LAB1006267-029	3/B	1	LONGERON INSTALLATION WITH STA 114 ISOLATION
LAB1006267-010	3/B	1	LONGERON INSTALLATION/ ISOLATED TRUSS
LAB1006267-009	3/B	1	LONGERON INSTALLATION/HARD MOUNTED TRUSS
8085A49000	3/C	1	GUIDANCE TRUSS
LAB1006269-013	7/D	1	LONGERON COVER
LAB1006269-012	7/B	1	LONGERON COVER
LAB1006269-011	5/B	1	FRAME SIMULATOR
LAB 006269-019	4/E	1	PULLEY ASSEMBLY
LAB1006269-010	7/E	1	SUPPORT COLUMN
LAB1006269 009	1/C	1	TEST FIXTURE BASE STRUCTURE
-130		1	STRUCTURAL TEST ASSEMBLY
-129			FIXED LONGERON/FULL ISOLATION/TWO .052 ORIFICES/TWO SEPARATION NUTS FIRED
-120			FIXED LONGERON/FULL ISOLATION/TWO SEPARATION NUTS FIRED
-119			FIXED LONGERON/STA 114 ISOLATOR/ TWO SEPARATION NUTS FIRED
-110			STA 114 JOINT REMOVED/TWO 0.052 ORIFICES PERPENDICULAR TO NUT CENTERLINE
-109			STA 114 ISOLATION / TOP JOINT TRUSS REMOVED
-100			STA 114 JOINT REMOVED / ONLY TOP TRUSS JOINT
-099			STA 114 ISOLATION/ TOP JOINT TRUSS HARD MOUNTED/ TWO 0.052 ORIFICES PERP.
-090			STA 114 ISOLATION/ TOP JOINT OF TRUSS HARD MOUNTED
-089			ONE 0.052 ORIFICE PERPENDICULAR TO NUT CENTERLINE
-080			TWO 0.052 ORIFICES PERPENDICULAR TO NUT CENTERLINE
-079			TWO 0.052 ORIFICES PERPENDICULAR TO NUT CENTERLINE/RECESSED NUT
-070			0.052 ORIFICE
-069			0.062 ORIFICE / CUP MODIFIED PISTON
-060			0.082 ORIFICE
-059			SILICONE RUBBER SHIM / PHENOLIC WASHERS AT STA 133.6
-050			CRUSHABLE WASHERS
-049			PADDED STUD
-040			VIKING STANDARD INITIATOR
-039			TWO SEPARATION NUTS FIRED/ 0.062 ORIFICE
-030			REDUCED BEARING AREA WASHERS
-029			0.062 ORIFICE
-020			SEPARATION NUT TORQUE VARIATIONS
-019			FIXED LONGERON/ STAGE II SIDE SEPARATION NUT ONLY FIRED
-010			FIXED LONGERON/ TWO SEPARATION NUTS FIRED (BASELINE)
-009			FREE LONGERON / TWO SEPARATION NUTS FIRED

Figure II-2 Bench Test Assembly, LAB1006268

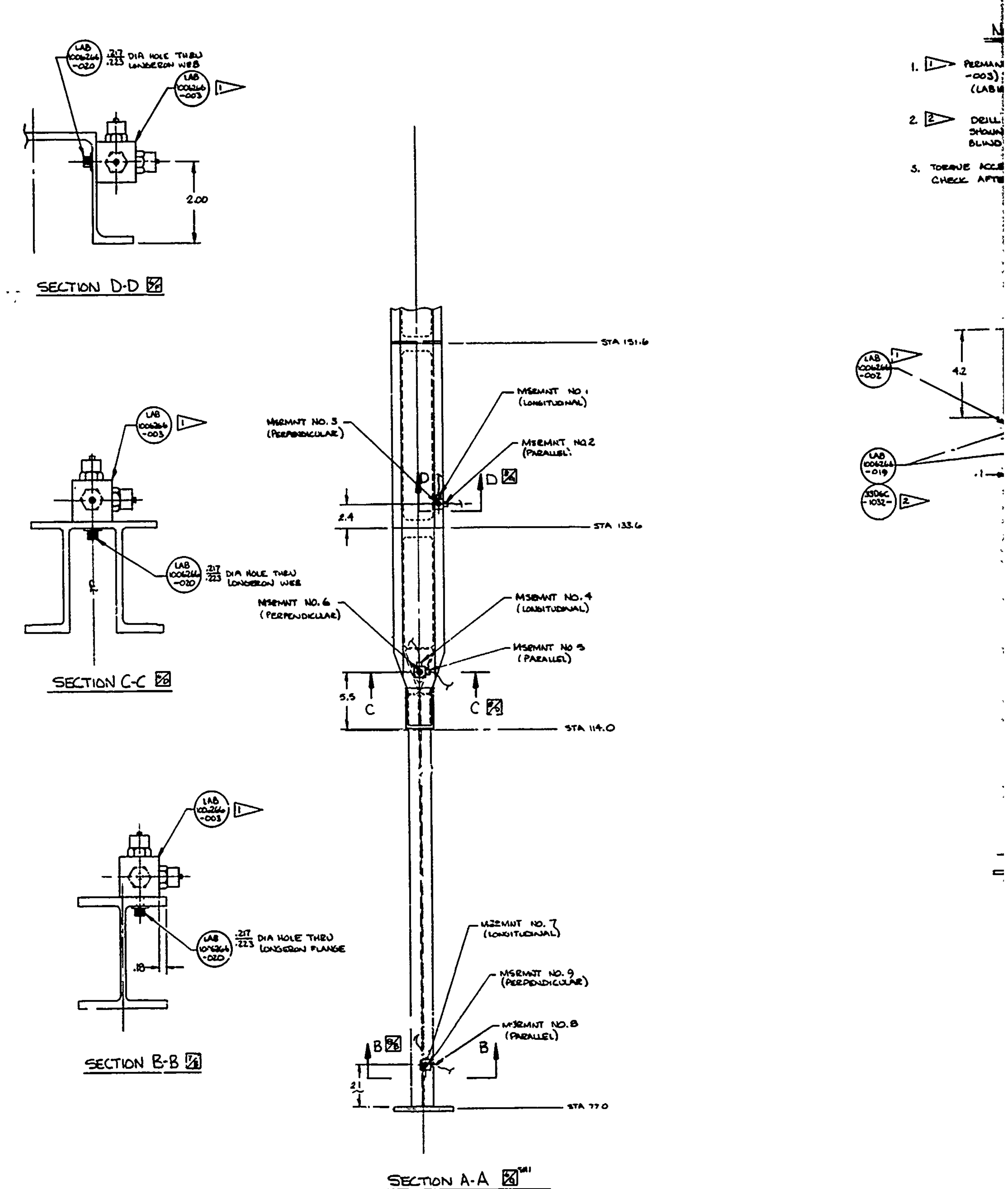


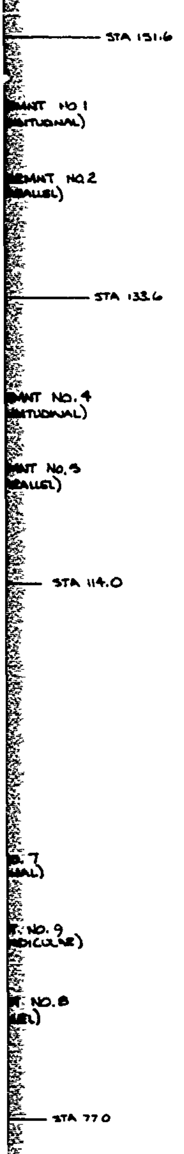
Figure II-2 (cont)

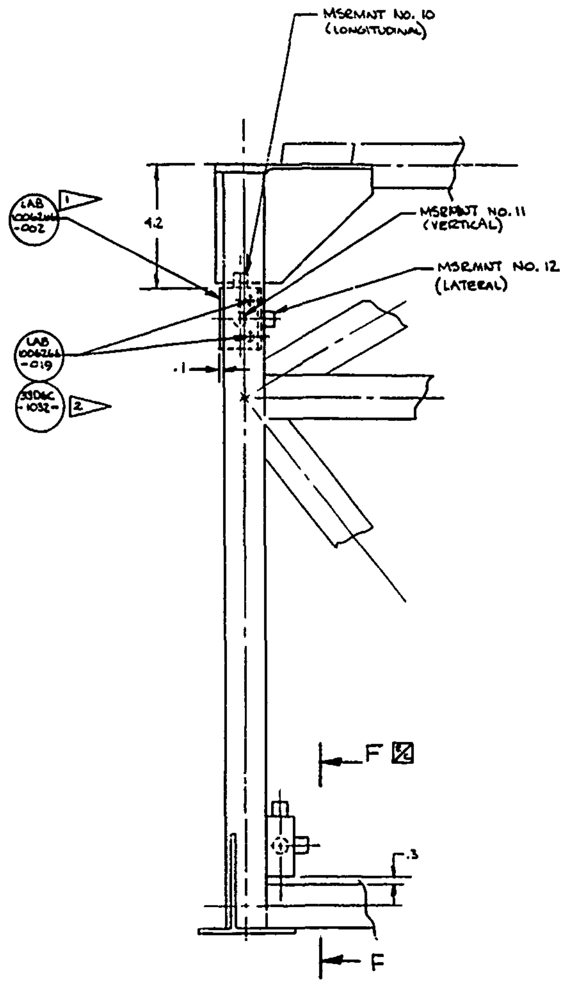
NOTES:

1. [1] PERMANENTLY ATTACH ACCELEROMETER BLOCK (LAB1006266-002, -003) TO STRUCTURE USING MECHANICAL FASTENERS (LAB1006266-019, -020) AND ARMSTRONG A-6 ADHESIVE.

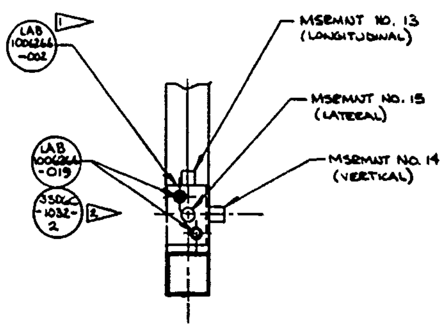
2. [2] DRILL HOLES FOR 33D6C-1032 BLIND NUT PICKING UP HOLES SHOWN IN ACCELEROMETER BLOCK. INSTALL 33D6C-1032 BLIND NUTS PER EPS20403.

3. TORQUE ACCELEROMETERS TO 25 ± 2 IN-LB AT INSTALLATION AND CHECK AFTER EACH SHOCK TEST.





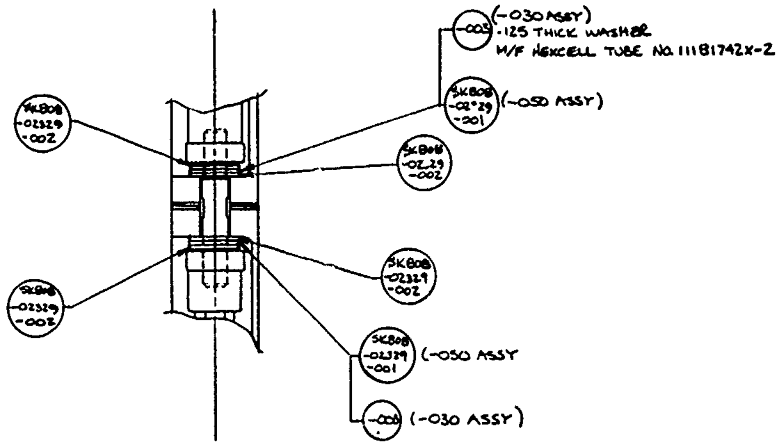
SECTION E-E (ROT 33°CW)



SECTION F-F

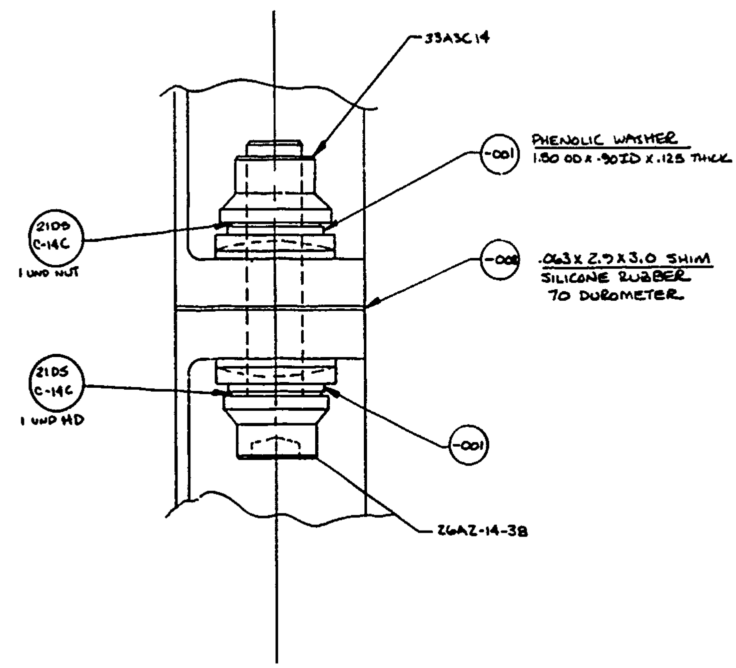
"INSTRUMENTATION DRAWING"

2

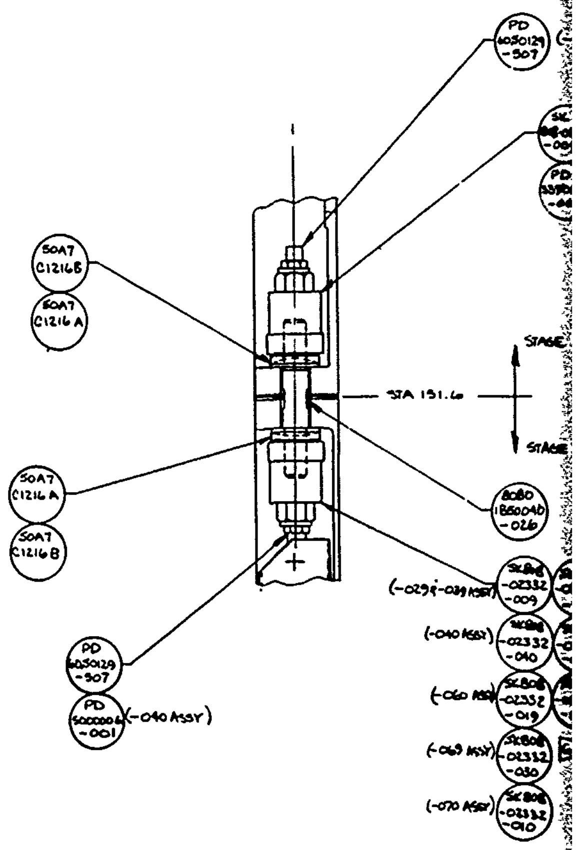


DETAIL K-K (-050 ASSY)

DETAIL L-L (-030 ASSY)



SECTION J-J (-059 ASSY)



SECTION I-I

(-039, -040, -060, -069, -070, -029, -079, -08:, -089, -099, -110 ASSY)

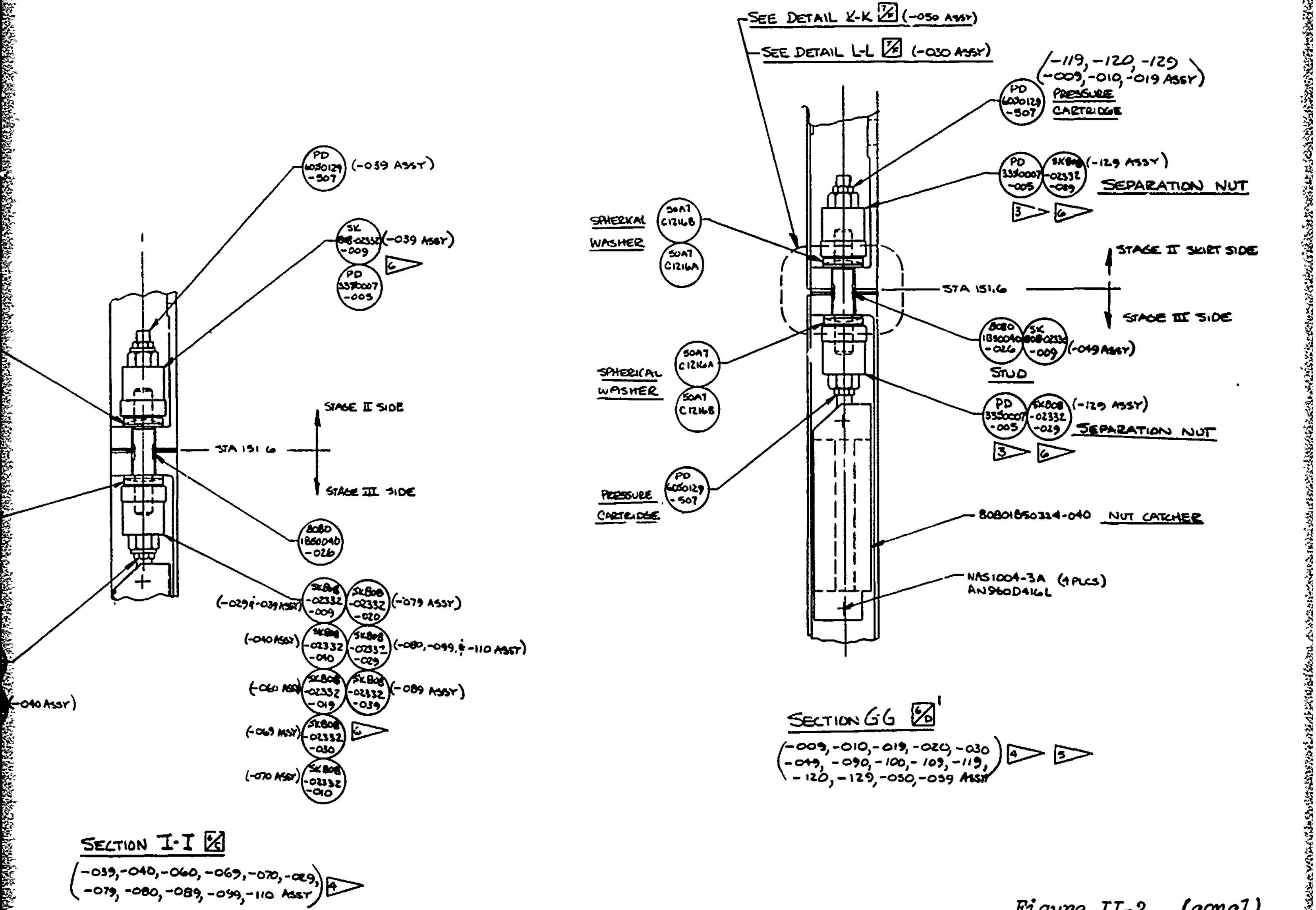


Figure II-2 (concl)

