LSPE SAFE/ARM SLIDE

FAILURE EVALUATION REPORT

Approved by: L. R. Lewis
L. R. Lewis, Manager
Lunar Seismic Profiling Experiment

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ATTACHMENTS

1.0 PURPOSE

The purpose of this ATM is to (1) review the Safe-Arm Slide failure failure which occurred at the United States Naval Ordnance Laboratory (NOL), (2) evaluate the cause of the failure, (3) review the changes in Qual/Flight Slide design incorporated to eliminate problems, and (4) review the measures taken to ensure that the Qual/Flight slides were properly made.

2.0 BACKGROUND

The basic Safe-Arm Slide design for the LSPE experiment is very similar to the Space Ordnance Systems (SOS) Active Seismic Experiments (ASE) Slide-Safe Block Assembly (Drawing 14-10298-704). The ASE design was qualified and flown on the Apollo 14 mission and will be flown on Apollo 16.

Early in the LSPE Program approximately 65 test evaluation slides (BxA Drawing 2348307)* were fabricated by Bendix for use by NOL in evaluating the LSPE explosive train design and the astronaut safety aspects of a premature detonation of the explosive train initiator (i. e., end detonating cartridge). Table 1 shows a comparison of the dimensions of the test slides with the ASE slides.

The flight type slides (2348593) were intended to be identical to the test evaluation slides with the exception of an increase in length and the addition of arms and tabs for performing such functions as activating microswitches, holding springs, attaching safe/arm indicator arms, and a hole for insertion of slide-safing pin.

In the spring and summer of 1971 a series of vericom tests using the test slides were performed by NOL to verify the margin in the explosive train design. Then a final series of safety tests were conducted on 18 test safe slides in August. The safety tests consisted of 18 EDC firings into the RTV-21 filled safety bores to verify that the explosive lead or explosive charge would not detonate and that the slide maintained its integrity. The tests were 100 percent successful and no cracking or spalling of the slides were noted.

The remaining item in the safety test program was to perform a confirming test on two test baseplate units with slides, baseplates, and EDC housings built with flight type drawings and processing.

*Seven digital numbers in parenthesis throughout the remainder of the text refer to Bendix Drawing Numbers.

TABLE 1

COMPARISON OF ASE AND LSPE SAFETY SLIDES

	Slide-Safe Block Assy (ASE) 14-10298-704	Safe/Arm Test Slide (LSPE) 2348307
Material:	17-4 PH stainless steel condition H-1025 per AMS-5643	17-4 PH stainless steel condition H-1025 per AMS-5643
Slide Width:	.747 in. max. .744 in. min.	.76 in. max. .74 in. min.
Slide Thickness:	.183 .181	.184 .182
Safety Bore Depth:	.103 .083	.102 .077
Dia.:	.495 .505	.495 .505
Safety Bore Fillet Radius	.030 .020	.030 .020
Safety Bore Fill Material:	RTV-21	RTV-21
Finish:	Passivated	Passivated
	Malcomized	----------
	Teflon Coated #954 Series	Teflon Coated #954 Series

3.0 DESCRIPTION OF FAILURE

On 16 September 1971, the LSPE safety tests were conducted at the Naval Ordnance Laboratory on two test baseplate assemblies. These test baseplate assemblies (2364708) were intended to duplicate flight-type hardware and consisted of a baseplate (2348592X6), EDC housing (2348594X3), safe-arm slide (2348593X3), EDC (2348421-1), and lead (2364734). The explosive charges consisted of a 6-pound and a 1/8-pound charge and were mounted in simulated housings in the same manner as the LSPE design (see Figure 1). The safe-arm slides were set in the "safe" position and the EDC's were fired. Neither the charges nor the leads detonated but when the baseplate assemblies were disassembled from the explosive housing assemblies it was discovered that both the charges were fractured due to a slide failure.

As shown in Figures 2 through 5, the slide failed in a manner such that a disk was coined-out and impacted the HE charges. The 1/8 lb charge was badly shattered, while the 6 lb charge was chipped and cracked by the impact.

4.0 ANALYSIS AND INVESTIGATION

Following the failures, an investigation was initiated to establish the differences between the test fixture slides which had been fired successfully 18 times and the flight configuration slides which failed on their first firings. The results of these investigations are presented in the following sections.

4.1 Critical Dimension Comparison

Figure 6 compares the critical dimensions for the test slides (2348307) and the slides used in safety test (2348593X3). The only significant dimensional difference existed in the fillet radius call-out at the base of the RTV filled safety bore. A 0.025 ± .005 radius was specified for the test slide. By drafting error no radius was called out for the prototype, qualification, and flight model slides. Several prototype, qualification, and flight slides were selected and the RTV removed from holes and corner radius measured. Measurements indicated that corner radii in all cases were 0.005 in. or less

4.1.1 Effect of Fillet Radius

The effect of the fillet radius was evaluated in memo 71-982-B38 (Attachment 1), and is summarized in Figure 7.

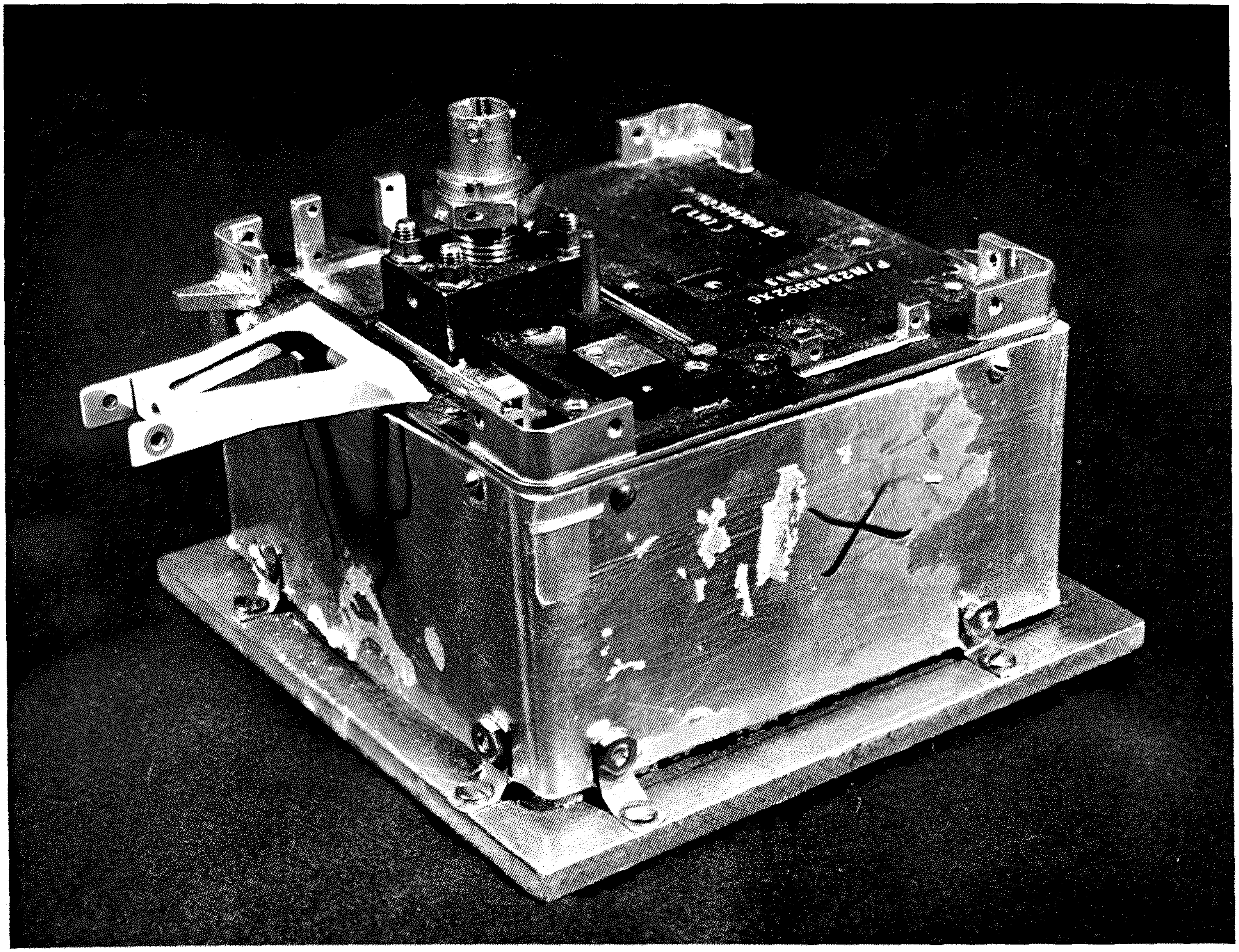


Figure 1: NOL Safety Test Configuration 1/8 Lb Charge

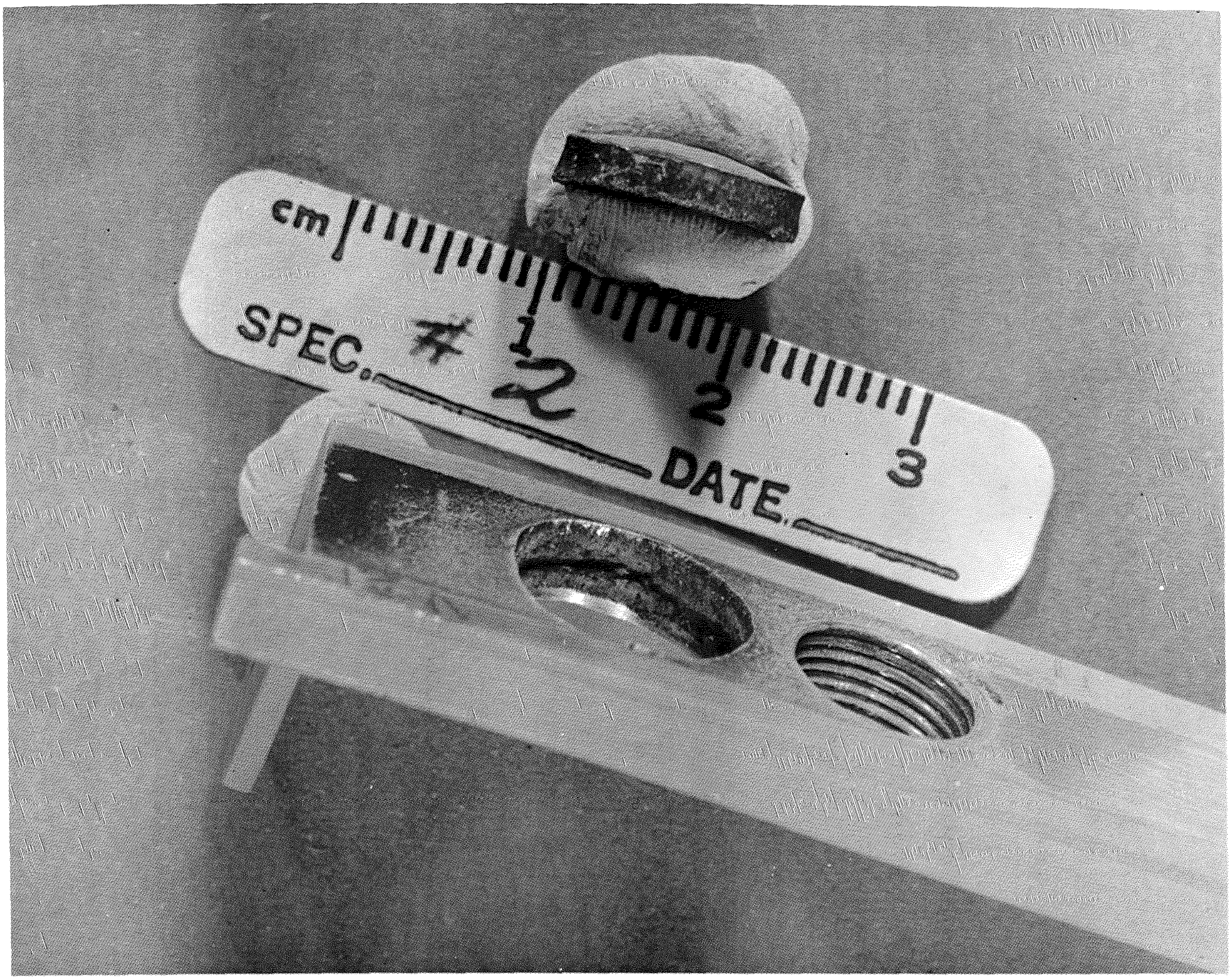


Figure 2a: Failure Slide Showing Coined Disks (Top View)

