EVALUATION OF CADMIUM PLATING SYSTEMS FOR

HYDROGEN EMBRITTLEMENT

THE BOEING COMPANY
MASD, WICHITA BRANCH

19 SEP[redacted]62, ~~B3-4657~~
~~ARTC~~ PROJE[redacted] 6-61

This was accomplished by the Aerospace Research and Testing Committee under the sponsorship of Boeing Wichita.

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The Bendix Corporation - South Bend, Indiana

The Boeing Company - Seattle (Transport Division)

The Boeing Company - Wichita (Military Aircraft Systems Division)

Cleveland Pneumatic Tool Company - Cleveland, Ohio

Douglas Aircraft Company - Santa Monica, California

General Dynamics/Fort Worth - Fort Worth, Texas

Grumman Aircraft Engineering Corporation - Bethpage, L.I., New York

Kaman Aircraft Corporation - Bloomfield, Connecticut

Lockheed-California Company - Burbank, California

Lockheed-Georgia Company - Marietta, Georgia

Lockheed Aircraft Corporation-Missiles & Space Co. - Palo Alto, Calif.

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INTRODUCTION

In December 1959 ARTC established Project 13-59, "Standardization of Methods of Testing for Hydrogen Embrittlement". Considerable testing was performed to determine a standard specimen configuration for evaluating plating systems for hydrogen embrittlement. The results of this program are summarized in Boeing-Wichita Report D3-3655. This work demonstrated that the .003 inch root radius notched tensile specimen configuration was adequately sensitive to the effects of hydrogen and was preferentially recommended. It was also concluded that the Douglas static ring test indicated embrittlement with reliability.

ARTC Project 6-61, "Evaluation of Cadmium Plating Systems for Hydrogen Embrittlement" was established in August 1961 to evaluate various available plating systems believed to be suitable for high strength steels using the types of specimens found satisfactory by Project 13-59. This report, which describes the work accomplished, completes Project 6-61.

SUMMARY

A cooperative testing program to compare the hydrogen embrittlement characteristics of several available plating systems was conducted by ARTC Project 6-61. Eleven plating systems that showed promise of being non-embrittling were selected for evaluation. The plating systems evaluated approached the problem of reduction of hydrogen entry and/or subsequent removal from steel by:

(1) Porous deposits and subsequent baking to remove and/or distribute hydrogen absorbed.

(2) High efficiency (low hydrogen producing bath) with subsequent baking.

(3) Suppression of hydrogen formation by additives.

(4) Organic baths with no hydrogen formation.

(5) Organo brush plating baths.

The .003 inch notch root radius tensile specimen and the Douglas ring specimen evaluated in ARTC 13-59 were selected to test and evaluate the plating systems. The same heat of material evaluated in ARTC 13-59 was used for fabricating test specimens for this project. The notched tensile specimens were heat treated and fabricated by Boeing-Wichita. Ring specimens were heat treated and fabricated by Douglas-Santa Monica.

The program was arranged so that the plating and testing of the notched tensile specimens was accomplished by different ARTC participants. The objective was to provide good comparison and demonstrate the practical usage of the test methods. The test grips and the alignment procedure for the sustained load notched tensile test was shown to produce the specified minimum bending stress. All testing of ring specimens by the stressed ring method was performed by Douglas-Santa Monica. The cadmium plating of ring and notched tensile specimens for evaluation of the individual plating systems was identical insofar as possible.

The sustained load notched tensile test appeared to be more sensitive to the relative degree of hydrogen embrittlement than the stressed ring test. The plating systems evaluated by both test methods were grouped for comparison and are presented as part of the Discussion of Results.

PROCEDURE

Selection Of Plating Systems To Be Evaluated

In June 1961, questionnaires were issued to ARTC members requesting information as to the plating systems which were then being used for plating cadmium. It was also requested that members suggest plating systems that might be non embrittling and indicate a willingness to participate in plating and testing. The Summary of Replies to the questionnaire was circulated with ARTC-61-99 in July 1961. The most promising plating systems were selected for testing and circulated to ARTC members who had agreed to participate. A total of eleven plating systems was finalized for testing and plating of test specimens was assigned. A condensed detail procedure for each plating system selected is given in Appendix C.

Materials and Test Methods

AISI 4340, per MIL-S-5000A AMD 2, aircraft quality, transverse physicals, hot rolled steel bars, 3 inch square and of random length, heat number 3350427 (surplus from ARTC Project 13-59) was used to fabricate specimens for this project. The chemical composition furnished by the supplier and Boeing analyses are given in Table XXVII of Appendix A. Due to segregation and some difference in properties inherent in bar stock, specimen location was randomized as shown in Figure 1 of Appendix A.

ARTC 13-59 suggested both the .003 inch root radius notched tensile sustained load test and the Douglas stressed ring test indicated high sensitivity to embrittlement with reasonable scatter of test results. These two test methods were selected for evaluating the plating systems for hydrogen embrittlement characteristics. To obtain uniformity of test specimens all the notched tensile specimens were fabricated by Boeing-Wichita and all the ring specimens were fabricated by Douglas-Santa Monica. Details of the specimen configurations and test apparatus are presented in Appendix D. Heat treatment of each type of test specimen is described in Table XXVI of Appendix A. Standard tensile tests on unnotched and notched tensile specimens were performed to establish that the desired physical conditions of the material were obtained. The results are presented in Table I, II and III of Appendix A.

Testing

Test work was performed by eight(1) of the participating companies in Project 6-61. The numerical results were tabulated as shown in Appendix A and the data were plotted as shown in Figure 1 through 14.

(1) Part of the testing assigned to Boeing-Wichita was accomplished by Boeing Aerospace Division due to unavailability of test apparatus.

Static Notched Tensile Tests

Prior to stressing of plated notched tensile specimens the creep rupture machines were aligned to produce a bending stress on a test cell of less than 3% of axial load in the range of 73,000 to 163,000 psi. The calibration test cells and grip adapter assemblies were identical to those used in ARTC Project 13-59. The calibration procedure, a sketch of the adapter grip assembly, and a compilation of the various participating companies test results are presented in Appendix B.

As only ten specimens were plated for testing of each plating sytem, a step loading procedure was performed to approximate the lower critical stress level. The step loading procedure consisted of loading a specimen at approximately 150 KSI and stressing for 10 - 20 hours and if no failure occurred, the specimen was reloaded at a stress 20 - 25 KSI higher and held an additional 10 - 20 hours. This increase in stress was continued until fracture occurred.

The remaining test specimens were to be tested at a constant stress. However, a few participants step loaded additional specimens and the data is presented in Appendix A. Sustained load testing was continued on the remaining specimens to at least 100 hours or failure except at least one specimen was carried to 200 hours. It was optional to each participant to extend the test time further. It was desired to obtain a curve of Failure Time versus Stress with most emphasis placed on obtaining the lower critical stress level.

Douglas Stressed Ring Tests

All the ring specimens plated by the various systems were returned to Douglas-Santa Monica for testing. The ring specimens were stressed by protecting the ring with a rubber pad and slowly squeezing in a vice until the stress bar could just be slipped into the ring. Subsequently the vice was relaxed slowly. Four stress levels were obtained by varying the length of the stress bar. The stress levels were 240, 210, 170 and 130 KSI.

Not all of the 15 rings plated with each plating system were tested. Three rings from each system were stressed to approximately 240 KSI with the proper stress bar. If any of the rings failed (fractured) within 500 hours, three more rings of the specific system were stressed at the next lower level, approximately 210 KSI. This procedure was repeated for each stress level. If the first three rings stressed at 240 KSI did not fail prior to 500 hours, two additional rings were stressed at the same level, making a total of five rings tested at 240 KSI. If all five stressed rings passed this level no more rings were stressed at a lower level. The assumption was that rings passing at one level would not have failed at a lower level.

PLATING AND TESTING PROGRAM ASSIGNMENTS

Notched Tensile Specimen Group	Plating System Evaluated	Ring & Notched Tensile Specimens Plated By	Notched Tensile Specimens Tested By	Ring Specimens Tested By	Test Report Notched Tensile Specimen
A	Boeing - BAC 5718	Boeing-Wichita	Convair-Fort Worth	Douglas-Calif.	Letter Report 27 July 1962
B	Bendix - PS 1008	Bendix-South Bend	Kaman-Bloomfield	Douglas-Calif.	Letter Report 20 June 1962
C	Dalic Brush	Bendix-South Bend	Convair-Fort Worth	Douglas-Calif.	Letter Report 27 July 1962
D	Cleveland Pneumatic Tool CPT 8206	Cleveland Pneumatic Tool-Cleveland	Lockheed-Georgia	Ring Specimens were not plated or tested for CPT-8206	Engineering Report VE-508 19 July 1962
E	Douglas-DPS 9.28 K.2 Cyanide Bath	Douglas-California	Lockheed-Missile & Space	Douglas-Calif.	Letter Report 28 May 1962
F	Douglas-DPS 9.28 K.3 Fluorobrate Bath	Douglas-California	Lockheed-Missile & Space	Ring Specimens were not plated or tested for Douglas DPS 9.28 K.3 Fluorobrate Bath	Letter Report 28 May 1962
G	Lockheed-PS 491g Type II Class B	Lockheed-California	Grumman-Bethpage	Douglas-Calif.	Letter Report 2 August 1962
H	Lockheed-PS 491g Type II Class C	Lockheed-California	Grumman-Bethpage	Douglas-Calif.	Letter Report June 1962
J	Boeing-BAC 5804	Boeing-Renton	Martin-Baltimore	Douglas-Calif.	Letter Report 16 July 1962
K	Grumman-GAEC	Grumman-Bethpage	Boeing-Wichita	Douglas-Calif.	Letter Report 5 July 1962
1 thru 10	NRL-Triethanolamine	Naval Research Lab.	Lockheed-Georgia	Douglas-Calif.	Engineering Report VE-508 19 July 1962
As Listed in Table IV of Appendix A	Unplated	------------------	Boeing-Wichita	-------------	

DISCUSSION OF RESULTS

The results of tensile testing of unnotched tensile specimens agrees with the data obtained in ARTC Project 13-59. The sustained load curve for unplated, as machined, notched tensile specimens established the lower critical stress limit at approximately 240 KSI. Shortly after ARTC Project 6-61 had begun, investigations at Boeing-Wichita indicated that an increase in the lower critical stress limit of test specimens was obtained when plated with the BAC 5718 system. To ascertain if the 23 hours baking at 375°F after plating might be responsible, a group of 10 notched specimens were tensile tested. Five of the notched specimens were tested in the as machined condition and five were tested after a 23 hour bake of 375°F. No significant benefits could be detected. The results are presented in Table II and III of Appendix A. Subsequently, preliminary testing of highly blasted unplated notched tensile specimens indicated that a beneficial effect was obtained from the abrasive blasting. It must be emphasized that only the minimum of investigation was performed and since several variables are involved in abrasive blasting, the amount of benefit was not thoroughly investigated. The three top rated plating systems evaluated in this work have lower critical stress limits in excess of the unplated notched tensile specimens. Beneficial abrasive blasting used by all three may be an explanation for this situation.