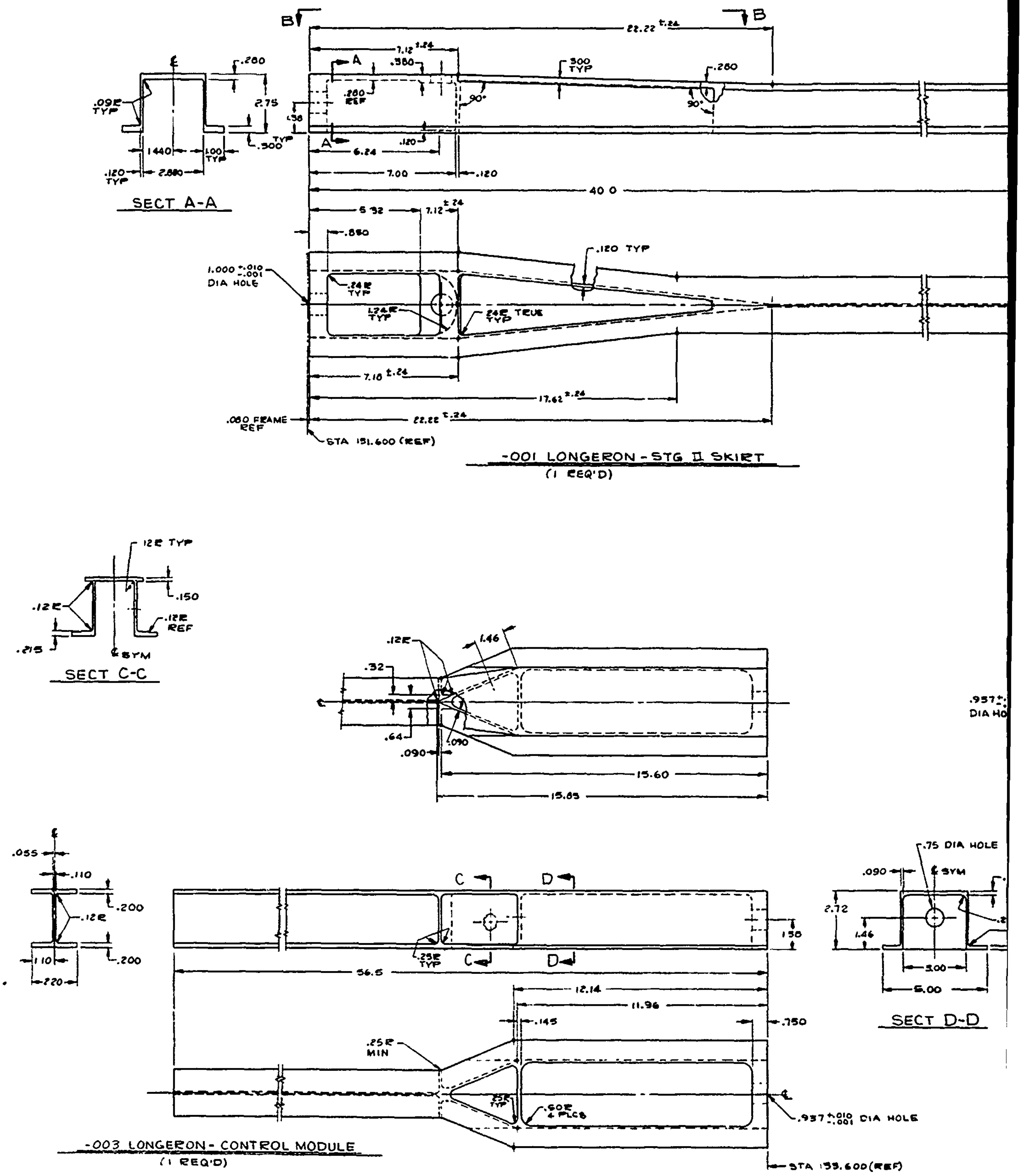
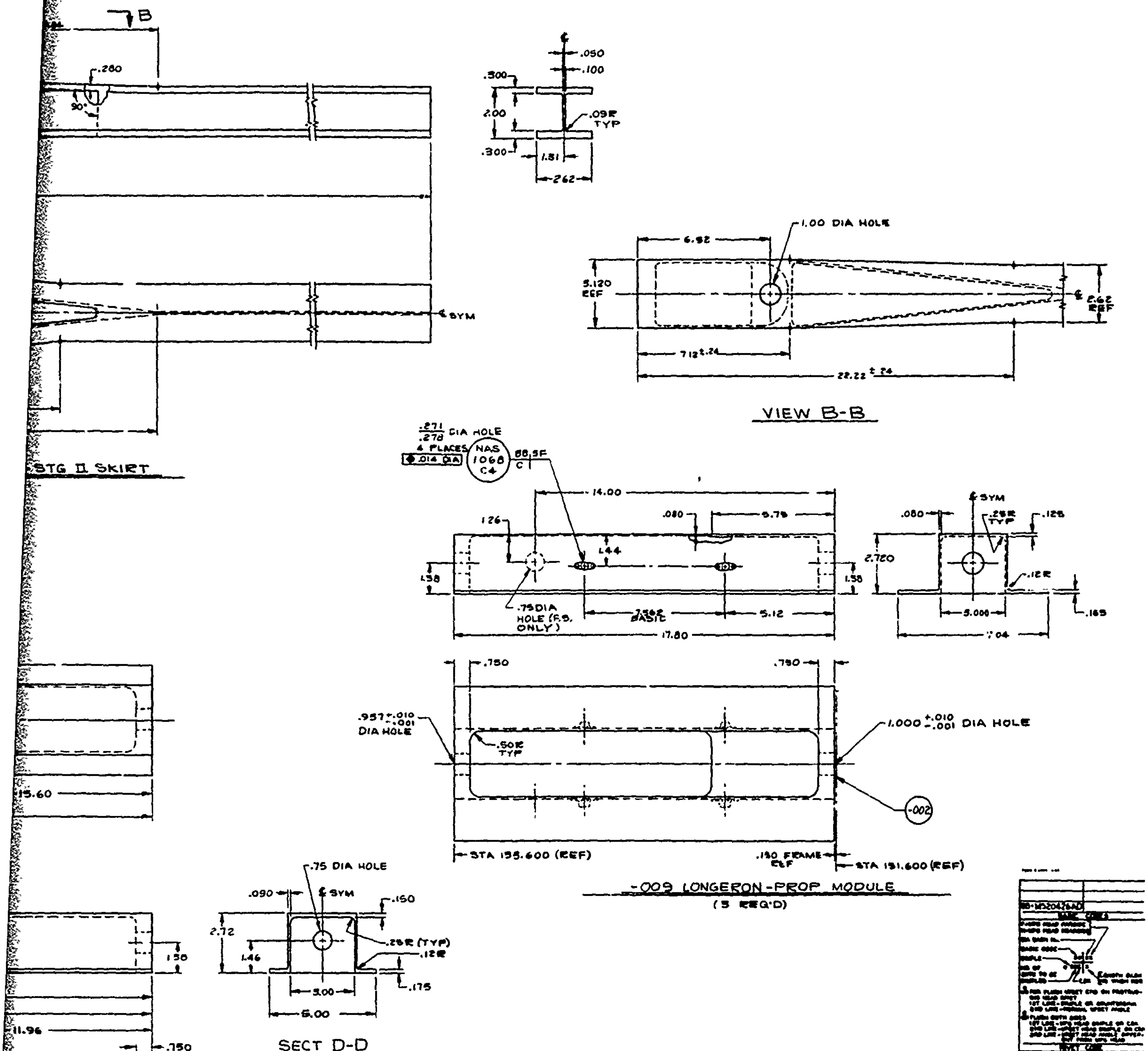
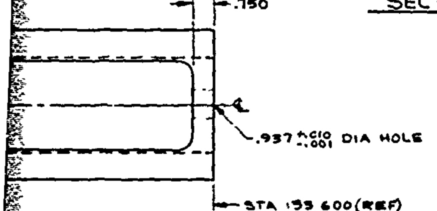


Figure II-3 Longeron - Transtage Shock Test, SK0437-87306



		8	MS20426AD5	RIVET		
		4	NAS1068C4	NUT PLATE		
—			-003	LONGERON	3.00X5.50X58.0	AL BAR
		1	-002	LONGERON	3.00X7.50X19.0	AL BAR
	—		-001	LONGERON	3.00X4.75X42.0	AL BAR
-003	-001	-002	-009	LONGERON		

LIST OF MATERIAL



06

2

NOTES:

1. ▷ COMPARABLE STEEL STOCK MAY BE SUBSTITUTED IF AVAILABLE.
2. ▷ THIS PART SAME AS 8080IA61233-013 IN CONFIGURATION.
3. ▷ THE -009 IS TO BE REWORKED INTO THE -010 CONFIGURATION

NOTE: THE -029 ASSY IS AN INTERMEDIATE STEP WITH THE LOWER TRUSS PAD SHOCK-MOUNTED AND THE UPPER TRUSS-PAD FIRM BOLTED TO THE LONGERON

REVISIONS

A		ADDED -010 -019 -020 & -029 ASSY ADDED NOTE No. 3	75 SEP 24	

	AR		AR	AR	AN960D416L			WASHER, FLAT, LIGHT				
	AR		AR	AR	AN960D416			WASHER FLAT				
	AR		AR	AR	MS21043-4			NUT, SELF-LOCKING				
6			6	6	NAS1004-6A	2-C	2	BOLT				
				1	NAS1005-3A	2-D	2	BOLT				
1			1	1	AN960D516	2-D	2	WASHER, FLAT				
4				4	NAS1004-12A	4-H	2	BOLT				
2				2	NAS1004-10A	4-D	4	BOLT				
AR				AR	NAS1671-3K	4-D	3	JO BOLT				
1			4		NAS1004-20A	4-H	4	BOLT				
AR			AR	AR	AN960D516			WASHER, FLAT				
1			1		-017	2-B	3	BRACKET	2.00 x 3.00 x 4.50	2219-T62 AL ALY PL	MMS 1117	LEACH IRIDITE
			1		-016	5-F	4	PLATE	.190 x 2.00 x 2.00	2024-T351 AL ALY SH	QQ-A-250/4	LEACH IRIDITE
			1		-015	5-B	4	PLATE	.190 x 2.00 x 2.00	2024-T351 AL ALY SH	QQ-A-250/4	LEACH IRIDITE
			2		-014	5-E	4	ISOLATOR RUBBER	.125 x 2.00 x 2.00	SILICONE RUBBER SH	60 DUROMETER	
					-013			NOT USED				
	1				-012	5-C	4	SPACER	.500 DIA x 1.00	4130 BAR STL HT 125	MIL-S-6758 ▷1	
	1				-011	5-C	4	ISOLATOR	.032 x 1.00 x 1.50	SILICONE RUBBER SH	60 DUROMETER	
		1			-008	5-B	4	ISOLATOR	.032 x 1.50 x 2.00	SILICONE RUBBER SH	60 DUROMETER	
				1	TITAN IIIB STAGE II EQUIPMENT TRUSS							
				1	SK043787306-003			LONGERON				
		1			-007	6-B	4	SPACER	.500 DIA x 1.500	4130 BAR STL HT 125	MIL-S-6758 ▷1	
1					-006	4-B	4	RETAINER ISOLATOR	.250 x 2.00 x 2.00	2024-T351 AL ALY PL	QQ-A-250/4	LEACH IRIDITE
2					-005	3-A	4	ISOLATOR RUBBER	.125 x 1.75 x 1.75	SILICONE RUBBER SH	60 DUROMETER	
				1	-004	2-B	2	BRACKET ▷2	2.00 x 3.00 x 4.50	2219-T62 AL ALY PL	MMS 1117	
				1	-003	3-G	2	SPACER	.100 x 2.25 x 2.50	6061-T6 AL ALY SH	COMMERCIAL	
				1	-002	4-F	3	BRKT, TRUSS, UPPER	2.50 x 4.50 x 6.25	2219-T62 AL ALY PL	MMS 1117	
				1	-001	7-F	3	BUSHING, THREADED	.500 DIA x 2.50	4130 BAR STL HT 125	MIL-S-6758 ▷1	
			1		-029			TRUSS INSTL TO LONGERON SEMI-SHOCK MOUNTED				
			4		-020			BUSHING ASSY				
1					-019			BUSHING ASSY				
					-010			TRUSS INSTL TO LONGERON SHOCK MOUNTED				▷3
029	020	019	010	009	-009			TRUSS INSTL TO LONGERON BASELINE CONFIGURATION				▷3

LIST OF MATERIAL

Figure II-4 Truss Modification and Attachment to Longeron, LAB1006267

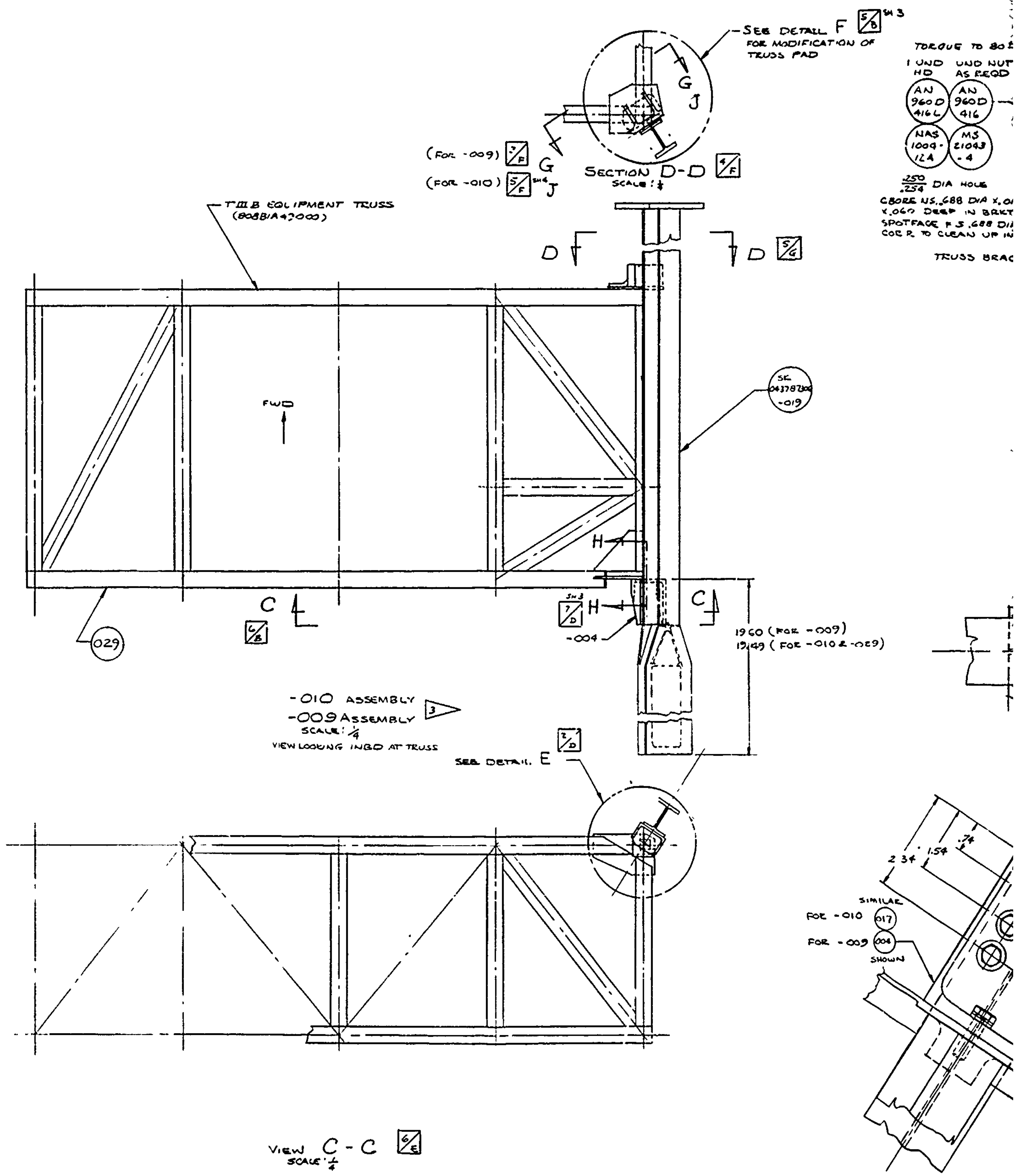
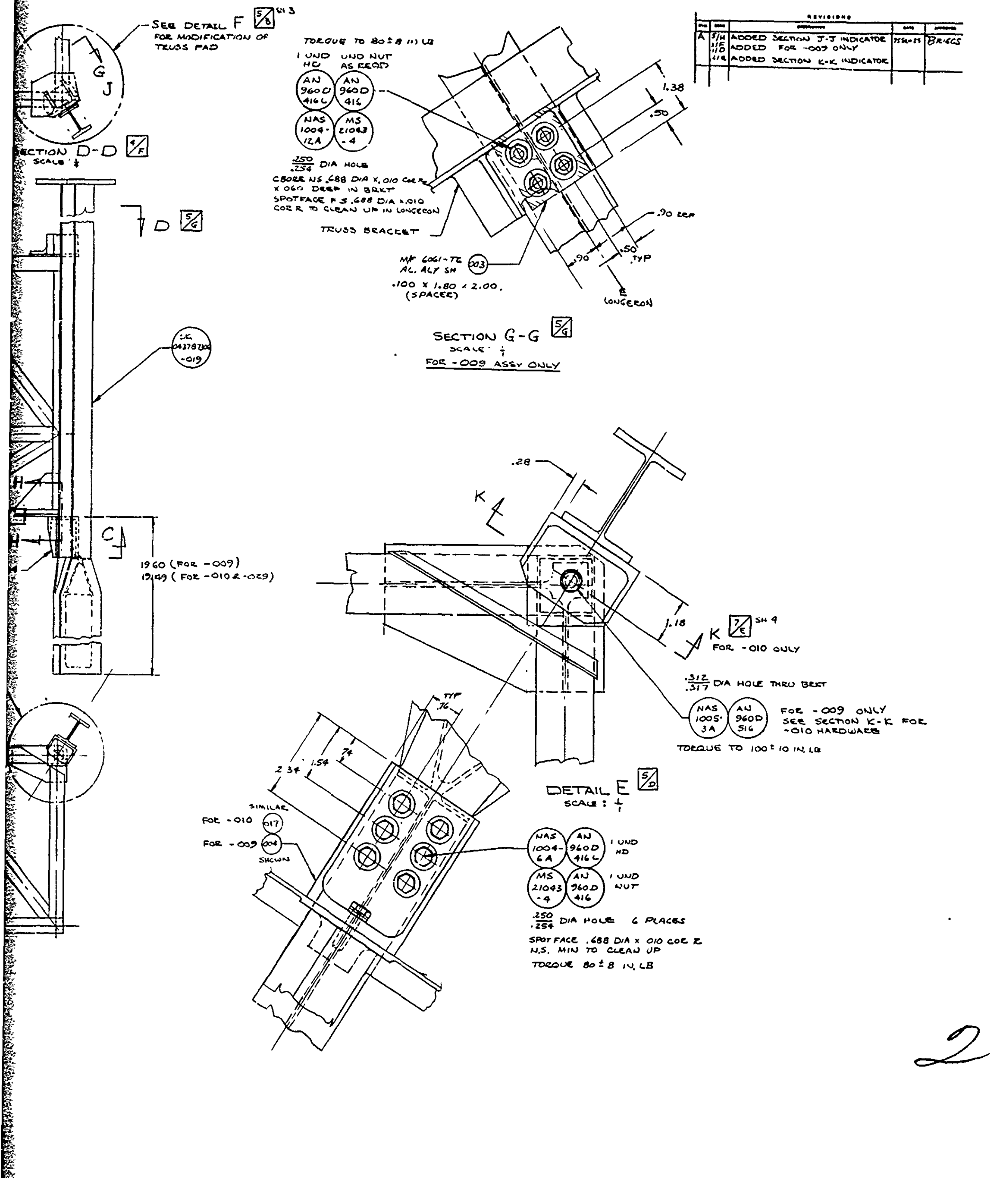
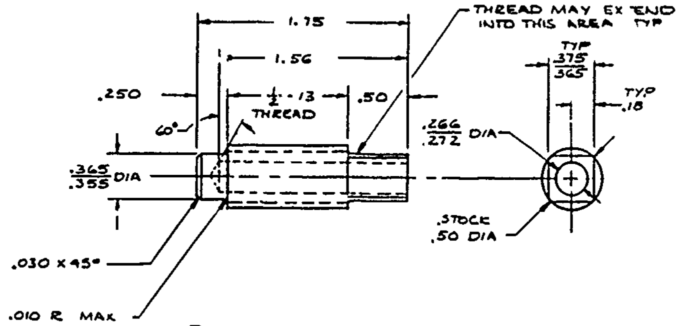


Figure II-4 (cont)



SEE DETAIL F 5/B SH 3
FOR MODIFICATION OF TRUSS PAD
SECTION D-D 4/F
SCALE 1/4
TORQUE TO 80 ± 8 IN LB
1 UND HD
UND NUT AS REQD
AN 960D 416L
AN 960D 416
NAS 1004-12A
MS 21043-4
.250/.254 DIA HOLE
CBORE NS .688 DIA X .010 COR R X .060 DEEP IN BRKT
SPOTFACE F.S .688 DIA X .010 COR R TO CLEAN UP IN LONGERON
TRUSS BRACKET
M/F 6061-T6 AL ALY SH 003
.100 X 1.80 X 2.00 (SPACER)
1.38
.50
.90 REF
.90
.50 TYP
LONGERON
SECTION G-G 5/G
SCALE 1/4
FOR -009 ASSY ONLY
REVISIONS
A
ADDED SECTION J-J INDICATOR
ADDED FOR -009 ONLY
ADDED SECTION K-K INDICATOR
BRIGGS
D 5/G
1960 (FOR -009)
19.49 (FOR -010 & -029)
.28
K
.18
K 7/E SH 4
FOR -010 ONLY
.312/.317 DIA HOLE THRU BRKT
NAS 1005-3A
AN 960D 516
FOR -009 ONLY
SEE SECTION K-K FOR -010 HARDWARE
TORQUE TO 100 ± 10 IN LB
DETAIL E 5/D
SCALE 1/4
TYP
.76
.74
1.54
2.34
SIMILAR
FOR -010 017
FOR -009 004
SHOWN
NAS 1004-6A
AN 960D 416L
1 UND HD
MS 21043-4
AN 960D 416
1 UND NUT
.250/.254 DIA HOLE 6 PLACES
SPOTFACE .688 DIA X .010 COR R N.S. MIN TO CLEAN UP
TORQUE 80 ± 8 IN LB
2



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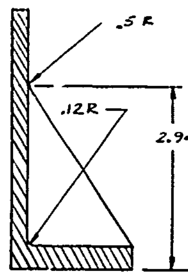
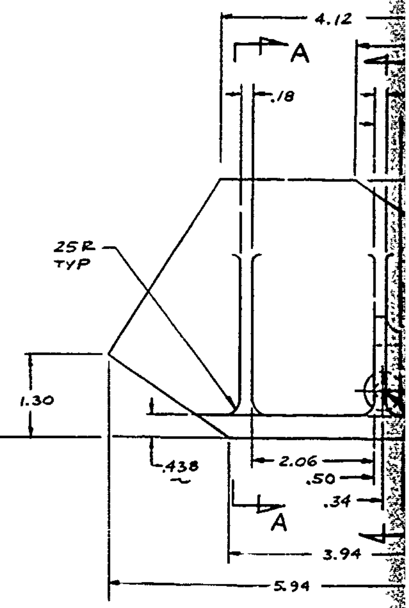
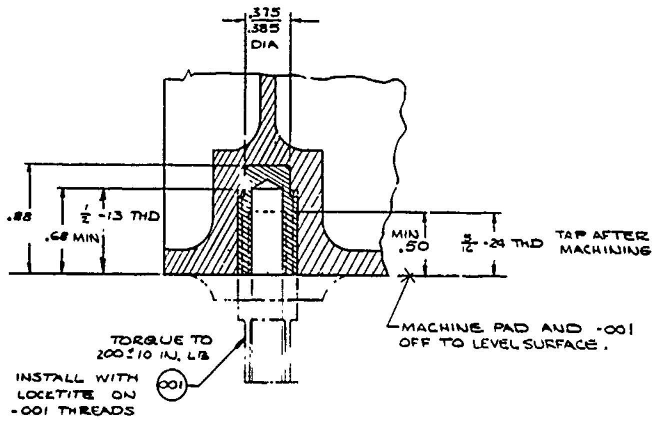
SCALE: 2/1