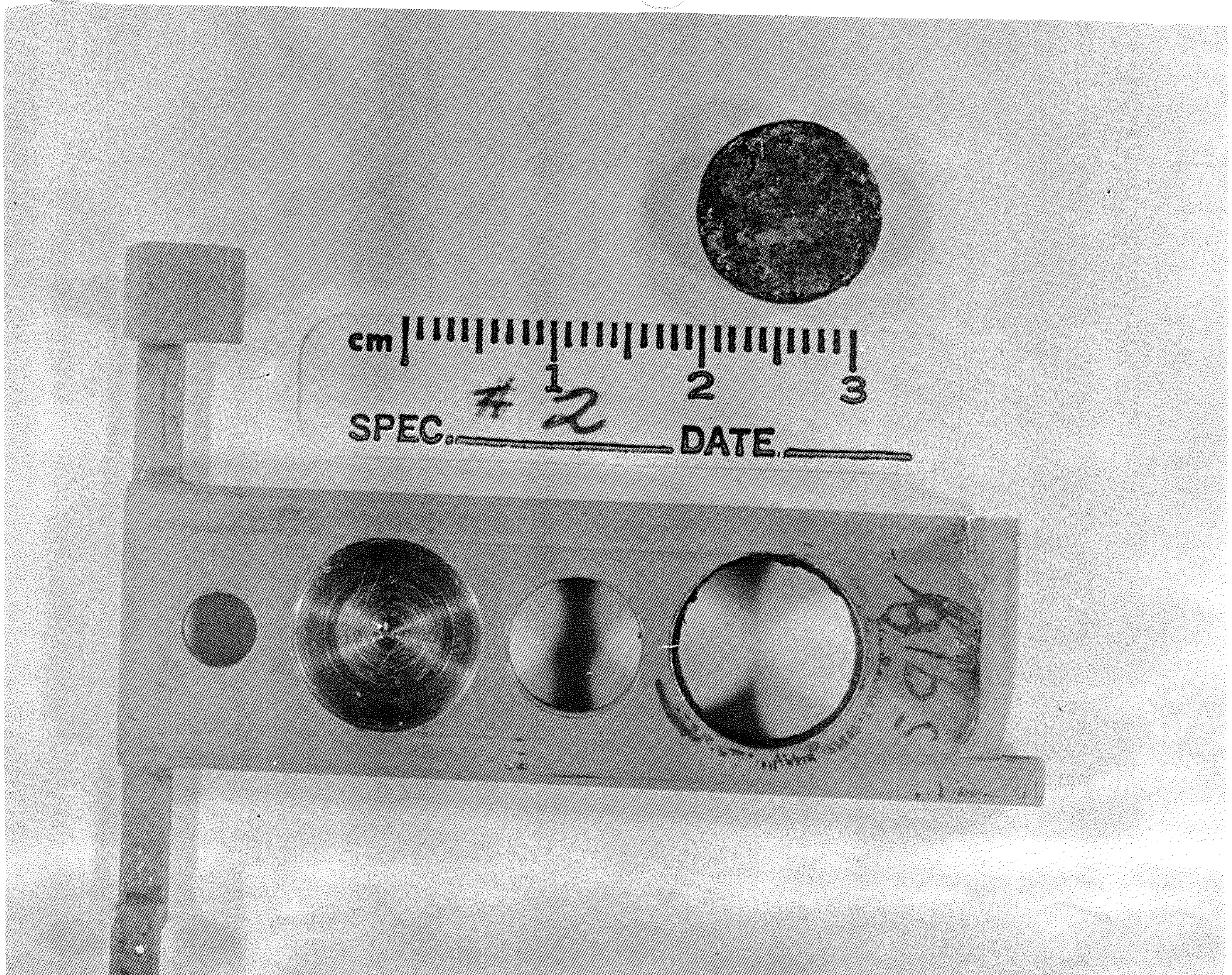


Figure 2b: Failure Slide Showing Coined Disks (Side View)

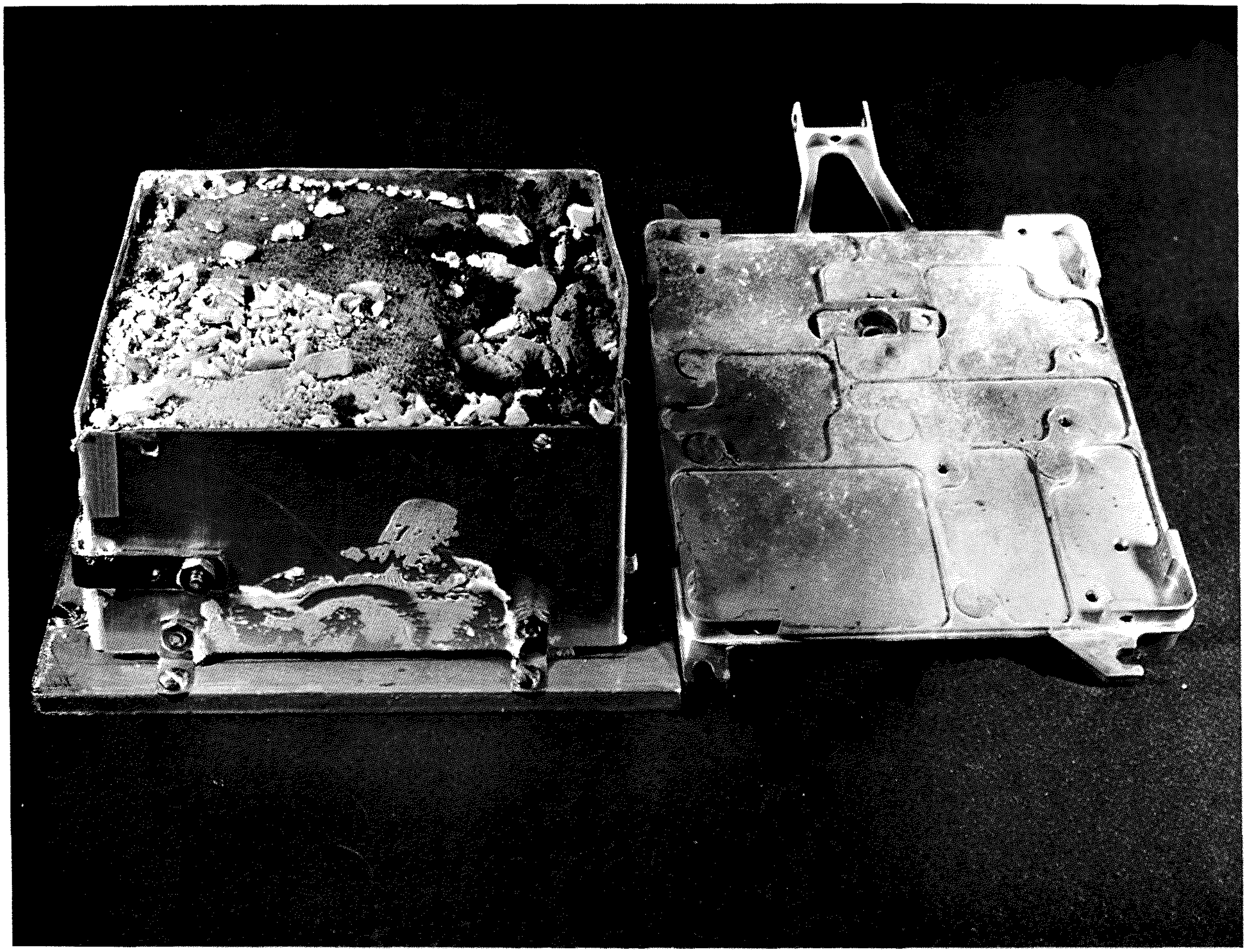


Figure 3: Shattered But Undetonated 1/8 Lb Charge After Test

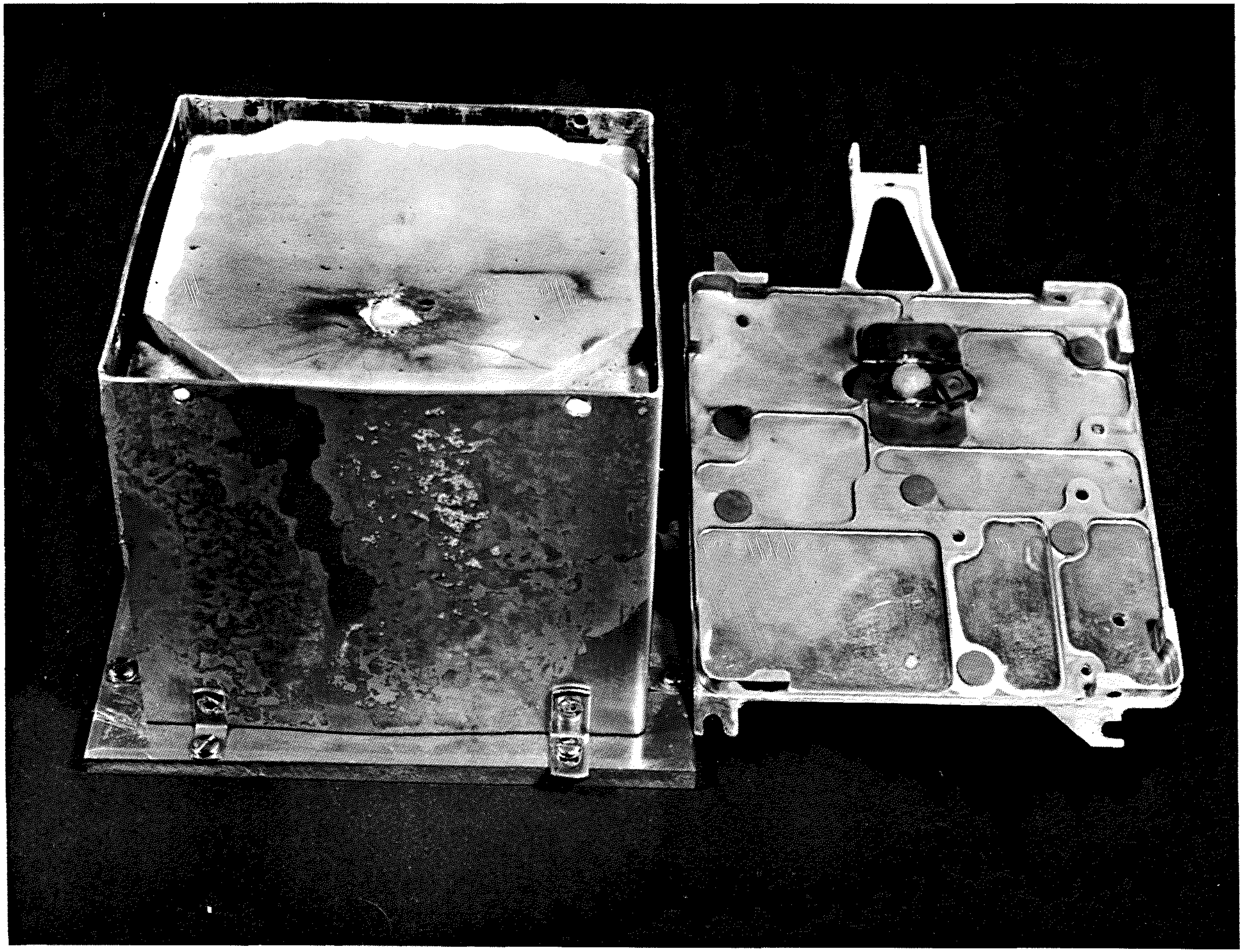
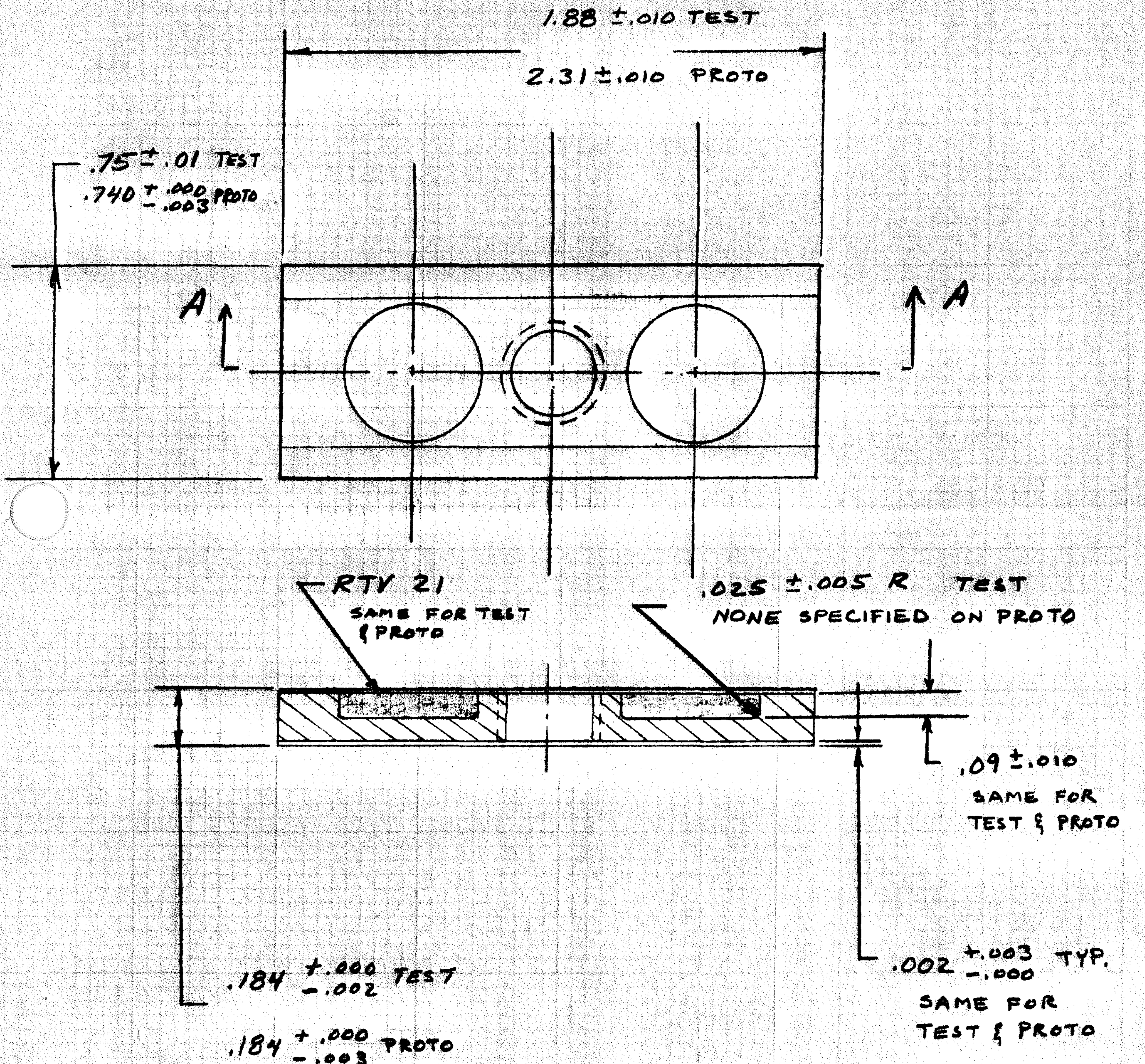