Three of the plating systems evaluated did not use abrasive blasting as a preplating treatment. These were Douglas DPS 9.28 K.2 Cyanide - K.3 Fluoborate and Lockheed PS 491g Type II, Class B. It may be noted that the Douglas DPS 9.28 K.2 Cyanide plating system resulted in a lower critical stress level of 225 KSI which is 15 KSI below the observed lower critical stress level of the as machined unplated notched specimens. As a result this system could possibly have been rated higher as a non embrittling plating system.

It was desired to obtain data to establish the lower critical stress level with a reasonable degree of certainty in this work. This was not accomplished in all cases. For the purpose of this work the lower critical stress level is considered the stress level below which failure did not occur and the level at which specimens survived for at least 100 hours. If the data was not available to satisfy this condition then a level was arbitrarily selected approximately 5 KSI below the lowest stress level where failure occurred and this was considered the lower critical stress level.

The effects of step loading on the endurance of plated specimens is not well established. It may be observed that some scatter did occur on the step loaded test specimens. In some cases the step loaded specimens fractured well below the lower critical stress level while others fractured well above this level. For this reason the step loaded data was not considered valid for establishing the lower critical stress level. However, the data for all step loaded specimens are included in Appendix A and at least one step loaded specimen data point was included in each graphic presentation when available.

The primary effort in testing of notched tensile specimens was directed toward establishing the lower critical stress level and only a meager amount of data was obtained for determining the upper critical stress limit. The upper critical stress limit is considered the stress level at or above which a specimen will fracture on loading. As a result the regions of the plotted curves in Figures 1 - 12, where insufficient data is available, are presented as dotted lines.

Limitations On Accuracy Of Results

It should be pointed out that the lower critical stresses indicated on the plots are approximate, not precise, values. There are several reasons for this which will be discussed.

1. The preplate treatment of the specimen, especially sand blasting, affects the notch tensile strength of the specimens due to cold work of the notch root. This appears to increase the lower critical strength.

2. In many cases there were not sufficient specimens to determine one or both of the lower and upper critical stress accurately.

3. In some cases specimens were plated by laboratory set ups while others used production equipment.

4. In a few cases satisfactory plating was not obtained the first time. Specimens were stripped and replated. This appeared to have a detrimental effect even though standard stripping processes were followed.

5. Variables involved in the actual testing. The chart showing bending moments for all tests in Appendix B shows a variation that could affect results by several percent.

6. When the upper and lower critical stresses are well defined, the difference between the two may be a better criterion of the effectiveness of the system in preventing hydrogen embrittlement than the actual value of the lower critical stress.

Even with the above limitations it is believed that the plating systems, as represented by the specimens tested, were fairly evaluated except in a few cases discussed below. The systems can be grouped for comparison as follows, with the approximate lower critical stress in parenthesis.

1. Trioethonolamine (260,000) and BAC 5718 (270,000)
   Very little embrittlement shown. Lower critical stress approximate 10,000 psi below upper critical stress.

2. Lockheed Type II Class C (245,000) and Douglas K.2 Cyanide (225,000)
Only slightly more embrittlement shown than the two under 1, above.

Lower critical stress approximately 20,000 psi below upper critical stress. (K.2 cyanide based on 245,000 psi upper value).

Although the Dalic brush plating appears to be in this class there were not sufficient good points to prove this.

3. Cleveland Pneumatic Tool, CPT 8206 (215,000)
The lower critical stress is quite well defined at 215,000 psi. The upper limit is not well defined. Using 245,000 psi for the upper limit, which is the unplated notch tensile strength, the lower critical stress is 30,000 psi below the upper (which is probably above 245,000).

4. The remaining five plating systems showed lower critical stresses from 185,000 psi down to 65,000 psi. The following notes apply to these systems.

Titanium Cadmium Plating (185,000)

Two sets of specimens were tested. The first set had a lower critical stress of approximate 55,000 psi. It was determined later that these specimens had been stripped 3 times and re-plated by a vendor. A second set was plated in a laboratory. They were stripped once and replated. A lower critical stress of 185,000 psi was obtained on the second set. Baking time 12 hours. In tests, not a part of this project, a lower critical stress between 250,000 and 300,000 psi was indicated with .003 notch radius and baked 23 hours. Further testing and possibly development appears necessary before the process is suitable for 260-280 KSI 4340 steel.

Grumman Non-Aqueous Plating (175,000)

This process was believed to be non-embrittling. However, the results of this test did not indicate this. At the writing of this report no explanation for this difference is available. Further investigation appears warranted.

Lockheed Type II Class B (110,000)

Douglas Fluoborate (65,000)

The fluoborate plating process has been considered relatively non embrittling. On the notch tensile specimens for this project the first attempt at plating did not plate in the notch. Douglas contacted the sponsor on this problem. No material was available for new specimens and Douglas was requested to strip the plating and replate. Whether the stripping and re-plating was responsible for the low values from the specimens we cannot say for sure, but suspect that it had an influence on them. Further investigation of the affect of stripping and replating is needed.

In comparing the results of the notch tensile specimens and the Douglas ring specimens, it should be noted that the ring specimens correctly indicated the most embrittling plating systems but indicated less embrittlement than the notch tensile specimens. For the less embrittling plating systems the ring specimens did not indicate any difference in embrittlement of the eight plating systems. The notch tensile specimens did indicate significant differences. From this series of tests it appears that the ring specimens are considerably less sensitive than the .003 notch specimens. The results of ARTC 13-59 also indicated the ring specimens to be less sensitive than the .003" notch but more sensitive than the .005" notch. The exact significance of these differences in sensitivity cannot be accurately evaluated. However it appears that for comparative evaluation of different plating systems the most sensitive specimen should be used, assuming that it is practical to use.

Of the ten(1) plating systems evaluated by the Douglas stressed ring test only two showed evidence of embrittlement. Those plating systems withstanding a sustained load at 240 KSI for 500 hours were:

Boeing-Wichita	BAC 5718
Bendix-South Bend	Dalic Brush Plating
Naval Research Laboratories	Triethanolamine(not shot-peened)
Naval Research Laboratories	Triethanolamine(shotpeened)
Douglas-California	DPS 9.28,K.2(Cyanide)
Lockheed-California	PS491g, Type II Class C
Boeing-Renton (Transport)	BAC 5804(Cadmium-Titanium)
Grumman-Bethpage	GAEC Non Aqueous

(1) The Naval Research Laboratories Triethanolamine plating system was performed on ring specimens which were shot peened and not shotpeened. Each plating was tested individually.

The two plating systems not withstanding a sustained load of 240 KSI for 500 hours were:

Bendix-South Bend	PS 1008
Lockheed-California	PS 491g Type II Class B

CONCLUSIONS

A. The cooperative test program demonstrated that the sustained load notched tensile test provided a practical method, based on the lower critical stress level, for evaluating the hydrogen embrittlement characteristics of a plating system. It was possible to rank all the plating systems in this work by the lower critical stress level as presented in the Discussion of Results.

B. The processing operations performed in association with some of the plating systems appeared to cause a change in the upper critical stress limit, as defined herein, when compared to the as machined unplated notched tensile specimens.

C. The Douglas stressed ring test was considerably less sensitive in detecting the degree of hydrogen embrittlement of a plating system than the notched tensile test using the .003 inch radius notched specimen.

RECOMMENDATIONS

A. Further investigation should be performed on the Cadmium-Titanium, Grumman GAEC, and Fluoborate plating systems.

B. Investigation should be performed to determine the effects of stripping and replating of specimens.

C. An effort should be made to reduce the eccentricity of the test loading apparatus below the 3% specified.

D. A test procedure should be developed using a greater number of specimens to more accurately establish the embrittlement characteristics of a plating system. The following is a recommended test procedure to accomplish the above:

1. Three unplated notched tensile specimens tested to determine the notched tensile strength.

2. Three notched tensile specimens pre-plate processed but not plated to determine the notched tensile strength of this condition.

3. Seven notched tensile specimens pre-plate processed but not plated to establish hydrogen embrittlement curve of this condition.

4. Use 20 plated specimens as follows:

   Two plated specimens to determine the plated notched tensile strength.

   One plated specimen step loaded to establish approximate lower critical stress level.

   Thirteen plated specimens to establish curve.

   Four plated specimens to be tested at or just below the lower critical stress level established above for a minimum of 200 hours.