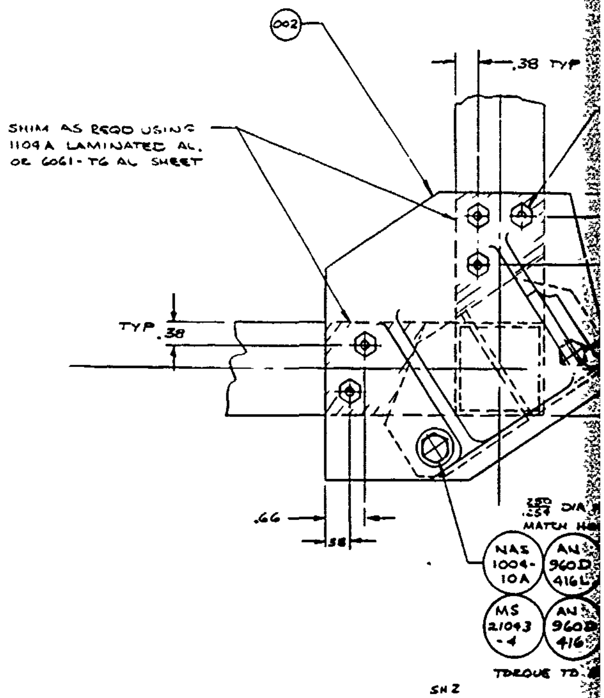
SECTION A-A



DETAIL -002
SCALE: 1/1

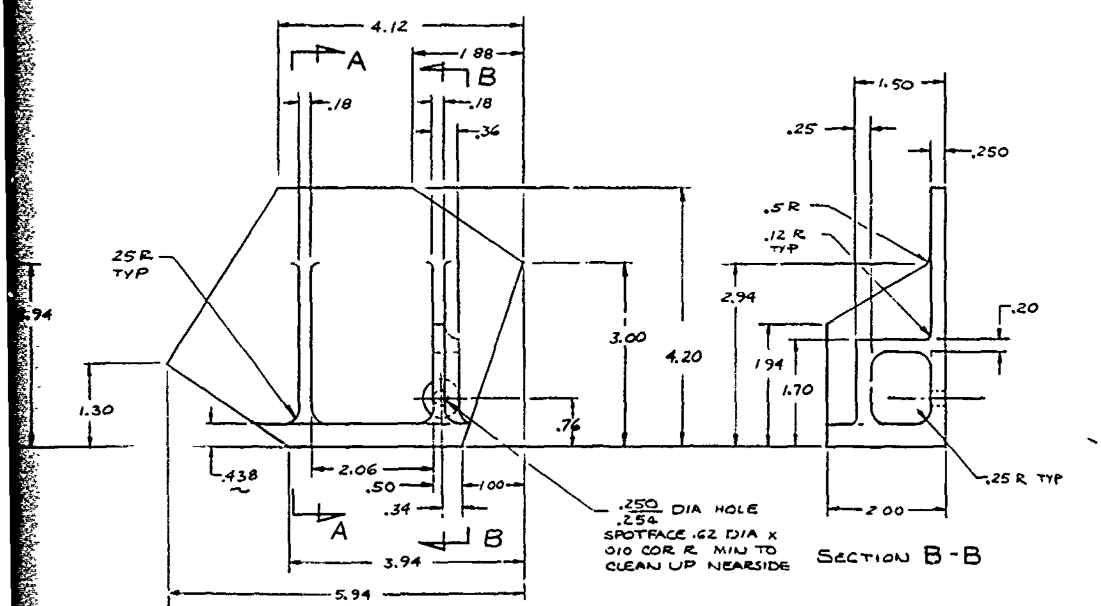


SECTION H-H 5/E (SH 2)
-004 BRACKET NOT SHOWN
(TRUSS FOOT MODIFICATION)



DETAIL F 4/11 (SH 2)

		REVISIONS		
A		ADDED -017		BRIGGS



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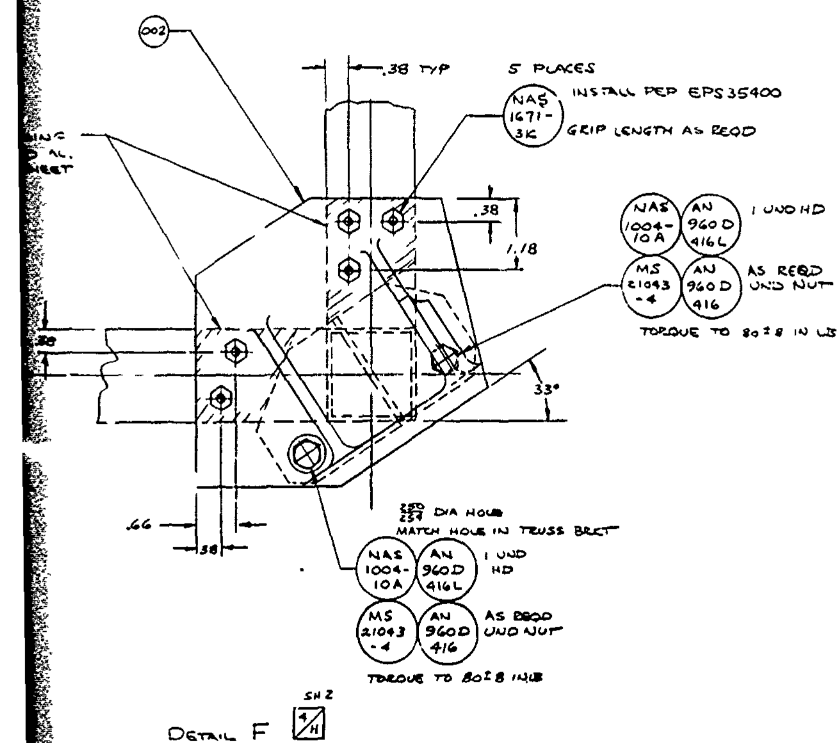
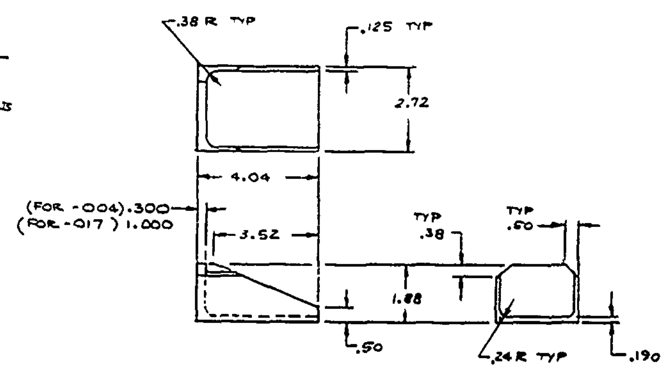
SCALE: 1/1



DETAIL F SH 2 4/H



DETAIL -004 SHOWN
DETAIL -017 SIMILAR

Figure II-4 (cont)

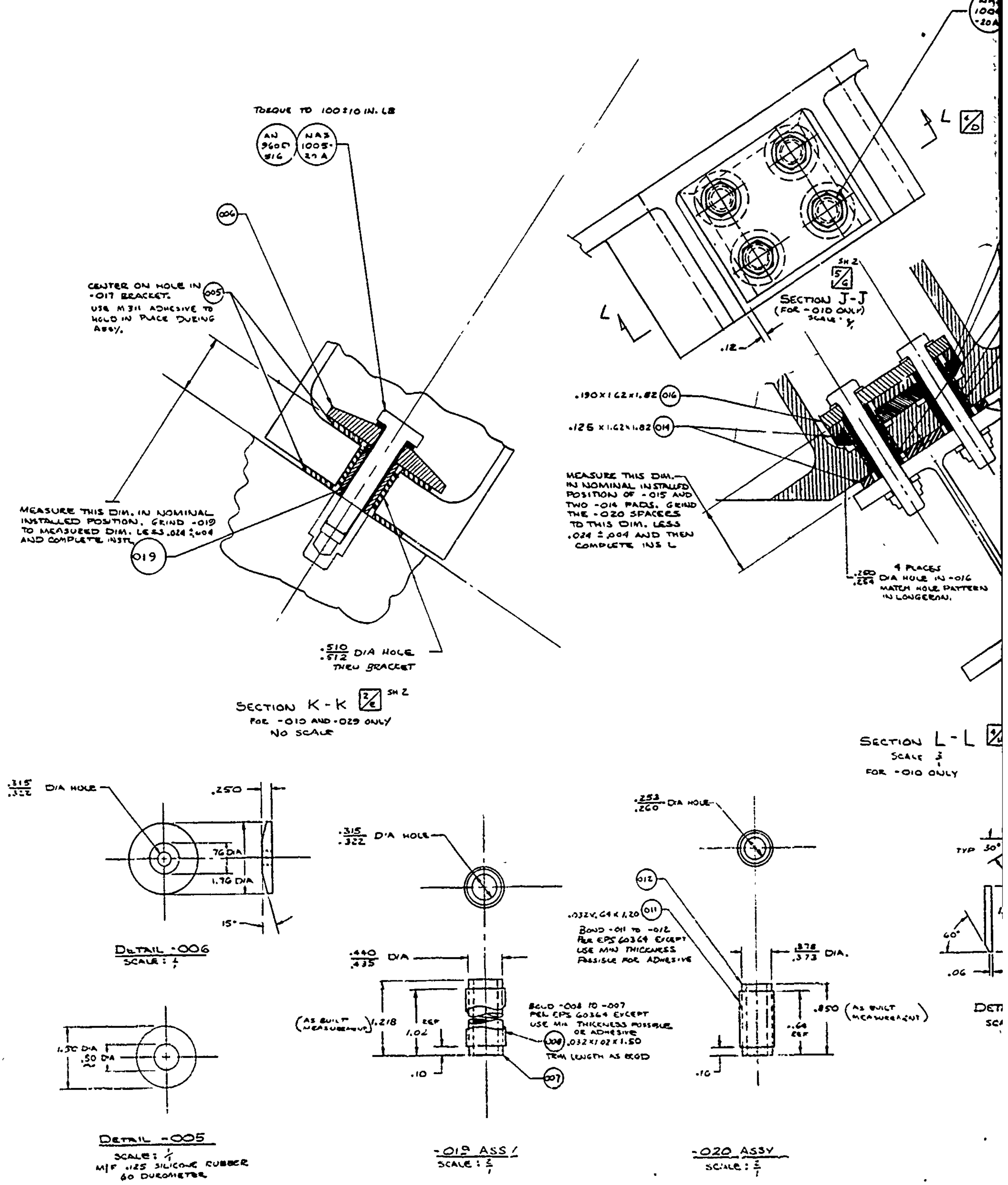
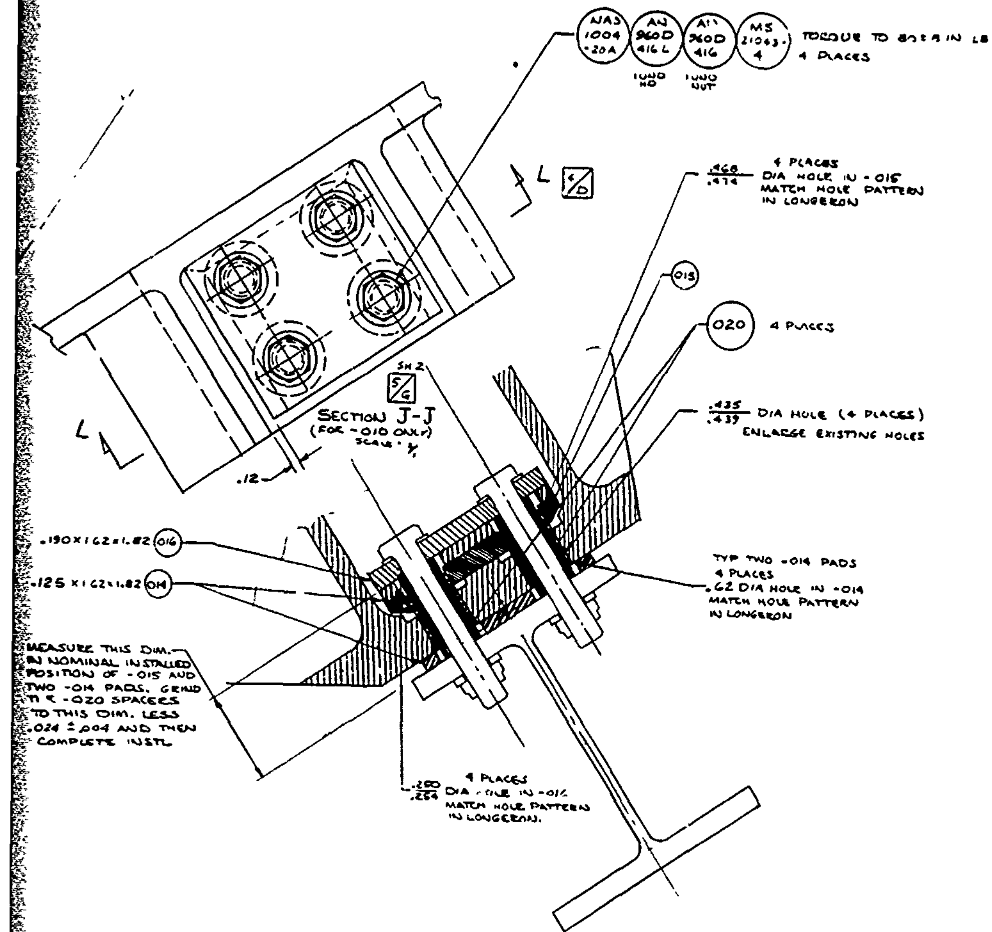
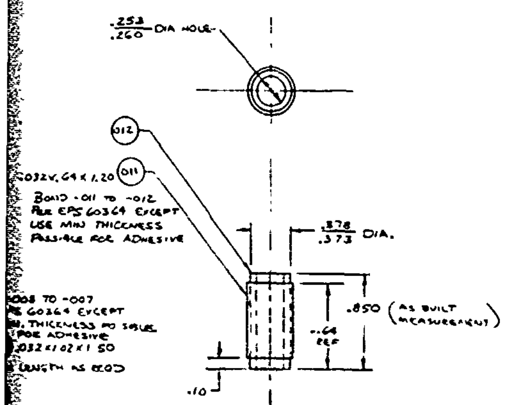


Figure II-4 (concl)

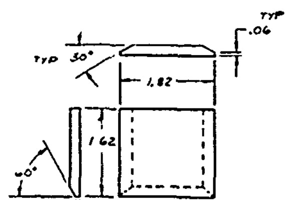
REVISIONS				
		DESCRIPTION	DATE	APPROVED
A		NEW	[illegible]	[illegible]



SECTION L-L
SCALE 3/1
FOR -010 ONLY



-020 ASSY
SCALE: 2/1



DETAIL -015
SCALE: 1/1

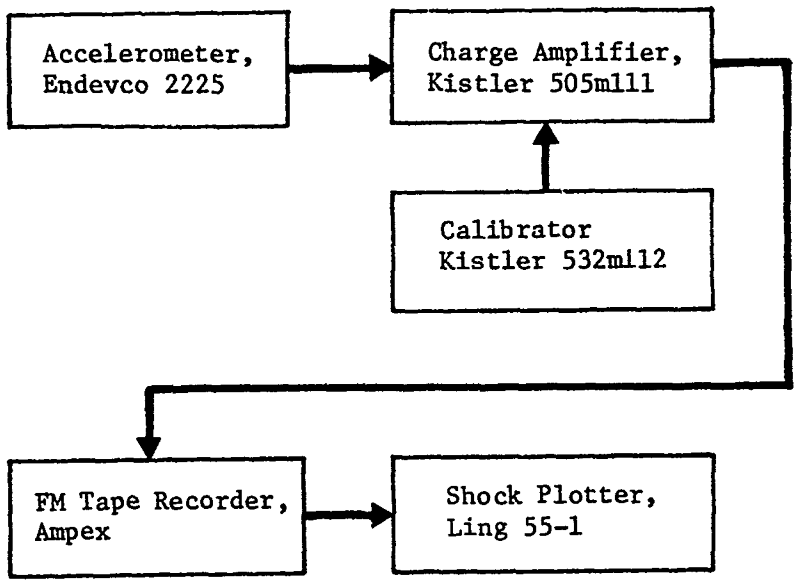
2

B. INSTRUMENTATION

Instrumentation consisted of 15 accelerometers in groups of three at five locations analogous to the three locations on the longeron and two on the truss used for the Transtage shock test reported in MCR-75-414.* Figure II-2 and the photographs (Fig. II-5 through II-9) show accelerometer locations.

For some of the tests, an accelerometer (16) was mounted on the test fixture to evaluate shock transmission from the fixture to the truss. The instrument is not shown in Figure II-2 because it was intended for use as a monitor in several locations.

The data acquisition system for the instrumentation is shown schematically below.



**Titan IIIC Transtage/Stage II Separation Shock Test Final Report.* Martin Marietta Corporation, Denver Division, November 1975.