Figure 4: Damaged 6 Lb Charge After Safety Test

Figure 5: Coined Slide Material Wedged in Slot in Baseplate, 6 Lb Charge

Figure 6: Critical Dimension Comparison of Test Slide and Proto Slide



NOTE: SURFACE COATED WITH TEFLON 954-101 PER MP 99 ON PROTO SLIDE; ONLY PASSIVATED FINISH ON TEST SLIDE.

MATL. – STAINLESS STEEL 17-4 PH COND. H1025 PER AMS 5643 FOR TEST & PROTO SLIDE

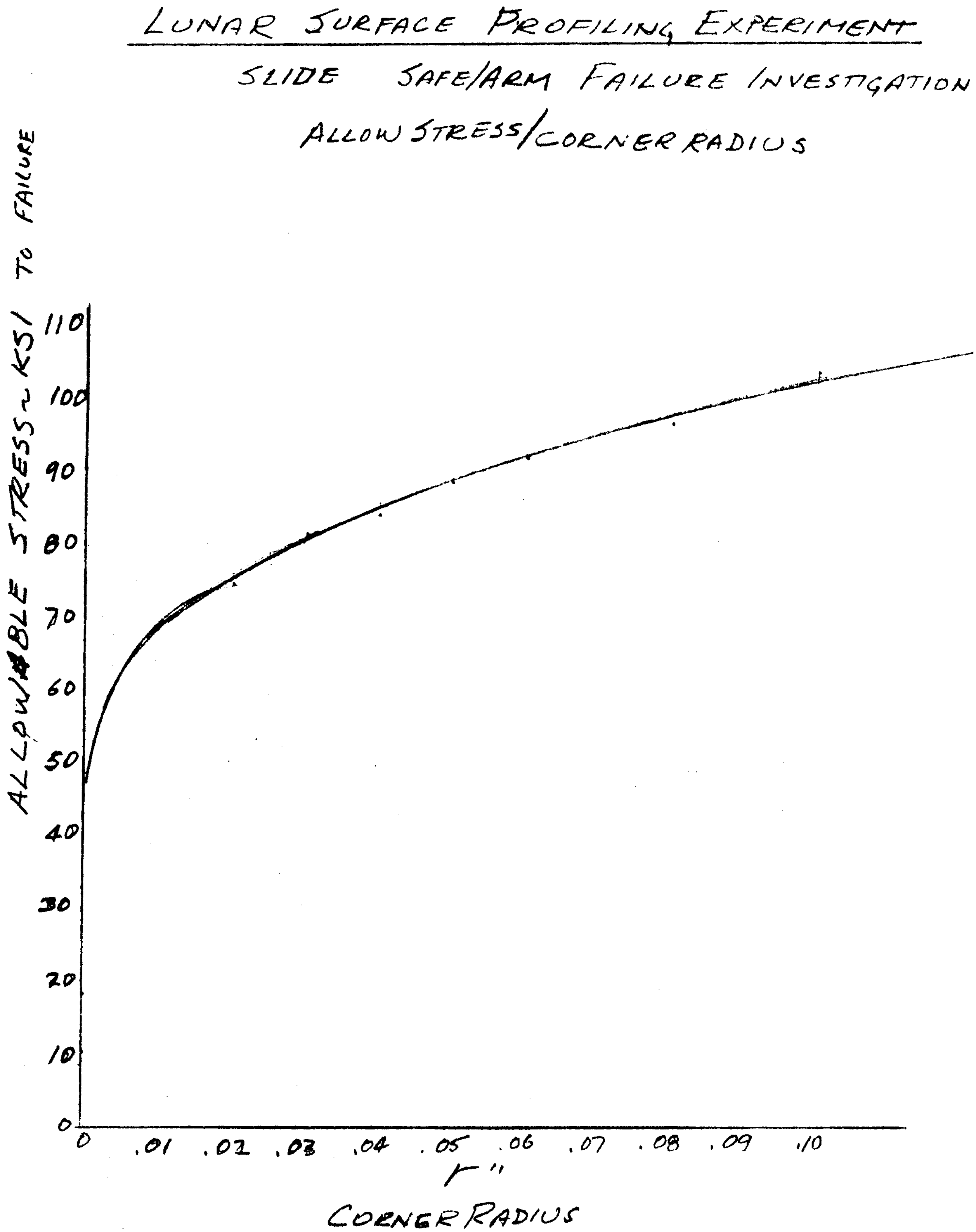

LUNAR SURFACE PROFILING EXPERIMENT
SLIDE SAFE/ARM FAILURE INVESTIGATION
ALLOW STRESS/CORNER RADIUS
ALLOWABLE STRESS ~ KSI TO FAILURE
110
100
90
80
70
60
50
40
30
20
10
0
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
r"
CORNER RADIUS

FIGURE 7

This evaluation shows that a loss of 25 percent in allowable stress to failure is associated with the reduction in fillet radius from .025 to .005 inch. Increasing the fillet radius over .025 inch continues to increase the stress to failure although the rate of improvement diminishes. For instance, at a radius of .040 inch the stress to failure is increased by 37 percent over stress for a .005 inch radius.

4.1.2 Change of Fillet Radius

In a meeting at MSC on 24 September 1971, Bendix recommended and MSC concurred that the qualifications and flight model slides be remade with safety bore fillet radius of .040+.000, -005 inch and change the call-out for depth of the safety bore from .09 ± .01 to .09+.000, -.005 inch to better control the thickness of the steel below the RTV-21 pocket. (See Figure 8.) The minutes of the MSC meeting are included as Attachment 2.

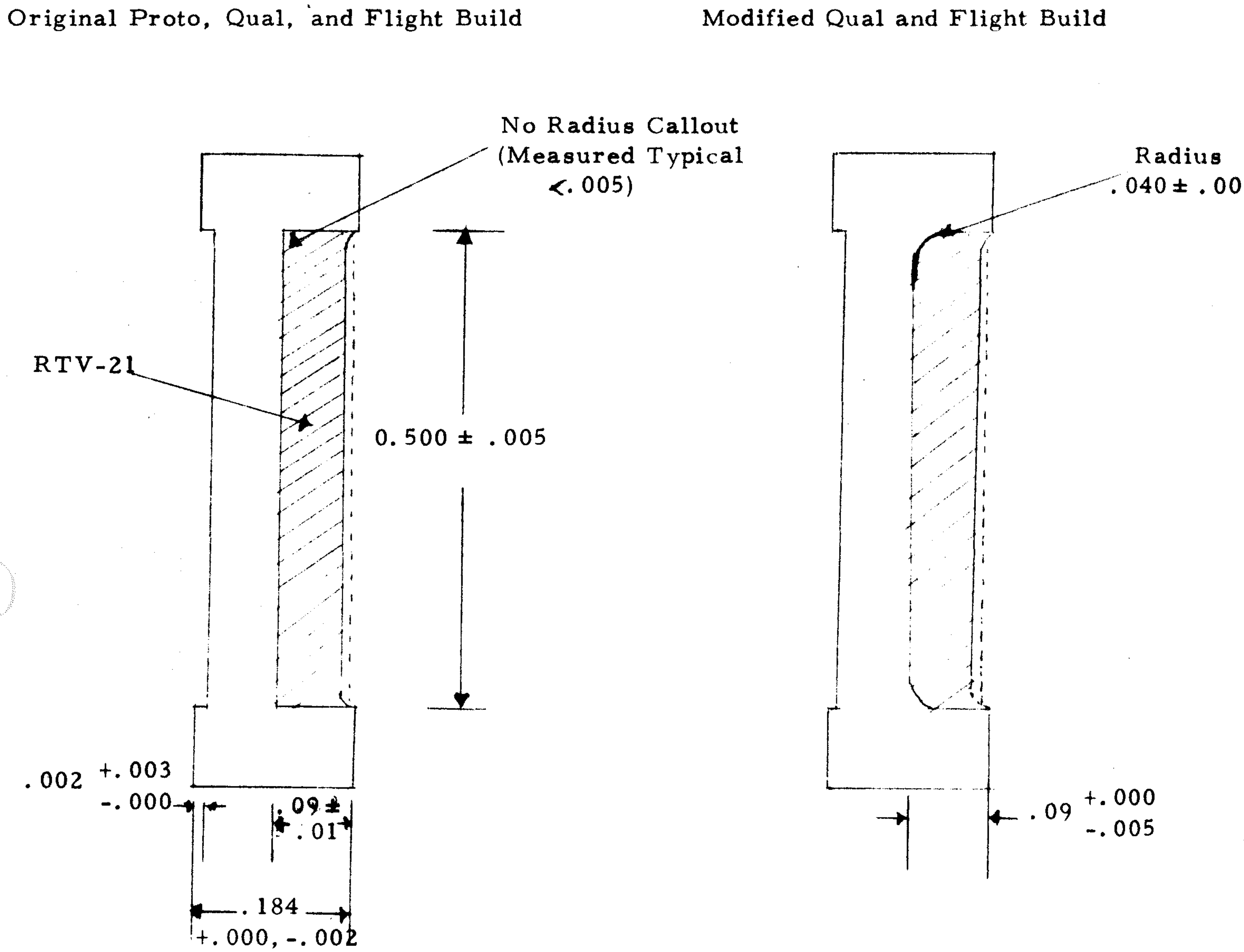
4.2 Material Evaluation

An investigation was also performed to assure that the RTV-21 silastic, stainless steel alloy, and heat treatment which had been used on the flight type slides was the same as had been used on the test slides. Reviews of work order operation sheets, purchase orders and supplier certifications revealed that the materials were similar between the two groups of slides; however, through a misinterpretation of the drawing requirements the flight like slides (2348593X3) had not been heat treated. The 17-4 PH stainless steel raw stock had been ordered in the easily machinable annealed condition A since the H-1025 condition is very tough and difficult to machine without carbide tip tools. By error, a heat treatment was not included in the work orders operations sheets between the machining and teflon coating steps in the fabrication cycle.

4.2.1 Effect of Failure to Heat Treat Slides

A comparison between the properties of the annealed and H-1025 17-4PH is given in Table 2. In the anneal state, the steel is martensite structure which lacks in toughness and impact strength, and is brittle. Heat treatment to H-1025 state results in about a 50 percent increase in both tensile strengths and elongation to fracture resulting in a material which has high impact strength and is relatively ductile. The increase in elongation to fracture is considered as the best indicator of the improvement of the material to withstand impact loads seen in EDC firing over a safety bore.

FIGURE 8



Dimension Changes Over Original Shown Only

Material: 17-4PH Stainless Steel Heat Treated to H-1025 Condition

TABLE 2

COMPARISON OF PROPERTIES OF ANNEALED AND H-1025 17-4PH STAINLESS STEEL

	Typical* CRES 17-4 PH Condition A Annealed	Typical* Condition H-1025 Per AMS-5643
Tensile Strength - Yield	110,000 psi	165,000 psi
- Ultimate	150,000 psi	170,000 psi
Shear Strength	87,000 psi	111,000 psi
Elongation to Fracture	10%	15%
Hardness (Rockwell)	C33	C38

*Metals Handbook

4.2.2 Hydrogen Embrittlement

Another effect that was investigated was the possibility of hydrogen embrittlement of the steel in the presence of RTV. This effect was eliminated since 17-4PH is not subject to hydrogen embrittlement in the presence of RTV at temperatures less than 800°F.

5.0 PLAN FOR INTERMEDIATE SOLUTION OF FAILURE

At a meeting at MSC on 24 September 1971 the following plan was agreed to between representatives of MSC-LSPO, ASPO, Safety, Power and Propulsion Division, Reliability, Structures, and Bendix:

1. Bendix will make new slides for Qual/Flight with:
   a. Fillet radius of .040 ± .005
   b. Better control of cavity depth
   c. Proper heat treatment to H-1025 condition
   d. Increased inspection at various stages of processing.

