(4)

Technical Report ARFSD-TR-89005

STRUCTURAL INTEGRITY OF THE M174 GUN MOUNT

Tim Dacier

August 1989

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Fire Support Armaments Center
Picatinny Arsenal, New Jersey

US ARMY
ARMAMENT MUNITIONS
& CHEMICAL COMMAND
ARMAMENT RDE CENTER

89

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER Technical Report ARFSD-TR-89005	5. MONITORING ORGANIZATION REPORT NUMBER
6a. NAME OF PERFORMING ORGANIZATION ARDEC, FSAC Artillery Armaments Div 6b. OFFICE SYMBOL SMCAR-FSA-S	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000	7b. ADDRESS (CITY, STATE, AND ZIP CODE)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ARDEC, IMD STINFO Br 8b. OFFICE SYMBOL SMCAR-IMI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (INCLUDE SECURITY CLASSIFICATION)
STRUCTURAL INTEGRITY OF THE M174 GUN MOUNT

12. PERSONAL AUTHOR(S)
Tim Dacier

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (YEAR, MONTH, DAY)	15. PAGE COUNT
Final	FROM 1988 TO 1989	August 1989	36

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)
FIELD	GROUP	SUB-GROUP	M174 gun mount M110A2 firing test
			M110A2 driving test
			Finite element model

19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

This report documents the efforts made to investigate the structural integrity of the M174 gun mount. Testing and finite element model results are presented and discussed. Current problems are listed.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT [X] UNCLASSIFIED/UNLIMITED [ ] SAME AS RPT. [ ] DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL I HAZNEDARI	22b. TELEPHONE (INCLUDE AREA CODE) (201)724-3316	22c. OFFICE SYMBOL SMCAR-IMI-I

DD FORM 1473, 84 MAR

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

TABLES

FIGURES

INTRODUCTION

Background

An increase in the number and severity of structural problems being found with M174 gun mount cradles brought to the depot for rework suggested a need to study the structural integrity of the gun mount. A project proposal was developed in September of 1986 and funds for the project were provided in December of 1987.

Objectives

The objectives of the proposed M174 gun mount study were to:

1. Determine the reliability of depot reclaimed mounts as compared to new mounts.

2. Determine how many effective full charges (EFC's) a new and reclaimed mount can safely withstand.

3. Identify weaknesses of and recommend improvements to the gun mount.

Project Plan

To accomplish these objectives it was proposed to either conduct extensive firing tests, to determine how many safe EFC's each mount can withstand and to get an estimate of the reliability of the mounts, or to develop a computer finite element model of the mount and conduct limited firing tests to obtain results which could be used as inputs to the model and as a comparison to the model results.

The first method was considered not feasible because of the excessive cost of testing and limited availability of projectiles. Therefore the second method was followed.

The project was broken down into the following four phases:

1. Research gun mount history to identify weaknesses

2. Develop a computer model of the gun mount

3. Conduct firing and driving tests

4. Recommend improvements to the gun mount

Progress

Depot personnel were contacted and literature was reviewed to determine what gun mount problems exist.

A computer model was developed using PATRAN® and ANSYS®, and the model was analyzed using ANSYS. Model results and stress plots are shown in figures 1 through 6.

Driving and firing tests were performed at Aberdeen Proving Ground, MD with strain gages mounted in specific areas of the gun mount. Sample results are shown in tables 1 through 7, and in figure 7. The results of testing show high dynamic stresses on the gun mount in the area just forward of the elevating gear and high stresses in the area of the trunnions from the static loading of the cannon and the equilibrators.

RESEARCH

Problems

The list below indicates the problems identified during the history research portion of the project:

1. Recoil cylinder

    a. Oil leaking from rear of cylinder

    b. Oil leaking from front of cylinder

    c. Inside surface of cylinder forward of head rusted

2. Recuperator

    a. Index pin failure

    b. Copper ring neoprene seal worn

    c. Pitted spur gear caused index pin failure

    d. Worn seals

3. Counterrecoil cylinder

    a. Leaks at rear of cylinder

b. Worn stuffing box packing

c. Leaks at front of cylinder

d. Clogged relief valve

4. Replenisher

   a. Worn neoprene seal

   b. Piston assembly frozen

5. Equilibrator

   a. Pressure loss

   b. Rusted equilibrator guide adjusting screw

   c. Roller bearing cracked or rusted in place

6. Accumulator

   a. Worn seals

   b. Flattened piston seals

   c. Inoperable high pressure valve

7. Trunnion

   a. Roller bearing failed

   b. Trunnion cracks

8. Distortion of cradle

Discussion

Most of the problems identified were not related to the structure of the gun mount but rather to sealing problems. The only structural problems identified were the trunnion cracks and the distortion of the cradle. Letterkenny Army Depot (LEAD) personnel claim that the trunnion cracking problem has been fixed by increasing the radius and making the surface finish smoother at the base of the trunnion cylinders. This has yet to be proven.

COMPUTER MODEL

A finite element model was developed using PATRAN. The model was developed one part at a time. The parts were put together as the project progressed.

The parts that were developed are shown in figures 1 through 4. When all the parts were put together, the model was transferred into ANSYS and the model analysis was run. The latest revision of the model is shown in figure 5.

Loads applied to the model represented firing torque loads and recoil mechanism rodpull. The model was constrained at the front equilibrator mounting location, the trunnions, and the elevating gear location. The boundary conditions are discussed further in the appendix.

Sample results of the analysis are shown in figure 6.

TESTING

Objective

Driving and firing tests were performed at Aberdeen Proving Ground, MD. The objectives of the tests were to obtain data to be used as inputs to the computer model and as a comparison to the model results, and to gather data indicating the stress levels in critical areas of the gun mount.

The test was initially scheduled as part of the M110 MAPS test, and the number of instrumentation channels available was limited. Therefore, only strain gage information was requested. The M110 MAPS test was postponed and later cancelled. At that time a separate test was requested for the gun mount study. Additional instrumentation was requested for measuring recoil mechanism rodpull and equilibrator pressure. Neither of these were accomplished.

Results

Strain gages were mounted on the mount in the locations shown in figure 8 through 12. Road tests using the six-inch washboard course were performed at speeds of 3, 6, 9, and 12 mph. Firing tests were performed using zone 5, 7, and 9 charges at elevations of 8, 28, and 60 degrees with the gun at center and 25 degrees right azimuth. Sample test results are shown in tables 1 through 7.

Of particular interest in the results are the stresses indicated in the area of the trunnions due to the static loading of the mount with the cannon and equilibrators (table 1). Also of interest are the high dynamic levels of stress indicated by the strain gages in front of the elevating fear (8 to -28 ksi) (figure 7 and table 3).

The highest dynamic stress results were on the right trunnion upper vertical strain gage and the gage forward of the elevating gear in the firing direction of the cannon.

Driving test results indicate small variations in stress from the static loading. The highest variations for the trunnions were 9 ksi at the right upper vertical gage.

DISCUSSION

Comparison of Model and Test Results

The peak stress results of the firing test compared with the values obtained from the computer model for the locations listed are shown in table 7. The x direction is along the centerline of the trunnions and the z direction is along the centerline of the cannon. The data listed for the test were taken directly from the firing record for the test. There is a considerable difference between the test results and the model results for several of the locations. The differences can be attributed to incomplete model boundary conditions and inaccuracies in the test data. For example, in the elevating gear location of the model the amount of deformation that can occur is limited because the nodes are constrained. The difference in the values of stress seen in the trunnion location are partly due to the fact that the inertial and weight effects of the cannon were not included in the model boundary conditions. The values listed for the test results are the highest peaks recorded for the test. Values from other rounds compare more favorably.

Model Improvements

The following improvements could be made to increase the accuracy of the model results:

1. Use of shell elements in thin areas (i.e., the body and plate assembly)

2. Increasing the element mesh in sections where radii exist and improving the aspect ratio in other areas

3. The addition of the elevating gear, equilibrators, trunnion supports, recoil mechanism cylinders, and the cannon to the model

4. The use of submodeling techniques

The body and plate parts of the cradle are 0.25 inch thick. It is recommended that shell elements be used in ANSYS for parts that are thin relative to their length or width. STIF45 solid elements were used during the initial development of the model, to avoid the complexity associated with the interface between dissimiliar elements.

The recommended aspect ratio between the lengths of any two sides of an element in ANSYS is less than 4:1. Several of the elements in this model do not meet this recommendation (especially the thin elements which make up the plate and body). The model would be more accurate if the aspect ratios were less than 4:1.

Another problem that exists with the model are sharp corners where radii should be. To model radii with finite elements many elements must be used to create a gradual curve because all element types are inherently square. If high stresses exist in a portion of a model where radii should be, the element mesh must be increased in order to obtain accurate results. Relatively high stresses are seen in the section of the trunnion where a radius should be. This area is the same area where cracks have been found. This section should be redone with a finer mesh so that a gradual curve can be represented instead of the right angle interface between elements that currently exists. This is a section where submodeling would be beneficial.