TEST RESULTS

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

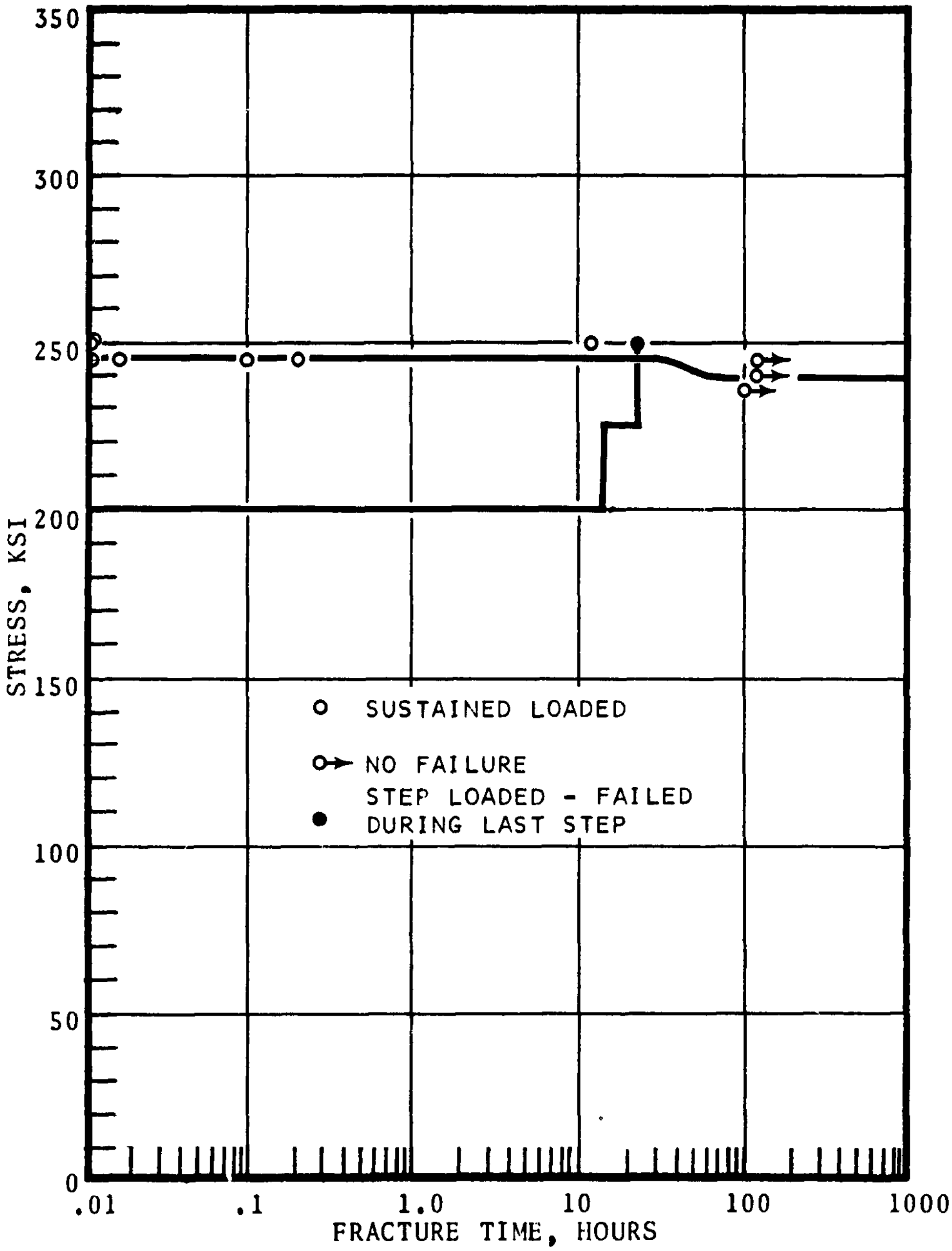

FIGURE 1 - SUSTAINED LOAD - .003 NOTCH - UNPLATED
TESTED BY BOEING-WICHITA

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

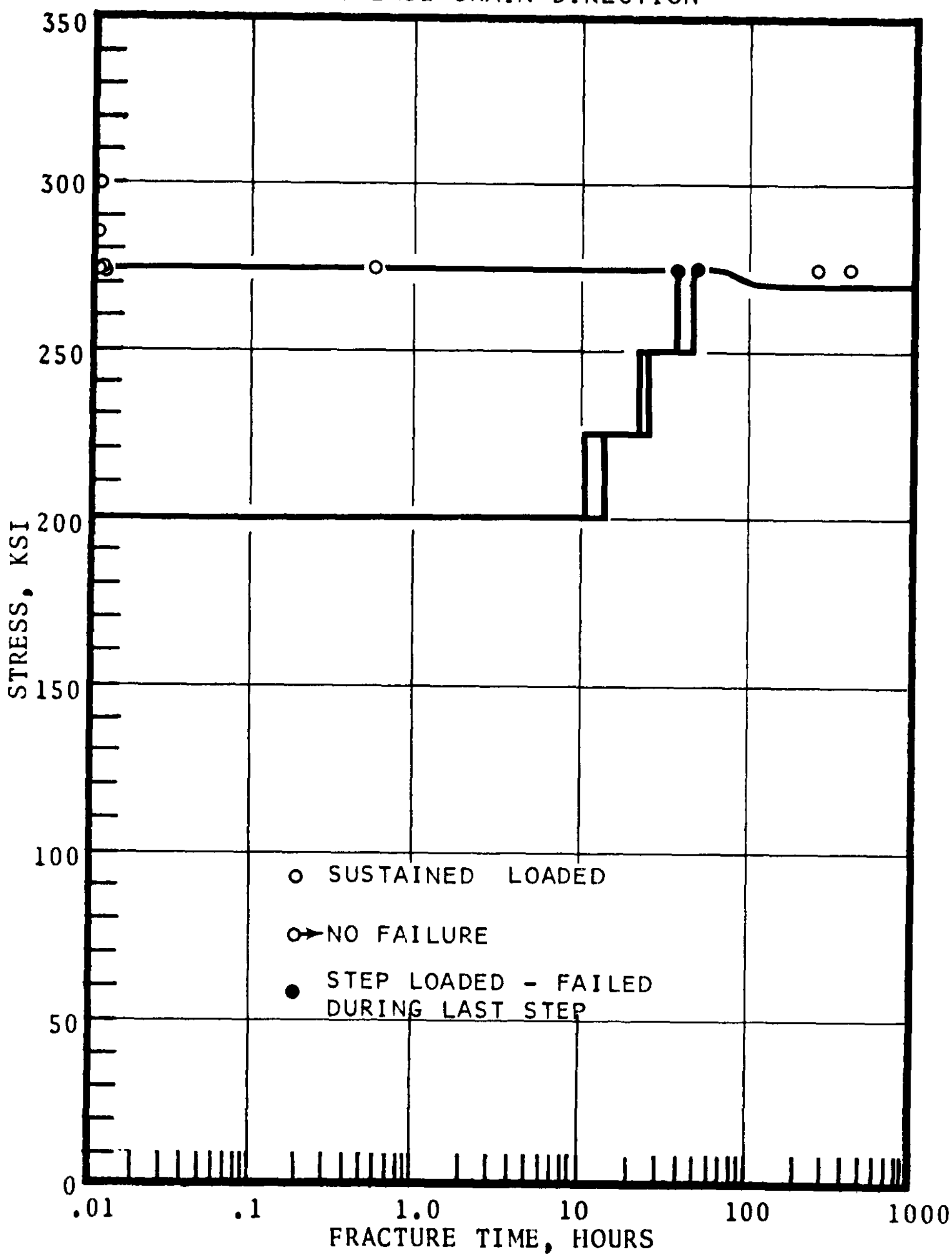

FIGURE 2 - SUSTAINED LOAD - .003 NOTCH - PLATED BY BOEING-WICHITA (BAC 5718) TESTED BY CONVAIR-FORT WORTH

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

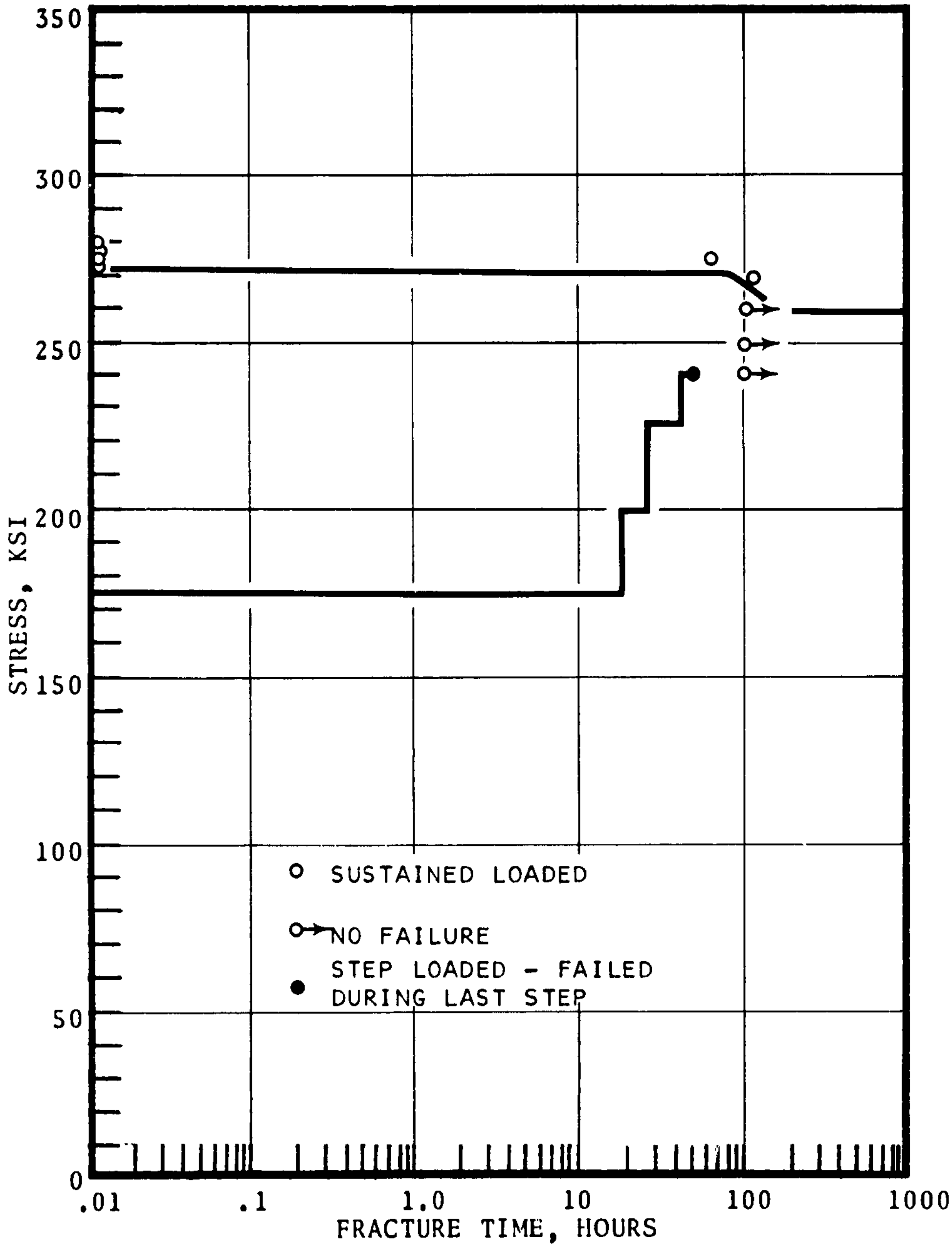

FIGURE 3 - SUSTAINED LOAD - .003 NOTCH - PLATED
BY NAVAL RESEARCH LABORATORY (TRIETHANOLAMINE)
TESTED BY LOCKHEED - GEORGIA