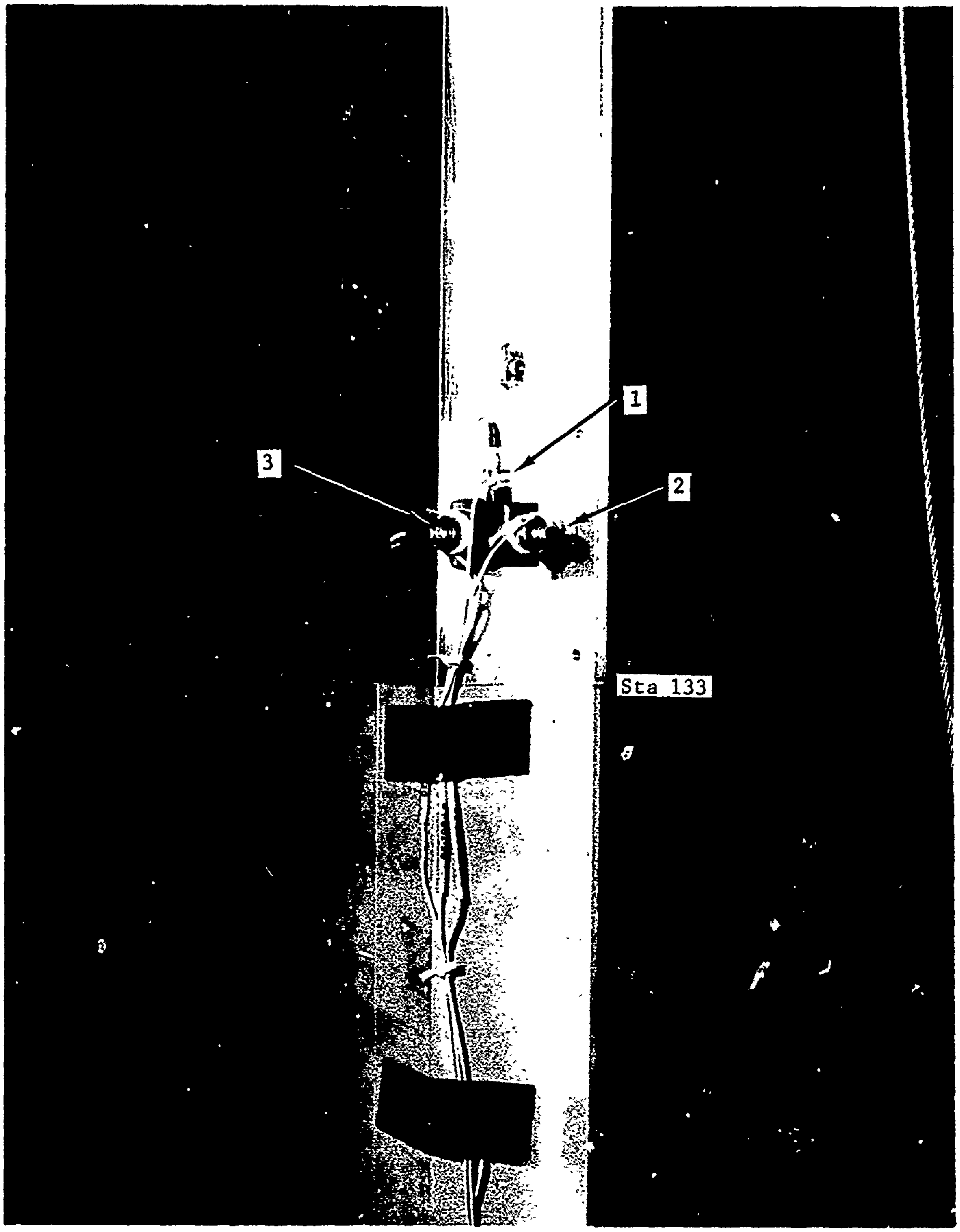


Figure II-5 Accelerometer 1, 2, and 3 Locations

Figure II-6 Accelerometer 4, 5, and 6 Locations

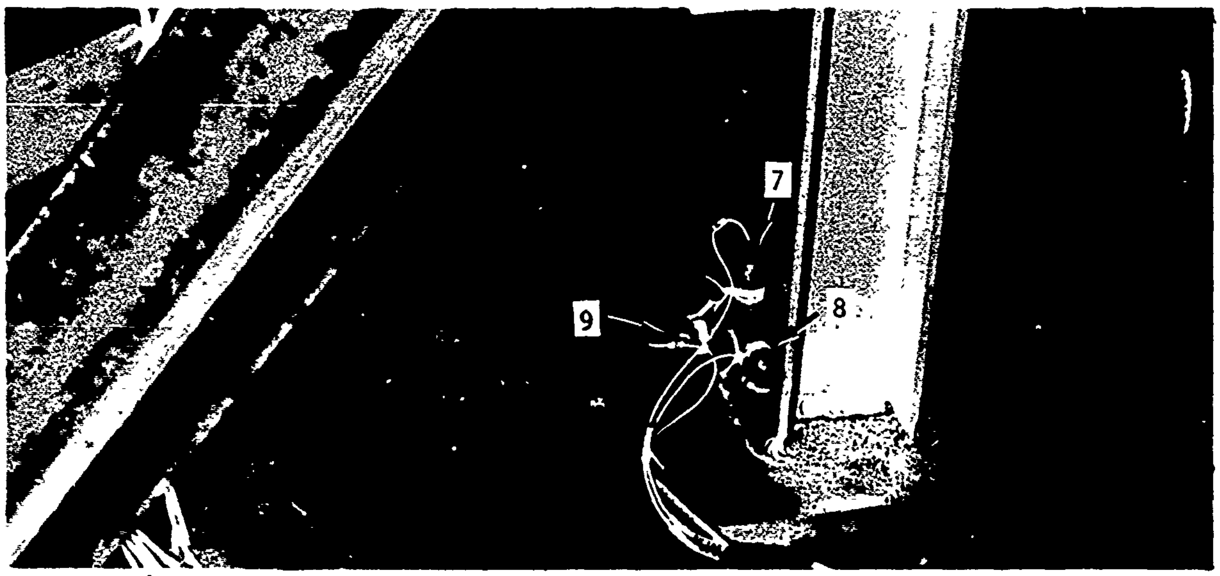


Figure II-7 Accelerometer 7, 8, and 9 Locations

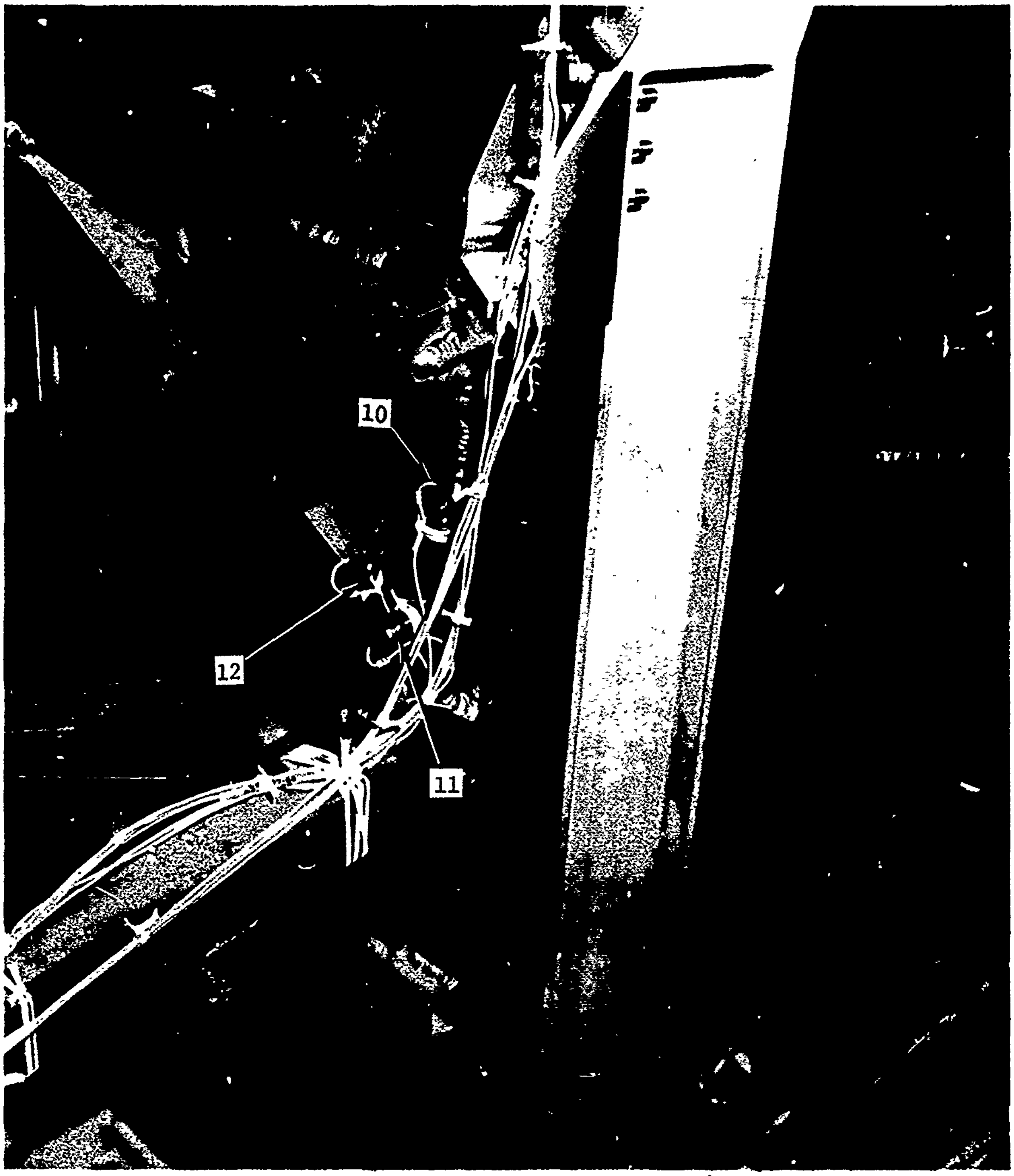


Figure II-8 Accelerometer 10, 11, and 12 Locations

Figure II-9 Accelerometer 13, 14, and 15 Locations

III. Test Specimens

III. Test Specimens

III. TEST SPECIMENS

A. ORDNANCE MODIFICATIONS

1. General

a. Firing Circuit - A Titan I battery set, charged to 28 V, was the power source for all firings. The firing switch distributed the output of this very large battery to the cartridge bridge wires through a cable and connector set. Because the connector mating the power cartridge was damaged by the firing, the connector and associated cable were replaced for each shot. Firing current was not measured, but could not have been less than 10 A per bridge wire. Safety-required disconnect and shorting points were provided in the circuit. Voltage at the connector was verified to be 28 V for each shot.

b. Installation Torque - Installation torque of the separation nuts was 200±20 ft-lb except where mated. A torque wrench was used on the Stage II side of the interface, and the Stage II nut was prevented from turning with a box wrench.

Torques on the catcher mounting bolts and door bolts were not controlled. During the bench tests, shims were not used at the end of the catcher farthest from the separation nut.

2. Shot Configuration

Seventeen configurations were used, as summarized by run number in Table III-1:

1) Normal Installation - Figure III-1 shows the installation of the separation nuts, cartridge, etc in a Titan III at Station 151.60, the Stage II/III joint. The figure is also an accurate reflection of a normal installation for the bench tests.

Table III-1
Ordnance Configuration Index

Run	Ordnance Configuration
1	1
2	1
3-5	1
6	2
7-8	2
9	3
10	3
11-13	8
14	4
15	9
16, 17, 19	10
18	6
20	5
21, 22	7
23, 24	11
25, 26	12
27, 28	13
29	14
30, 32, 34	15
31, 33	16
35-37	2
38	15
39	2
40	2
41	17
42, 43	15
44	1
45, 46, 47, 51	1
48, 50	17

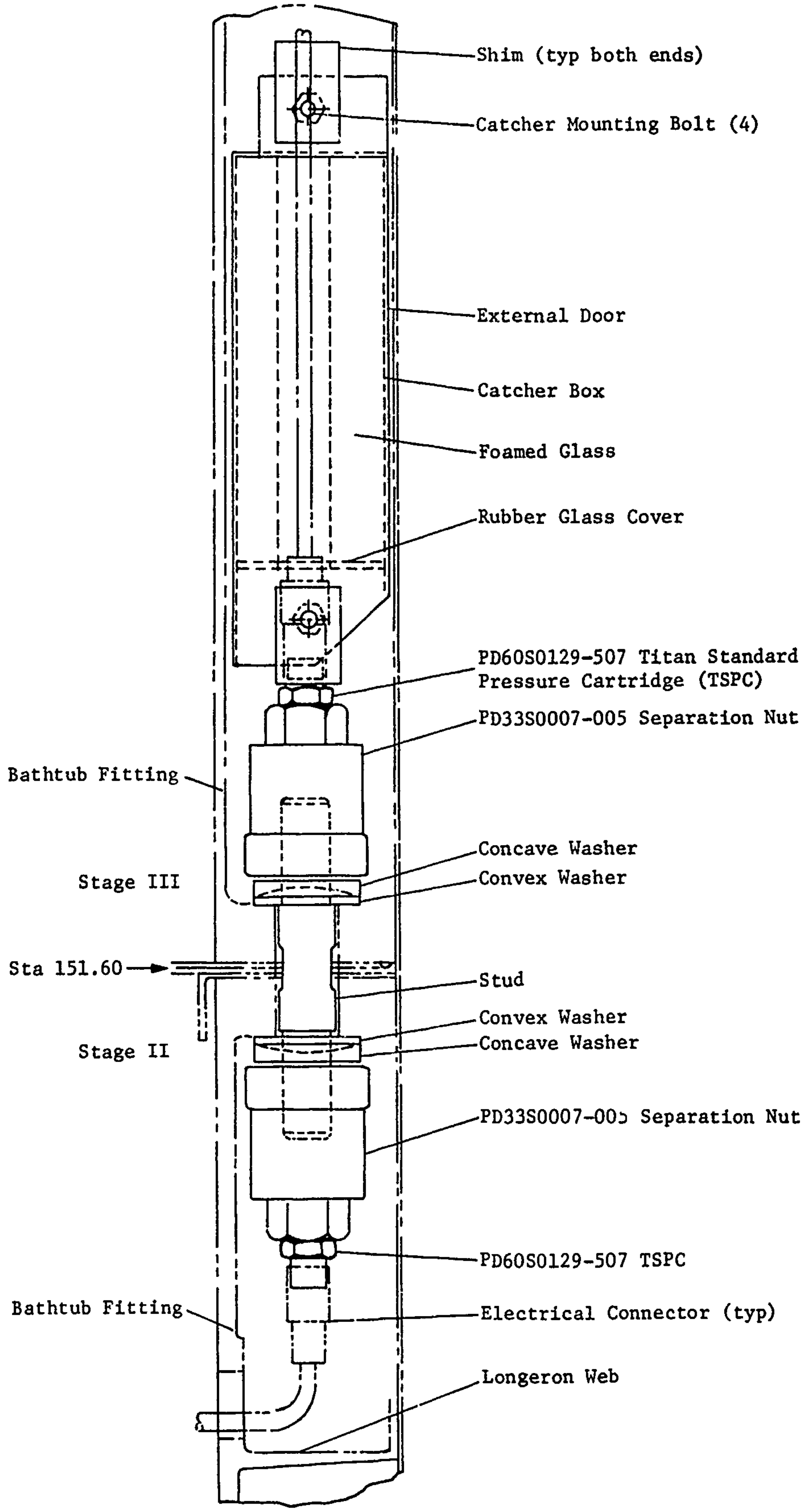


Figure III-1 Station 151.6 Separation Point

2) Single-Nut Normal Installation - For single-nut firings, the installation shown in Figure III-1 was modified. The cartridge on the unfired side of the installation was omitted and the socket filled with a 1/2-20 UNF bolt to simulate the mass of the cartridge and connector. For Run 6, this modification was made on the Stage III side; for all other single-nut runs, the modification was made on the Stage II side.

3) Torque Variations - A single-nut installation was made as described in 2 except that the torque applied to the nuts was 75 ft-lb (Run 9) or 300 ft-lb (Run 10).

4) Castellated Washers - A single-nut installation was made as described in 2 except that the spherical washer set on the Stage II side was replaced with a washer stack consisting of an SK808-02329-001 washer sandwiched between two SK808-02329-002 washers. In addition to the spherical washer set on the Stage III side, a single SK808-02329-001 washer and an SK808-02329-002 washer (next to the nut) were installed.

5) Honeycomb Washer - This installation was similar to that described in 4 except that a washer consisting of a 0.125-in. thick slice of aluminum honeycomb tube, 1½-in. OD and ¾-in. ID, was substituted for the castellated washers (Fig. III-2). Torque was reduced to 75 ft-lb for this shot.

6) Padded Stud - This installation was similar to that described in 2 except that a stud with a 0.25-in. pad of silicone rubber on each end was used (Fig. III-5).

7) Isolation at Station 133 - The installation at Station 133 was similar to that described in paragraph 4 except that a phenolic washer (0.125-in. thick) was used instead of castellated washers. Torque was 200 ft-lb, as is normal. In addition, a 0.063-in thick silicone rubber shim, 2-in. in diameter, was used to isolate the longeron at Station 133. The shim and phenolic washers are shown in Figure III-5.

8) In-Line Orifice (0.062-in. dia) - This installation at the separation point was similar to that described in 2 except that an SK808-02332-009 orifice-modified separation nut was used on the Stage III side. This configuration interposed a 0.062-in. diameter orifice between the nut and cartridge. The cartridge chamber was about 1 cc. The piston was modified to accept an O-ring.

9) In-Line Orifice (0.062-in. dia) with Dual Nuts - This installation at the separation point was similar to that described in 1 except that an SK808-02332-009 orifice-modified separation nut was used on both sides of the interface.

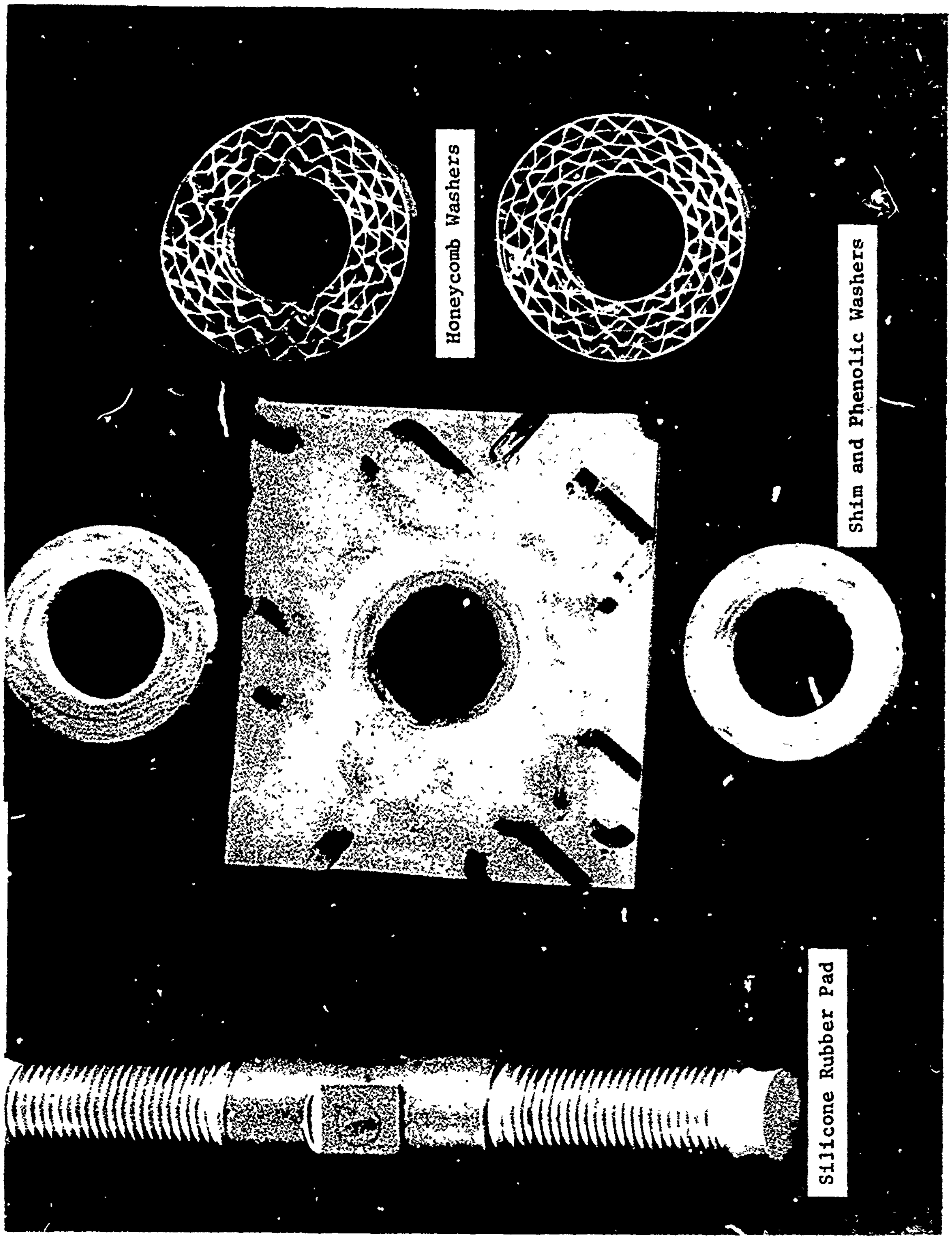


Figure III-2 Honeycomb Washers, Silicone Rubber Pads, Shim, and Phenolic Washers

Figure III-2

10) Viking Standard Initiator as Power Cartridge - This installation at the separation point was similar to that described in 2 except that an SK808-02332-040 nut was used and a PD5000006-001 (Viking Standard Initiator) was used as a power cartridge instead of a PD60S0129-507 TSPC. Electrical connectors were changed as required. Firing current was the same as before.

11) In-Line Orifice (0.081-in. dia) - This installation was similar to that described in 2 except that an SK808-02332-019 separation nut was used. The nut orifice was drilled out to 0.081 in. instead of the previously used 0.062 in.

12) In-Line Orifice (0.062-in. dia), Modified Piston - This installation was similar to that described in 2 except that an SK808-02332-030 separation nut was used. This nut was similar to the 0.062-in. orifice-modified nuts previously used (para 8) but with a "drop-center" piston (SK808-02332-006), which increased nut chamber volume by 2.5 cc.

13) In-Line Orifice (0.052-in. dia) - This installation was similar to that described in 2 except that an SK808-02332-010 separation nut was used. This nut was similar to the 0.062-in. diameter orifice-modified nut except that the orifice diameter was reduced.

14) Single Perpendicular Orifice (0.052-in. dia) Undercut Case - This installation was similar to that described in 2 except that an SK808-02332-020 separation nut was used. The nut had a 0.052-in. diameter orifice drilled from the side of the fitting, and the case head was undercut to provide clearance for the gas stream.

15) Perpendicular Orifices (0.052-in. dia) - This installation was similar to that described in 2 except that an SK808-02332-029 separation nut was used. The nut had an orifice fitting with two 0.052-in. diameter orifices drilled perpendicular to the cartridge centerline, and a case without undercut.

16) Single Perpendicular Orifice (0.052-in. dia), Normal Case - This installation was similar to that described in 2 except that an SK808-02332-039 separation nut was used. The orifice fitting had a single 0.052-in. diameter orifice drilled perpendicular to the cartridge centerline, and a nut case without undercut.

17) Dual Perpendicular Orifice (0.052-in. dia), Dual Nuts - This installation was similar to that described in 1 except that two SK808-02332-029 nuts were used.

B. BENCH TEST OBSERVATIONS

Certain observations were made during most of the firings conducted in the bench test series that should be reported.

1. Stud Impulse

Most of the single-nut firings were conducted with the active nut in the Stage III side of the interface. The Stage II longeron was suspended by counterweighted cable. A separation nut, with a mass-simulating bolt installed in the cartridge port, was used on the Stage II side. When separation occurred by firing the Stage III side, the Stage II longeron appeared to separate only under the influence of the counterweight. During the firings in which the nut on the Stage II side fired and smashed against the web of the longeron, the separation was quite violent, with the Stage II longeron violently driving upward, in some cases damaging the pully over which the suspension cable passed. The difference in behavior of the longeron in the two cases was marked. The conclusion is inescapable that the actuating nut imparted little if any impulse to the stud. This is just as would be expected based on the description of nut operation previously presented.

2. Nut Catcher

In firings using unorificed separation nuts on the Stage III side of the interface, the nut case generally penetrated the catcher until only the steel collar protruded from the catcher; in some cases, penetration was even deeper. In the three firings in which the VSI was used instead of the TSPC, the nut case did not penetrate the rubber cover over the foamed glass insert, although there was some minor fracturing of the glass under the rubber. In the firings with orificed separation nuts, the case penetrated the rubber and went into the glass for about 1/2 the length of the case; i.e., about 1 in. of penetration. Two conclusions can be drawn from this.

The foamed glass insert in the existing catcher is more than two case lengths long (about 6 in.). The catcher is so long that it is very difficult to install the connector on the TSPC with the catcher in place; it is impossible to install the catcher after connection. With the orifice fitting in the separation nut, connection is even more difficult. It is therefore proposed that, if the orificed nut is used on Titan III, the nut catcher be shortened at least 1 in. to permit easier connection to the TSPC. Plenty of foamed glass will still remain to stop the nut case.

It was shown earlier that the VSI should have provided at least 30% more energy than required to operate the nut, and perhaps as much as 100%. The behavior of the VSI-powered nut case and catcher contrasted with the behavior of a TSPC-powered orificed nut and catcher provides a rough measure of the vigor of separations of the orificed nut. It appears that the vigor (and hence the margin) of the orificed nut is about halfway between that of the VSI-powered nut and the unorificed TSPC-powered nut. Because the margin of the VSI-powered nut is at least 30%, and the margin of the TSPC-powered nut is about 460%, it is concluded that the margin of the orificed nut is about 200%, for a very rough assessment.

C. TRUSS ISOLATION

For bench tests, two basic isolator configurations were designed--one for the aft truss attachment (Fig. III-3), and one for the forward truss attachment (Fig. III-4). Both configurations use the existing bracket and bracket attachment design, with the following exceptions:

1) Aft Bracket (Fig. III-3)

   a) To accommodate a rubber washer with 10% precompression, the forward surface (mating to the truss) is lower with respect to the longeron attachment holes.

   b) The forward pair of fasteners to the longeron is eliminated to allow the pad that mates with the truss to be made thicker. This allows the rubber-coated bushing that goes through the pad to have enough bearing area to approach the stiffness criteria.

   c) The hole through the pad has an increased diameter to accommodate the bushing.

   d) The fastener mating the pad to the truss is now longer and has a specially designed bearing washer.

2) Forward Bracket (Fig. III-4)

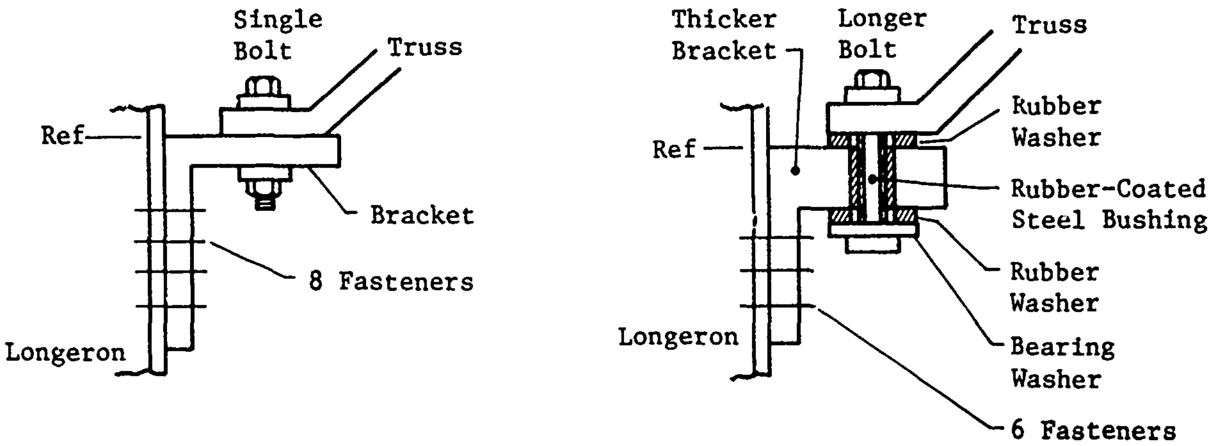
   a) The shim between the truss mounting pad and longeron is replaced by a rubber pad and thinner shim.

   b) The four attachment holes in the pad are drilled to a larger diameter to accommodate the bushing around each fastener.

   c) A bearing plate and a rubber pad, both with the larger holes, and a second bearing plate with original holes, are added to the inboard face of the pad.