During testing, high stresses were indicated in the area just forward of the elevating gear. Because of this it is recommended that the elevating gear be added to the cradle model so that the effects of loading in this area can be more accurately predicted.

The nodes on the outer surface of the trunnion portions of the model are constrained to support the cradle. Constraining these nodes prevents the model from deforming in that area. The use of gap elements is recommended in this area. Gap elements can be configured to resist motion when loaded in compression and not resist motion when loaded in tension. With this configuration the trunnions could be constrained where they would normally compress against the trunnion supports and be allowed to deform elsewhere.

Addition of the trunnion supports to the cradle model would help in yielding more accurate results. The base of the trunnion supports could be constrained, rather than the trunnions, and gap elements could be used between the trunnions and the trunnion supports.

Because the equilibrators play an important role in supporting the cradle, it would be beneficial to add them to the cradle model. This would affect the boundary conditions on the front of the cradle as well as the trunnions or trunnion supports.

The boundary conditions currently being used do not account for the weight of the cannon and breech assembly. Adding the cannon and breech to the model and performing a static analysis with the cradle supported with and without the travel lock is recommended.

Adding the recoil and counter recoil cylinders to the model would make the model more accurate. The cylinders add weight and rigidity to the cradle. A more accurate recoil pressure boundary condition could be applied as well.

The use of submodeling in high stress areas to obtain better results is recommended. Submodeling is a process in which sections of the model where high stresses exist are removed and analyzed separately. The boundary conditions for the sections removed are automatically applied from the results of the full model analysis. The element mesh for the removed section is made finer to yield more accurate results.

Areas of Concern

1. The high stresses seen in front of the elevating gear during firing should be further investigated. Depot personnel should be asked if any problems have been found in this area.

2. The problem with the trunnion cracks should be followed. Those cradles with the new trunnion configuration should be checked periodically to determine whether the new configuration is indeed a solution to the problem.

3. The index pin has been redesigned as part of the PIP KIT-6. If the new index pins are being installed, they should be tracked to assure that they work correctly.

CONCLUSIONS

The original objectives of this study focused on making a comparison between new and reclaimed M174 gun mounts. The objective was changed to focus on determining whether the gun mount is structurally adequate to withstand firing loads with higher zone charges and a larger cannon than it was originally designed.

The highest stress results recorded during testing were just forward of the elevating gear and on the trunnions. Both results were well below the yield point for the steel used to make the cradle, which is in the 130 to 140 ksi range.

The strain gages were mounted on the back face of the trunnions, though, not on the front where a stress concentration exists at the base of the outer cylinder. The gages were not mounted on the front because of the tight fit between the trunnions and the trunnion supports. The gages were mounted on the back so that their results could be compared to the model results. Unfortunately, the model results were not accurate in that region of the trunnion because of the problems caused by the boundary conditions as discussed in the model improvements section

The finite element model developed for this project needs to be further improved before it can produce accurate results. Even so, the results show stress patterns which indicate problems in the same sections of the trunnions where cracks have been found.

It was decided that further work on the finite element model be postponed until testing was completed. This was done so that the test effort could be concentrated on and a better feeling could be gained as to whether structural problems really exist before more effort was spent on the model.

The stress fluctuation, from -8 to 28 ksi in the area in front of the elevating gear was not anticipated. Although the magnitude is low relative to the yield strength of the materials, a large fluctuation in such a thin section could cause fatigue problems.

This report was written to document the work done for the M174 gun mount study project so that it can be determined whether further work is required. More work could be done on the computer model and further testing could be done to gain more accurate results in critical areas of the cradle.

BIBLIOGRAPHY

Information pertinent to the M174 gun mount study was obtained from the following sources.

1. Letterkenny Army Depot (LEAD).

2. The Sample Data Collection Agency, RIA (AMSMC-QAL-A)

3. Follow-up reports from PECO representative at LEAD.

4. System assessment for M110 A1/A2 SP 8" howitzer, March 1980.

5. AMCCOM SDC Recoil Mechanism Study, February 1985.

6. High Failure Component Reliability Report M110 SP Howitzer, April 1986.

7. M174 Gun Mount Study, Proposal, August 1986.

8. Know Your 8-Inch Howitzer, November 1986.

9. AMC Pamphlet, AMCP 706-341, Research and Development of Materiel, Engineering Design Handbook, Carriages and Mount Series, Cradles, September 1963.

Table 1. Round-by-round data

Date	Round no.	Time fired	Propelling charge	Projectile type	Zone	Elevation (deg)
890201	-	1144	M2	XM844	5	-
890201	1	1313	M2	XM844	5	-
890201	2	1404	M2	XM844	5	-
890202	3	1124	M2	XM844	7	8
890202	4	1143	M188A1	XM844	9	8
890202	5	1157	M188A1	XM844	9	28
890202	6	1316	M188A1	XM844	9	60
890202	7	1413	M188A1	XM844	9	8 *
890202	8	1419	M188A1	XM844	9	28 *
890202	9	1427	M188A1	XM844	9	60 *

* The hull of the howitzer was rotated approximately 25 degrees to the left prior to firing these rounds. The line of fire of the gun tube was unchanged.

Table 2. Static offset loading: M174 gun mount

Channel	Description	Axis	Static offset (ksi)
1	RIGHT TRUNNION UPPER	Vertical	32.39
2	RIGHT TRUNNION UPPER	Longitudinal	1.16
3	RIGHT TRUNNION LOWER	Vertical	36.13
4	RIGHT TRUNNION LOWER	Longitudinal	40.68
5	LEFT TRUNNION AFT	Vertical	-8.06
6	LEFT TRUNNION AFT	Longitudinal	-6.63
7	LEFT TRUNNION FORWARD	Vertical	-0.79
8	LEFT TRUNNION FORWARD	Longitudinal	-2.25
9	LEFT GUIDE FORWARD	Transverse	-3.36
10	LEFT GUIDE AFT	Transverse	-0.43
11	RIGHT GUIDE FORWARD	Transverse	-3.80
12	RIGHT GUIDE AFT	Transverse	-2.43
13	ELEVATING GEAR FORWARD	Transverse	-1.93
14	ELEVATING GEAR FORWARD	Longitudinal	2.29
15	ELEVATING GEAR AFT	Transverse	-5.93
16	ELEVATING GEAR AFT	Longitudinal	-4.76
17	CENTER OF GUIDE	Transverse	-11.77
18	CENTER OF GUIDE	Longitudinal	-15.01

Table 3. Combination of static and peak dynamic loading of right trunnion

Channel	Description	Peak dynamic stress (ksi)*	Static offset (ksi)	Total (ksi)
1	(V) RIGHT TRUNNION UPPER	17.74 T	32.39 T	50.13 T
2	(L) RIGHT TRUNNION UPPER	3.25 C	1.16 T	2.09 C
3	(V) RIGHT TRUNNION LOWER	5.88 C	36.13 T	30.25 T
4	(L) RIGHT TRUNNION LOWER	3.73 T	40.68 T	44.41 T

* T means that the indicated stress is in tension
C means that the indicated stress is in compression

Table 4. Summary of peak firing stress

Channel	Description[a]	Peak stress[b] (ksi)	Round no.
1	(V) RIGHT TRUNNION UPPER	17.74 T	9
2	(L) RIGHT TRUNNION UPPER	3.25 C	9
3	(V) RIGHT TRUNNION LOWER	5.88 C	6
4	(L) RIGHT TRUNNION LOWER	3.73 T	8
5	(V) LEFT TRUNNION AFT	6.20 C	5
6	(L) LEFT TRUNNION AFT	4.86 C	8
7	(V) LEFT TRUNNION FORWARD	9.55 T	6
8	(L) LEFT TRUNNION FORWARD	2.95 T	2
9	(T) LEFT GUIDE FORWARD	4.25 C	9
10	(T) LEFT GUIDE AFT	11.76 C	7
11	(T) RIGHT GUIDE FORWARD	4.74 C	8
12	(T) RIGHT GUIDE AFT	6.67 C	4
13	(T) ELEVATING GEAR FORWARD	3.67 C	4
14	(L) ELEVATING GEAR FORWARD	28.45 C	4
15	(T) ELEVATING GEAR AFT	8.39 C	6
16	(L) ELEVATING GEAR AFT	3.61 T	9
17	(T) CENTER OF GUIDE	6.46 T	5
18	(L) CENTER OF GUIDE	5.55 T	5

[a] V-vertical, L-longitudinal, T-transverse

[b] T means that the indicated stress is in tension
C means that the indicated stress is in compression