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

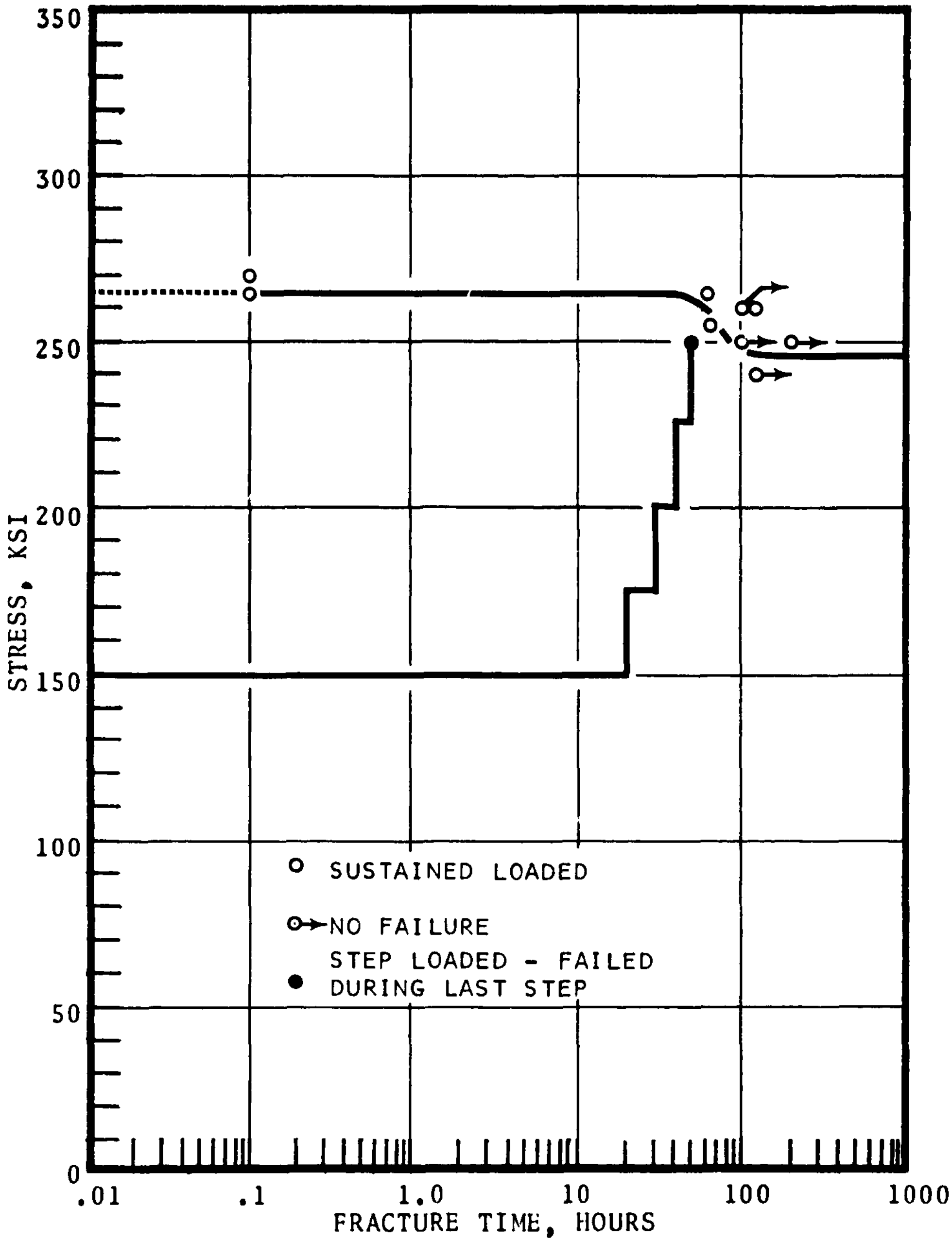

FIGURE 4 - SUSTAINED LOAD - .003 NOTCH - PLATED BY LOCKHEED-BURBANK (PS 491G TYPE II CLASS C) TESTED BY GRUMMAN-BETHPAGE

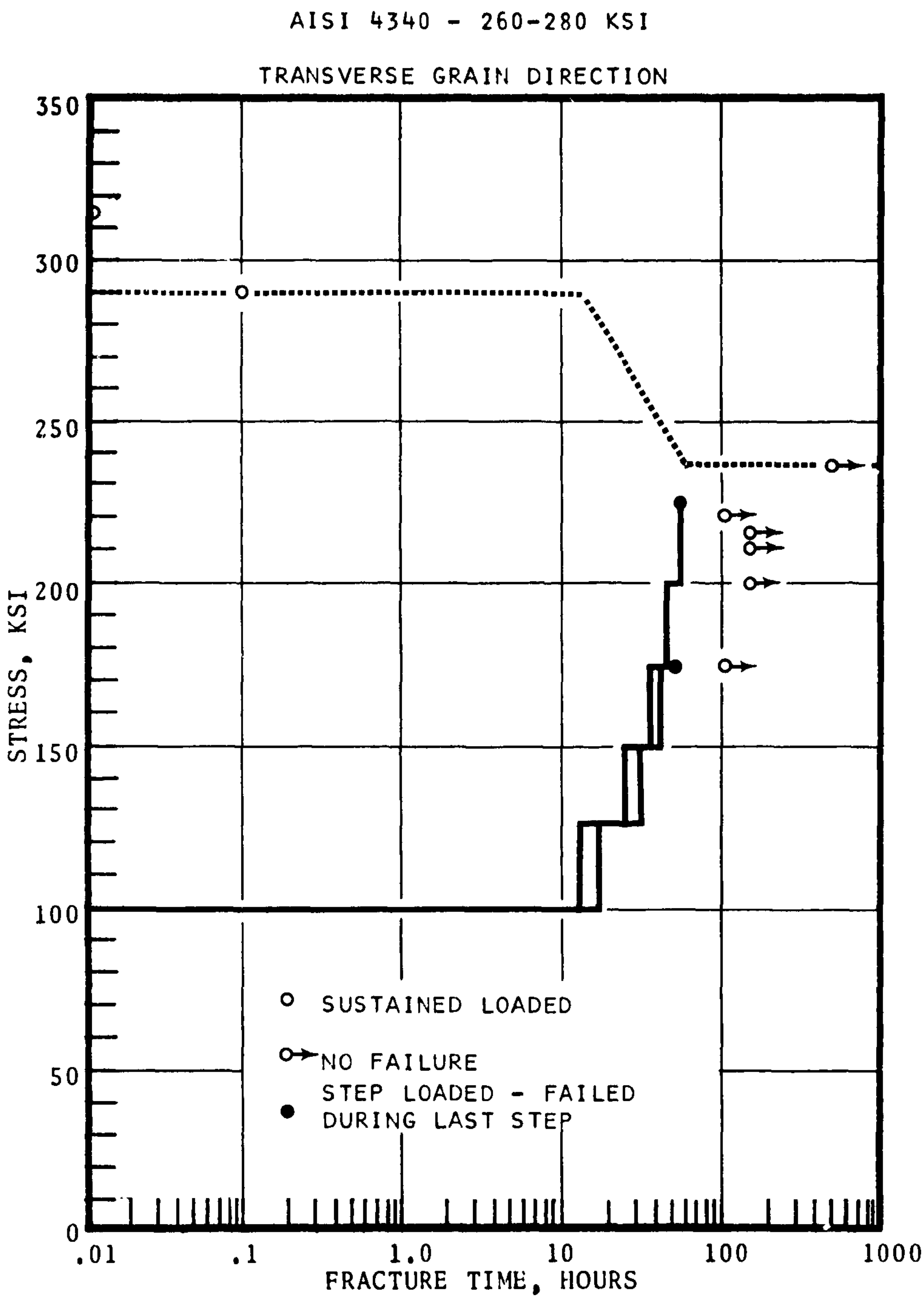

FIGURE 5 - SUSTAINED LOAD - .003 NOTCH - PLATED BY BENDIX - SOUTH BEND (DALIC BRUSH) TESTED BY CONVAIR-FORT WORTH

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

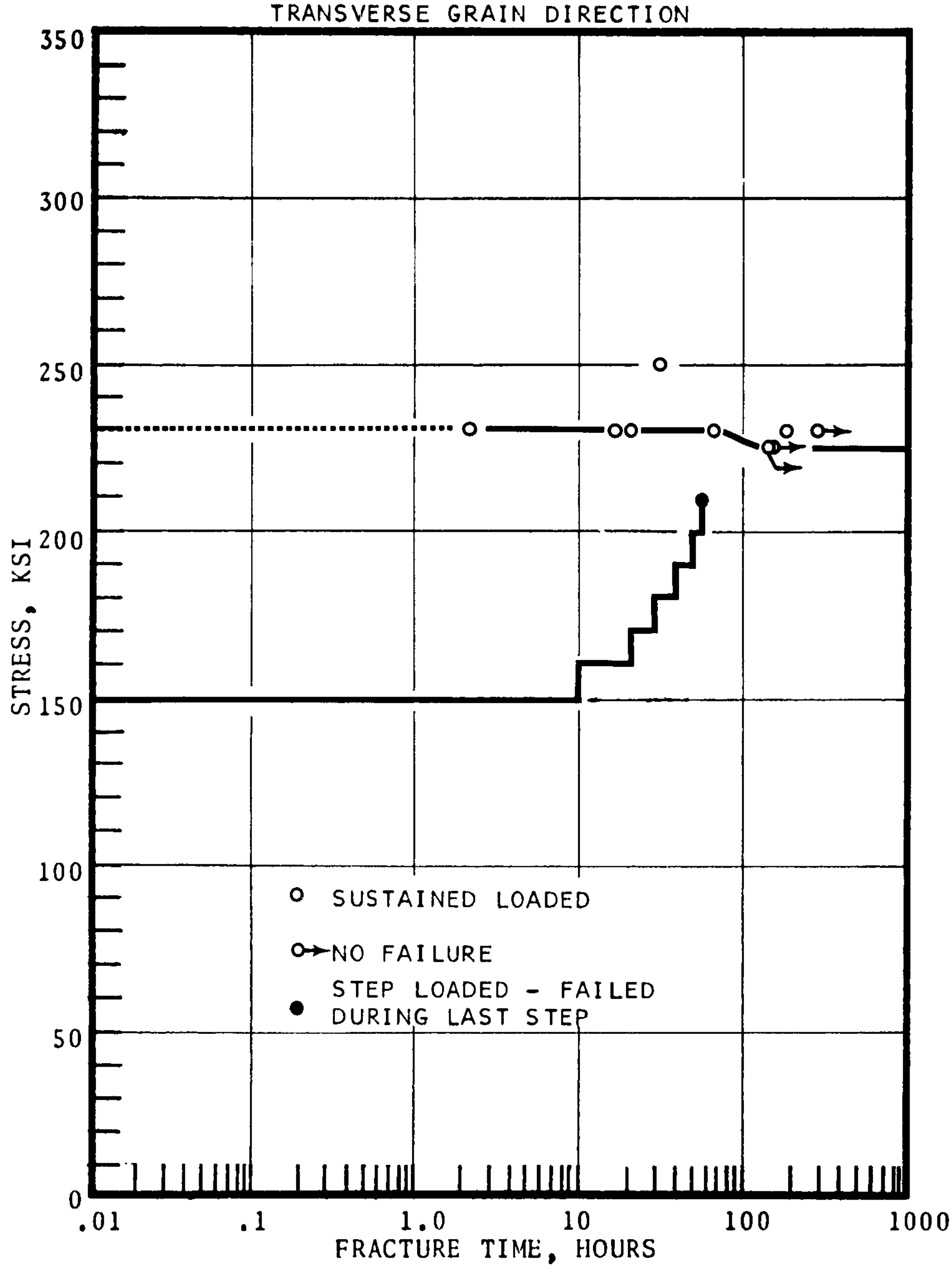