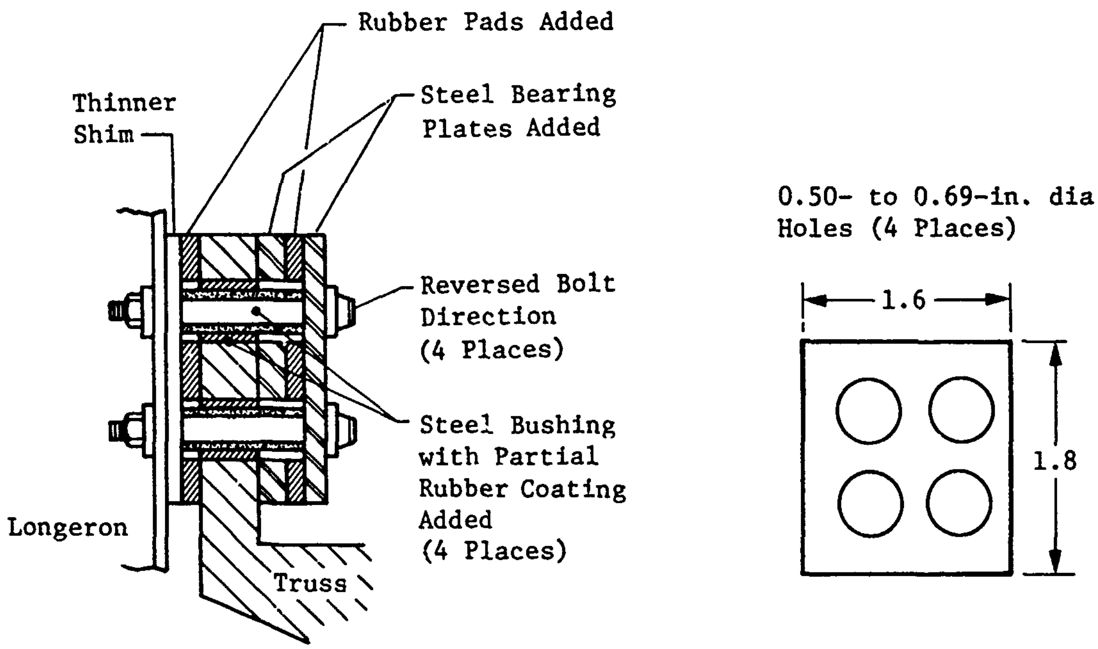
   d) A longer fastener is required for mating the new configuration to the longeron and must now be installed with the head inboard rather than outboard.

This design was selected because it required minimum change to existing hardware while allowing an isolator contact area sufficient to exceed the stiffness requirements. By intentionally exceeding the stiffness criteria in the design phase, the isolated version of the brackets can be machined in advance (but not drilled), leaving only the thickness and area of rubber as parameters that are easily changed to reduce the stiffness pending vibration test results.



a. Present Attachment *b. Isolated Attachment*

Figure III-3 Aft Bracket



a. Isolated Bracket *b. Approximate Dimensions of Rubber Pads and Steel Plates*

Figure III-4 Forward Bracket

IV. Test Results

IV. TEST RESULTS

The Stage II/III separation bench shock test was performed to find a technique for reducing the shock experienced by the Transtage trusses. Toward this end, 51 separations were performed. Table IV-1 summarizes the runs. Runs 1 and 2 were only used to determine the best configuration for all subsequent tests. Run 1 was performed with the payload end of the Stage III longeron (Sta 77) fixed to the test fixture, while Run 2 was performed with the longeron end free. It was found that the truss response levels were more representative of the system shock test (Ref IV-1) with the longeron fixed. Therefore, all subsequent tests were performed with a fixed longeron. Runs 3, 4, and 5 were then performed to establish a baseline for this series of testing. These runs consisted of a separation using two pyrotechnic separation nuts for each run. A composite spectrum of all measurements on the truss is shown in Figure IV-1 for the baseline runs. Figure IV-2 compares this baseline envelope with the envelope obtained from the system shock test at similar truss locations. As can be seen from the figure, the bench test produced shock responses comparable to those obtained from the system test.

Table IV-2 identifies the location of each accelerometer on the bench test structure. All shock response spectra obtained during the bench test are in Volume III.

Table IV-1 Bench Shock Test Summary

Run	Configuration	Results for 2000-Hz Range
1	Dual separation nuts, fixed longeron at Sta 77	Levels similar to system test
2	Dual separation nuts, free longeron at Sta 77	Levels exceeded system levels
3	Dual separation nuts, fixed longeron on this and all subsequent tests	Baseline
4	Dual separation nuts	Baseline, measurements on Accelerometers 10, 11, and 12 appeared abnormally low
5	Dual separation nuts	Baseline
6	Only Stage II nut fired	No reduction from baseline
7	Only Stage III nut fired	No reduction from baseline
8	Only Stage III nut fired	Measurements on Accelerometers 10, 11, and 12 appeared abnormally low
9	Stage III nut fired, 75 ft-lb torque	No reduction from baseline
10	Stage III nut fired, 300 ft-lb torque	No reduction from baseline
11	Stage III nut only, 0.063-in. orificed nut	$\gtrsim$ 6-dB reduction from baseline
12	Stage III nut only, 0.063-in. orificed nut	$\gtrsim$ 3-dB reduction from baseline
13	Stage III nut only, 0.063-in. orificed nut	$\gtrsim$ 3-dB reduction from baseline
14	Stage III nut only, castellated washer	No reduction from baseline
15	Dual nuts fired, 0.063-in. orificed nuts	$\gtrsim$ 3-dB reduction from baseline
16	Stage III nut only, reduced initiator charge	$\gtrsim$ 6-dB reduction from baseline
17	Stage III nut only, reduced initiator charge	$\gtrsim$ 5-dB reduction from baseline
18	Stage III nut only, padded stud	No reduction from baseline
19	Stage III nut only, reduced initiator charge	$\gtrsim$ 6-dB reduction from baseline
20	Stage III nut only, crushable washer	No reduction from baseline
21	Stage III nut only, isolation at Sta 133	Slight reduction from baseline
22	Stage III nut only, isolation at Sta 133	No reduction from baseline
23	Stage III nut only, 0.081-in. orificed nut	Similar to reduction with 0.063-in. orificed nut
24	Stage III nut only, 0.081-in. orificed nut	Similar to reduction with 0.063-in. orificed nut
25	Stage III nut only, 0.063-in. orificed nut with modified piston	Similar to reduction with 0.063-in. orificed nut
26	Stage III nut only, 0.063-in. orificed nut with modified piston	Similar to reduction with 0.063-in. orificed nut
27	Stage III nut only, 0.052-in. orificed nut	Greater reduction than with 0.063-in. orificed nut
28	Stage III nut only, 0.052-in. orificed nut	Greater reduction than with 0.063-in. orificed nut
29	Stage III nut only, dual 0.052-in. orificed nut, internal nut cavity recessed	Levels slightly greater than other orificed-nut runs
30	Stage III nut only, dual 0.052-in. orificed nut, [illegible] internal recess	Similar to reductions obtained with single 0.052-in. orificed nut
31	Stage III nut only, single 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
32	Stage III nut only, dual 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
33	Stage III nut only, single 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
34	Stage III nut only, dual 0.052-in. orificed nut	Similar to other 0.052-in. orificed-nut runs
35	Stage III nut only, isolator at truss bottom bracket	Reduction of levels at truss bottom, truss top similar to baseline
36	Stage III nut only, isolator at truss bottom	Reduction only at truss bottom
37	Stage III nut only, isolator at truss bottom	Reduction only at truss bottom
38	Stage III nut only, dual 0.052-in. orificed nut, truss bottom-bracket isolation	Reduction at truss bottom greater than with orificed nuts alone
39	Stage III nut only, truss bottom bracket removed	Truss bottom level similar to that with isolation
40	Stage III nut only, truss bottom bracket isolated, top bracket removed	Truss level very low
41	Dual separation nuts, dual 0.052-in. orificed nuts	Similar to other 0.052-in. orificed-nut runs
42	Dual separation nuts, truss bottom isolation, dual 0.052-in. orificed nuts	Levels similar to orificed-nut run without isolation
43	Dual separation nuts, truss bottom isolation, dual 0.052-in. orificed nuts	$\gtrsim$ 6-dB reduction from orificed-nut run without isolation
44	Dual separation nuts, truss bottom isolation	Levels similar to baseline
45	Dual separation nuts, full truss isolation	$\gtrsim$ 6-dB reduction from baseline
46	Dual separation nuts, full truss isolation	Longeron levels very high, truss levels slightly lower than baseline
47	Dual separation nuts, full truss isolation	$\gtrsim$ 6-dB reduction from baseline
48	Dual separation nuts, full truss isolation, dual 0.052-in. orificed nuts	Levels slightly lower than with orificed nuts only
49	Dual separation nuts, full truss isolation, dual 0.052-in. orificed nuts	Levels slightly lower than with orificed nuts only
50	Dual separation nuts, full truss isolation, dual 0.052-in. orificed nuts	Levels slightly lower than with orificed nuts only (measurement on Accelerometer 13 appeared abnormally high
51	Dual separation nuts, full truss isolation	$\gtrsim$ 6-dB reduction from baseline

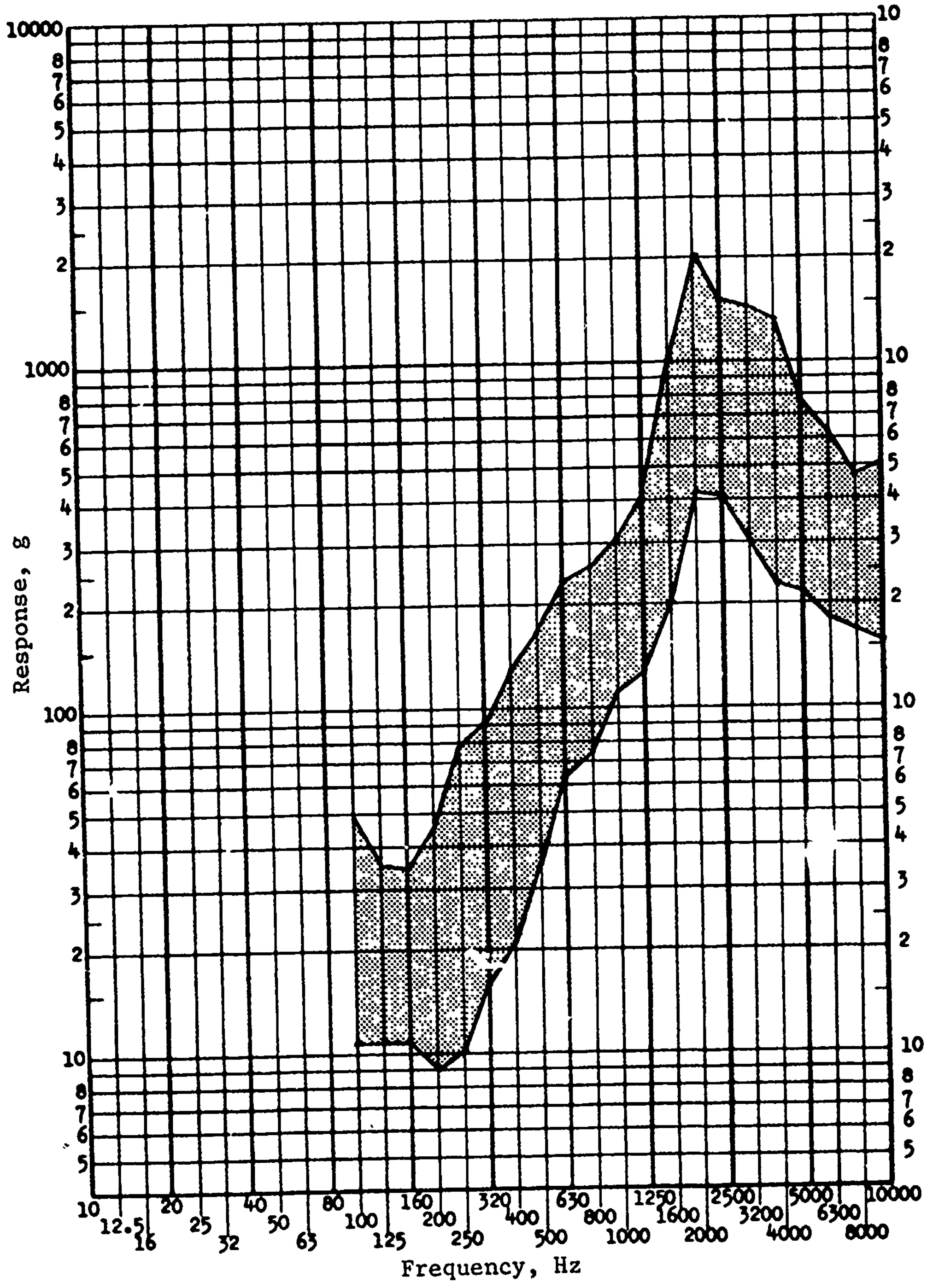


Figure IV-1
Run 3, 4, 5 (Baseline) Shock Response Envelope on Truss near Longeron Attachments

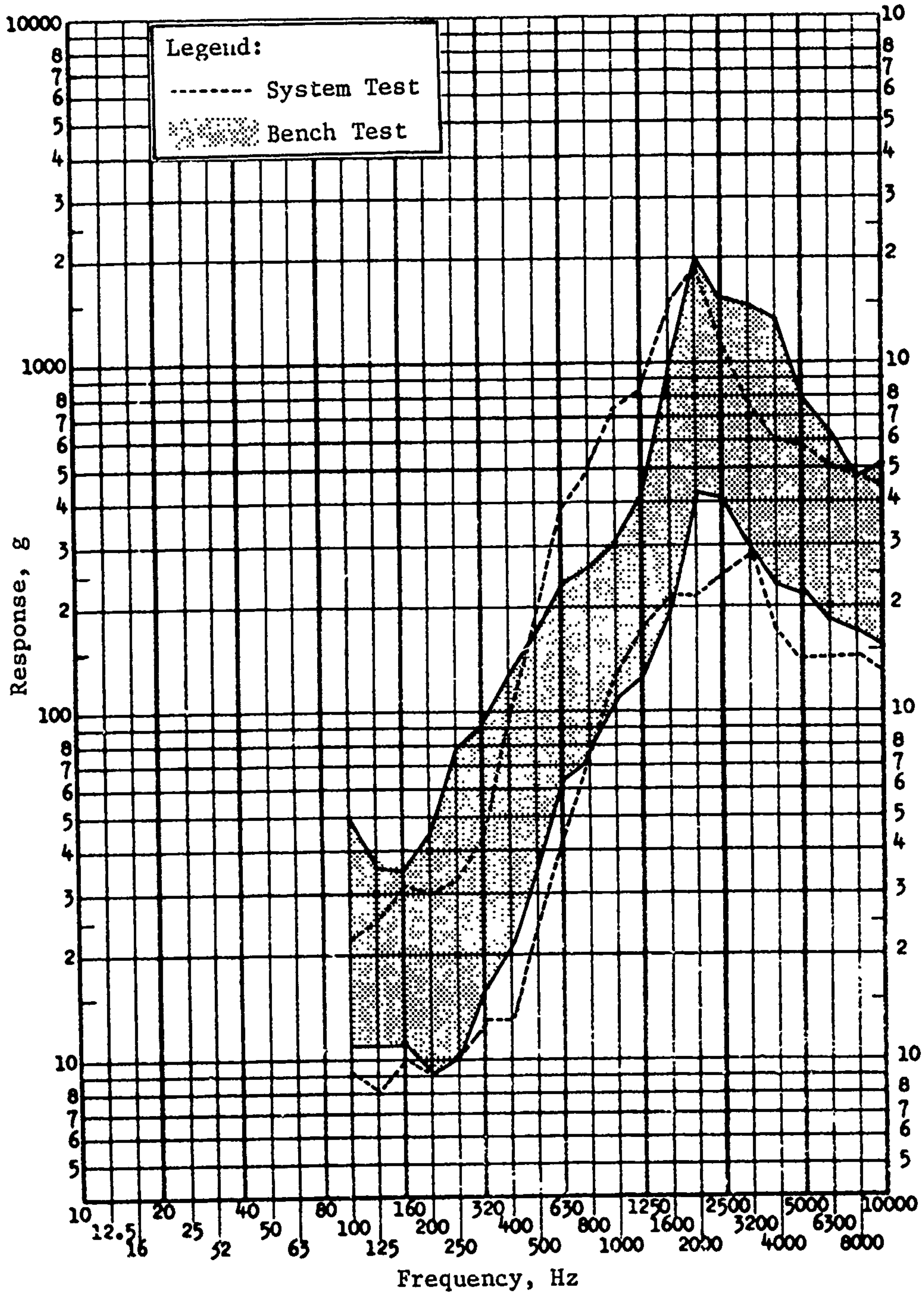


Figure IV-2 Bench versus System Test Corner-Truss Shock Levels

Table IV-2 Bench Shock Test Instrumentation

Location No.	Measurement No.	Direction*	Location
1	1 2 3	Longitudinal Tangential Radial	Longeron, 2 in. below Sta 133
2	4 5 6	Longitudinal Tangential Radial	Longeron, 2 in. below Sta 117
3	7 8 9	Longitudinal Tangential Radial	Longeron, 2 in. below Sta 77
4	10 11 12	Longitudinal Lateral Vertical	Near truss bottom, 5 in. above longeron attachment point, Sta 114
5	13 14 15	Longitudinal Lateral Vertical	Near truss top, 4 in. below longeron attachment point, Sta 114

*Longitudinal relative to vehicle axis
Tangential to vehicle skin
Radial from vehicle centerline
Lateral is normal to longitudinal axis of vehicle and parallel to long axis of truss
Vertical is normal to longitudinal axis of vehicle and normal to long axis of truss

A. SHOCK REDUCTION TECHNIQUES

Many proposed shock reduction techniques were tried during the bench test series, including modifications to the structure, as well as to the separation nut itself. Each of these proposed techniques, along with the observed results, are discussed in this section.

1. Time between Nut Actuations

A normal separation is performed with the near-simultaneous actuation of two separation nuts. If it were found that firing one nut at a time resulted in a reduced shock at the truss, a time delay could be programmed into the actuation. To test this theory, the separation nut on the Stage II side of the interface was actuated by itself. The envelope of the truss shock response resulting from this run (Run 6) is presented in Figure IV-3. By comparing Figure IV-3 with the baseline envelope in Figure IV-1, it can be seen that no apparent reduction in levels resulted. In Runs 7 and 8, the separation nut on the Stage III side of the interface was actuated. Again, as can be seen in Figure IV-4, no reduction in the shock levels occurred. On the contrary, there was an obvious increase in the response at frequencies below 1000 Hz. The implications of this observation will be discussed later.

Because it was found that firing the Stage III nut did not result in a significant change in peak response at the truss, much of the further testing was performed with only the one nut. Dual-nut firings were only used for final verification of a proven reduction technique.

2. Torque Variations

The nominal torque applied to the separation nuts at installation was 200 ft-lb. To determine whether a change in this torque would alter the shock levels, two runs were performed with first a lower torque (Run 9) and then an increased torque (Run 10). Run 9 was performed with a torque of 75 ft-lb on the nut. As can be seen in Figure IV-5, no reduction in shock was obtained. Run 10 was performed with a torque of 300 ft-lb on the nut. Figure IV-6 presents the results. Again, no reduction in shock was obtained. Both runs were performed by actuating only the Stage III nut, and as can be seen in the figures, the low-frequency hump, which is apparently characteristic of one-nut actuation, is present.