Table 5. Sample amplitude distribution data from road test

RUN 3: SIX-INCH WASHBOARD 9MPH M174 (ON M110) 300TRKS UNITS: ksi

Description	rms	+Peak	-Peak	+99.9%	-99.9%	+99%	-99%	+90%	-90%	Mean
(L) CENTER OF GUIDE	14.87	-11.52	-16.93	-12.81	-16.16	-13.32	-15.90	-14.10	-15.64	-14.86
(T) CENTER OF GUIDE	11.98	-9.44	-13.47	-10.45	-12.96	-10.95	-12.71	-11.45	-12.46	-11.97
(L) ELEVATING GEAR AFT	6.03	-3.51	-7.86	-4.28	-7.35	-4.79	-6.84	-5.30	-6.58	-6.01
(T) ELEVATING GEAR AFT	6.52	-3.00	-8.77	-4.05	-7.72	-5.10	-7.46	-5.89	-7.20	-6.50
(L) ELEVATING GEAR FWD	1.79	5.18	-2.23	3.64	-1.72	3.13	-1.21	2.62	-0.70	1.29
(T) ELEVATING GEAR FWD	2.62	-0.13	-4.23	-0.90	-3.72	-1.92	-3.20	-2.18	-2.95	-2.61
(T) RIGHT GUIDE AFT	4.58	-0.47	-9.62	-2.00	-9.11	-2.76	-8.10	-3.27	-6.57	-4.38
(T) RIGHT GUIDE FWD	4.69	-1.80	-6.44	-3.09	-5.92	-3.86	-5.66	-4.12	-5.15	-4.68
(T) LEFT GUIDE AFT	1.32	2.55	-5.08	1.03	-4.57	0.52	-4.06	0.02	-2.53	-0.89
(T) LEFT GUIDE FWD	4.11	-0.84	-5.95	-2.12	-5.44	-3.14	-4.03	-3.65	-4.68	-4.09
(L) LEFT TRUNNION FWD	3.25	0.35	-5.05	-1.19	-4.54	-2.22	-4.28	-2.74	-3.76	-3.22
(V) LEFT TRUNNION FWD	2.14	2.44	-4.75	0.64	-4.50	0.13	-3.73	-0.64	-3.21	-1.93
(L) LEFT TRUNNION AFT	7.15	-4.35	-9.21	-5.37	-8.44	-6.14	-8.19	-6.65	-7.67	-7.14
(V) LEFT TRUNNION AFT	9.10	-6.19	-11.55	-7.21	-11.04	-7.98	-10.28	-8.49	-9.51	-9.09
(L) RIGHT TRUNNION LOWER	39.37	42.19	37.60	40.92	38.37	40.15	38.88	39.90	39.13	39.37
(V) RIGHT TRUNNION LOWER	34.12	37.41	29.99	36.13	31.01	35.62	32.55	34.85	33.31	34.11
(L) RIGHT TRUNNION UPPER	1.13	4.17	-0.94	2.89	-0.43	2.38	-0.18	1.61	0.08	0.97
(V) RIGHT TRUNNION UPPER	32.53	41.64	27.26	40.87	27.78	39.08	28.55	36.51	29.57	32.43

RUN 4: SIX-INCH WASHBOARD 12MPH M174 (ON M110) 300TRKS UNITS: ksi

Description	rms	+Peak	-Peak	+99.9%	-99.9%	+99%	-99%	+90%	-90%	Mean
(L) CENTER OF GUIDE	14.85	-11.52	-16.93	-12.81	-16.42	-13.58	-16.16	-14.10	-15.64	-14.84
(T) CENTER OF GUIDE	11.95	-9.19	-13.97	-10.20	-13.22	-10.95	-12.71	-11.45	-12.21	-11.95
(L) ELEVATING GEAR AFT	6.15	-2.75	-8.37	-4.28	-7.35	-5.05	-6.84	-5.56	-6.58	-6.14
(T) ELEVATING GEAR AFT	6.27	-1.16	-8.25	-2.21	-7.72	-3.32	-7.20	-5.36	-6.93	-6.24
(L) ELEVATING GEAR FWD	1.69	5.43	-2.23	3.90	-1.46	3.13	-0.95	2.37	0.07	1.41
(T) ELEVATING GEAR FWD	2.54	0.63	-3.97	-0.65	-3.72	-1.67	-3.20	-2.18	-2.95	-2.52
(T) RIGHT GUIDE AFT	3.92	-0.22	-8.35	-1.75	-7.34	-2.51	-6.57	-3.27	-4.54	-3.86
(T) RIGHT GUIDE FWD	4.57	-1.28	-6.44	-2.57	-5.66	-3.60	-5.41	-4.12	-4.89	-4.55
(T) LEFT GUIDE AFT	0.97	3.06	-5.08	1.28	-4.31	0.26	-3.55	-0.24	-1.26	-0.73
(T) LEFT GUIDE FWD	4.02	-0.84	-5.95	-1.87	-5.19	-3.14	-4.68	-3.65	-4.42	-4.01
(L) LEFT TRUNNION FWD	3.10	0.35	-5.31	-1.19	-4.28	-1.96	-4.02	-2.48	-3.51	-3.07
(V) LEFT TRUNNION FWD	1.82	2.44	-3.98	0.38	-3.47	-0.39	-2.96	-0.90	-2.44	-1.74
(L) LEFT TRUNNION AFT	6.94	-2.81	-8.95	-5.12	-8.19	-5.88	-7.93	-6.40	-7.42	-6.92
(V) LEFT TRUNNION AFT	9.09	-5.93	-11.04	-6.70	-10.53	-7.47	-10.02	-8.49	-9.76	-9.08
(L) RIGHT TRUNNION LOWER	39.41	42.70	37.09	41.17	38.37	40.41	38.62	39.90	39.13	39.41
(V) RIGHT TRUNNION LOWER	34.55	37.92	31.78	36.38	32.55	35.87	33.06	35.36	33.83	34.55
(L) RIGHT TRUNNION UPPER	1.03	4.17	-1.46	2.89	-0.69	2.13	-0.18	1.61	0.08	0.86
(V) RIGHT TRUNNION UPPER	32.25	40.62	25.47	38.82	27.01	37.54	28.03	35.22	29.57	32.18

Firing Record No. P-83157

Table 6. Sample amplitude distribution data from firing test

RUN 8: ROUND 4, ZONE 9, ELEV 8, AZIMUTH: CENTER, M174, 25TRKS UNITS: ksi

Description	rms	+Peak	-Peak	+99.9%	-99.9%	+99%	-99%	+90%	-90%
(L) CENTER OF GUIDE	1.20	5.46	-3.47	4.95	-2.71	4.70	-1.69	1.12	-1.18
(T) CENTER OF GUIDE	1.15	3.36	-4.78	3.10	-4.27	2.59	-3.76	1.83	-0.71
(L) ELEVATING GEAR AFT	0.41	1.83	-2.73	1.83	-1.97	1.32	-0.70	0.56	-0.45
(T) ELEVATING GEAR AFT	0.89	5.52	-3.37	4.25	-2.10	4.00	-1.34	0.95	-0.58
(L) ELEVATING GEAR FWD	6.21	8.86	-28.45	8.10	-27.68	7.85	-26.67	5.56	-4.84
(T) ELEVATING GEAR FWD	0.61	1.62	-3.67	1.37	-3.17	0.86	-2.66	0.36	-0.40
(T) RIGHT GUIDE AFT	1.48	3.20	-6.67	2.68	-5.37	2.42	-4.85	1.64	-1.47
(T) RIGHT GUIDE FWD	0.55	1.78	-3.24	1.51	-2.45	0.98	-1.66	0.72	-0.60
(T) LEFT GUIDE AFT	1.51	2.91	-6.49	2.65	-6.49	1.89	-5.47	1.38	-2.42
(T) LEFT GUIDE FWD	0.64	1.93	-3.99	1.68	-2.70	0.90	-2.19	0.65	-0.90
(L) LEFT TRUNNION FWD	Channel damaged beyond repair								
(V) LEFT TRUNNION FWD	2.11	4.85	-7.92	4.33	-7.66	4.08	-7.15	2.29	-1.79
(L) LEFT TRUNNION AFT	0.95	3.79	-2.56	3.28	-2.31	3.02	-1.80	0.99	-1.04
(V) LEFT TRUNNION AFT	1.71	4.58	-4.70	4.33	-3.41	3.81	-2.89	1.75	-2.38
(L) RIGHT TRUNNION LOWER	0.39	3.17	-1.85	2.42	-1.60	1.16	-0.84	0.41	-0.34
(V) RIGHT TRUNNION LOWER	0.91	3.64	-3.19	3.39	-2.68	2.38	-1.67	1.37	-0.91
(L) RIGHT TRUNNION UPPER	0.30	1.50	-2.29	1.25	-1.54	0.74	-1.03	0.24	-0.27
(V) RIGHT TRUNNION UPPER	2.84	8.18	-13.79	7.41	-13.54	5.37	-12.00	2.30	-1.78