FIGURE 6 - SUSTAINED LOAD - .003 NOTCH - PLATED BY DOUGLAS (DPS-9.28, K.2 CYANIDE) TESTED BY LOCKHEED-MISSILES & SPACE

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

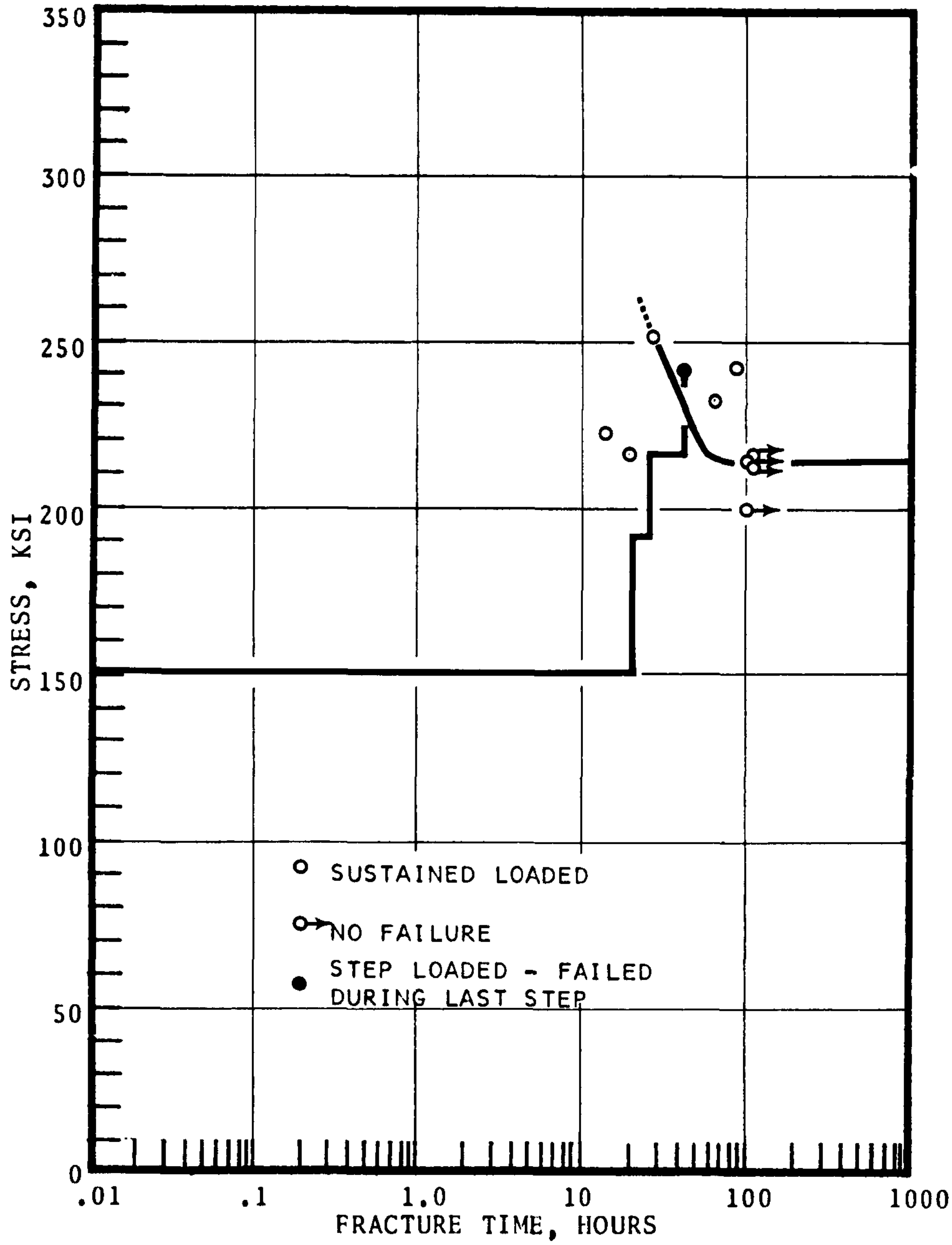

FIGURE 7 - SUSTAINED LOAD - .003 NOTCH - PLATED BY CLEVELAND PNEUMATIC (CPT-8206) TESTED BY LOCKHEED-GEORGIA

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

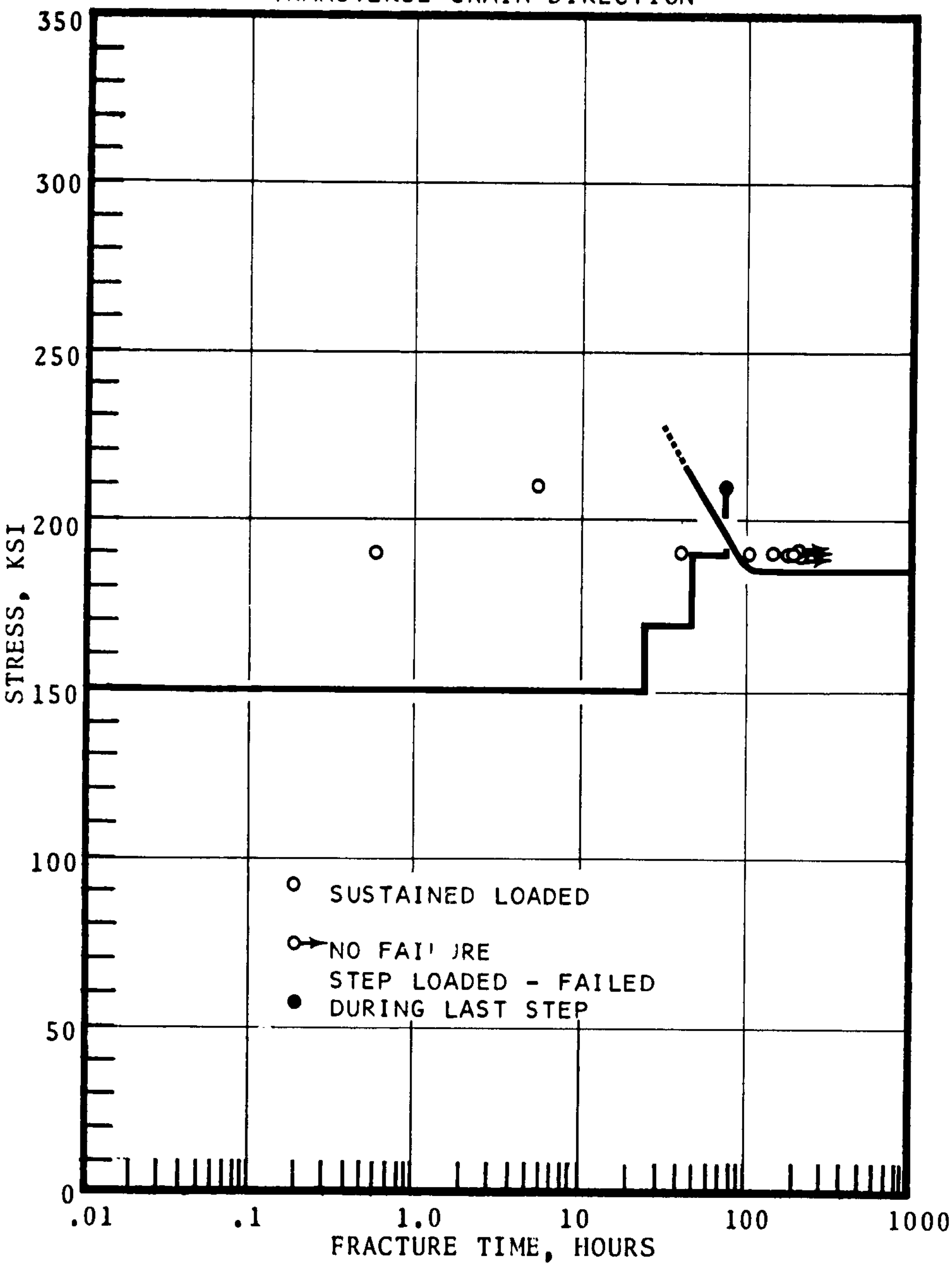

FIGURE 8 - SUSTAINED LOAD - .003 NOTCH - PLATED
BY BOEING-RENTON (CADMIUM-TITANIUM BAC 5804)
TESTED BY MARTIN-BALTIMORE