2. Due to schedule considerations, heat treated original Qual/Flight slides (2345893A) will be used on the prototype.

3. Additional tests of the sharp radius slides will be conducted at NOL to assure there is no safety hazard associated with the prototype during field handling. Ten slides will be fired in these tests, eight of the original qual/flight design (2345893A) and two heat treated original prototype slides (2345893X3). Should any failures occur during these additional tests Bendix will buy additional slides and incorporate new design changes in the prototype model also.

4. Bendix will place metallurgical samples in the Qual/Flight heat treatment lot and verify by metallurgical examination and tensile tests that the new Qual/Flight slides are properly heat treated.

5. BxA will provide two additional test baseplate assemblies with new slides for a repeat of the safety verification test with the new larger fillet radius slides (2345893C).

6. Bendix will prepare a report summarizing the investigations and test results.

The minutes of the meeting held at MSC on 24 September 1972 are included as Attachment 2.

6.0 ADDITIONAL TESTING RESULTS AND CONCLUSIONS

6.1 Baseplate Assembly Tests with Slides Having Larger Fillet Radius

Two test baseplate assemblies having new larger radius slides (2345893C) were tested at NOL in configuration similar to the one in which the original failure occurred (see Section 3.0). The results were 100 percent successful in that the slides did not coin, nor show signs of cracking or spalling.

6.2 Slide Tests With 10 Heat Treated Sharp Radius Slides

The test configuration consisted of 2348593A and heat treated 2348593X3 sharp radius slides mounted in NOL simulated baseplate and EDC housing. Eight room temperature tests with six of the original Qual/Flight slides (2348593A) and two heat treated prototype slides (2348593X3) were highly successful with no coining or serious deformation of the slides. However, the last two firings of the series using original sharp radius Qual/Flight slides (2348593A) heated to 200°F failed by coining in a manner similar to the original failures (see Figure 2). These tests were conducted during October 1971.

Additional details on the results of the NOL testing can be obtained from the NOL Progress Reports to MSC.

7.0 FINAL PLAN

As a result of the failure of the sharp radius slides in NOL testing, the .040 inch radius slides which had been made were reassigned to the 16 prototype explosive packages and designated 2348593X4 slides. An additional 24 .040 inch radius slides were made for Qual/Flight usage. To distinguish these last .040 inch radius slides from previous slides and to make it impossible to inadvertently mix slides from previous builds into Qual and Flight, the teflon coating was changed from a green to a black, changing the part number letter revision to 2348593D. Also, as each of the sharp radius slides was removed from the prototype unit on both changeouts (i.e., (1) removing original non heat-treated sharp radius prototype slides 2348593X3 and replacing them with heat treated original Qual/Flight slides 2348593A and (2) their replacement with larger radius new build slides 2348593X4), the slide arm indicator tabs were deformed to prevent inadvertent mix up on any subsequent disassembly and reassembly of the prototype model.

In addition to the tensile and metallurgical samples to be included in the heat treatment, Bendix instituted an x-ray examination of the new build Qual/Flight slides (2348593D) to detect any imperfections in the stainless steel, particularly in the pocket area which may have reduced the impact strength of the slides.

Also, one additional NOL test was defined which is to fire two additional test baseplate assemblies using the 2348593D slide. At the time of compilation of this ATM, that test had not been performed. On completion of the NOL test an addendum will be issued to this ATM to include the results of that test.

8.0 RESULTS OF METALLURGICAL EXAMINATIONS, TENSILE STRENGTH, AND X-RAY EXAMINATIONS

8.1 Metallurgical Examinations

Metallurgical examinations were made on the following items:

a. Prototype sharp radius slide (2348593X3) built in same lot as slides that failed originally at NOL.

b. One slide from the first set of new build .040 inch radius slides which were finally designated for prototype use.

c. A metallurgical sample heat treated with the second set of new build larger radius slides (2348593D) used for Qual/Flight.

In cases (a) and (b) where slides were examined, the surface examined was the end-face of the tab to which the safe/arm slide indicator is attached.

In cases (a) the examination indicated that the 17-4PH stainless steel was in a predominately martensite structure characteristic of what one would expect prior to age tempering by a precipitation heat treatment. This confirmed the documentation which indicated that this set of slides was not heat treated and were in an "as received" annealed condition.

Examination after heat treatment of the end tab on large radius slide from the first set of new build (item (b) above) and the metallurgical sample from the heat treatment of the second set of new build slides (item (c) above) both show a basic ferritic matrix with areas characteristic of dispersed martensite phase. This is the structure to be expected after age-tempering 17-4PH stainless steel at 1025°F for four hours. Photomicrographs of the metallurgical samples heat treated with Qual/Flight slides are included in Attachment 4.

8.2 Tensile Strength Tests

Tensile samples were included with the new build Qual/Flight slides during heat treatment. Subsequent load-elongation tests on four samples gave yield strengths varying from 161,765 to 164,130 psi and ultimate strengths varying from 163,957 to 164,674 psi. This is well above the minimums of 145,000 and 155,000 psi specified for the 17-4PH H-1025 material. The data on each sample and load elongation curves are contained in Attachment 4.

8.3 X-Ray Examination

The X-ray examination of the new build .040 inch Qual/Flight slides (2348593D) resulted in a rejection of three slides. These slides were rejected for existence of a small amount of porosity and non-metallic inclusions in or near the safety bore region of the slide.

9.0 ACCOUNTABILITY FOR ALL SLIDES

Table 3 shows the status of all flight configuration Safe/Arm Slides made on LSPE program. The bad "sharp-radius" and non heat treated slides were part numbers 2348593X3 and 2348593A. As shown in the table, the "sharp-radius" slides have been deformed in one of the following means: (1) they have been used in NOL safety tests and failed by coining, (2) they have been used in NOL safety tests and were deformed by EDC firing removing material from RTV-2 filled pocket and bulging bottom of slide, or (3) the indicator tabs have been bent to prevent inadvertent use in the prototype system. The 2348593D revision used in the qualification and flight model Explosive Packages are coated with black teflon rather than the green used on previous slides to prevent possible mix-ups. Also, the large radius slides (2348593X4) used in prototype are marked with a black teflong strip on top of the indicator tab to distinguish them for previously made green teflon coated sharp radius slides. Verification has been made that all slides installed in prototype packages are to the X4 configuration. Two A revision slides have not been positively accounted for but are believed to have been deformed for metallurgical examination. Documentation of shipment of slides to NOL and Bulova is available at Bendix.

TABLE 3. STATUS OF ALL FLIGHT CONFIGURATION SLIDES

Drawing Number	Rev.	Original Designation	Present Allocation	Total Quantity Made	NOL	Present Location: BxA: LSPE Lab	Present Location: BxA: Installed in Hardware	Present Location: BxA: Bonded Stores	Present Location: Bulova	Total Accounted For	Slide Vendor
2348593	X3	Prototype No Heat Treatment, Sharp Radius	Scrap, deformed.	20	5(1)	7(2)	---	---	8(2)	20	Bendix in-house fabrication
2348593	A	Qual/Flight No Heat Treatment, Sharp Radius	Scrap, deformed.	20	18(3)	---	---	---	---	18*	Valiant Industries June 1971
2348593	X4	New Build Qual/ Flight as 2348593C Heat Treatment, .040 Radius	Redesignated to Prototype Use and Designated X4	22	2	---	16	4	---	22	Valiant Industries October 1971
2348593D		Qual/Flight Heat Treatment, .040 Radius	Qual/Flight	24	2	---	20	2	---	24	Standrite
			TOTAL	86	27	9	36	6	8	84	

(1) Three coined, two fired into safety bore but not coined.
(2) Deformed by bending indicator tab.
(3) Six fired into safety bore but not coined, two coined. Ten deformed by bending indicator tab, used in baseplate separation barrier test at NOL.

*Two unaccounted slides are believed to have been deformed during metallurgical examination. Present location is unknown.

10.0 CONCLUSIONS

Based on the results of the analysis of the causes of the original failure, the redesign of slide, additional testing performed at NOL, and additional quality control measures instituted, the following conclusions are reached:

1. The differences between the test configuration slides (2348307) and original Qual/Flight configuration slides (2348593X3) responsible for the failure at NOL on 16 September 1971 were:

   a. The less than .005 inch fillet radius on safety bore holes,

   b. The omission of heat treatment.

2. The modified design of slide to increase fillet radius corrects the problem as verified by NOL testing.

3. The metallurgical examinations and tensile strength tests verify the proper heat treatment of the new build Qual/Flight slides.

4. X-ray examination has precluded the possibility that a flaw in the steel may present a problem.

Therefore, it is further concluded that the potential safety problem presented by the original failure has been resolved. *

*Pending successful completion of NOL test described in the final paragraph of Section 7.0.

Internal Memorandum

ATTACHMENT 1

Bendix Aerospace Systems Division

Ann Arbor, Michigan

Date 22 September 1971 Letter No. 71-982-B-38

To L. R. Lewis

cc: D. Dewhirst
M. Katz
W. Hamill
R. Worcester

From J. H. Owens, Jr.

Subject LSPE Safe/Arm Slide Failure Investigation, Dwg 2348533

Ref: (1) MIL-HDBK-5A "Metallic Materials and Elements for Aerospace Vehicle Structures"
(2) Roark, R. J., "Formulas for Stress and Strain", McGraw-Hill Book Company, Inc.
(3) Peterson, R. E., "Stress Concentration Design Factors", John Wiley and Sons, Inc.
(4) Rinehart, J. S. and Pearson, J., "Behavior of Metals Under Impulsive Loads," Dover Publications, Inc.

Per your request, an evaluation was performed to determine the effect of fillet radius on the failure characteristics of safe/arm slide holes.

The attached curve, page 4 shows the effect of an internal corner radii "r" in the explosive cavity. Changing the corner from r = 0 to r = .02 improves the local stress condition drastically and further increase in the radius continues to lower the stress level although the rate of improvement diminishes. Thus, it is evident that increasing the radius will increase the load necessary to cause fracture.

The writer would like to make the following additional comments:

(1) Material allowables are based on information in Ref. (1) MIL HDBK-5A. These are guaranteed minimum. Ultimate and yield stresses could be higher.

(2) The thickness of the bottom of the cavity can vary between .099" and .086". This can affect the failing load by 30 percent.

(3) In a small cavity such as this shear effects will be significant.

(4) As discussed in Ref. (4) materials behave somewhat differently under impulsive loads than under static loads. To obtain a true understanding further investigation is necessary.

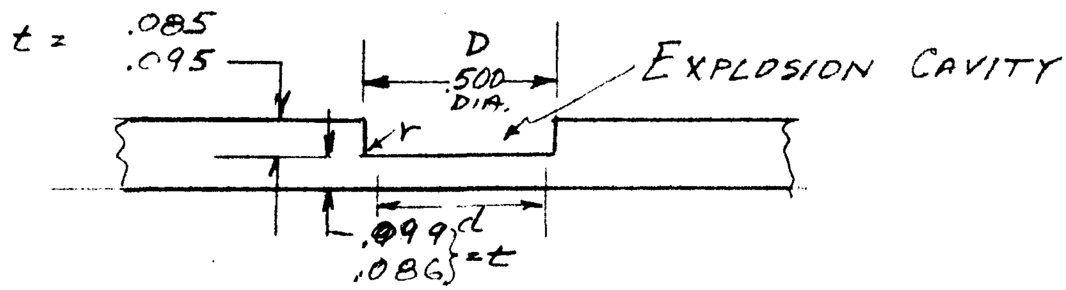
(5) In a small cavity such as this corner radius will also increase edge stiffness and reduce center deflection.