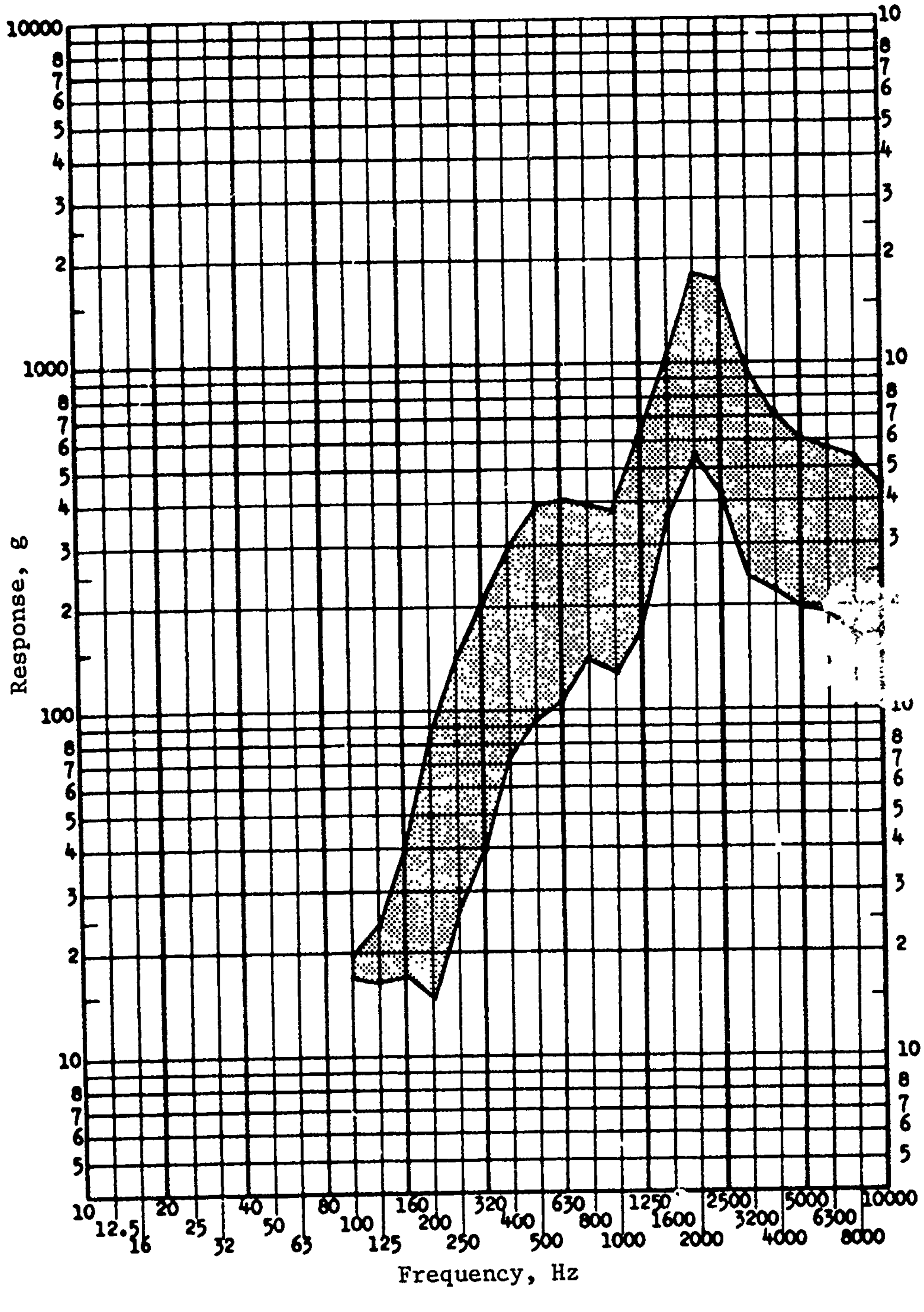


Figure IV-3
Run 6 Shock Environment Envelope on Truss near Longeron Attachment (Stage II Separation Nut Only)

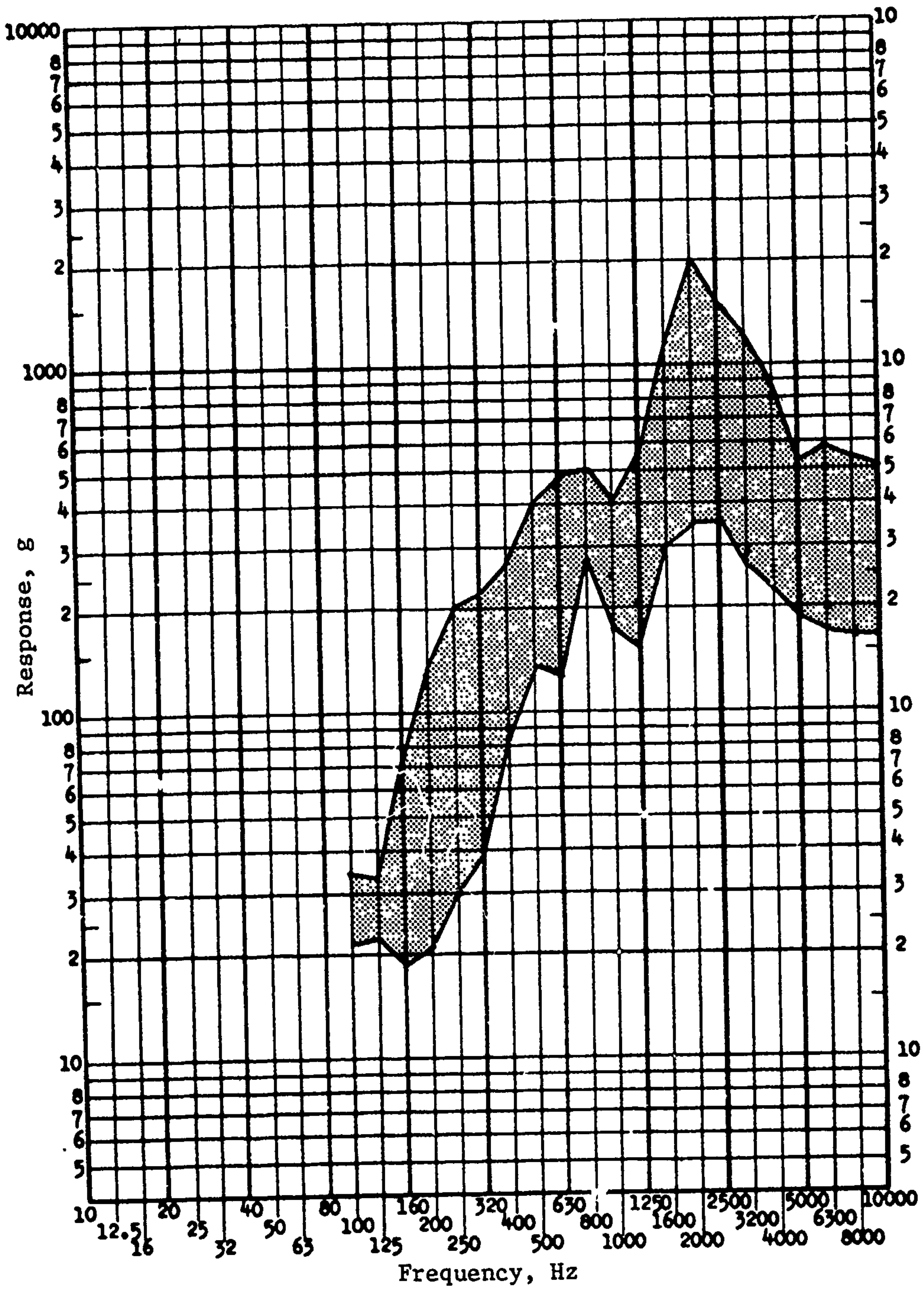


Figure IV-4
Run 7 and 8 Shock Environment on Truss near Longeron Attachments (Stage III Separation Nut Only)

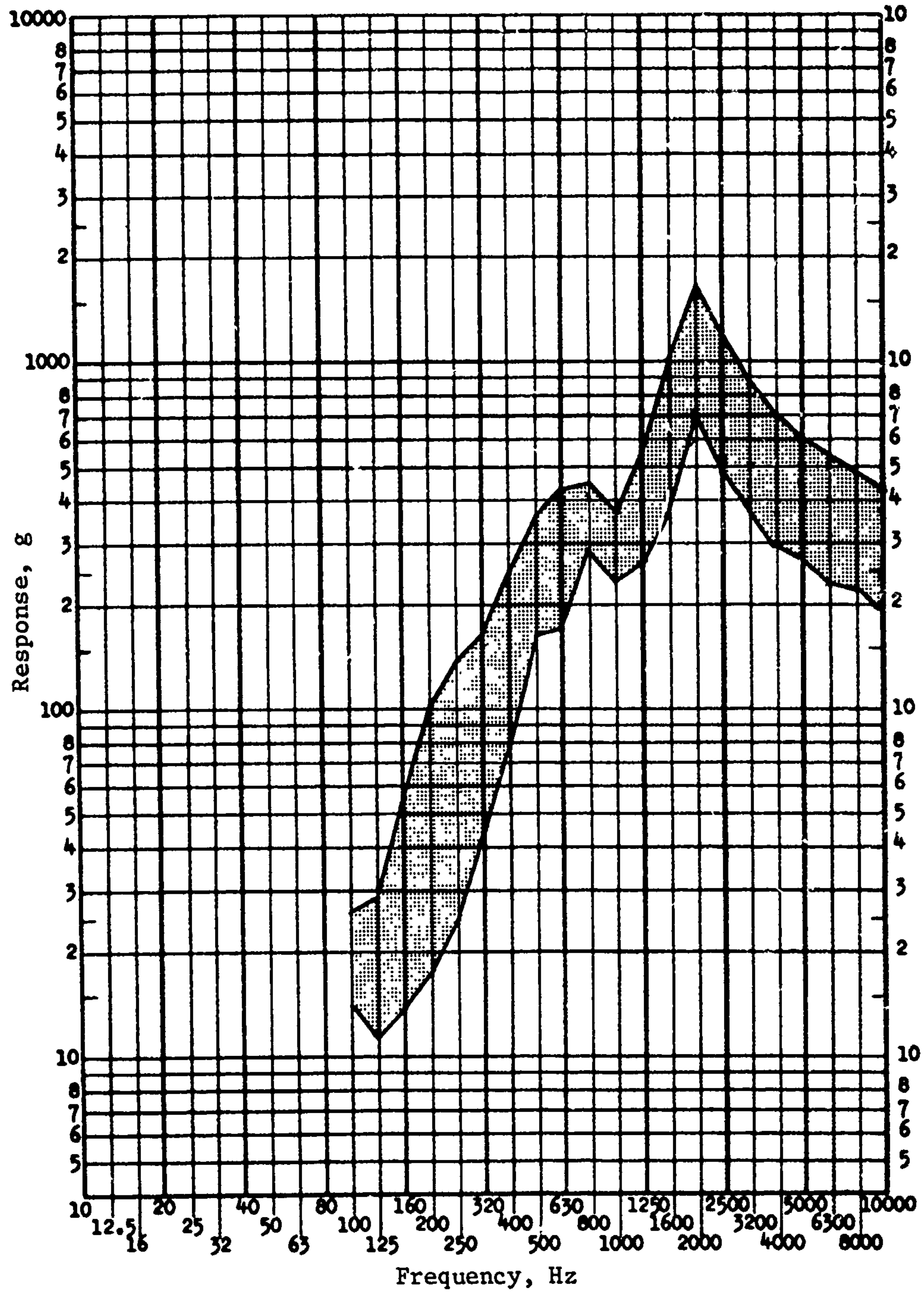


Figure IV-5
Run 9 Shock Response Envelope on Truss near Longcron Attachments (75-ft-lb Torque on Separation Nut)

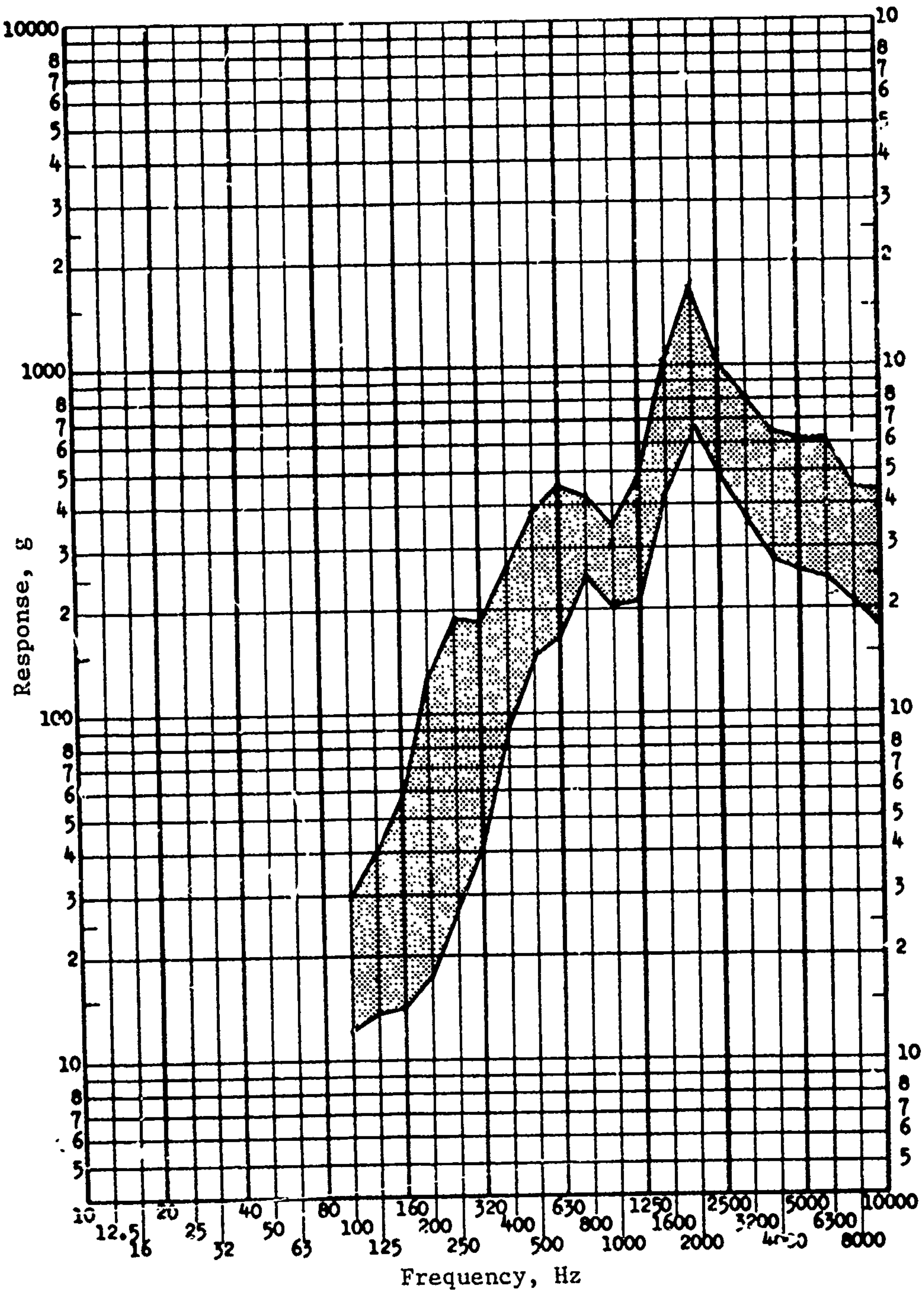


Figure IV-6
Run 10 Shock Response Envelope on Truss near Longeron Attachments (300-ft-lb Torque on Separation Nut)

3. Orificed Separation Nuts

When a pyrotechnic initiator is actuated, work is almost instantaneously performed on the piston of the separation nut. By metering the gas resulting from the actuated initiator through a small hole or orifice, the work done to the piston may be spread over a longer time, thereby reducing the shock level. This technique does indeed work. Many runs were performed with various orifice designs. The final design consisted of two 0.052-in. holes perpendicular to the nut axis. For a detailed discussion of the orifice designs, see Chapter III. Figure IV-7 presents the truss response envelope obtained when using the separation nut with two 0.052-in. orifices during Runs 30, 32, 34, and 41.

Other orifice configurations tried holes of varying size and numbers. All orificed-nut runs reduced shock. However, their results have not been summarized in this report. Shock response spectra for these other runs are in Volume III.

Of the orificed-nut runs using the final design, Runs 30, 32, and 34 were performed with only a single nut, while Run 41 was performed with dual separation nuts. Figure IV-8 shows the truss response envelope for only the single-nut orifice runs. Again, the one-nut low-frequency hump characteristic is present. Figure IV-9 is the envelope of Run 41 truss measurements, which was a result of a dual-nut firing. As can be seen from this figure, there is no hump at the lower frequencies.

4. Washer Variations

The two washers normally used between a separation nut and a longeron are self-aligning because of their curved interface (Fig. III-1). If the contact area of these washers with their mating surface is reduced, perhaps the shock levels would be lowered. To test this theory, a castellated washer was designed to reduce the contact area (Fig. II-4). In addition, it was believed that, if the washer fractured due to the shock, energy would be absorbed. Run 14 was performed with one separation nut to test the effects of the castellated washer. As can be seen from Figure IV-10, no shock reduction was obtained. Again, the hump characteristic of a one-nut shot is present at the lower frequencies. The washer was inspected after the test and found to be intact. No fracture had occurred.

Another washer concept was an aluminum honeycomb design (Fig. III-5). The thought was that the reduced contact area, as well as a deformation of the washer during the shock pulse, might reduce shock levels to the truss. Run 20 tested the crushable washer concept. A torque of only 75 ft-lb was used on the separation nuts to prevent crushing the washer during installation. As can be seen from Figure IV-11, no shock reduction was obtained. Again, the low-frequency hump was present, characteristic of a one-nut shot. Inspection of the washer after the test revealed no deformation.

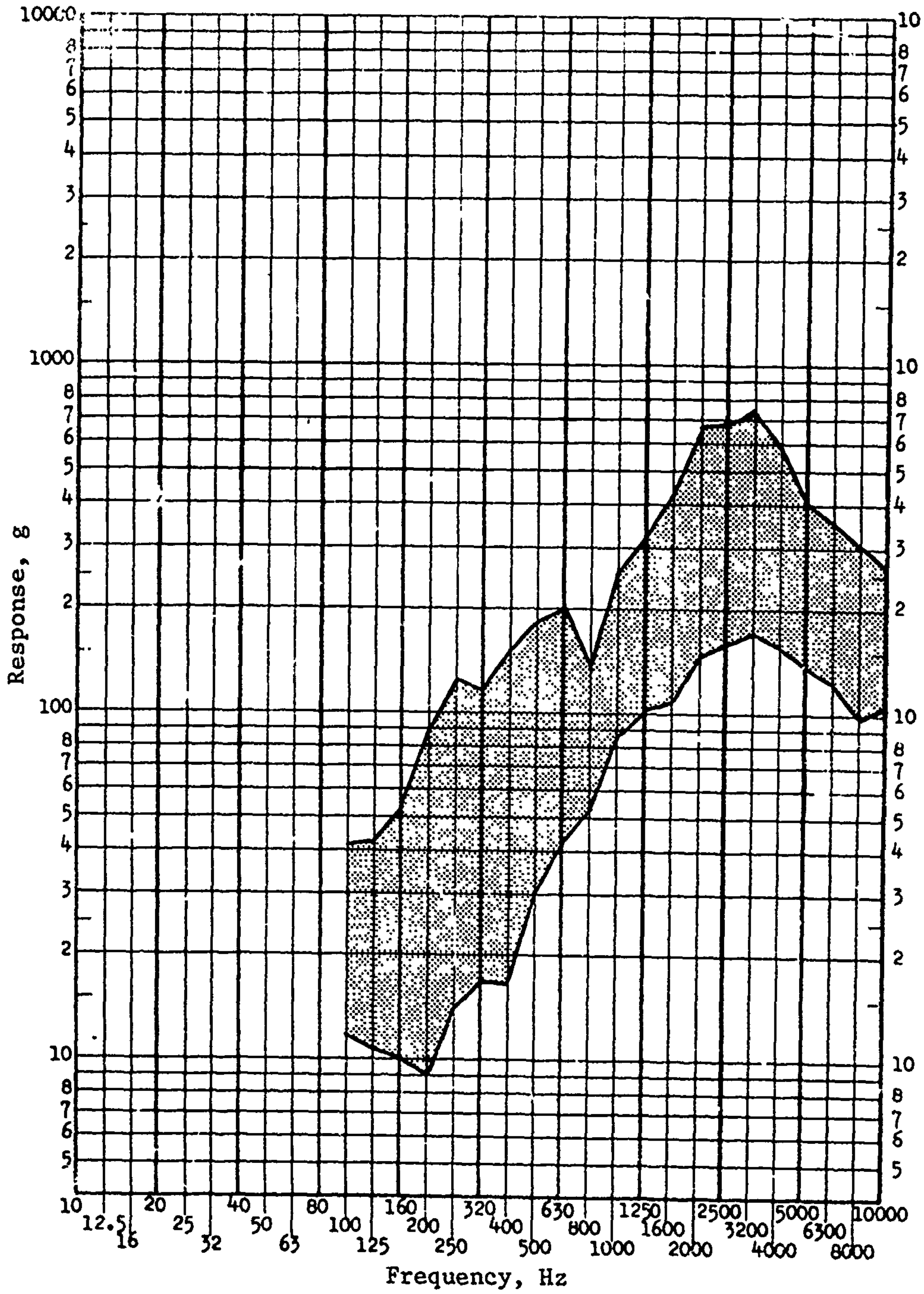


Figure IV-7
Run 30, 32, 34, and 41 Shock Response Envelope on Truss near Longeron Attachments (Dual 0.052-in. Orificed Nuts)

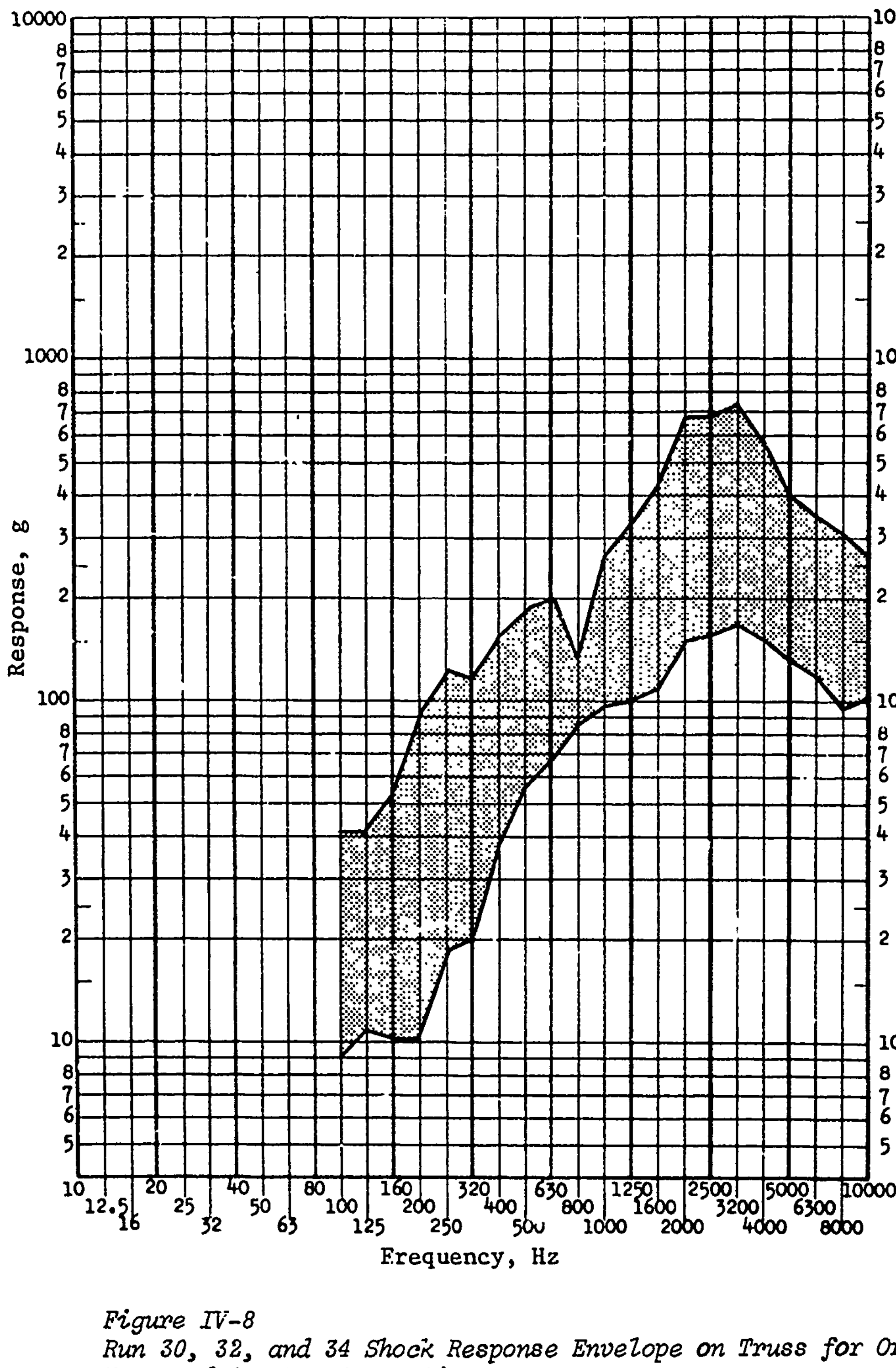


Figure IV-8
Run 30, 32, and 34 Shock Response Envelope on Truss for Orificed Nuts and One-Nut Separation