RUN 13: ROUND 9, ZONE 9, ELEV 60, AZIMUTH: 25 LEFT, M174, 37TRKS UNITS: ksi

Description	rms	+Peak	-Peak	+99.9%	-99.9%	+99%	-99%	+90%	-90%
(L) CENTER OF GUIDE	0.66	3.62	-3.28	3.36	-2.26	2.85	-1.23	0.55	-0.72
(T) CENTER OF GUIDE	1.15	6.38	-3.28	4.60	-2.52	3.58	-1.50	1.80	-0.74
(L) ELEVATING GEAR AFT	0.54	3.61	-2.72	3.10	-2.47	2.59	-0.95	0.32	-0.19
(T) ELEVATING GEAR AFT	2.30	6.08	-7.65	5.57	-6.63	5.06	-6.13	2.01	-3.58
(L) ELEVATING GEAR FWD	2.87	7.33	-12.97	6.57	-11.71	6.31	-10.94	3.52	-2.31
(T) ELEVATING GEAR FWD	0.34	1.80	-2.48	1.55	-2.23	0.80	-0.97	0.29	-0.21
(T) RIGHT GUIDE AFT	1.40	4.54	-4.80	3.76	-3.24	2.73	-2.72	1.95	-1.69
(T) RIGHT GUIDE FWD	0.55	2.03	-4.04	1.77	-2.98	1.24	-1.40	0.71	-0.61
(T) LEFT GUIDE AFT	1.13	3.06	-7.35	2.55	-6.08	2.04	-3.29	1.28	-1.51
(T) LEFT GUIDE FWD	0.52	2.18	-4.25	1.67	-3.22	1.15	-1.68	0.38	-0.65
(L) LEFT TRUNNION FWD	Channel damaged beyond repair								
(V) LEFT TRUNNION FWD	2.12	8.83	-5.72	8.57	-4.19	7.30	-3.68	2.70	-2.14
(L) LEFT TRUNNION AFT	1.01	3.02	-3.83	2.52	-3.32	2.26	-2.82	1.25	-1.29
(V) LEFT TRUNNION AFT	1.80	4.32	-4.96	4.06	-4.45	3.54	-3.68	2.26	-2.39
(L) RIGHT TRUNNION LOWER	0.67	3.70	-3.08	2.95	-2.07	2.69	-1.07	0.69	-0.57
(V) RIGHT TRUNNION LOWER	1.13	5.81	-4.32	5.56	-3.30	4.29	-2.04	1.25	-1.28
(L) RIGHT TRUNNION UPPER	0.42	2.07	-3.25	1.56	-2.24	1.05	-0.97	0.55	-0.47
(V) RIGHT TRUNNION UPPER	3.76	17.74	-12.41	15.95	-10.36	10.08	-8.32	3.69	-5.51

Table 7. Peak firing stress (ksi)

Location	Test X	Test Y	Test Z	Model X	Model Y	Model Z
Right trunnion upper	---	17.74	3.25	---	6.70	2.90
Right trunnion lower	---	5.58	3.73	---	6.70	2.90
Left trunnion aft	---	6.20	4.86	---	3.60	1.90
Left trunnion forward	---	9.55	2.95	---	6.60	2.20
Left guide forward	4.25	---	---	0.86	---	---
Left guide aft	11.76	---	---	0.86	---	---
Right guide forward	4.74	---	---	1.60	---	---
Right guide aft	6.67	---	---	1.60	---	---
Elevating gear forward	3.67	---	28.45	5.40	---	6.20
Elevating gear aft	8.39	---	3.61	9.70	---	13.30
Guide center	6.46	---	5.55	4.70	---	5.10