J. H. Owens, Jr.

LUNAR SURFACE PROFILING EXPERIMENT

SLIDE, SAFE/ARM FAILURE INVESTIGATION

DWG 2348533



STRESS CONCENTRATION FACTORS

D	r	d	D/d	r/d	K_t*
.500	0	.50	1.00	0	∞
↓	.01	.48	1.04	.021	2.1
	.02	.46	1.09	.0435	1.95
	.03	.44	1.14	.068	1.78
	.04	.42	1.19	.0953	1.73
	.05	.40	1.25	.125	1.64
	.06	.38	1.32	.158	1.57
	.08	.34	1.47	.235	1.50
	.10	.30	1.67	.333	1.40

* REF. (3) "STRESS CONCENTRATION DESIGN FACTORS" FIG. 58

LUNAR SURFACE PROFILING EXPERIMENT

SLIDE SAFE/ARM FAILURE INVESTIGATION

DWG. 2348533 (CONTINUED)

STRESS & DEFLECTION CALCULATIONS

MATERIAL 17-4PH H1025

$F_{tu} = 155$ KSI
$F_{ty} = 145$ KSI
$e = 5\%$
$E = 28.5 \times 10^6$ PSI
$E_c = 30 \times 10^6$ PSI } SAY 29×10^6 PSI
$\mu = .27$

} REF. MIL HDBK5A TABLE 2.7.4.1

STRESS AND DEFLECTION RELATIONSHIPS

STRESSES ASSUME $K_t = 1.00$

AT EDGE $\sigma_r = \dfrac{3W}{4\pi t^2}$ $\quad \sigma_t = \dfrac{3W}{4\pi m t^2}$

AT CENTER $\sigma_r = \sigma_t = -\dfrac{3W(m+1)}{8\pi m t^2}$

$$Y_{MAX} = -\frac{3W(m^2-1)a^2}{16\pi E m^2 t^3}$$

} REF. ROARK "FORMULAS FOR STRESS & STRAIN" TABLE X CASE NO. 6

AT EDGE $\sigma_r = \dfrac{3W}{4 \times 3.14\, t^2} = \underline{\underline{\dfrac{.239\, W}{t^2}}}$ (MAX) $\quad \sigma_t = \dfrac{3W \times .27}{4 \times 3.14\, t^2} = \dfrac{.0645W}{t^2}$

DEFL. Y AT CENTER

$$Y = -\frac{3W(12.7) \times .25}{16 \times 3.14 \times 29 \times 10^6 \times 13.7 \times t^3}$$

$$= -.000477 \left(\frac{W}{t^3}\right) \times 10^{-6}$$

LUNAR SURFACE PROFILING EXPERIMENT

SLIDE SAFE/ARM FAILURE INVESTIGATION

DWG. 2348533 (CONTINUED)

STRESS & DEFLECTION CALCULATIONS

"t" PG. 1	"r" PG 1	K_t **	$\sigma_{ALLOW} = \frac{F_{ty}}{K_t}$	W FAILING LOAD	MAX DEFL. $Y \times 10^{-6}$
.086	0	>3.0 *	48.2	5520	4150
↑	.01	2.1	69	7900	5930
	.02	1.95	74.2	8500	6400
	.03	1.78	81.5	9350	6950
	.04	1.73	83.8	9600	7200
	.05	1.64	88.5	10100	7570
	.06	1.57	92.5	10800	7950
↓	.08	1.50	96.8	11100	8300
.086	.10	1.40	103.5	11850	8900
.099	0	>3.0 *	48.2	7350	3600
↑	.01	2.1	69	10500	5150
	.02	1.95	74.2	11250	5520
	.03	1.78	81.5	12350	6050
	.04	1.73	83.8	12700	6220
	.05	1.64	88.5	13420	6570
	.06	1.57	92.5	14000	6850
↓	.08	1.50	96.8	14700	7200
.099	.10	1.40	103.5	15700	7700

$$W = \frac{\sigma_{ALLOW}\, t^2}{.0645} \times 10^3 = 114.5\,\sigma_{ALLOW}$$
$$y = .75\, W \times 10^{-6}$$
} $t = .086$

$$W = 152\,\sigma_{ALLOW}$$
$$y = .49\, W \times 10^{-6}$$
} $t = .099$

** REF 3 "STRESS CONCENTRATION DESIGN FACTORS" FIG. 58

* ASSUMED ~ THEORETICALLY $Y = \infty$

ATTACHMENT 2

MINUTES

NOL SAFETY VERIFICATION TEST FAILURE INVESTIGATION

Sept. 24, 1971

ATTENDEES:

C. R. Murdock	EH/GE
T. J. Graves	EP431
E. D. Metcalf	SN/Boeing
L. G. Davis	ES221
D. T. Lackard	PG
R. D. Wolford	BxA
T. Elink-Schuurman	MSC/NB5/GE
Mario J. Falbo	EP43
B. J. Miller	SN
E. L. Weeks	EH2
L. R. Lewis	BxA

Did not attend — Quality

Introduction — E. L. Weeks

Synopsis of Problem

Failure occurred during Safety Verification Tests on 2 flight type base plates and safe/arm assemblies. The safe/arm plate was coined and the HE in the Housing was shattered. The base plates and the coined safe/arm slides were presented for examination. Bendix stated these parts were made to the proto/qual/flight drawings. The drawing for the safe/arm slides used in the previous 25 verification tests is different than the proto/qual/flight drawing.

Recommended Plan — L. Lewis

The BxA recommended plan was distributed by Mr. Lewis (see attachment 1).

An investigation into the causes of failure has been initiated. Differences between the NOL test slides used in preliminary NOL tests, the slides used in the Safety Verification Tests (Original BxA prototype slides) and original Qual/Flight slides were described and summarized below.

NOL test slides	Original Proto. Slides	Original Qual/Flight Slides
.020 - .030 rad. in.cavity	.005 rad.	.005 rad.
Heat treat - H1025	Annealed	H1025

Attachment 2 presents analyses of properties and characteristics of these differences.

NOL Tests to date — R. Wolford

The Safety Verification test conditions (9/16/71 tests) and earlier NOL tests were described and test hardware presented. Photos of Safety Verification Test failures were available for review.

Further tests --

A test was then conducted using an original qual/flight type slide in the NOL base plate assembly to verify that the problem was in the slide and not the test set-up. The slide coined during the test. Subsequent evaluation of both the test slide drawing versus the flight drawing had revealed the strain relief radius .025 ± .005 called out on the test slide drawing was not transferred to the flight drawing. The RTV was removed from test slides and the radius measured .020 - .030 inches. The RTV was removed from flight slides and the radius was measured to be less than .005 inches.

Additional review of the log books had revealed that the prototype slides were not heat-treated although the process was specified on the drawing. The material was in the 17-4 PH Cond. A annealed condition instead of the specified Condition H-1025. Bendix stated the test slides and the qual and flight slides were heat-treated properly. The log books state the process was accomplished. Rockwell hardness tests were conducted on all slides. From Rockwell hardness tests heat treat condition could not be verified.

To determine the effect of heat-treatment on the performance of the slides, two slides with the proper heat treat and the improper radius were tested. These slides did not coin but were considerably bowed.

For information, Mr. Miller made the following comment:

MSC Safety noted for information of those present the purpose of the Safety Verification Test in which the failure occurred. The test was designed to show that if all the other series safety features were by-passed, the EDC firing into the safe/arm slide in the safe or resafe positions would not detonate the HE.

The Bendix proposed redesign calls for a radius of .040 ± .005 and to control the depth of the hole to a greater tolerance; i.e., .09 + .000 - .005 instead of ± .01.

Further discussion continued on BxA analysis of cavity corner radius and effect of heat treat (See Attachment 2).

Mr. Falbo commented on difference in RTV appearance between original proto. and qual/flight slides. Qual/flight slides have "spongy", more porous RTV. BxA will remove vendor applied RTV on original qual/flight slides and rework to proper RTV application. L. Lewis noted BxA had DR'd qual/flight slides as RTV was not flush to .010 below surface as required.

Discussion continued on Program Plan.

1. Future Tests at NOL.

10 tests with original qual/flight slides or properly heat treated original proto-slides will be conducted at NOL. All slides will therefore have small radius (.005 or less), but be heat treated to H1025. Two firings have been successfully completed. These tests are for verification of personnel safety in proto. field tests. It is planned that proto. field tests will utilize original qual/flight slides or properly heat treated proto. slides. Verification of heat treat will be by BxA inspection and surveillance at vendor's plant. This plan is contingent on successful completion of tests at NOL.

Since these tests will expand original qual/flight slides, qual and flight slides will be redesigned and remade. Redesign will consist of following:

1. .040 ± .005 rad. at bottom of cavity.
2. Better control of cavity depth (.090 ± .005
3. Heat treat to H1025.

If any failure occurs in the NOL tests of small radius and heat treated slides (i.e., 10 test firings) all slides for proto., qual. and flight will be remade to redesign configuration.

Summarying Test Plan for remaining NOL tests.

8 original qual/flight slides

2 have been fired to date successfully, these two have "spongy" RTV.

6 to be tested will have reworked RTV.

2 original proto. slides - reheat treated to H1025 condition.

T. Graves noted that these last two tests will be Safety Verification tests with 1/8 lb. and 6 lb. charges, but with NOL test fixture configuration EDC housing and baseplates.

2 final Safety Verification Tests will then be conducted with redesigned qual/flight slides and full-up base plate assemblies (baseplate and EDC housings).

T. Graves noted that for this series of NOL tests HNS machinings from qual. and flight H.E. charge manufacturing would be used to press test charges. Sensitivity of these charges will be verified by test firings of small sample charges.

L. Lewis noted that the baseplates for these Safety Verification Tests will be vendors spares. One will be to prototype configuration and the other to qual/flight configuration.

Discussion followed of criteria for success or failure of NOL tests. T. Graves noted that by contractual agreement between MSC and NOL success is defined by no cracks, breaks or spalling of test slides.

Schedule for test slide delivery to NOL.

28 Sept. - 6 original qual/flight slides with reworked RTV.

4 Oct. - 2 reworked original proto slides (re-heat treated).

L. Lewis described BxA plan for report of this investigation and corrective plan. Report will include:

1. Description of failure.
2. BxA Investigations and Analyses.
3. Causes of Failure.
4. Corrective Action.
5. Plan, with Options.

Report will be in ATM form and transmitted to MSC. A draft will be completed by 1 Oct. 1971 including all results to that date. Final report will be completed by 11 Oct. 1971.

DR action was discussed. No DR was written at NOL. For rework and replacement of hardware at BxA a DR was written, basically to require heat-treat of original proto. slides. Resolution of NOL failure will be documented by meeting minutes and ATM.

E. Weeks summarized by the following questions put forth to the attendees.

Q. Is the investigation considered to be complete? Have the causes been pinned down?

A. Agreed.

Q. Is the plan of action for utilizing original proto. slides, reheat treated, and original qual/flight slides in proto. units satisfactory?

A. Yes, contingent on successful completion of the 10 test firings at NOL.

Q. Is the redesign of qual/flight slides for qual. and flight units (.040 rad., control of cavity depth, verification of heat treat) satisfactory?

A. Agreed.

Q. Are two additional firings of the slide redesign for qual and flight in full-up baseplate assembly sufficient for final Safety Verification?

A. Agreed.

Summary

All parties agree that the failure investigation presented, redesign and rework plans, and additional safety test plans presented are acceptable.

Concurrences by:

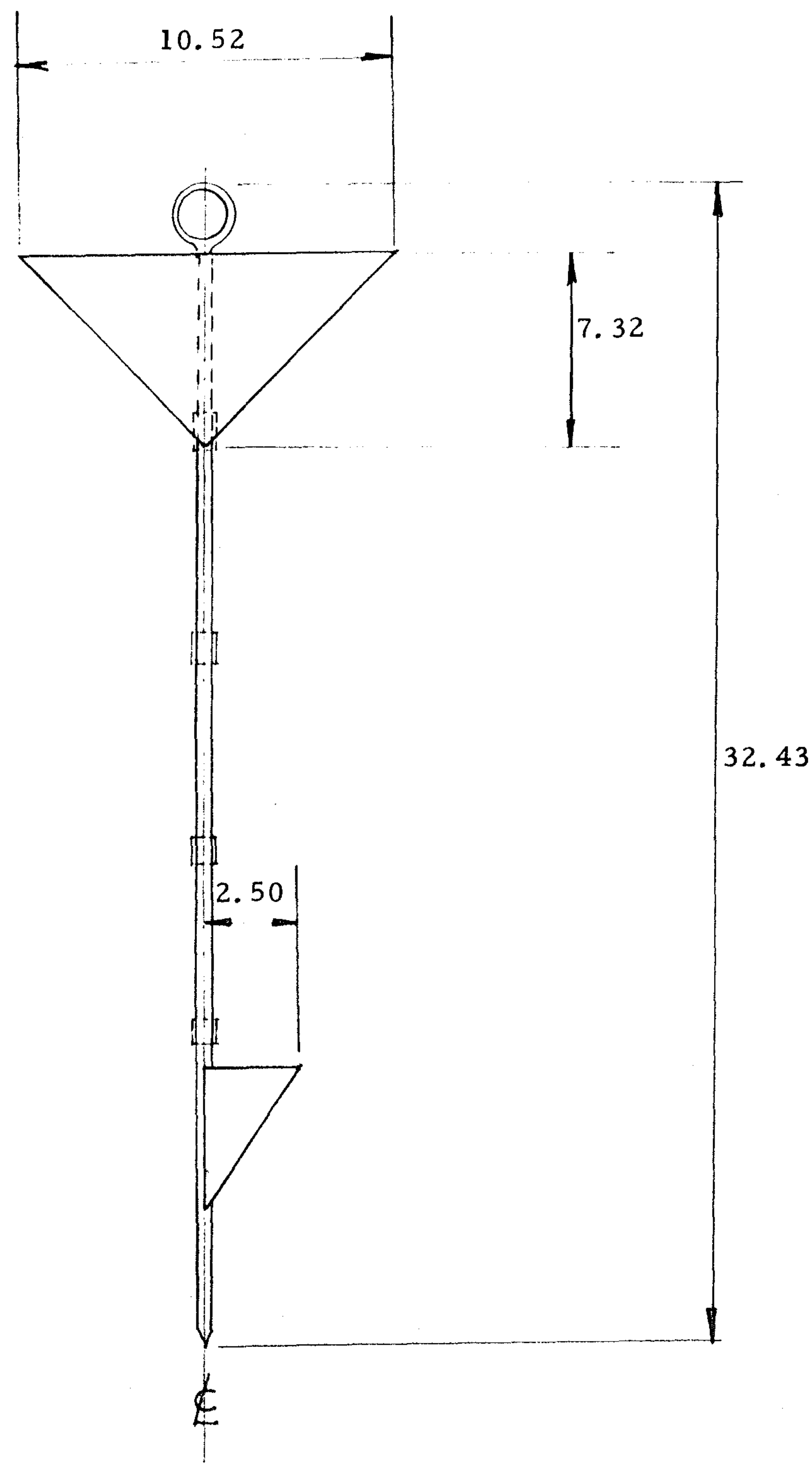
ASPO D. J. Lockard P/G
Safety B. J. Miller SN
PPD F. Graves
Reliability [illegible] ES MSC/ND-5/GE
Structures F. G. Davis ES12