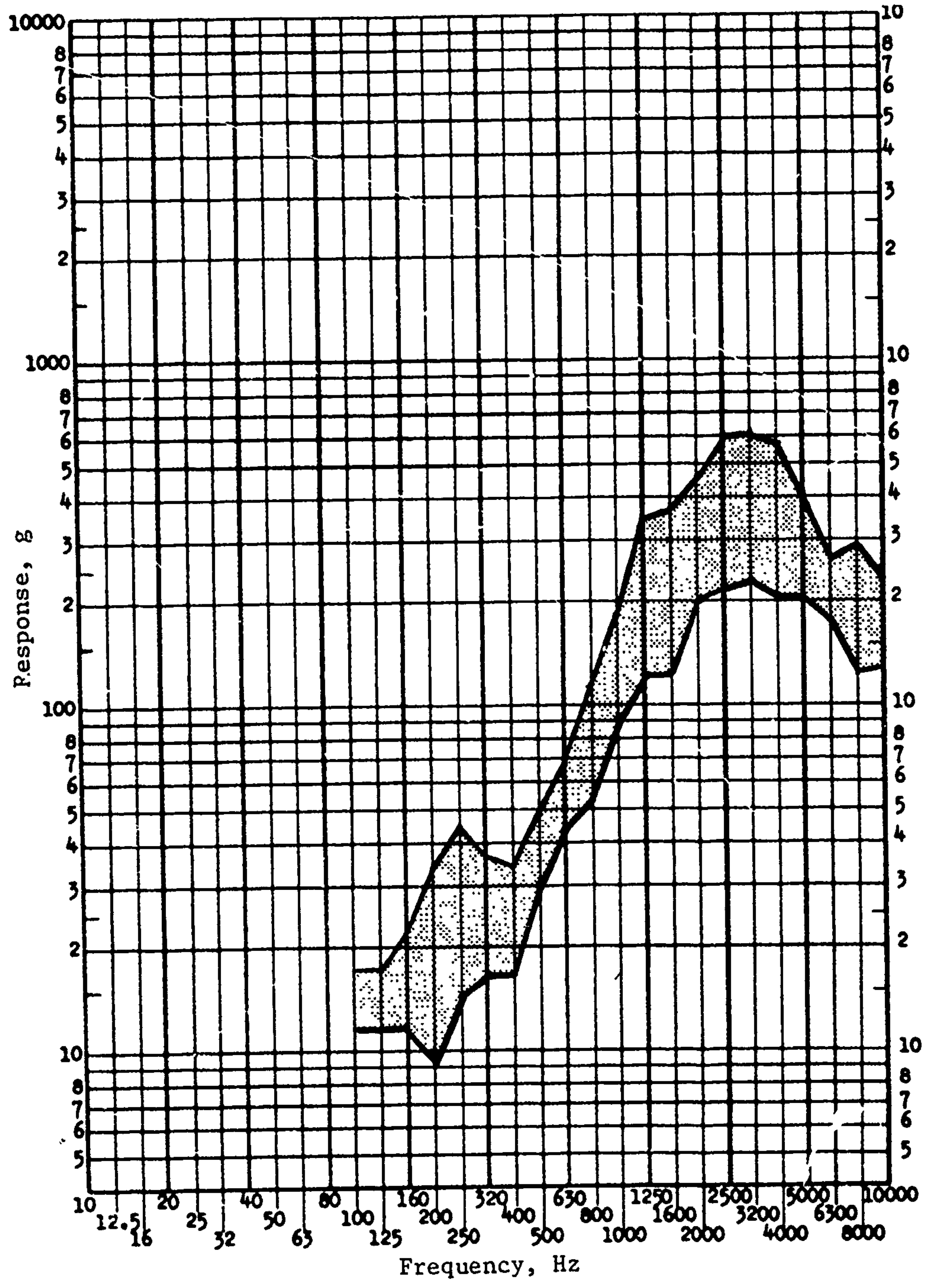


Figure IV-9
Run 41 Shock Response Envelope on Truss for Orificed Nuts and Dual-Nut Separation

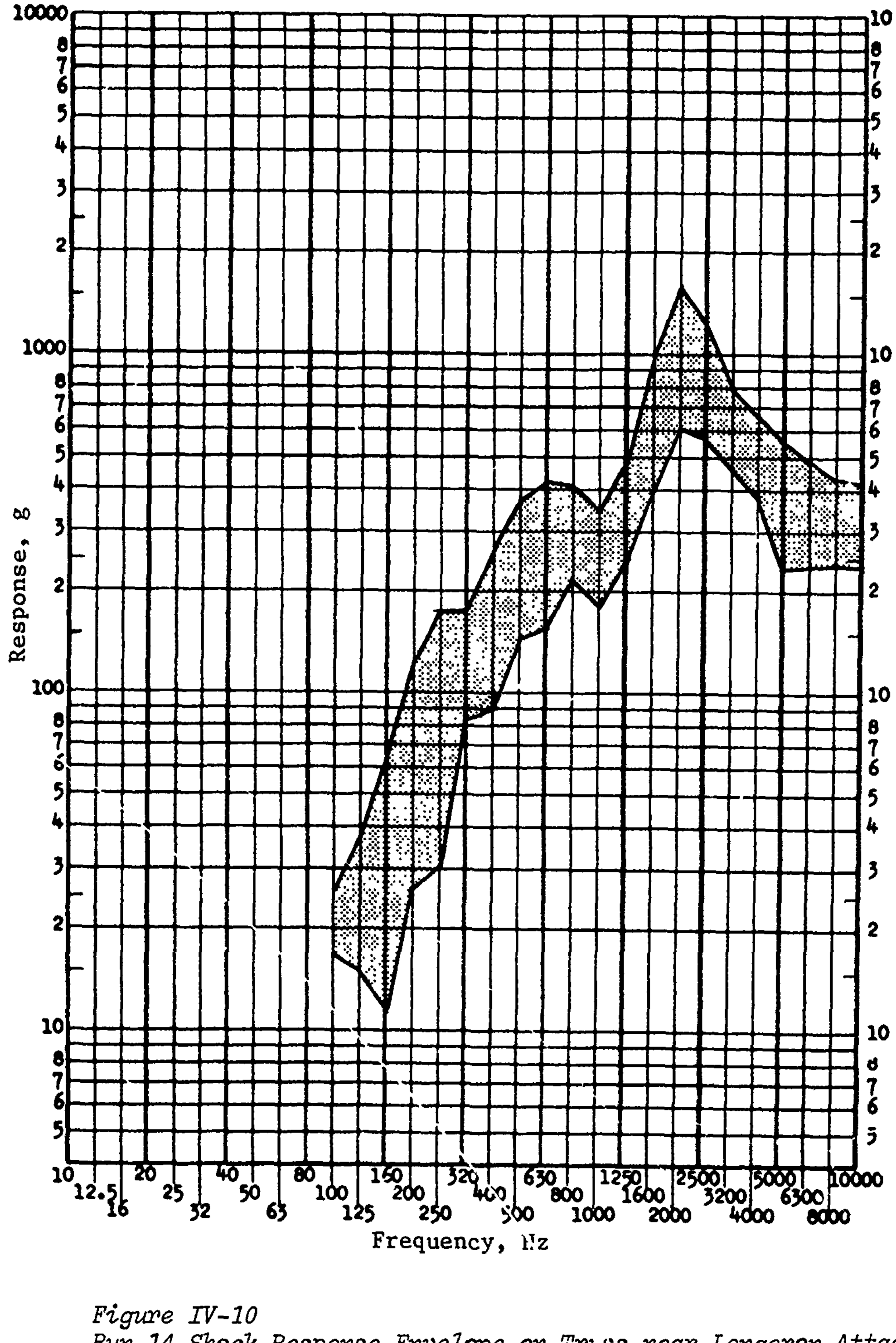


Figure IV-10
Run 14 Shock Response Envelope on Truss near Longeron Attachments (Castellated Washer under Separation Nut)

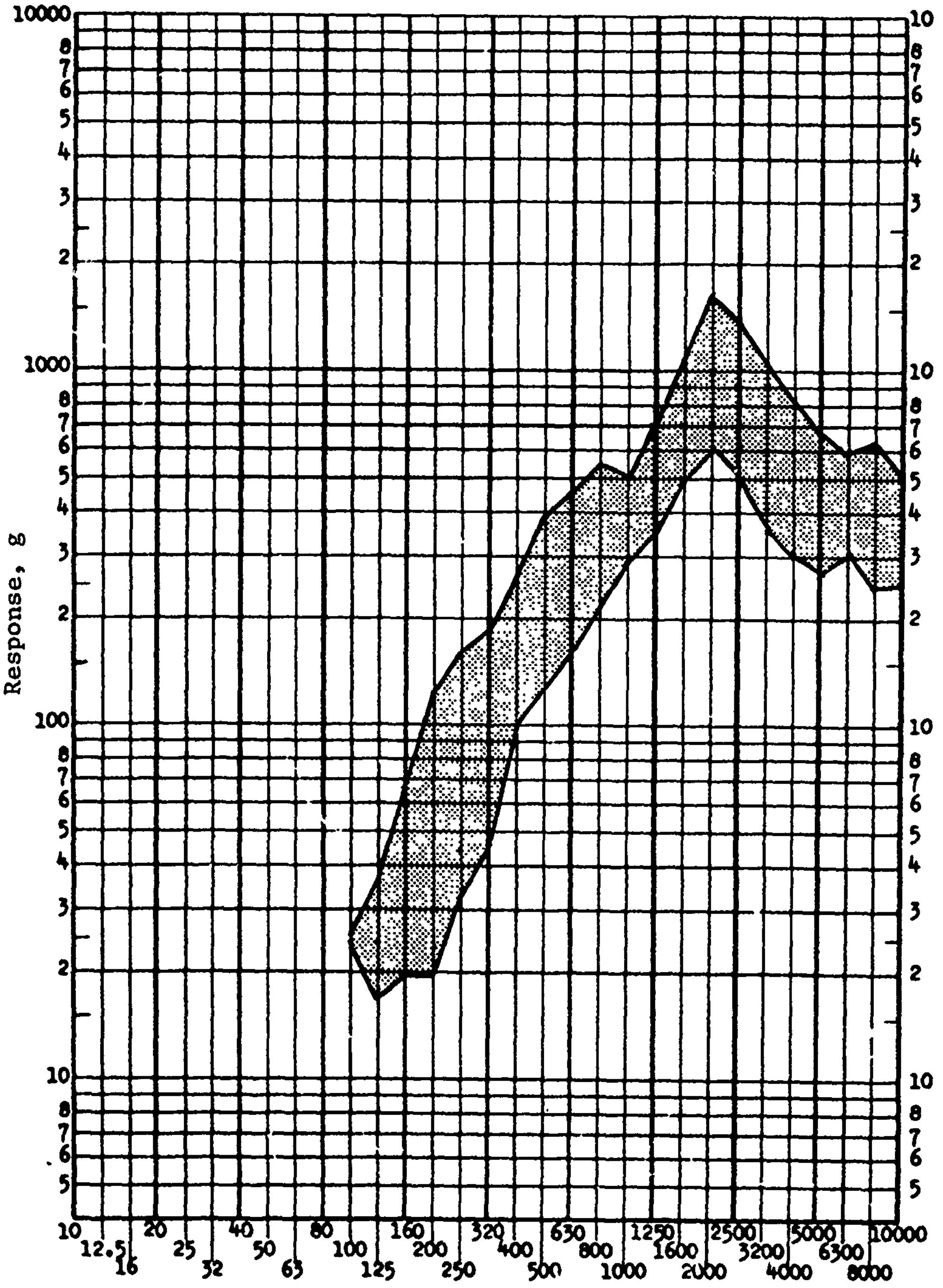


Figure IV-11
Run 20 Shock Response Envelope on Truss near Longeron Attachments (Crushable Washer)

5. Padded Stud

If the piston in a separation nut struck the bolt stud during nut actuation, resulting in a mechanical shock, a resilient pad on the end of the stud might reduce the shock levels. Run 18 was performed to test this theory using silicone rubber as the pad. As Figure IV-12 shows, no significant reduction occurred. The low-frequency hump was present as it had been before with other one-nut separations.

6. Reduced Initiator Charge

If the shock is due to initiator detonation, reducing the size of the initiator charge would reduce the shock levels. Runs 16, 17, and 19 were performed using a Viking Standard Initiator, which contains about one-sixth the charge used in the normal initiator. Figure IV-13 presents the results of the reduced charge concept. As the figure shows, a significant reduction in the truss shock response was obtained.

7. Isolation at Station 133

By introducing a density change of material at the Station 133 interface, it was hoped that the shock to the truss would be reduced. To accomplish this, silicone rubber was used at the interface, along with phenolic washers under the nuts. Figure IV-14 presents the results of this concept. Again, no shock reduction was obtained, the shock spectrum showed the one-nut signature at the lower frequencies.

8. Truss Isolation

Isolator systems consisting of silicone rubber were designed for the truss attachment points. They were constructed so that the system resonance would be near 200 Hz, therefore providing attenuation of the higher-frequency shock peaks. To better understand the isolators' effects on shock levels on the truss, a number of runs were performed with isolators. The results of these runs will be briefly summarized here. For specific shock response data, refer to Volume III.

The isolators were first installed at the lower truss attachment points, while leaving the upper attachment points hard mounted. The shock levels were attenuated significantly at the measurement location near the isolated attachment point. As was expected, shock levels at the top of the truss near the hard-mounted attachment point were similar to those experienced with the baseline tests.

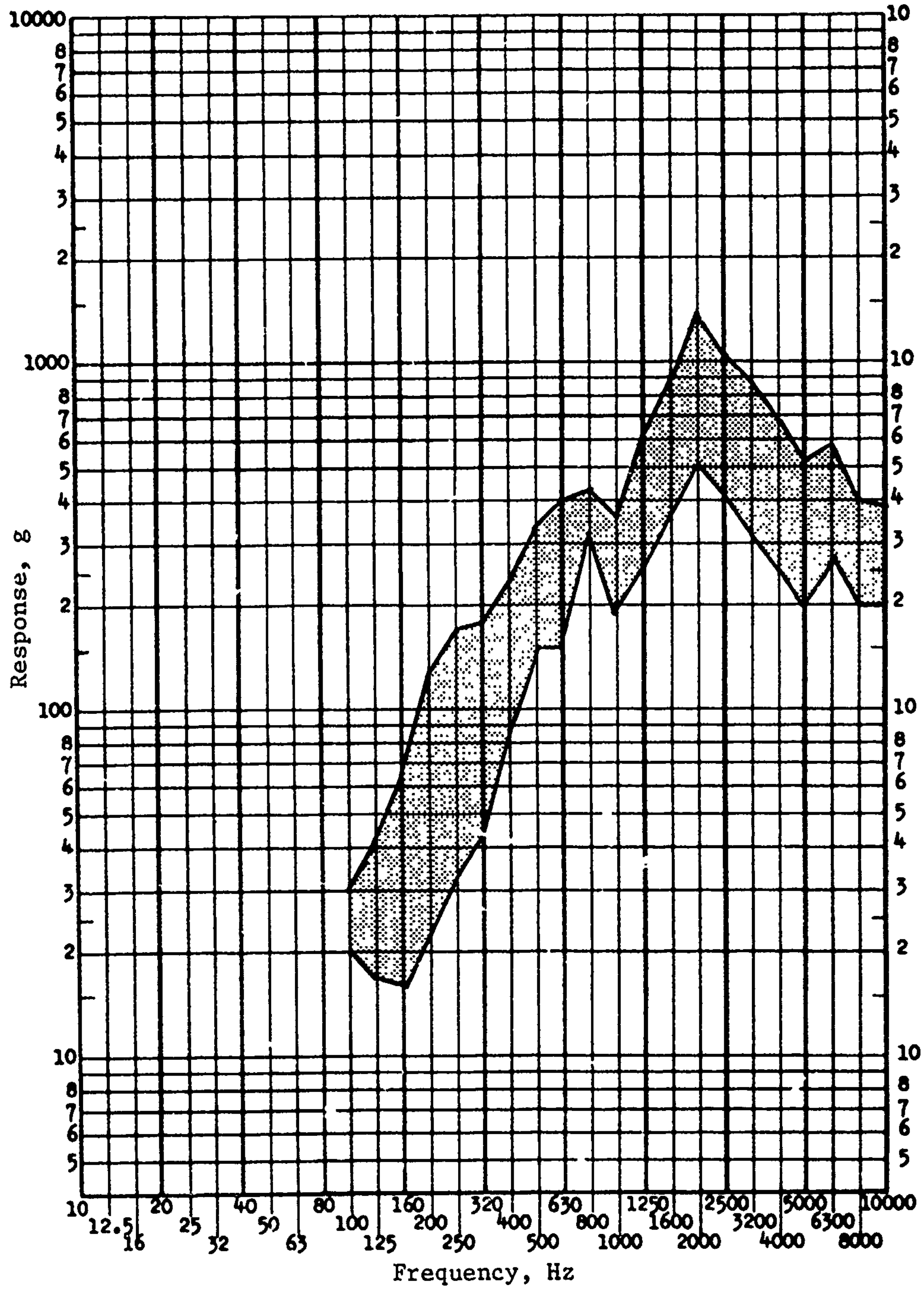


Figure IV-12
Run 18 Shock Response Envelope on Truss near Longeron Attachments (Padded Stud in Separation Nut)

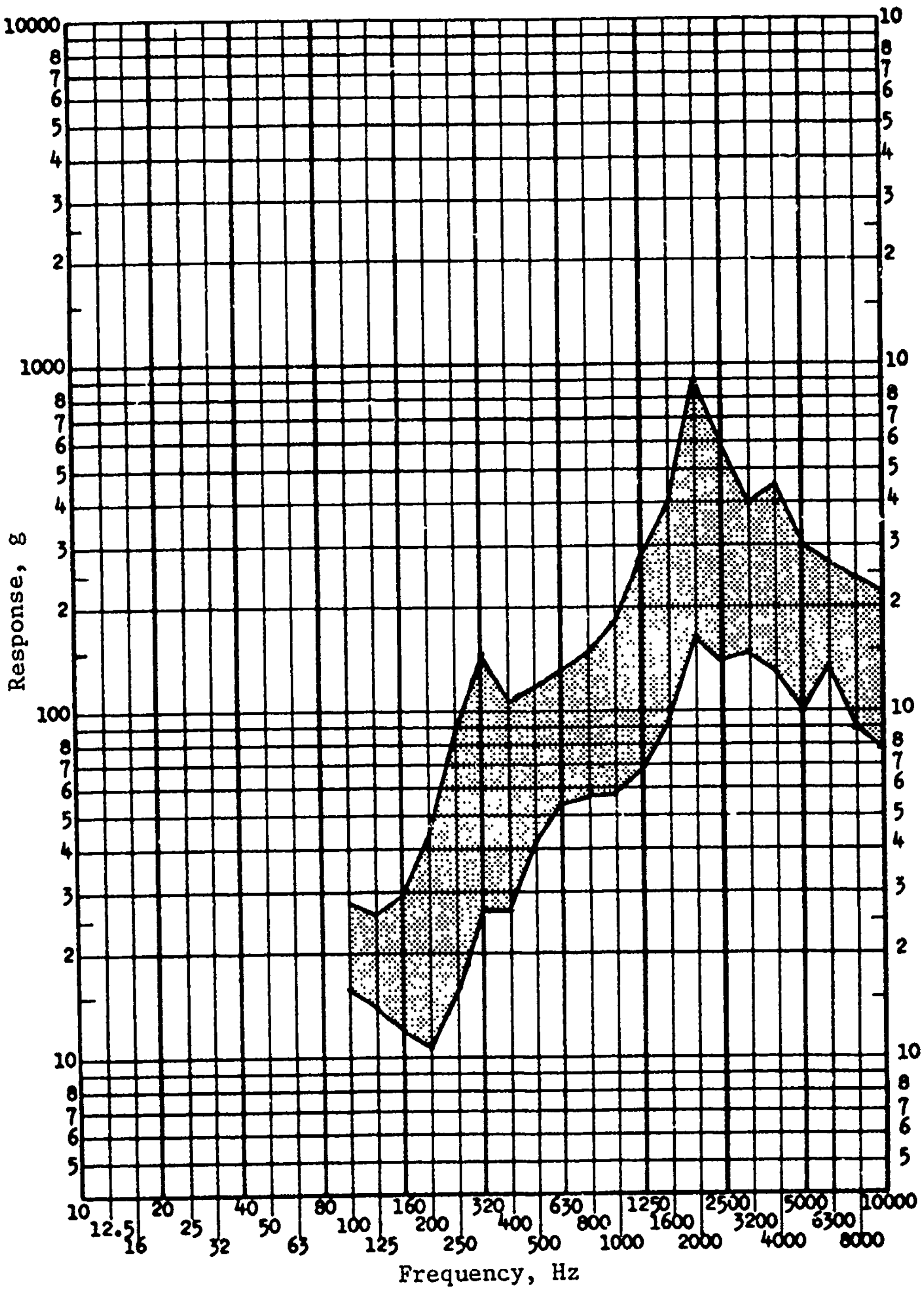


Figure IV-13
Run 16, 17, and 19 Shock Response on Truss near Longeron Attachments (Reduced Charge)