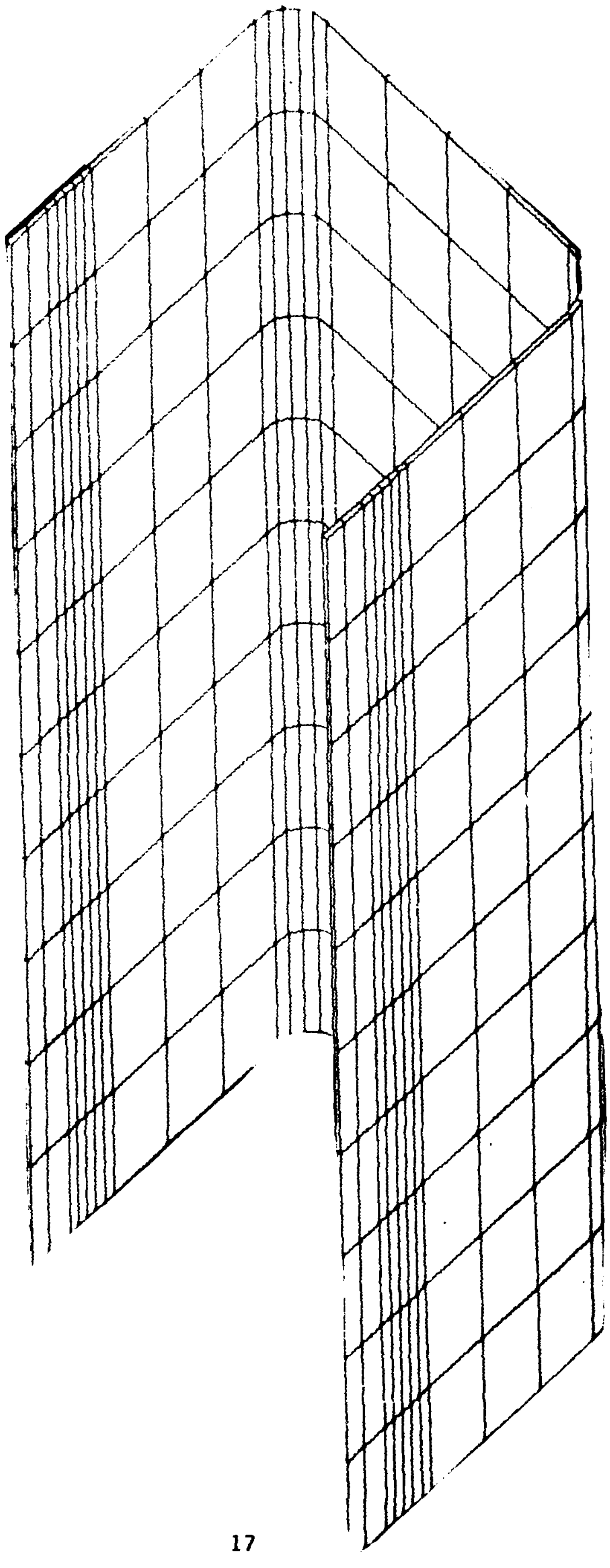

Figure 1. Body

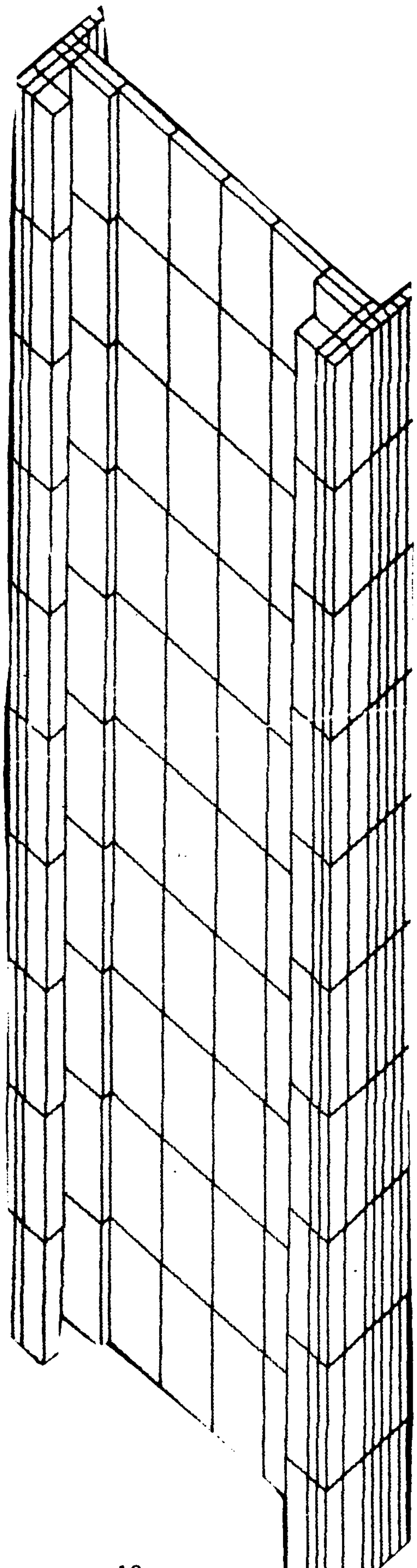

Figure 2. Guide

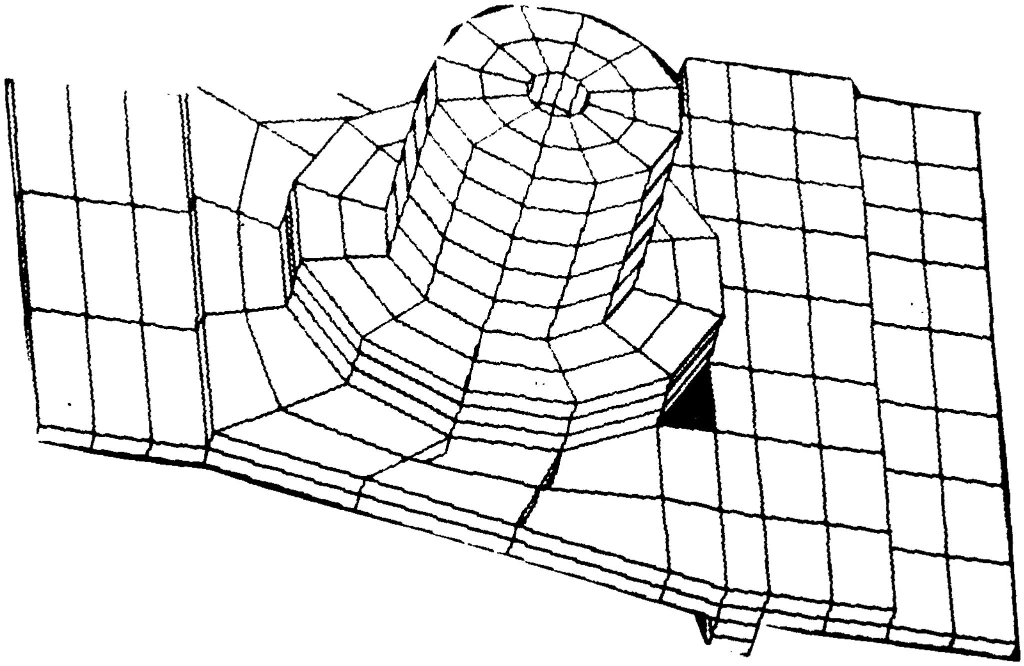

Figure 3. Trunnion

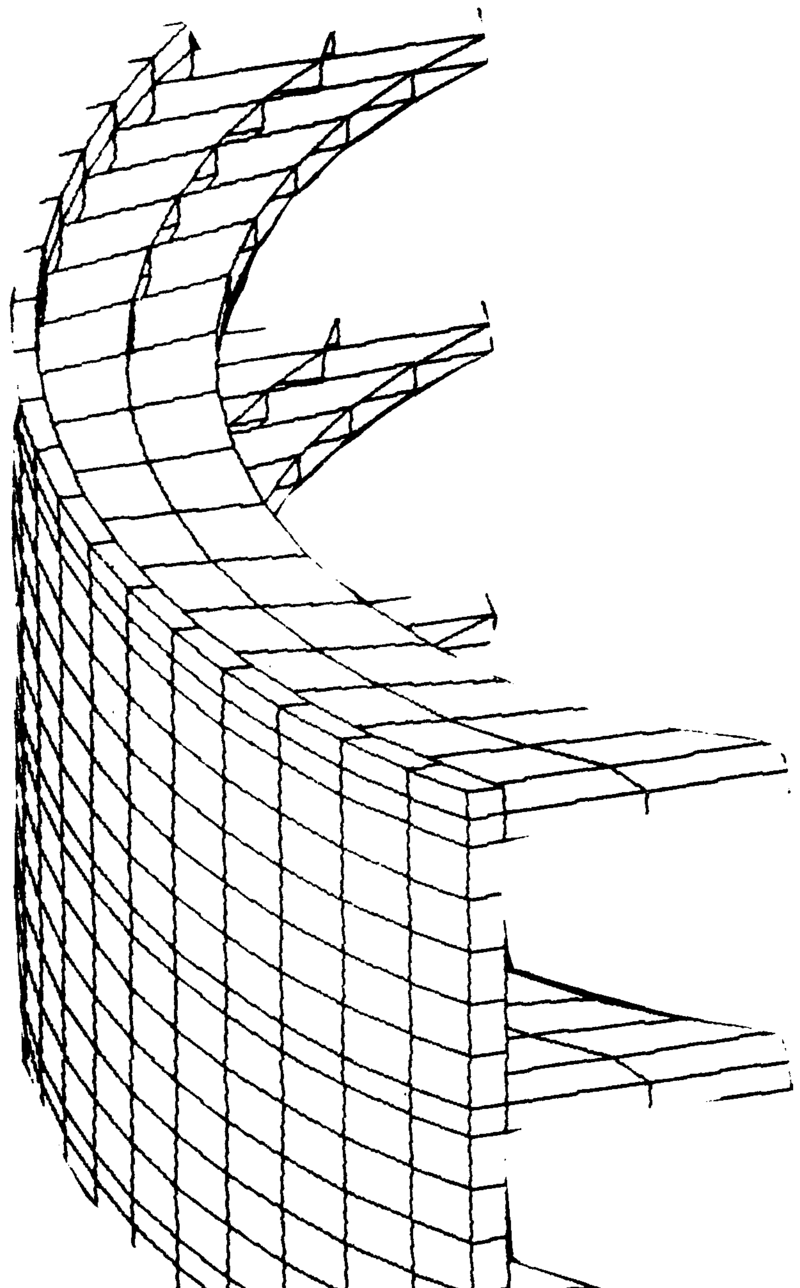

Figure 4. Bracket