Signed by:

BxA L. Lewis
LSPO E. L. Weeks

Attachments:

1. Bendix Recommended Plan
2. Properties of Stainless Steel Used in Slides



Stowed Length 8.74

Geophone Flag Assembly

2348520

Internal
Memorandum

ATTACHMENT 3

Bendix Aerospace Systems Division

Ann Arbor Michigan

Date Sept. 20, 1971 Letter No. 71-982-381

To L. R. Lewis

From W. R. Hamill

Subject Critical Dimension Comparison of Test and Prototype Slide

---

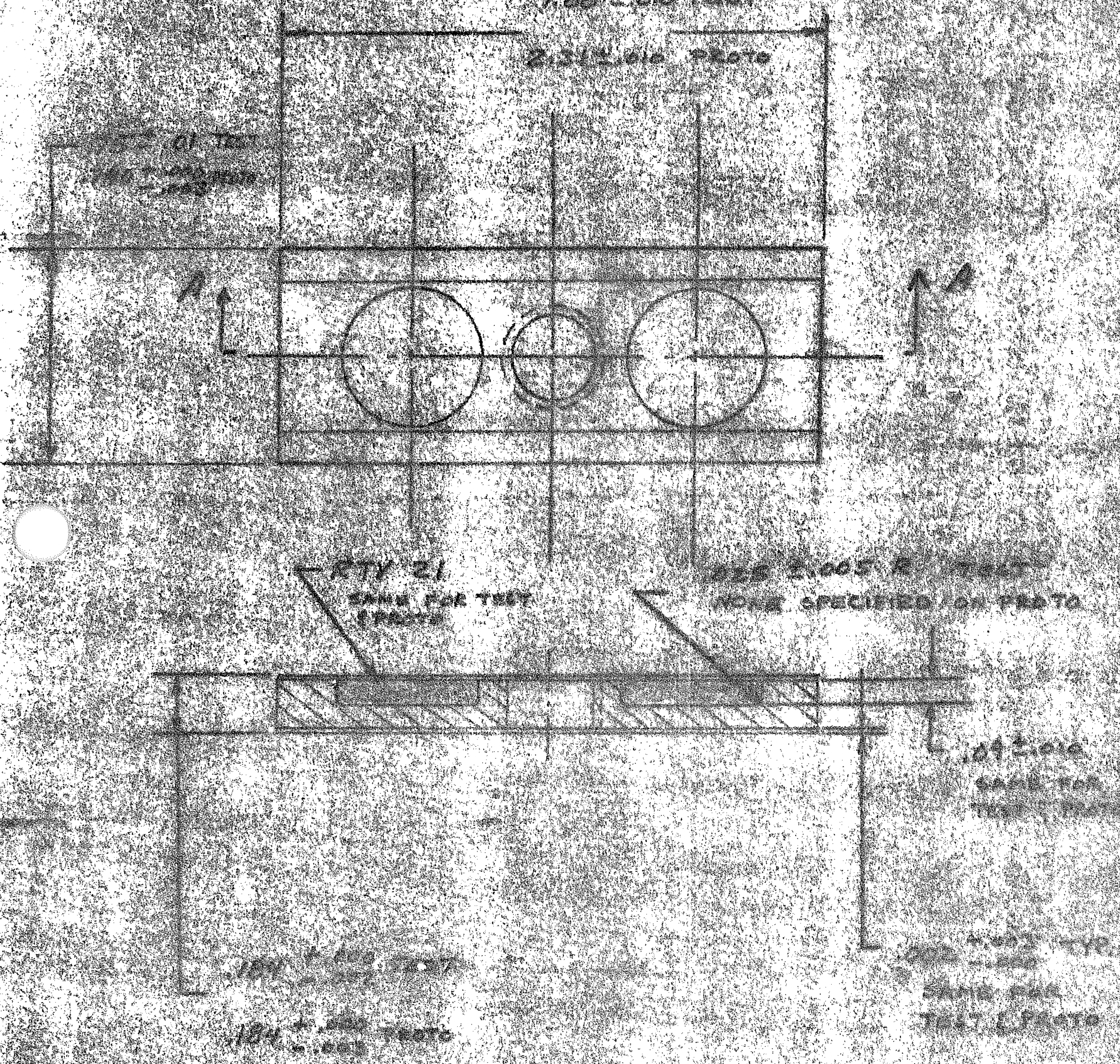
The attached sketch compares the critical dimensions of the Test Slide and the prototype slide. The only significant difference exists between the radius callout at the base of the RTV cavity. A .025 $\pm$ .005 radius was specified for the test slide while none was specified on the prototype slide. This difference could cause a significant stress concentration condition.

The addition of the teflon coating on the proto slide would subject the slide to a processing temperature of 375 to 500°F for a period not exceeding 50 minutes. This temperature exposure will not effect the properties of the steel.

Warren R. Hamill

WRH;cac

CRITICAL DIMENSION COMPARISON OF TEST SLIDE & PROTO SLIDE



NOTE: SURFACE COATED WITH TEFLON 954-101 PER [illegible] ON PROTO SLIDE; ONLY PASSIVATED FINISH ON TEST SLIDE.

MATL - STAINLESS STEEL 17-4PH COND. H1025 PER AMS 5643 FOR TEST & PROTO SLIDE.

Internal Memorandum

ATTACHMENT 4

Bendix Aerospace Systems Division

Ann Arbor, Michigan

Date 16 February 1972 Letter No. 72-210-085

To Lynn R. Lewis, Manager, LSPE, Dept. 982

From R. S. Johnson, Jr., AeroMechanical Engineering Department 210

Subject Safe/Arm Slide (2348593) - Metallurgical Investigation

Reference: BxA Internal Memorandum, 72-210-070, Safe/Arm Slide

INTRODUCTION

The material used in the subject slide (17-4 PH stainless steel) is normally supplied in the solution treated condition. The metallurgical structure of 17-4PH in this condition is essentially untempered martensite and, consequently, possesses very low ductility and limited formability. It is therefore necessary to age temper the material to give it greater ductility and toughness. This is accomplished through a precipitation heat treatment in the temperature range of 900°F to 1150°F for one to four hours, depending on the properties desired. For the part in question, the heat treating schedule was four hours at 1025° ±10°F.

When the material is heat-treated in accordance with MIL-H-6875, it is required that the heat treatment be confirmed by proof test of parts or tensile tests of representative specimens from the same heat or melt of material and heat treated with a production load (Reference paragraph 6.4.1). For critical parts, metallographic examination is also desirable.

The composition of the 17-4PH was specified to be in accordance with AMS 5643, as follows:

Element	Min. (wt. %)	Max. (wt. %)
Carbon	-	0.07
Manganese	-	1.00
Silicon	-	1.00
Phosphorous	-	0.040
Sulfur	-	0.030
Chromium	15.50	17.50
Nickel	3.00	5.00
Columbium + Tantalum	5 x C	0.45
Copper	3.00	5.00

The subject parts were accompanied by representative tensile specimens when exposed to the age tempering (precipitation) heat treatment. Following heat treatment these specimens were subjected to tensile test and metallographic examination.

DISCUSSION

A. Metallographic Examination

Considering steel, in general, a martensitic structure is a metastable phase formed by a transformation of the austenite structure below the M_s temperature (temperature at which the transformation of austenite to martensite starts during cooling). It is an interstitial supersaturated solid solution of carbon in iron having a body-centered tetragonal crystal lattice. This means, in effect, that solute atoms (carbon) are located at some of the lattice points of the solvent (iron), the distribution being random. Its microstructure is characterized by an acicular, or needle-like, pattern. Since it is a supersaturated solution, it is a metastable phase, hence easily modified by a change in temperature or stress.

Austenite is a solid solution of one or more elements in face-centered cubic iron. Unless otherwise designated, the solute is generally assumed to be carbon.

Martensite is the hardest and strongest structure of steel, but, as mentioned earlier, is so lacking in toughness that it is seldom, or never, used without a subsequent heat treatment known as TEMPERING. This is accomplished by heating the unstable martensite to a temperature sufficient for phase changes to occur, but below the austenite range. Stress relief and recovery of ductility are brought about through precipitation of iron carbide from the supersaturated, unstable solid solution (martensite), and through diffusion and coalescence of the carbide while the tempering operation proceeds. The carbide precipitated during tempering takes the form of a fine dispersion of more or less spheroidal particles, the size of which depends on the time-temperature conditions of the tempering operation. When the tempering operation is terminated, the resultant microstructure is a dispersion of carbide in a body-centered iron(ferrite) matrix.

The preceeding discussion covers the pertinent areas of ferrous metallurgy which can now be related to the precipitation hardening stainless steels. Some modification of the discussion is necessary as applied to the stainless steels.

The formation of the martensite phase when 17-4PH is cooled to below 90°F follows the same principles as previously mentioned. In addition, the chromium, nickel, columbium, tantalum and copper are retained in solid solution.

The remaining elements, manganese, silicon, phosphorus and sulfur are present for reasons not directly related to the precipitation process. Sulfur is present as an impurity. By itself, sulfur will form a sulfide, FeS, and freeze out along the grain boundaries in the metallurgical structure. The presence of iron sulfide renders steel brittle at elevated temperatures. However, when manganese is added to the alloy, manganese having a strong affinity for sulfur, forms the insoluble manganese sulfide (MnS), which either passes into the slag or is found as well distributed inclusions throughout the structure. Phosphorus in small amounts dissolves in the ferrite and increases strength and hardness. Silicon acts as a deoxidizing agent during the melting and refining of the alloy. It also contributes to increasing the strength of the alloy and promotes grain growth control; although, the latter is better controlled by the use of aluminum. Steels that are deoxidized with silicon exhibit coarse grained character, which is apparent in Figure 1. They also exhibit less toughness than fine-grained steels.

Copper does not form a carbide, and is only soluble in ferrite to about 0.8%. This limited solubility is employed to improve strength properties by precipitation hardening and to improve machinability. The resistance to atmospheric corrosion is also increased by the use of a combination of copper, phosphorus and chromium.

Figure 1 is a photomicrograph of as-received solution treated 17-4PH stainless steel taken at a magnification of 200X. The microstructure is predominantly martensitic with a small amount of retained austenite present. The acicular or needle-like structure characteristic of martensite is faintly discernable, although not well resolved at this magnification. The microstructure shown in Figure 1 is typical of what one would expect in a martensitic structure prior to age tempering by a precipitation heat treatment.

When the aging treatment is applied the following events take place: rather than iron carbide precipitating from the supersaturated solid solution, chromium carbide, columbium carbide, tantalum carbide, and complex carbides of iron, chromium and nickel are precipitated. Ordinarily, since chromium has a greater affinity for carbon than iron, chromium carbides would form. These carbides, characteristically precipitate along the grain boundaries, thus depleting the matrix of chromium and greatly reducing the corrosion resistance of the alloy. This also renders the alloy susceptible to intergranular corrosion. In order to overcome this difficulty, elements are added to the alloy which have a greater affinity for carbon than does chromium. In the case of the 17-4PH alloy, these elements are columbium and tantalum. The carbides formed by these two elements also possess the characteristics of preferential precipitation within the grains rather than along grain boundaries. Thus, most of the chromium is tied-up within the grains rather than precipitated in carbide form, which minimizes the loss of corrosion resistance characteristics. The complex carbides of iron, chromium and nickel can be found both within the grain and along the grain boundaries. Nickel does not ordinarily form a carbide, however, it commonly replaces some of the chromium without any changes in the crystalline structure of the carbide. The columbium and tantalum additions to the alloy also serve a secondary function. They act to suppress the tendency to overage hence any reasonable overshoot in aging time is not critical.

Figure 2 is a photomicrograph of 17-4PH stainless steel which has been solution treated and age-tempered at 1025^{o}F for 4 hours. The dark areas represent the dispersed martensite phase, while the light areas indicate the ferritic matrix. There is also no discernable retained austenite. During the age tempering process, the retained austenite decomposes or transforms to bainite. This structure has a feathery or acicular appearance and consists of ferrite and carbides. Its hardness range will overlap that of the tempered martensitic structures. Since the original amount of retained austenite was quite small, no appreciable affects on mechanical properties will be observed.

Figure 2 is representative of what one would expect to see in the microstructure of 17-4PH stainless steel when solution treated and age-tempered.