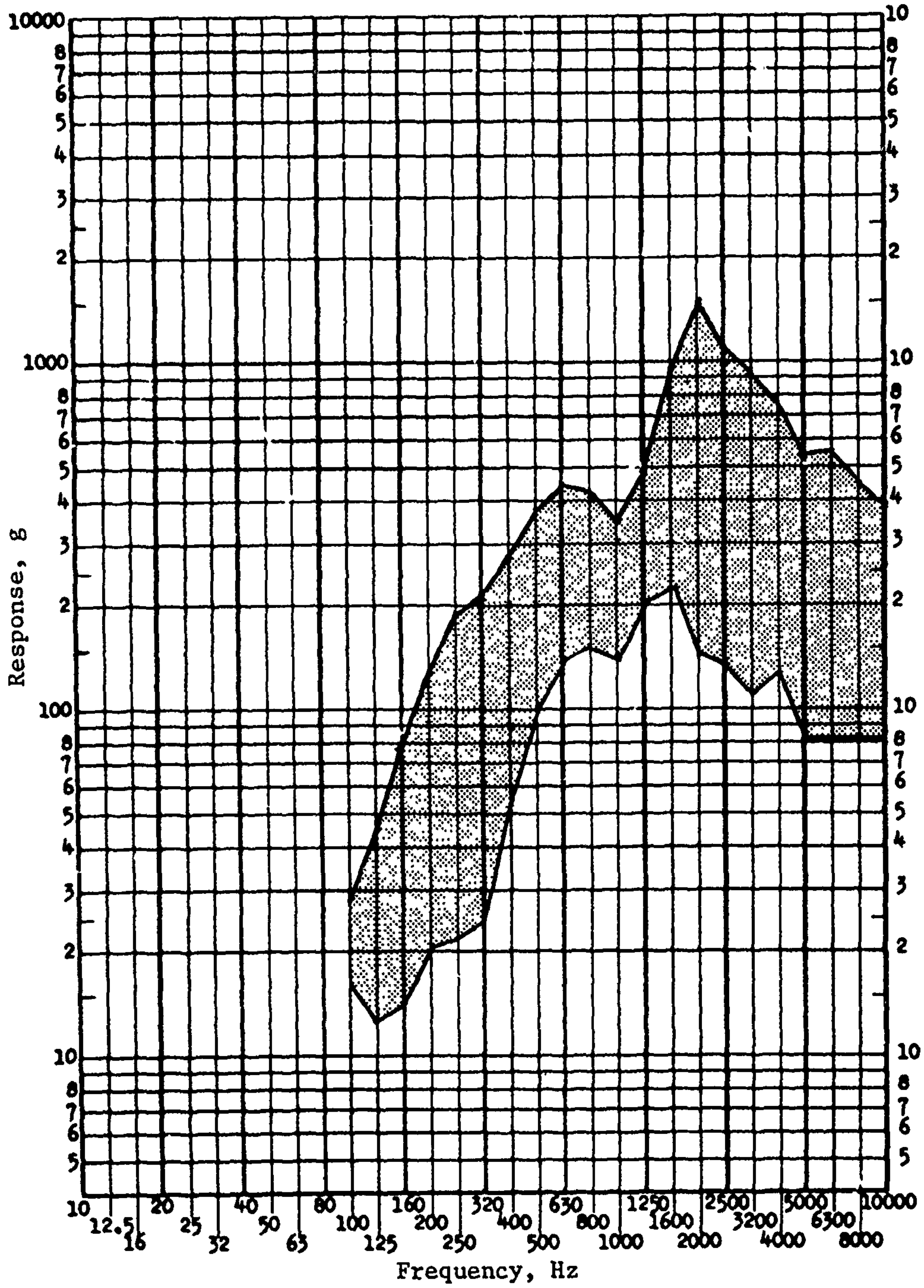


Figure 14
Run 21 and 22 Shock Response Envelope on Truss near Longeron Attachments (Silicone Shim at Sta 133)

To determine what shock reaches the lower measurement location through the hard-mounted upper attachment point, a separation run was performed with the lower truss bracket completely removed. The results were shock levels on the lower truss only slightly lower than those observed with the isolator installed, thus indicating that the path through the hard-mounted bracket was controlling the levels near the lower attachment point when the isolator was installed.

As confirmation, a run was performed with the lower isolator installed and the upper attachment bracket removed. This configuration gave good shock attenuation on the entire truss. Although addition of the lower truss isolator to the vehicle is a relatively simple design change, while addition of the upper truss isolator is a complex change, the above tests indicated that the only configuration that would provide adequate shock attenuation to the entire truss would be full truss isolation. This would include isolators at both upper and lower attachment points.

A number of separations were performed with full isolation. Figure IV-15 presents the envelope of shock responses observed on the truss during full isolation Runs 45, 46, 47, and 51. These four runs were performed by firing dual separation nuts. As can be seen by comparing this figure to the baseline (Fig. IV-1), shock attenuation to the truss was obtained. However, the upper envelope in Figure IV-15 is controlled entirely by the measurements obtained from Run 46, which appeared to be an extremely high-level shock. Because the truss isolators provided the same attenuation on Run 46, although both the longeron and truss levels were high, it appears that the isolated truss would give better attenuation than is apparent from Fig. IV-15.

9. Truss Isolation with Orificed Nuts

Runs 48, 49, and 50 were performed to determine the combined effects of using both orificed nuts and full truss isolation. Figure IV-16 shows the envelope of truss responses obtained from these runs. The peak in Figure IV-16 is controlled by Measurement 13 during Run 50, which appears to be a questionable data point. By discarding it, the envelope in Figure IV-16 would peak at about 550 g, thus indicating that the combination of techniques (orificed nuts and truss isolation) provided slightly better shock reduction than either technique by itself.

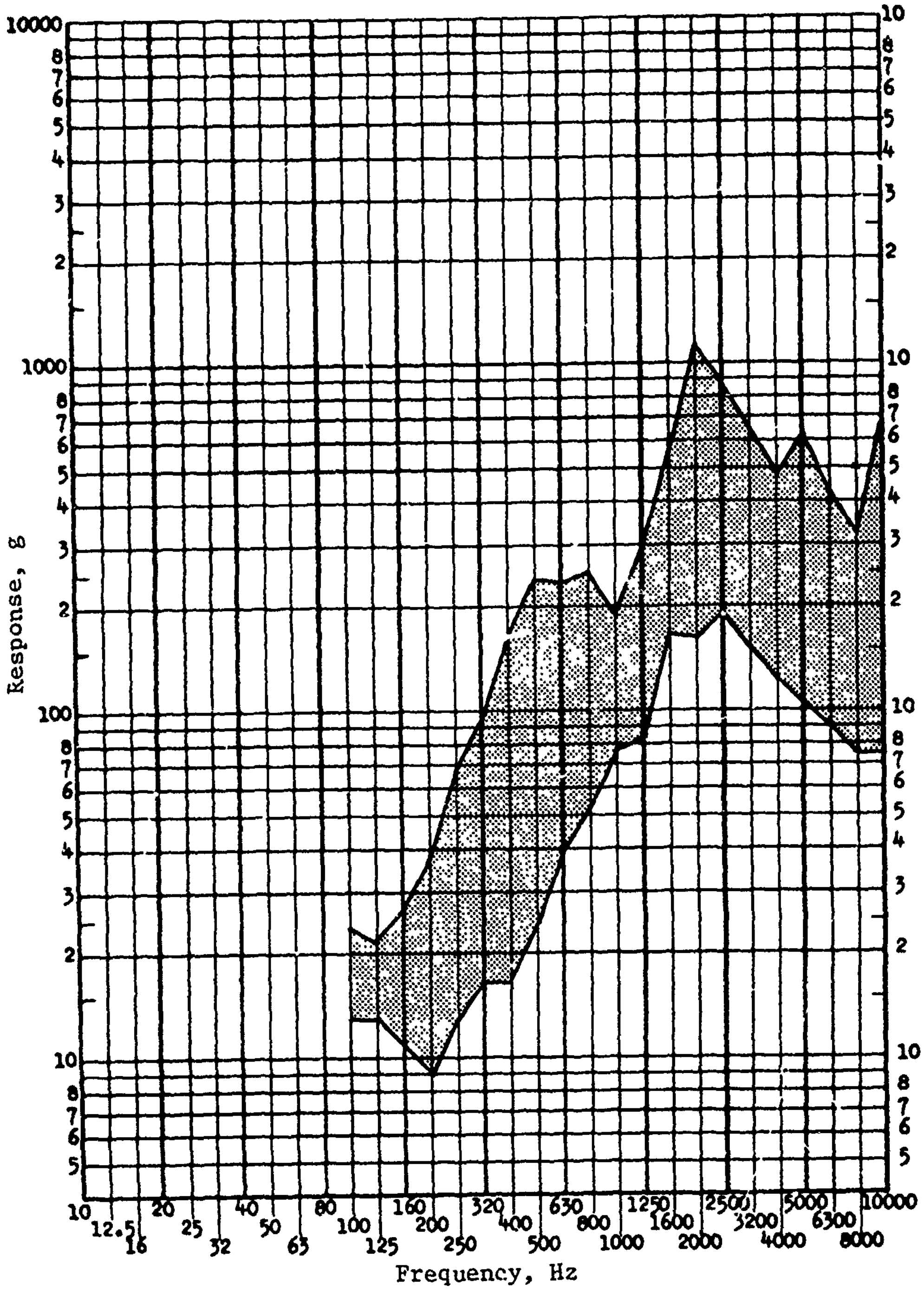


Figure 15
Run 45, 46, 47, and 51 Shock Response Envelope on Truss near Longeron Attachments (Full Truss Isolation)

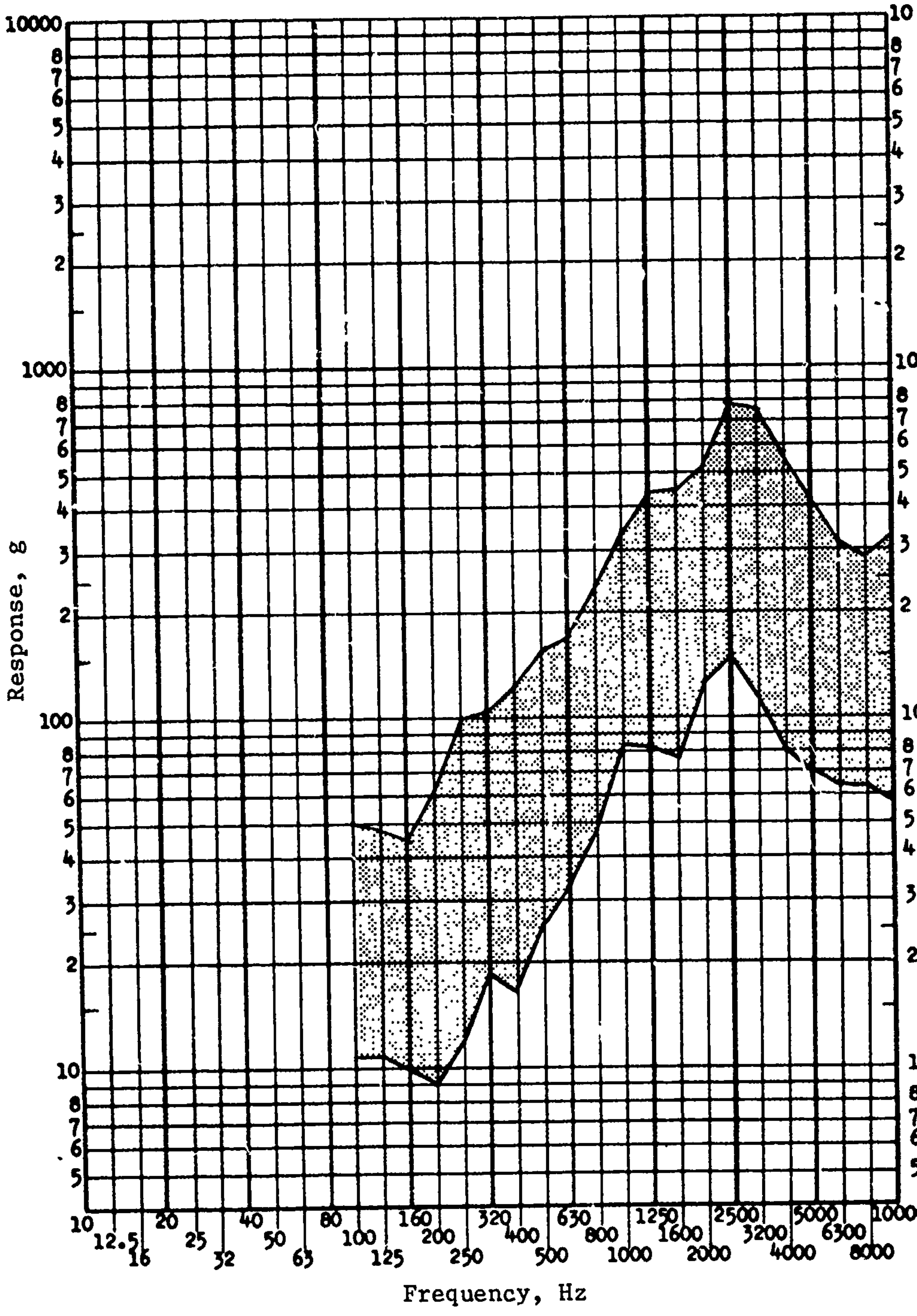


Figure IV-16
Run 48, 49, and 50 Shock Response Envelope on Truss near Longeron Attachments (Full Truss Isolation Using Orificed Nuts).

B. RUN-TO-RUN VARIATIONS

Variations in shock levels from one run to the next for the same configuration make it difficult to rank the shock reduction techniques by performance. For the same reason, quantitatively determining the absolute reduction obtained by any one technique is very difficult. To take the run-to-run variations into account when performing the tests, a minimum of three runs was performed for each concept that showed promise after the initial run. As an indication of the variations observed, Measurement 4 on the longeron near Station 133 was used as a reference. For all runs using a standard unmodified separation nut, the mean of the peak response of Measurement 4 was about 3000 g, with a maximum of 5000 and a minimum of 1800.

No concrete evidence is available to explain such variations from one shot to the next. However, it appears that the variations result from the charge in the initiator rather than any mechanical changes in the nut or structure.

C. ONE-NUT VERSUS TWO-NUT SEPARATIONS

As indicated previously, there appears to be a definite difference in the shock response in the frequency range from 200 to 800 Hz for a one-nut separation and a two-nut separation. Figure IV-17 presents an envelope of all one-nut separations in which no shock reduction was obtained using a standard unmodified nut. By comparing this figure with the baseline in Figure IV-1, which resulted from two-nut separations, an increase in response in the lower frequency can be seen for the one-nut configuration. This same difference can be seen when comparing the one-nut separation using orificed nuts (Fig. IV-8) and the two-nut separation using an orificed nut (Fig. IV-9).

The asymmetrical impulse applied to the structure, when one separation nut fires, appears to cause a rigid-body motion of the structure. Figure IV-17 could represent a composite spectrum, with the response of a pyrotechnic shock controlling the high frequencies, while the response of the rigid-body motion controlling the lower frequencies. A rigid-body rotational mode has been calculated at 609 Hz. As an asymmetrical impulse on the longeron would excite this mode, it is postulated that the hump in the response spectrum at 630 Hz is due to rigid-body rotation about the long axis of the truss. An analysis could be performed to further justify this conclusion. However, it is believed that the system shock test with flight trusses would be the best proof that this hump would not occur during flight.

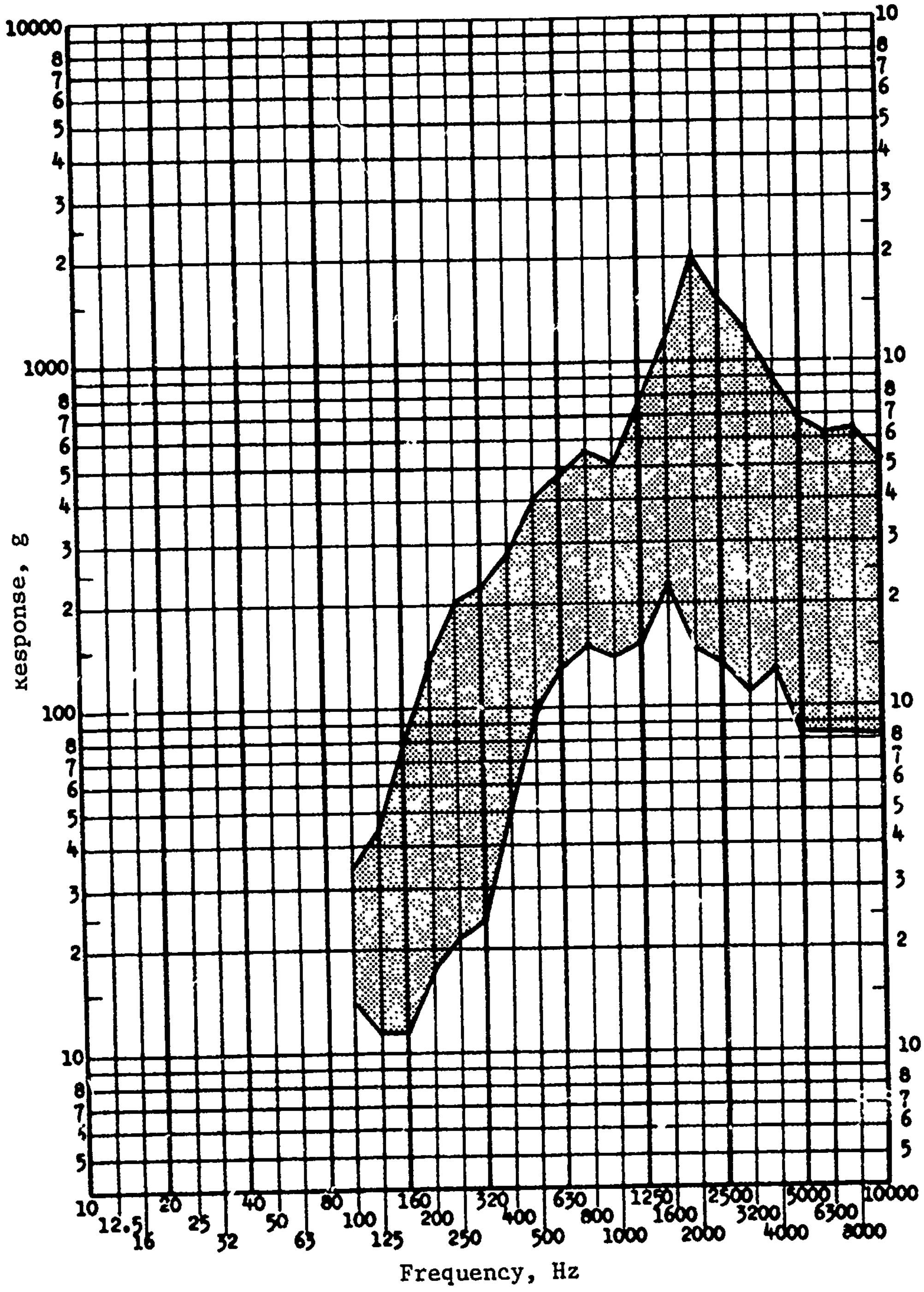


Figure IV-17
Run 7 through 10, 14, 18, 20, 21, and 22 Shock Response Envelope on Truss from Standard One-Nut Separations in which Shock Was Not Reduced

V. Conclusions and Recommendations

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Specific conclusions that can be drawn from this series of tests are:

1) The shock response in the frequency range from 200 to 800 Hz is more severe for a one-nut than a two-nut separation, all other parameters being equal;

2) There is no significant difference between the peak shock responses for a one-nut and a two-nut separation, all other parameters being equal;

3) At least a 50% reduction from the baseline shock is obtainable by using orificed separation nuts, reduced initiator charge, or full truss isolation;

4) Full truss isolation combined with orificed separation nuts appears to provide slightly more reduction of truss shock responses than any one concept by itself;

5) The most desirable orifice design is the dual 0.052-in. orifice at right angles to the separation nut axis. This design reduces shock responses at the truss for all frequencies, as can be seen by comparing Figure IV-9 to the baseline (Fig. IV-1) for dual nuts; or by comparing Figure IV-8 to Figure IV-17 for single nuts;

6) No reduction in shock resulted from variations in separation-nut torque, crushable or castellated washers, padded studs in the separation nuts, or change in material density at Station 133;

7) Isolation at the lower truss brackets, leaving the top brackets hard mounted, only reduced the shock on the truss near the isolation. The remainder of the truss levels remained high.

B. RECOMMENDATIONS

Based on the conclusions, the following recommendations are made:

1) If only Stage II/III separation shock reduction is desired, modify the separation nuts by inserting dual 0.052-in. orifices;

2) If Universal Payload Fairing (UPLF) and payload separation shock reduction is desired in addition to the Stage II/III shock reduction, consider full isolation of Transtage instrumentation and guidance trusses.

If the orificed nuts are used, a qualification program for the new nut design is required. In addition, a system shock test should be performed to establish the new shock environment. Because modification of the nut lengthens it slightly, it is also desirable to shorten the nut catcher on the Stage III side of the interface to facilitate the ordnance installation.

If full truss isolation is used, an isolator development program is required to finalize the isolator design, verify structural qualification, and determine the effects of isolators on other environments. Also, a system shock test should be performed to establish the total shock environment for the Transtage from Stage II/III, UPLF, and the payload separations.