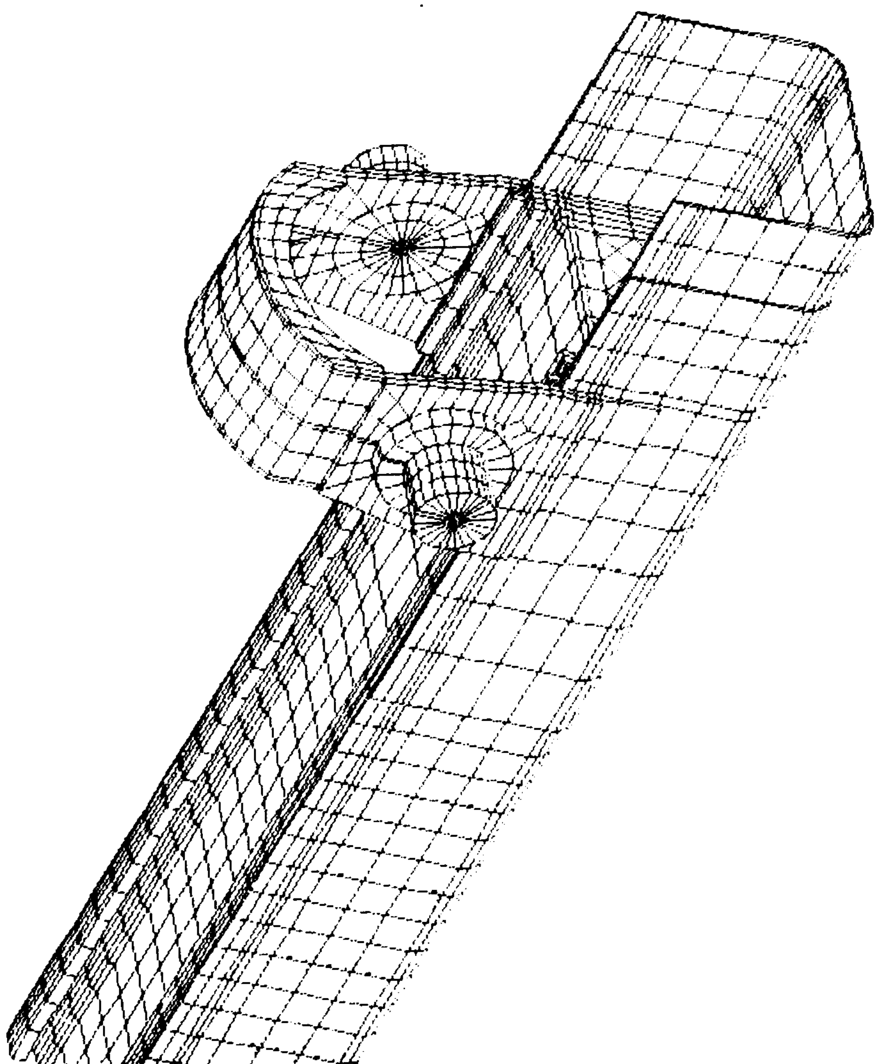

Figure 5. Cradle assembly

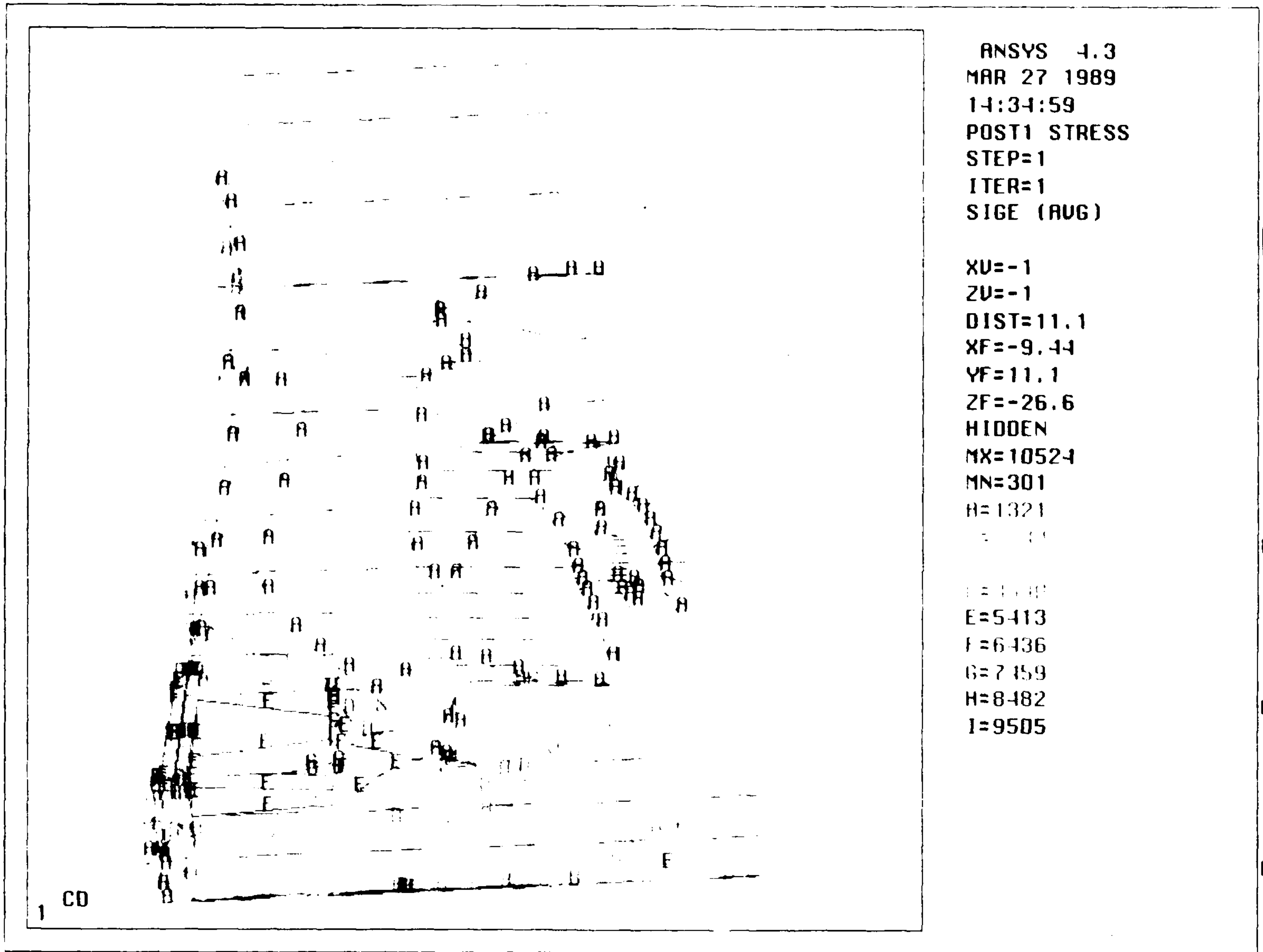

Figure 6. Stress contour plot

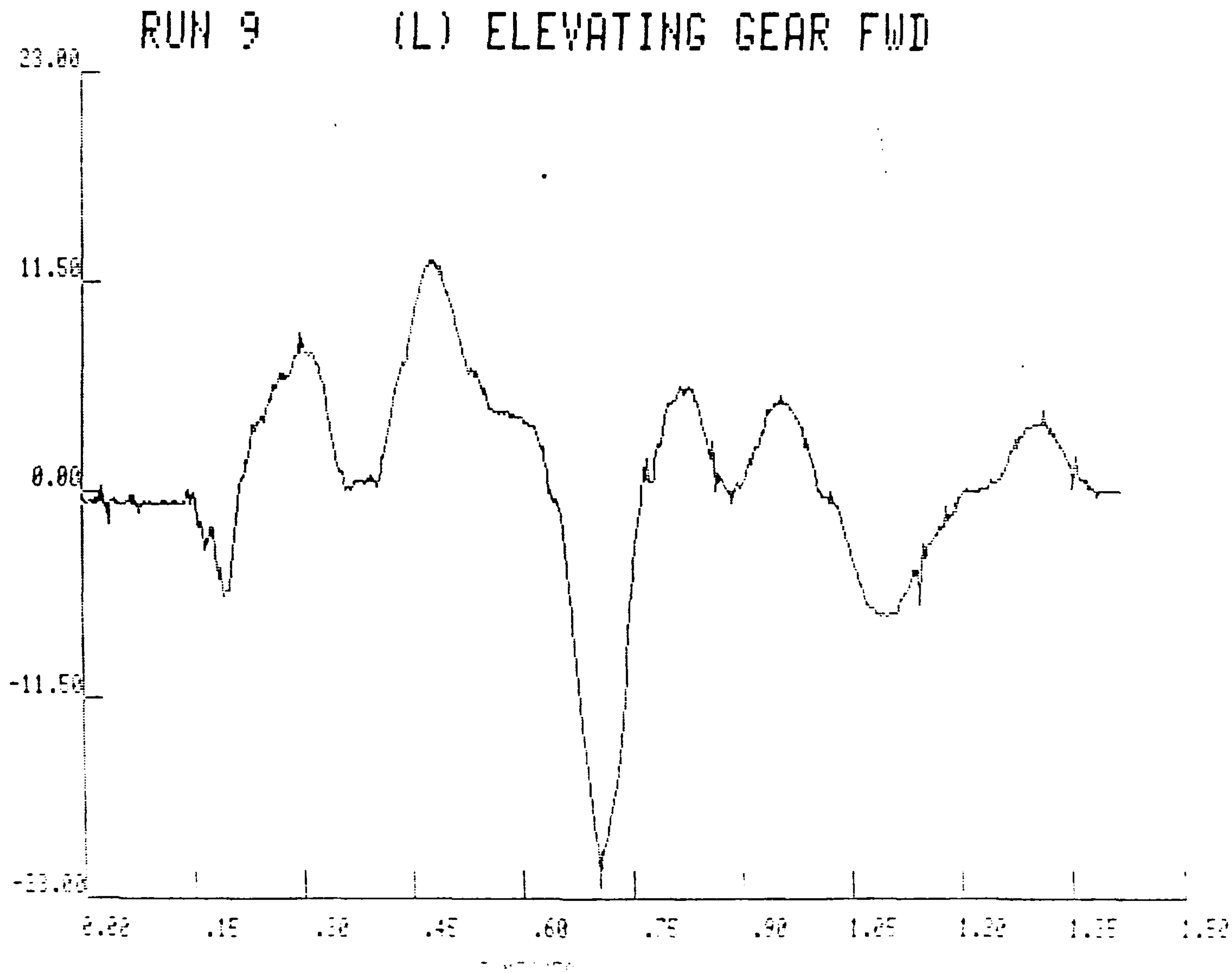

Figure 7. Dynamic stress plot, round 5, zone 9, elevation 28, elevating gear (forward)