B. Mechanical Properties

The load-elongation curves, obtained when tensile tests were run on the test specimens heat treated with the Safe/Arm Slides, are shown in enclosures 1, 2 and 3. The yield point and ultimate (or fracture) point are identified on each curve. The yield and ultimate tensile strengths for each specimen are identified in the following table:

Specimen	Area of Test Sect. (in^2)	Load in Pounds Yield	Load in Pounds Ultimate	Strength in PSI Yield	Strength in PSI Ultimate
A1 (Enclosure 1)	0.092	15,100	15,150	164,130	164,674
A2 (Enclosure 2)	0.0935	15,250	15,375	163,102	164,438
B1 (Enclosure 3)	0.0935	15,300	15,330	163,636	163,957
B2 (Enclosure 3)	0.0935	15,125	15,330	161,765	163,957

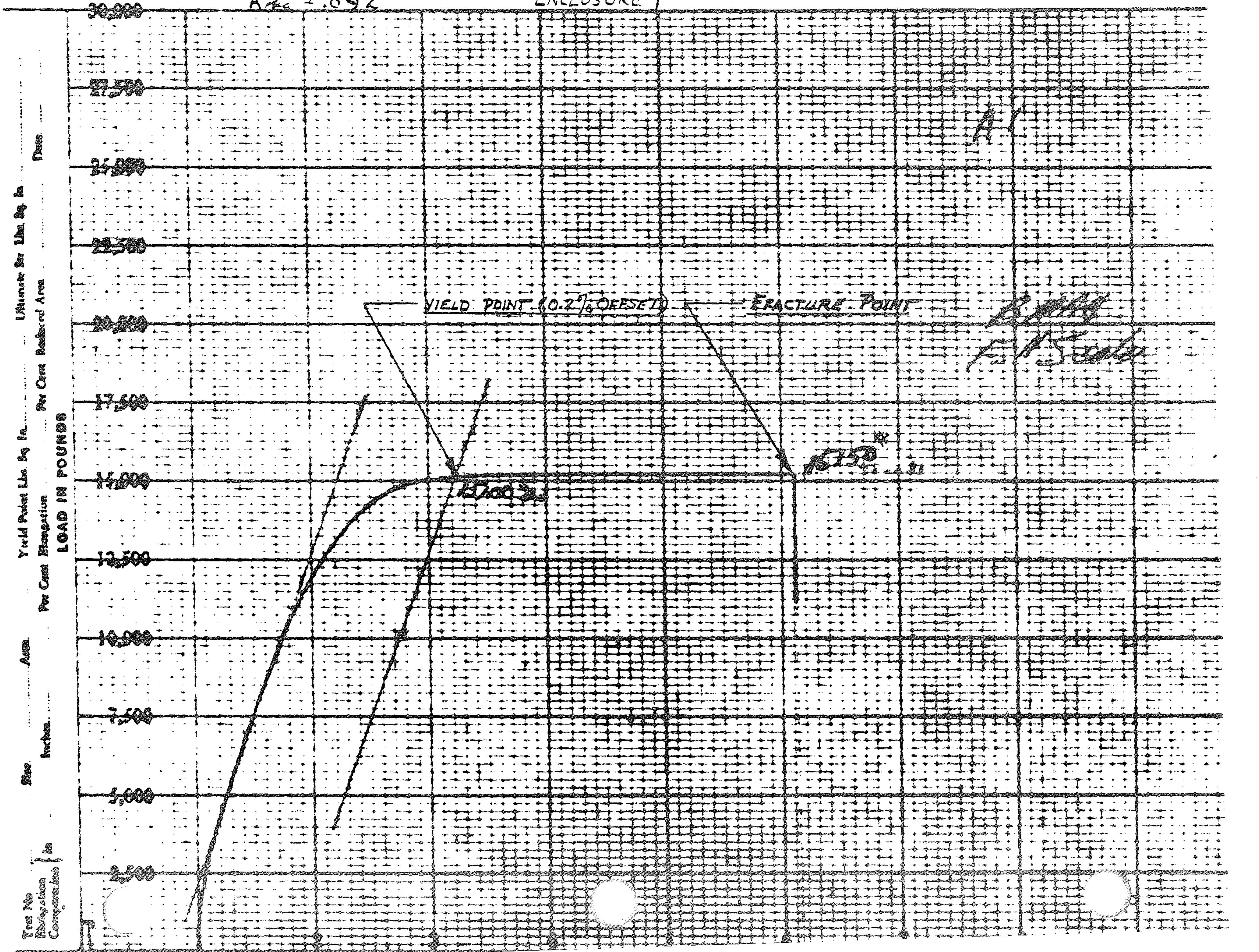
CONCLUSIONS

On the basis of the microstructure observed in Figures 1 and 2, and on the basis of the tensile test results obtained from enclosures 1,2 and 3, the lot of manufactured parts considered during this investigation have been satisfactorily heat treated.

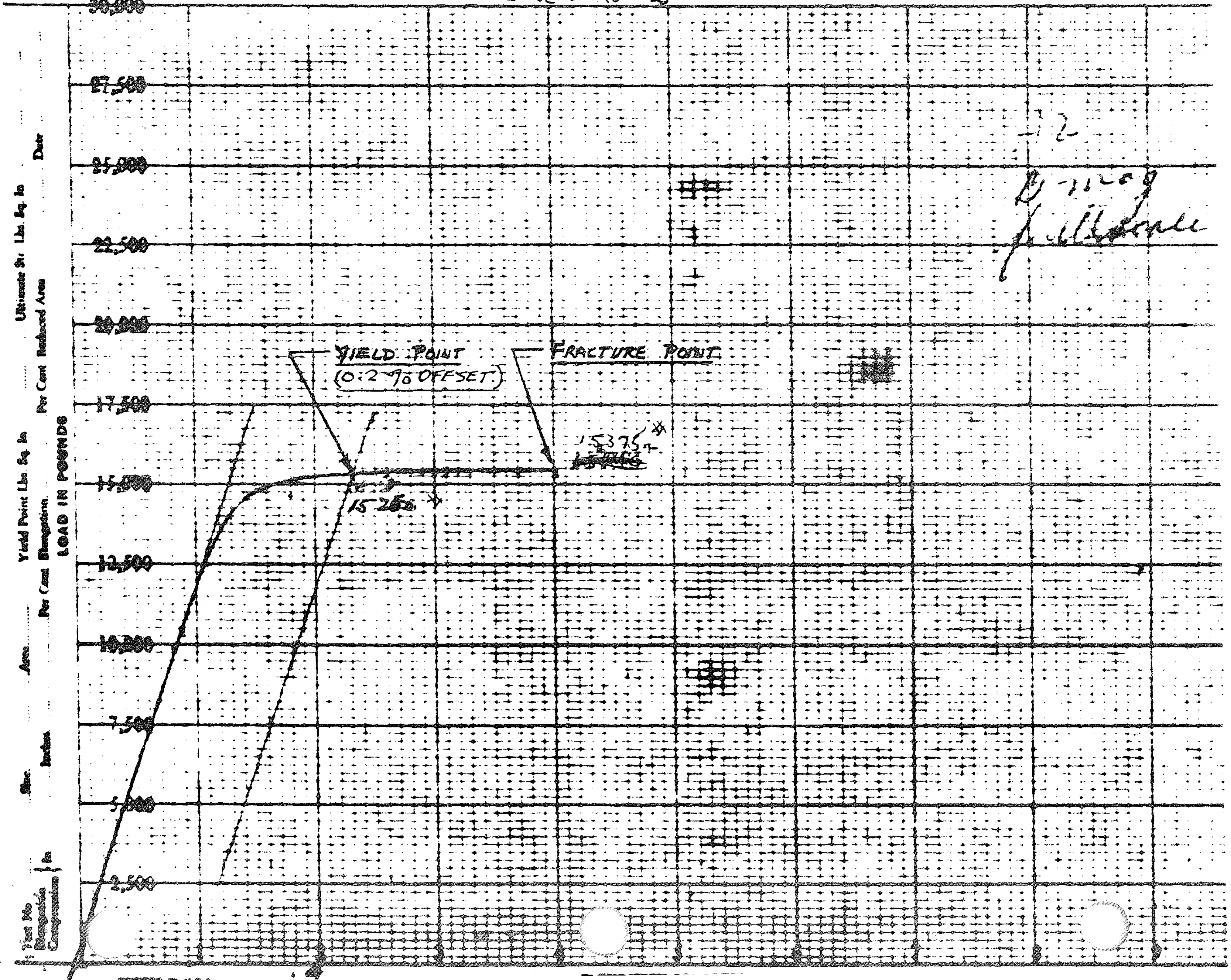
Dr. R. S. Johnson, Jr

RSJ/rd
cc: D. Dewhirst, W. Hamill, R. Johnston, M. Katz, J. Simo

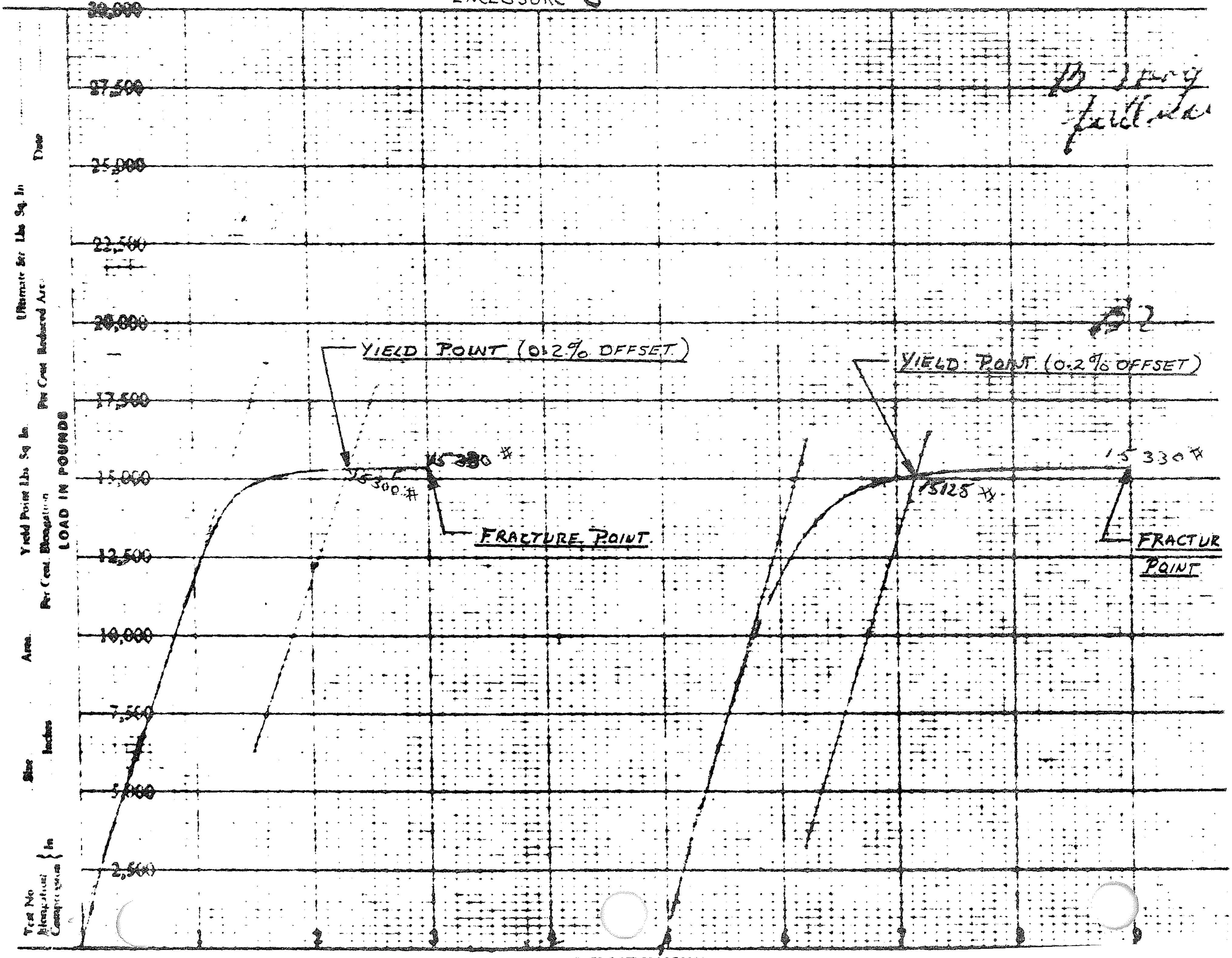
Area = .092 ENCLOSURE 1



ENCLOSURE 2


30,000
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
LOAD IN POUNDS
Test No.
Elongation
Compression
In.
Size
Inches
Area
Per Cent Elongation
Yield Point Lbs. Sq. In.
Per Cent Reduced Area
Ultimate St. Lbs. Sq. In.
Date
YIELD POINT
(0.2 % OFFSET)
FRACTURE POINT
15375
15250

ENCLOSURE 3



30,000
27,500
25,000
22,500
20,000
17,500
15,000
12,500
10,000
7,500
5,000
2,500
LOAD IN POUNDS
Date
Ultimate Str Lbs Sq In
Per Cent Reduced Area
Yield Point Lbs Sq In
Per Cent Elongation
Area
Size Inches
Test No
YIELD POINT (0.2% OFFSET)
15300 #
15 330 #
FRACTURE POINT
YIELD POINT (0.2% OFFSET)
15125 #
15 330 #
FRACTUR POINT

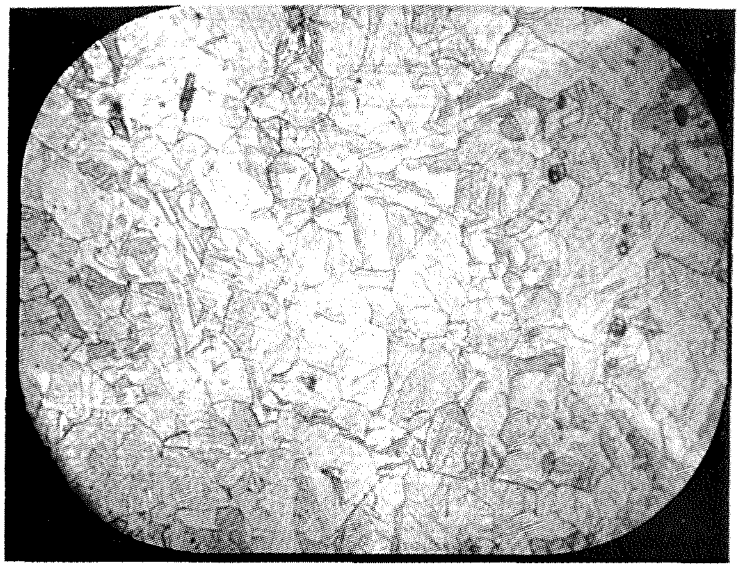


FIGURE 1 Photomicrograph showing microstructure of 17-4PH stainless steel, solution heat treated (200X).