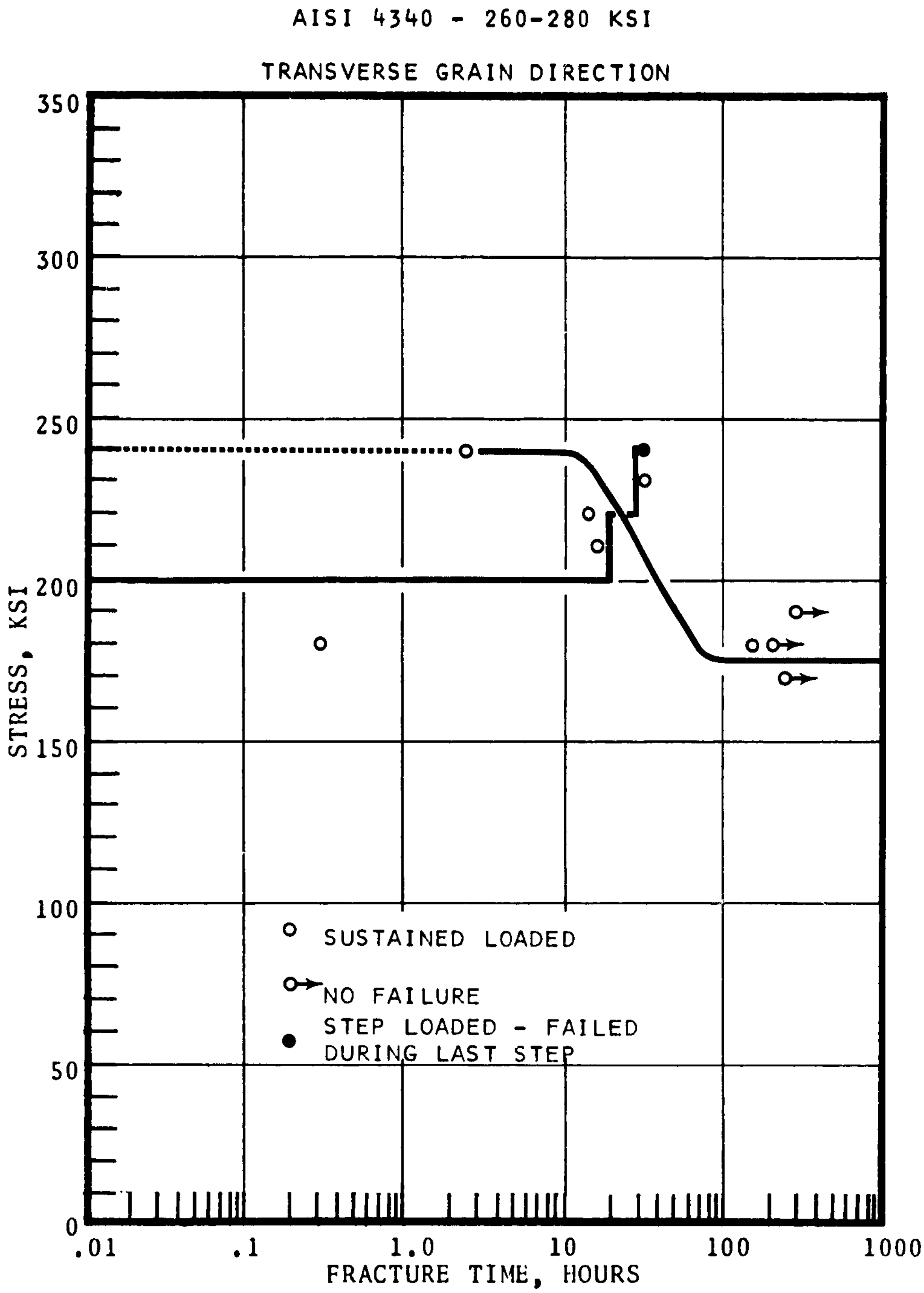

FIGURE 9 - SUSTAINED LOAD - .003 NOTCH - PLATED BY GRUMMAN -BETHPAGE (GAEC NON-AQUEOUS) TESTED BY BOEING-SEATTLE

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

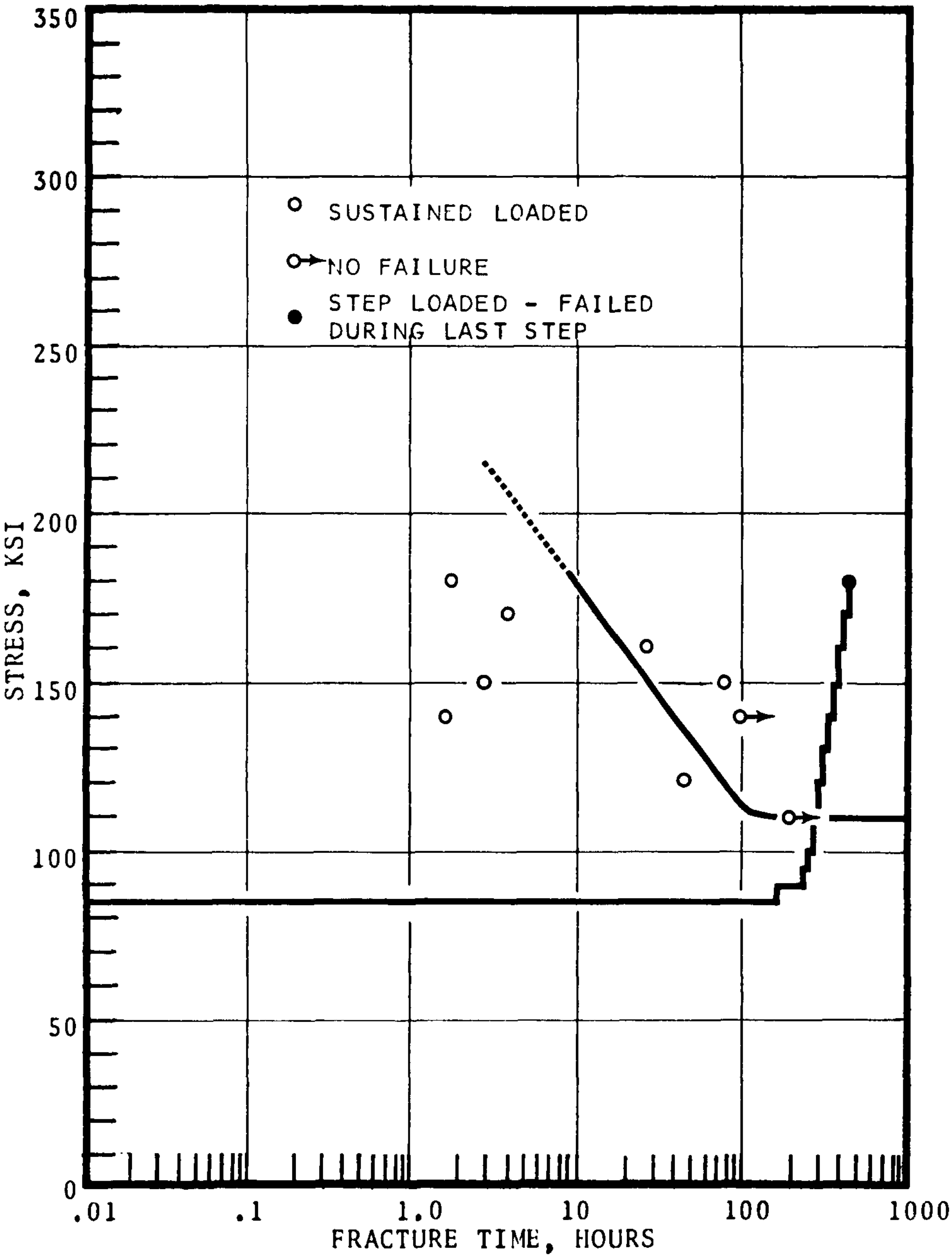

FIGURE 10 - SUSTAINED LOAD - .003 NOTCH - PLATED BY BENDIX - SOUTH BEND (PS 1008) TESTED BY KAMAN - BLOOMFIELD

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

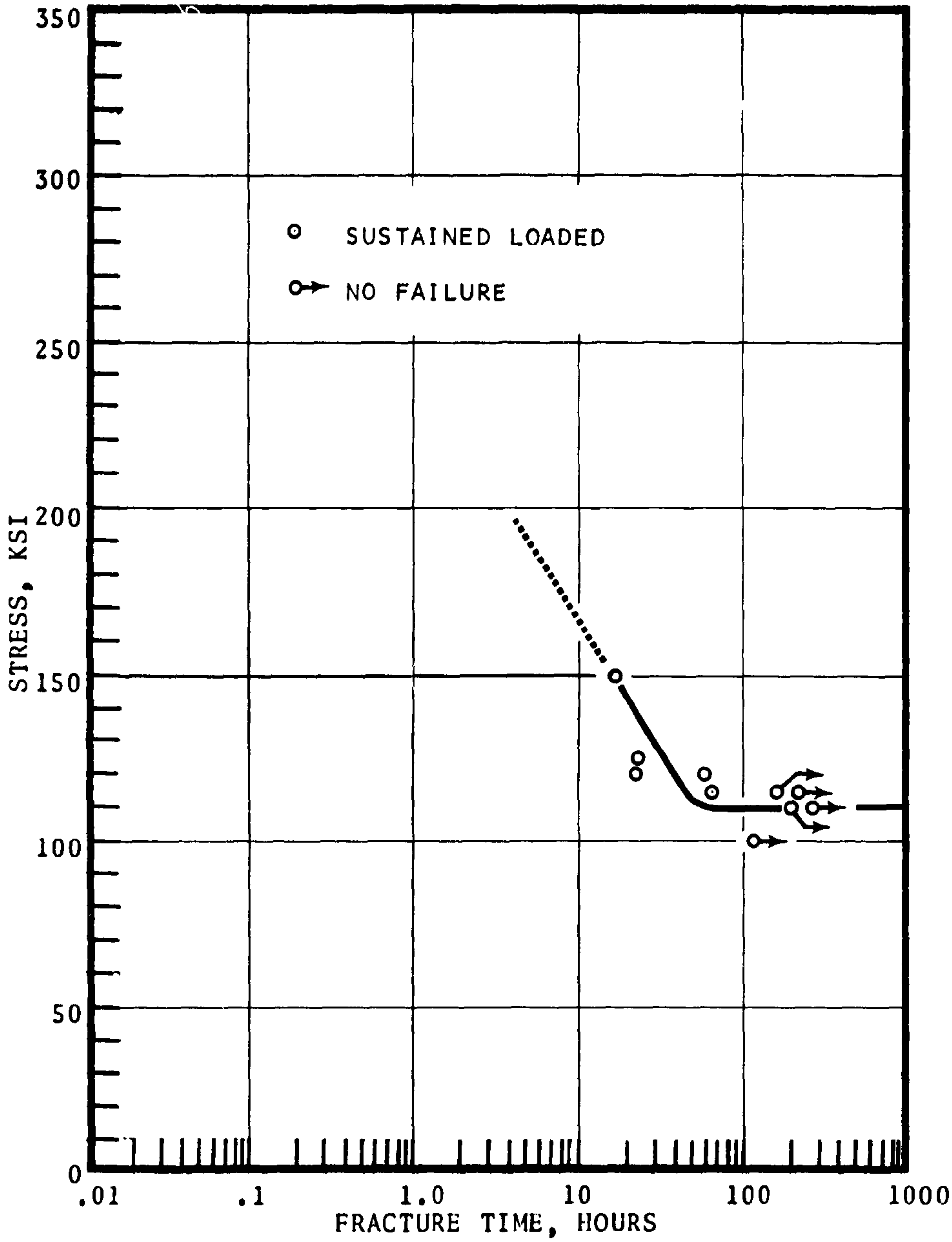