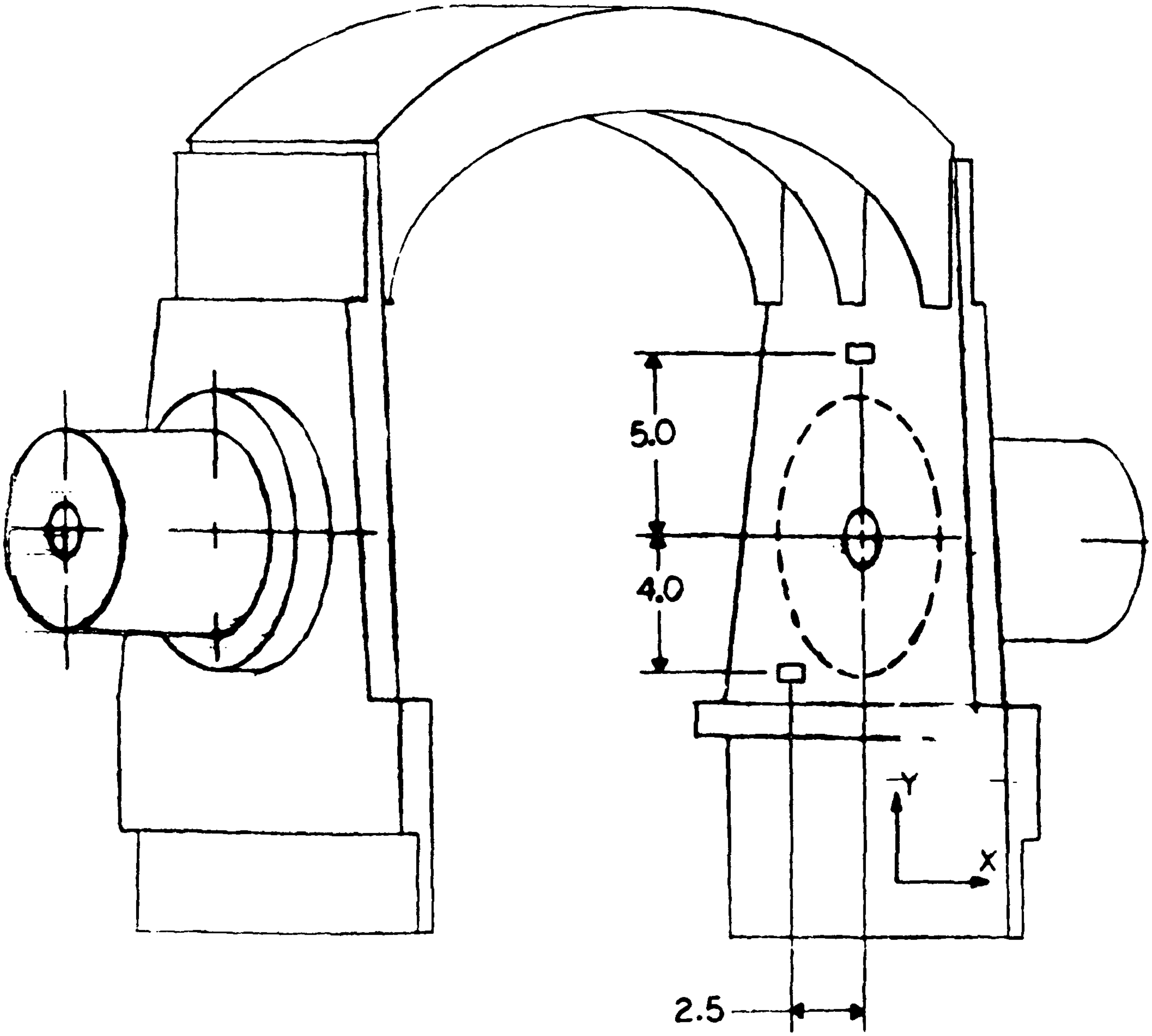

Figure 8. Strain gage locations on right trunnion

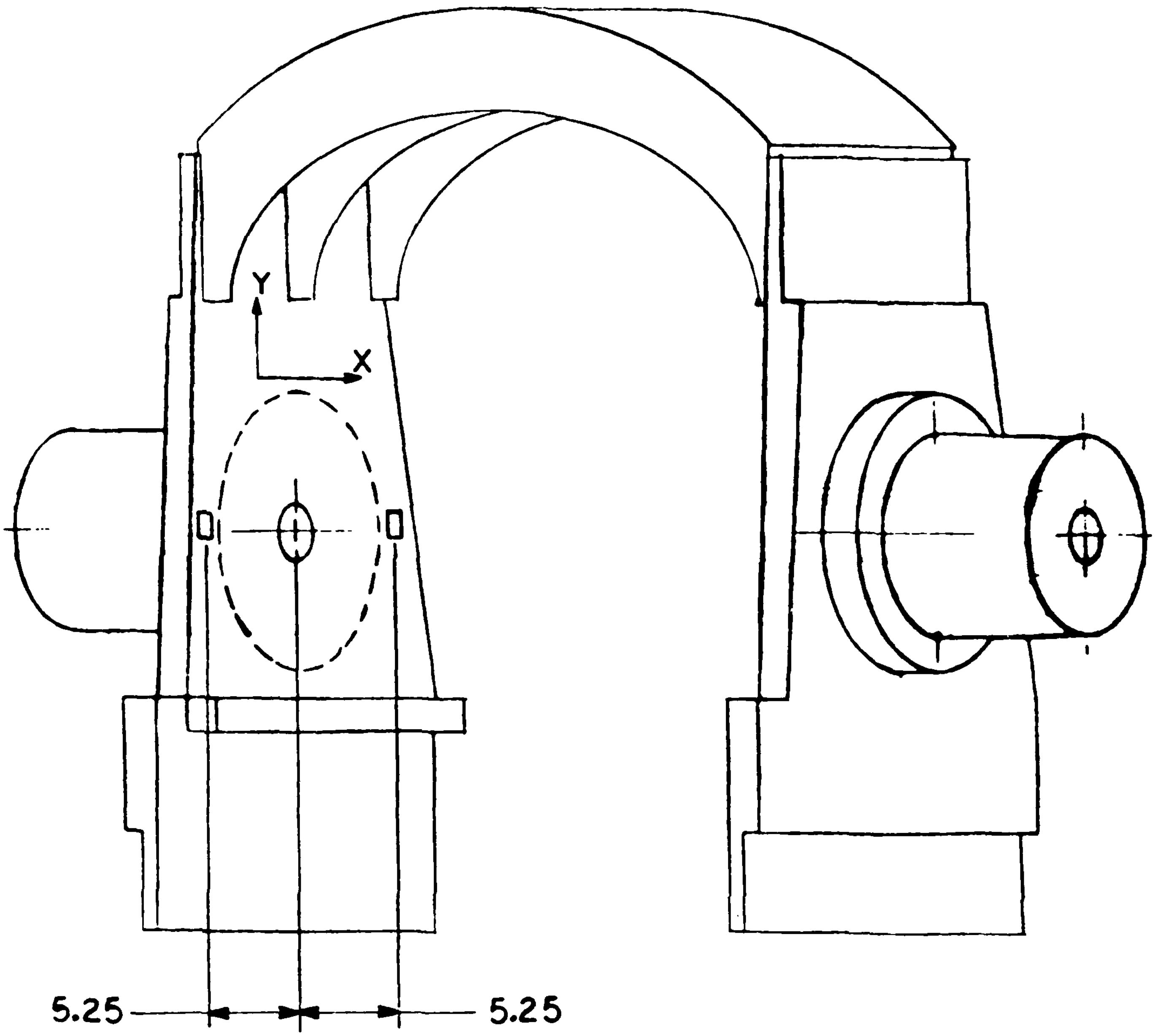

Figure 9. Strain gage locations on left trunnion

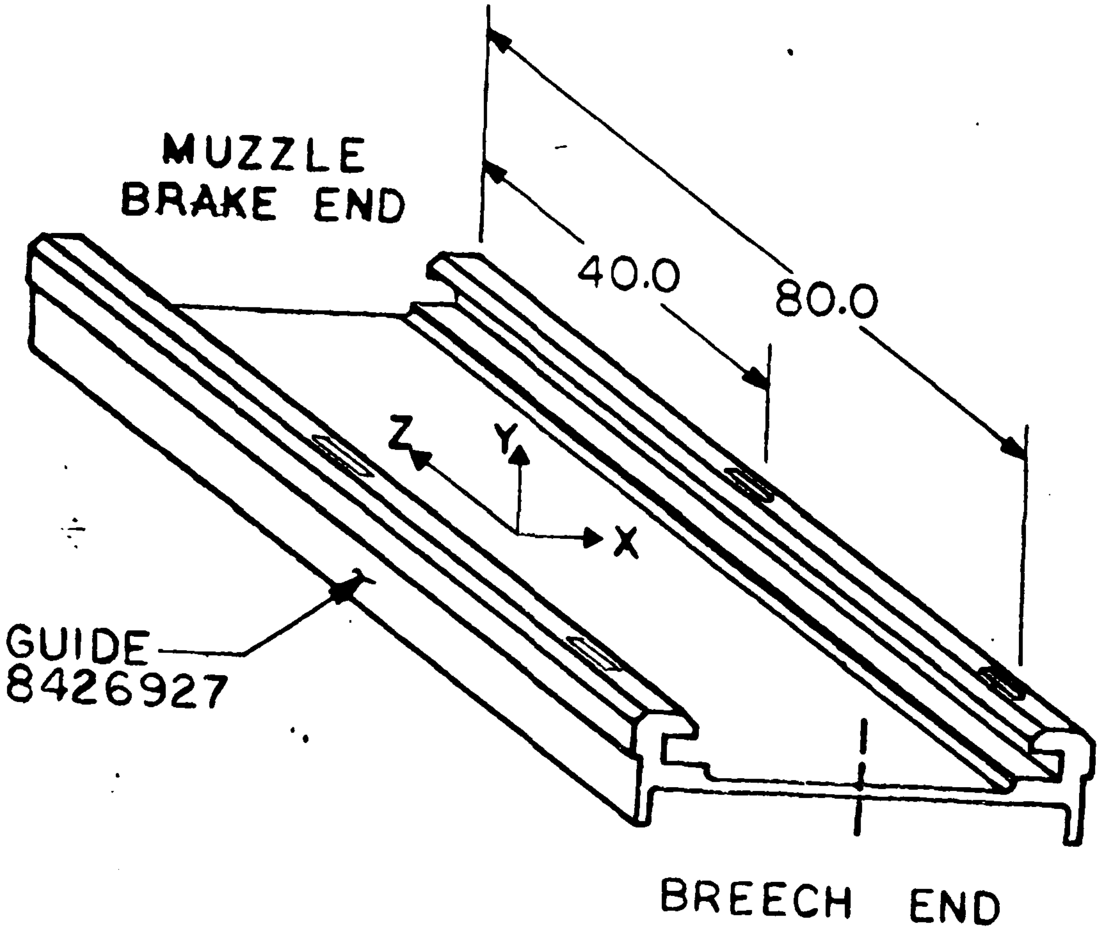

Figure 10. Strain gage locations on cannon guide

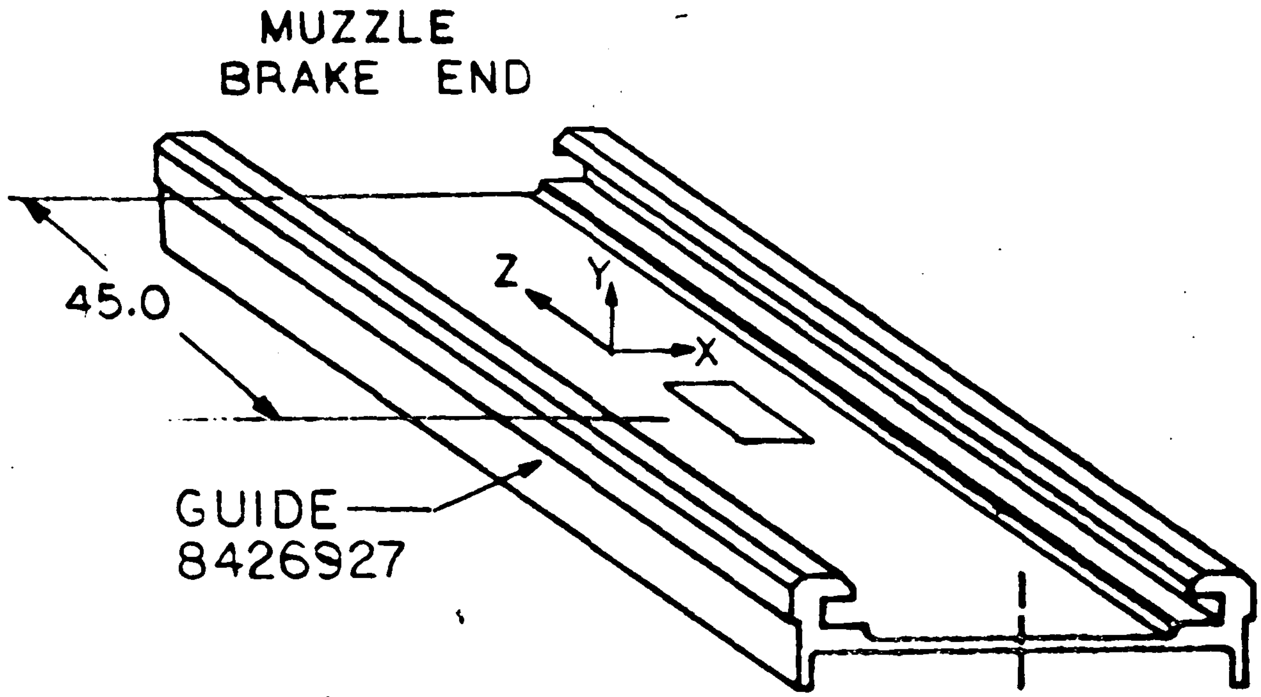

Figure 11. Strain gage location on center of guide

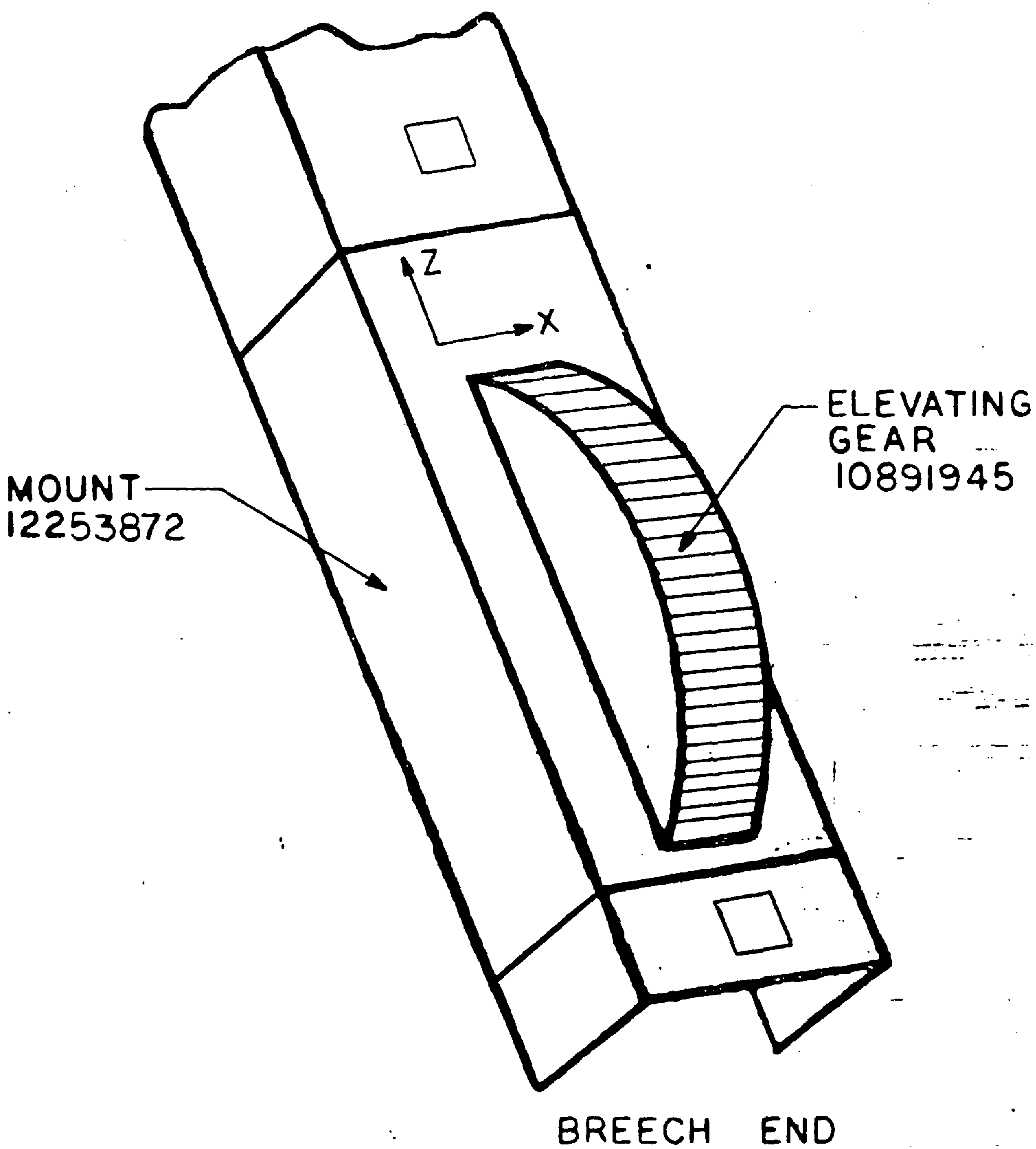

Figure 12. Strain gage locations in front and back of elevating gear

APPENDIX
COMPUTER MODEL
BOUNDARY CONDITIONS

The following loads and constraints were applied to the computer model:

1. The outer nodes on the trunnions were constrained from movement in all directions.
2. The front equilibrator mounting location was constrained in the model y and z directions.
3. The elevating gear location was constrained in the model y and z directions.
4. Cannon firing torque loads were applied to the guides.
5. Recoil rodpull loads were applied to a dummy recoil mechanism plate.
6. An acceleration was applied to the model to simulate the affect of gravity on the gun mount (i.e., the weight).

Equation 1 was used to calculate the load applied to the guides.

$$F_r = T_r/d_g \qquad (1)$$

for which

F_r = load from rifling torque
T_r = rifling torque
d_g = distance between guides = 15 in.

The rifling torque was calculated using equation 2.

$$T_r = [0.6\,(\pi)^2\,(R_b)^3\,(P_g)]/N_r \qquad (2)$$

for which

R_b = radius of bore = 4 in.
P_g = propellant gas pressure = 36,000 lbs/in^2 (a)
N_r = twist of rifling, calibers per turn = 20

Thus,