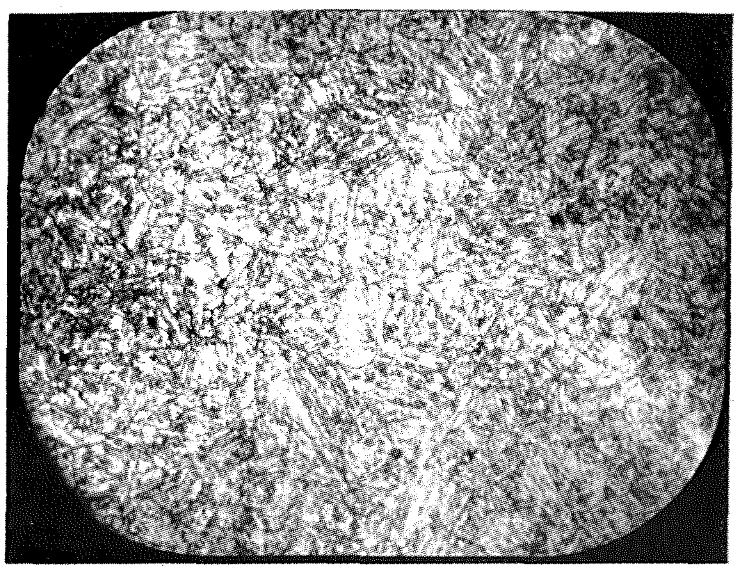
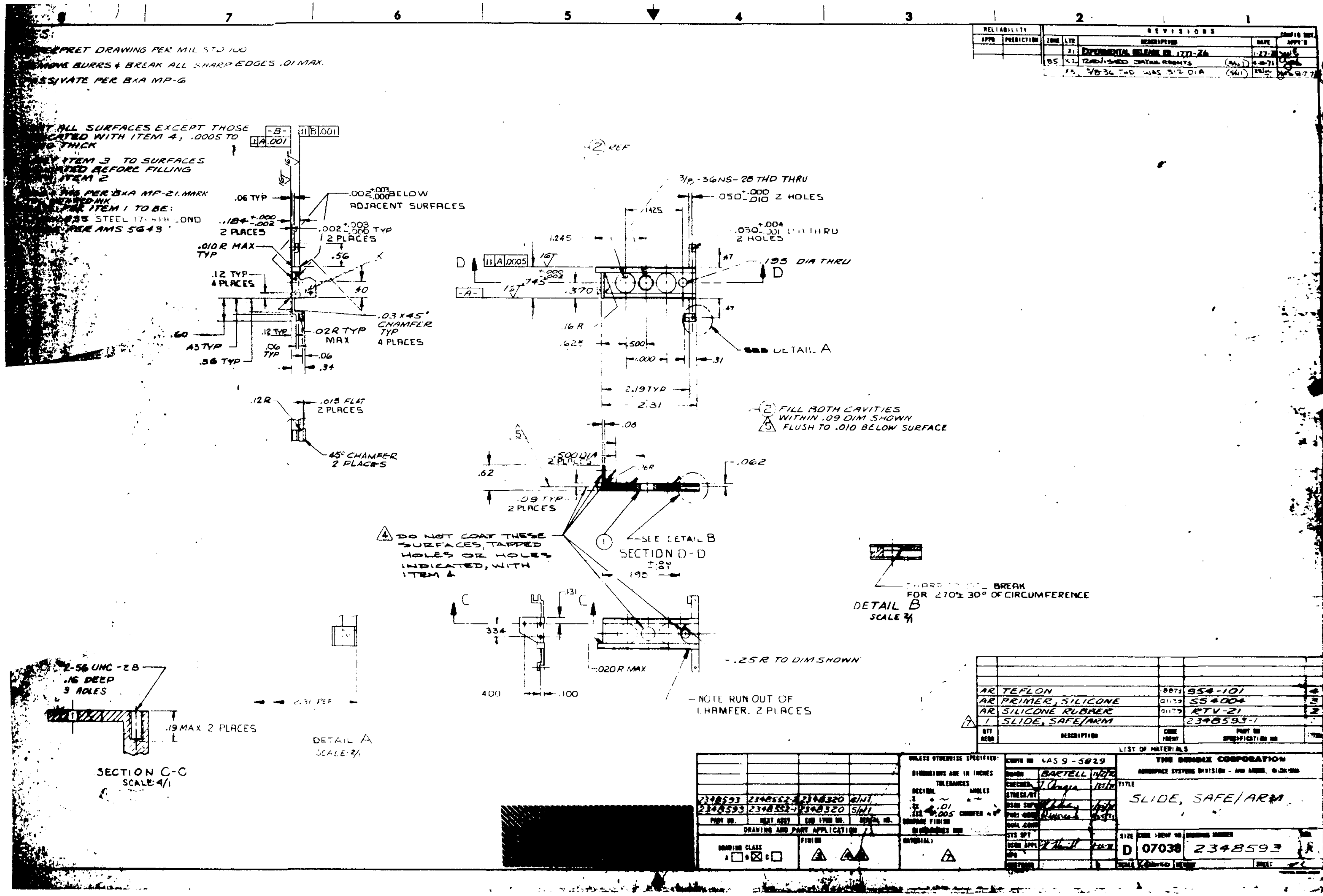


FIGURE 2 Photomicrograph showing microstructure of 17-4PH stainless steel, solution heat treated and artifically aged at 1025 $^{\circ}$F for 4 hours (200X).



ATTACHMENT 5

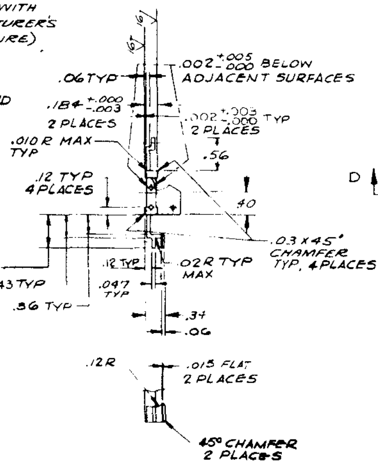
ATM-1088

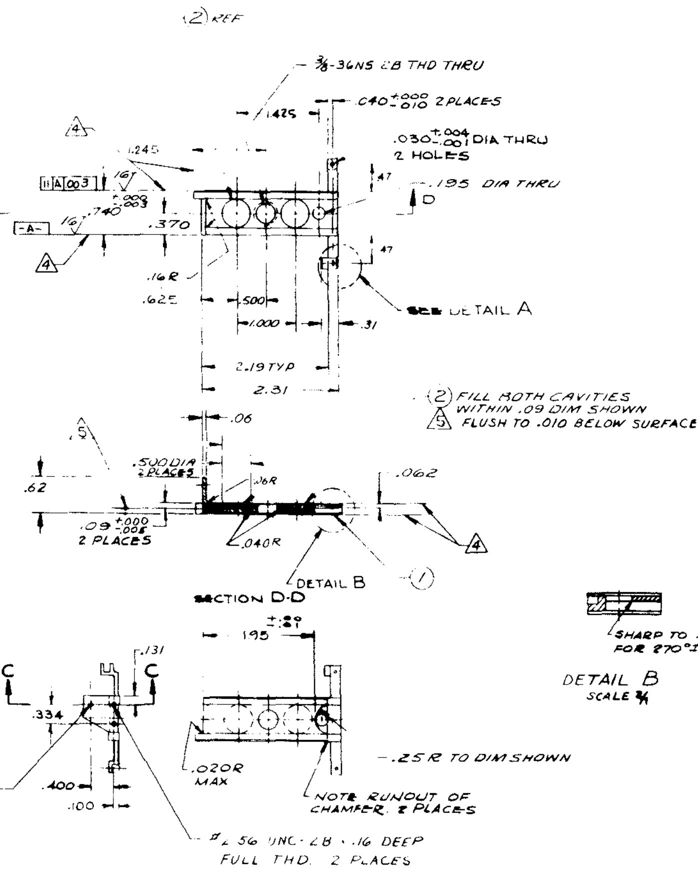
NOTES:

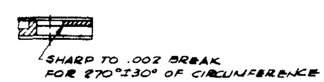
1. INTERPRET DRAWING PER MIL STD 100
2. REMOVE BURRS & BREAK ALL SHARP EDGES .01 MAX
3. (△) PASSIVATE PER BXA MP-6
4. (△) COAT ONLY SURFACES INDICATED WITH ITEM 4 (.0005 TO .0010 THK) PER MFR'S RECOMMENDED PROCEDURE. DIMENSIONS APPLY AFTER COATING
5. (△) APPLY ITEM 3 TO SURFACES INDICATED BEFORE FILLING WITH ITEM 2. (FOLLOW MANUFACTURER'S RECOMMENDED PROCEDURE)
6. BAG & TAG PER BXA MP-21
7. (△) MATL. FOR ITEM 1 TO BE: STAINLESS STEEL 17-4PH COND H-1025 PER AMS 5643
8. UNLESS OTHERWISE SPECIFIED, ALL INSIDE CORNER RADII TO BE .005R MAX

RELIABILITY	
APPD	PREDICTION

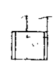
ZONE	LTR	DESCRIPTION	DATE	CONFIG MGT APPV'D
	–	STANDARD RELEASE 1777		
	A	ADD NOTE 8, CHG 3-2.61M TG 3/8 THD		
	B	ADD & CHG DIM F/O		
	C	CHG IN ...		
	D	ADD △ TO F/D		



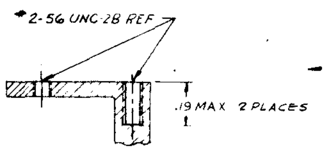




DETAIL B
SCALE 3/1



DETAIL A
SCALE 2/1



SECTION C-C
SCALE 4/1

QTY REQD	DESCRIPTION	CODE IDENT	PART OR SPECIFICATION NO.	ITEM
AR	TEFLON	8873	954-103 (BLACK)	4
AR	PRIMER, SILICONE	01139	SS 4004	3
AR	SILICONE RUBBER	01139	RTV-21	2
1	SLIDE, SAFE/ARM (△)		2348593-1	1

LIST OF MATERIALS

PART NO.	NEXT ASSY	END ITEM NO.	SERIAL NO.
2348593	2348592	2348320	S/N ...

DRAWING AND PART APPLICATION

DRAWING CLASS A ☐ B ☒ C ☐ — FINISH (△) (△)(△)

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES. TOLERANCES: DECIMAL .X ± ~ ; .XX ± .01 ; .XXX ± .005; ANGLES ± ~ ; CHAMFER ± 5°. SURFACE FINISH MICROINCHES RHR 63. MATERIAL: (△)

[redacted]

CONTR NO. NAS 9-5829

DRAWN	BARTELL	11/2/
CHECKED		
STRESS/WT		
DSGN SUPV		
PROJ ENGR		
QUAL CONT		
SYS SPT		
DSGN APPL		
MFG		
CUSTOMER		

THE BENDIX CORPORATION
AEROSPACE SYSTEMS DIVISION - ANN ARBOR, MICHIGAN

TITLE: SLIDE, SAFE/ARM

SIZE	CODE IDENT NO.	DRAWING NUMBER	REV
D	07038	2348593	D

SCALE ✓ NOTED — WEIGHT — SHEET of 1

ATTACHMENT 6

ATM-1088