FIGURE 11 - SUSTAINED LOAD - .003 NOTCH - PLATED BY LOCKHEED - MISSILE & SPACE (PS 491G TYPE II CLASS B) TESTED BY GRUMMAN-BETHPAGE

AISI 4340 - 260-280 KSI

TRANSVERSE GRAIN DIRECTION

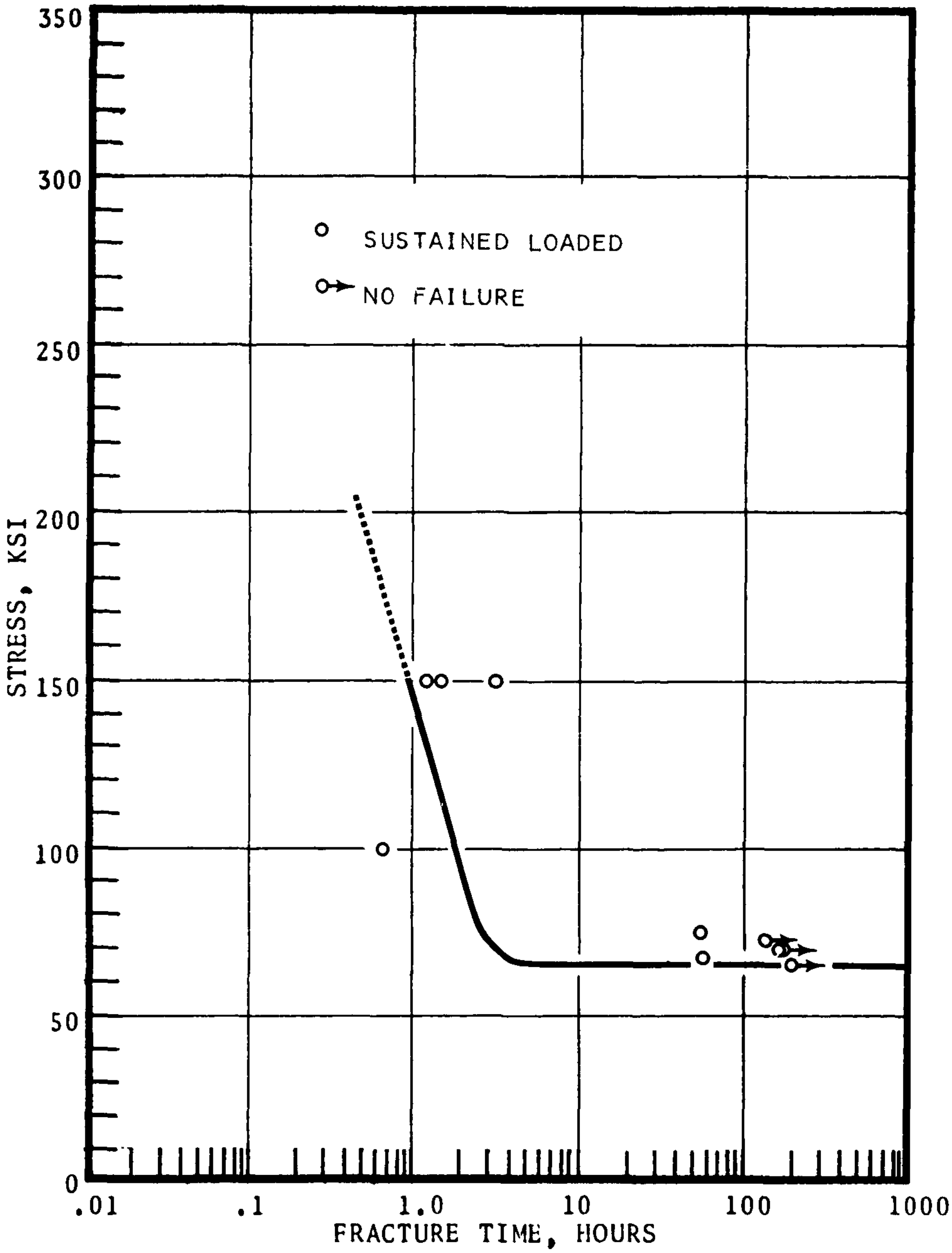

FIGURE 12 - SUSTAINED LOAD - .003 NOTCH - PLATED BY DOUGLAS (DPS - 9.28, K.3 FLUOBORATE) TESTED BY LOCKHEED-MISSILES & SPACE

AISI 4340 STEEL - 260-280 KSI

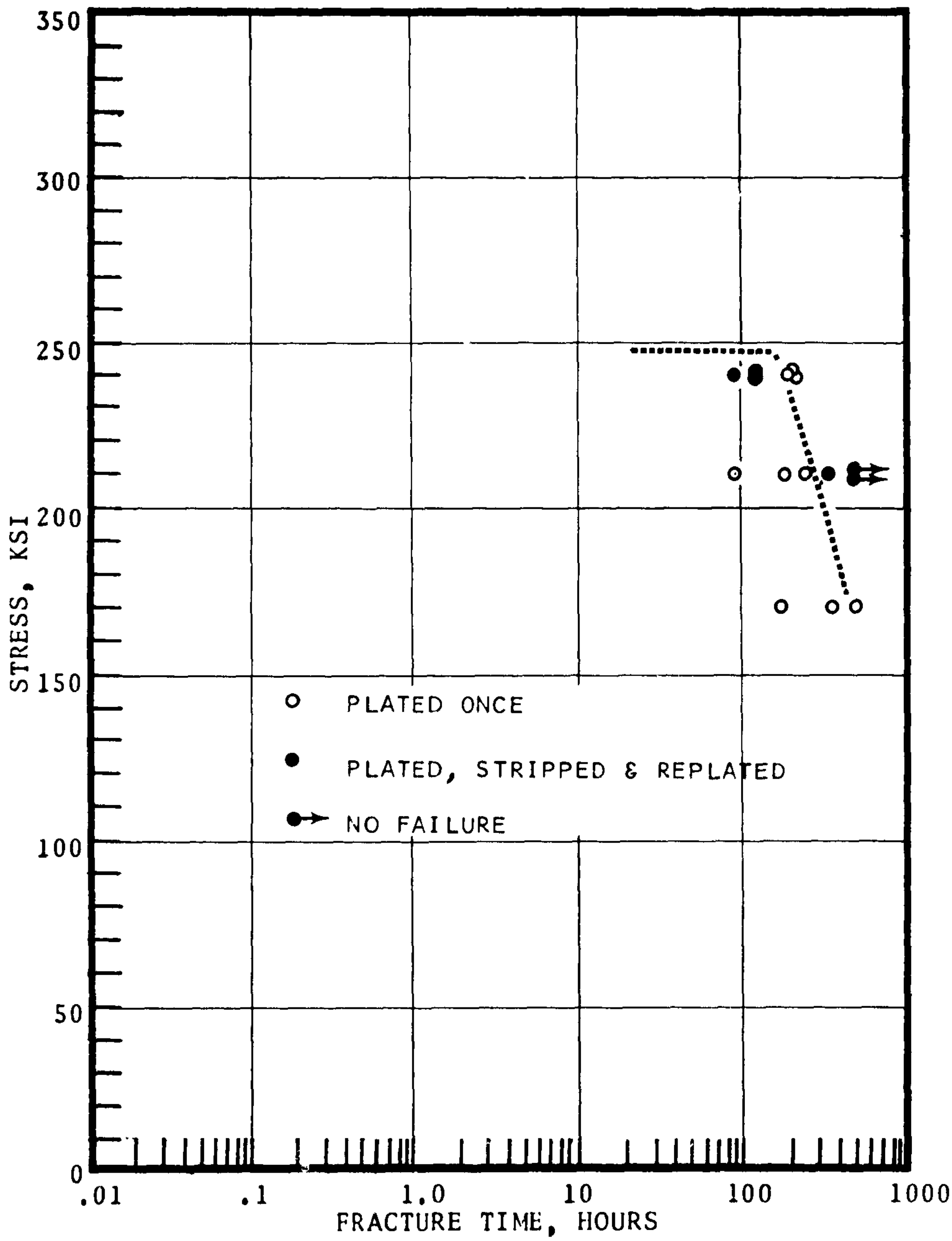

FIGURE 13 - DOUGLAS STRESSED RING TEST - PLATED BY LOCKHEED - MISSILE & SPACE (PS 491G TYPE II CLASS B) TESTED BY DOUGLAS - SANTA MONICA