$T_r = 0.6\ (\pi^2\ (4\ in)^3\ (3600\ lbs/in^2)/20$

$T_r = 682{,}185$ in-lbs

$F_r = 682185/15 = 45{,}479$ lbs

The load F_r was distributed evenly to the nodes on the guide surfaces. The recoil mechanism rodpull load was obtained from test data from APG firing record M-89561 for a zone nine firing at 40 mils elevation. The values of rodpull used were 112,000 lbs for recoil and 46,000 lbs for the counterrecoil cylinder. These values were summed and then divided evenly among the nodes of the model dummy recoil mechanism plate.

DISTRIBUTION LIST

Commander
Armament Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-IMI-I (5)
SMCAR-FSA-F (2)
Picatinny Arsenal, NJ 07806-50Q00

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-GCL(D)
Picatinny Arsenal, NJ 07806-5000

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22304-6145

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSY-MP
Aberdeen Proving Ground, MD 21005-5066

Commander
Chemical Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCCR-MSI
Aberdeen Proving Ground, MD 21010-5423

Commander
Chemical Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCCR-RSP-A
Aberdeen Proving Ground, MD 21010-5423

Director
Ballistic Research Laboratory
ATTN: AMXBR-OD-ST
Aberdeen Proving Ground, MD 21005-5066

Chief
Benet Weapons Laboratory, CCAC
Armament Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-CCB-TL
Watervliet, NY 12189-5000

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-MAW
SMCAR-ESM
SMCAR-ESP-L
Rock Island, IL 61299-6000

Director
U.S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002