AISI 4340 STEEL - 260-280 KSI

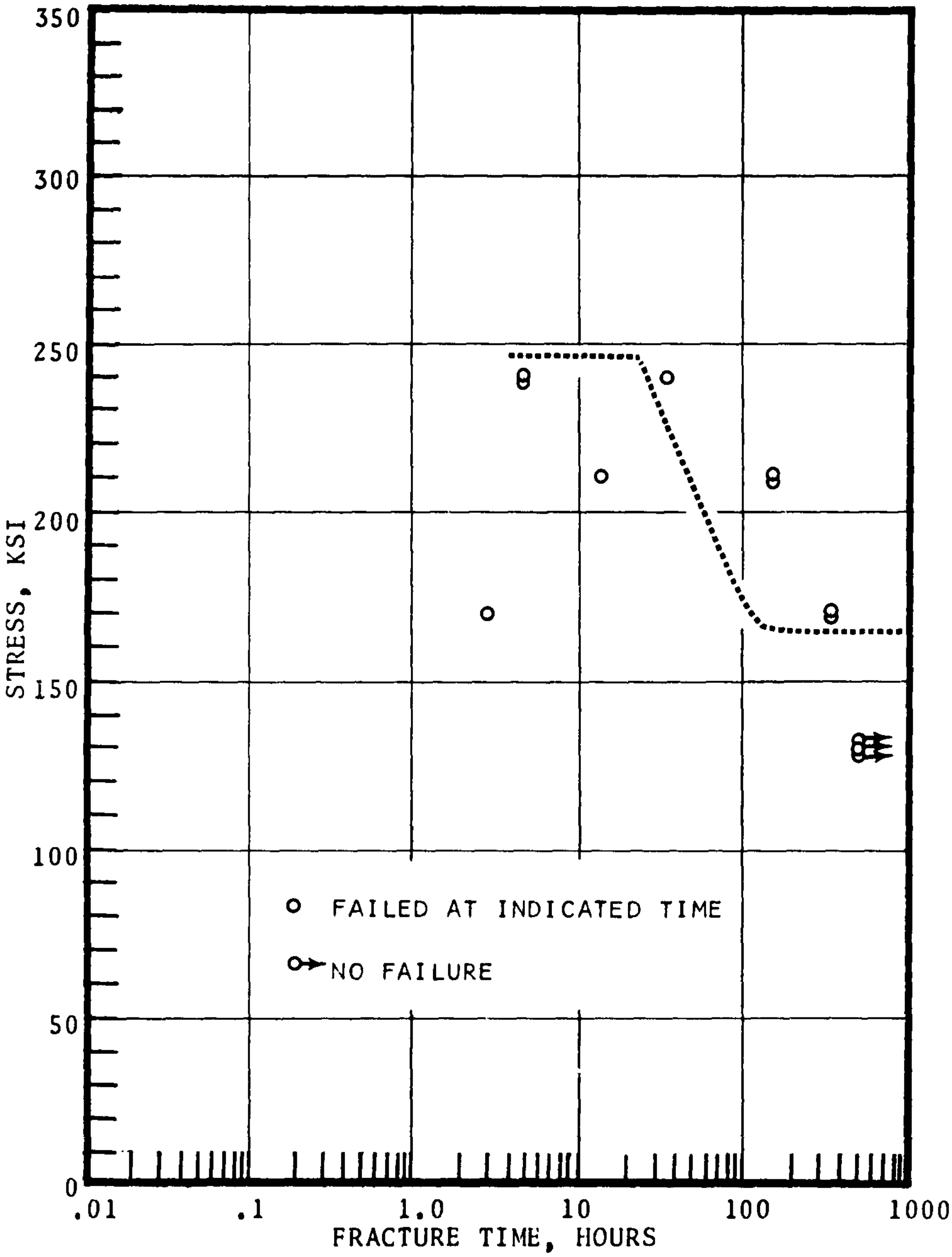

FIGURE 14 - DOUGLAS STRESSED RING TEST - PLATED BY BENDIX - SOUTH BEND (PS-1008) - TESTED BY DOUGLAS - SANTA MONICA

APPENDIX A

TABULATED TEST DATA

TABLE I - STANDARD TENSILE TESTS(1) - UNNOTCHED AND UNPLATED

SPECIMEN NO.	TENSILE, KSI	YIELD, KSI	ELONGATION, %
1	279.0	218.5	8.0
2	283.5	227.6	5.5
3	281.6	226.6	7.8
4	280.0	223.6	10.0
5	284.6	226.1	4.8
AVERAGE	281.7	224.5	7.2

(1) 1 INCH GAGE, .2% OFFSET YIELD STRENGTH
TESTED BY BOEING-WICHITA

TABLE II - STANDARD TENSILE TEST - .003 NOTCH, UNPLATED AS MACHINED

SPECIMEN NO.	FRACTURE STRESS,KSI
29	277.1
38	297.3
33	273.9
30	247.1
32	279.8
AVERAGE	274.3

TESTED BY BOEING-WICHITA

TABLE III - STANDARD TENSILE TEST - .003 NOTCH, UNPLATED BAKED 23 HOURS AT 375+25°F

SPECIMEN NO.	FRACTURE STRESS,KSI
18	276.3
20	237.8
21	221.4
22	276.9
25	306.3
AVERAGE	263.7

TESTED BY BOEING-WICHITA

TABLE IV - SUSTAINED LOAD - .003 NOTCH, UNPLATED

SPECIMEN NO.	FRACTURE STRESS, KSI	TIME, HR.(1)
23	240	113.4**
24	245	0.1
28	245	0.017
19	235	100.0**
31	245	0.2
17	250	11.1
34	245	0.01*
12(2)	250	0.01*
27	250	0.01*
26	245	114.3**

TESTED BY BOEING-WICHITA

(1) * INDICATES FAILURE ON LOADING.

** INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2) SPECIMEN NO. 12 STEP LOADED AT 200 KSI FOR 16.3 HRS. AND 225 KSI FOR 8.5 HRS. - SPECIMEN FAILED ON LOADING AT 250 KSI.

B2	H1	J6	C8	J2	D9	12	F3	16	A6	E4	J9	D3	2	H7	C4	G1
F1	E10	17	G8	H3	A5	F2	30	B10	K8	D2	33	G10	C1	H6	20	B6
D10	C7	J1	18	B3	31	E9	15	H8	35	E8	K3	19	D4	A1	F4	H2

13	B7	K1	C10	K6	D5	22	G6	5	E1	A3	J10	1	B4	F7	25	K4
E3	G2	14	J5	26	F6	K2	C5	A10	J4	21	H5	G9	27	G4	34	D1
E2	29	F5	3	A9	32	K7	G7	7	B8	D6	A4	J7	C6	28	B1	K10

A7	H4	6	G3	J8	23	B9	K9	D7	H10
F8	C2	A8	8	B5	J3	H9	9	C3	A2
24	F9	10	E5	K5	G5	11	C9	F10	E7

1J	4J	7J	10J
2J	5J	8J	11J
3J	6J	9J	12J

FIGURE 1 - RANDOMIZED LAYOUT OF BAR

NOTE: THE BAR SECTIONS SHOWN ARE FROM THE SAME BAR AND ARE CONTINUOUS FROM THE RIGHT EXTREMITY OF THE UPPER SECTION TC THE LEFT EXTREMITY OF THE NEXT LOWER SECTION EXCEPT THAT PORTION ENCLOSED BY DOTTED LINES WHICH WAS A SHORT SECTION FROM ANOTHER BAR OF THE SAME HEAT.

TABLE V - SUSTAINED LOAD - .003 NOTCH - PLATED BY BOEING-WICHITA (BAC 5718) TESTED BY CONVAIR-FORT WORTH

SPECIMEN NO.	FRACTURE STRESS, KSI[2]	TIME, HR.[1]
	**(SEE STEP LOADED DATA BELOW)	
A2	275	.01*
A3	275**	.01*
A4	275	261.2
A5	300	.01*
A6	275	.6
A7	275	417.6
A8	285	.01*
A9	275	.01*
A10	275	.01*
35	275**	2.5

(1) * INDICATES FAILURE ON LOADING.

(2) ** STEP LOADED DATA - SPECIMEN NUMBERS 35 AND A-3

	STRESS LEVEL, KSI	TIME, HR.
SPECIMEN NO. 35	200	12
	225	12
	250	24
	275	2.5
SPECIMEN NO. A-3	200	10.5
	225	12.0
	250	12.0
	275	.01

SPECIMEN FAILED →

TABLE VI - SUSTAINED LOAD - .003 NOTCH - PLATED BY NAVAL RESEARCH LABORATORY (TRIETHANOLAMINE) TESTED BY LOCKHEED-GEORGIA

SPECIMEN NO.	FRACTURE STRESS,KSI[2]	TIME,HR.[1]
1	***SEE STEP LOADED DATA BELOW	
1	240***	8.4
2	240[3]	100.0**
3	250	100.0**
4	260[3]	113.6**
5	280	.01*
6	275	61.2
7	277.5	.01*
8	275	.01*
9	272.5	.01*
10	270.0	127.0

(1) * INDICATES FAILURE ON LOADING.

** INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2)*** STEP LOADED DATE - SPECIMEN NUMBER (1)

STRESS LEVEL,KSI	TIME, HR.
175	18.5
200	8.4
225	16.5
240	8.4

(3) THESE SPECIMENS, AFTER NOT FAILING AT INDICATED TIME, WERE SUSTAINED LOADED AT INDICATED LEVELS AND TIME TO FAILURE OR AS NOTED.

SPECIMEN NO.	STRESS LEVEL,KSI	TIME, HR.[4]
2	268	100.0*
4	270	23.4*
	275	23.9*

(4)* INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

TABLE VII - SUSTAINED LOAD - .003 NOTCH - PLATED BY LOCKHEED-BURBANK (PS 491G TYPE II CLASS C) TESTED BY GRUMMAN-BETHPAGE

SPECIMEN NO.	FRACTURE STRESS, KSI (2)	TIME, HR. (1)
	**SEE STEP LOADED DATA BELOW	
G1	250	200.0*
G2	250**	51.0
G3	240	117.0*
G4	270	0.1
G5	250	100.0*
G6	264	63.7
G7	260	100.0*
G8	264	0.1
G9	260	116.5
G10	255	65.5

(1) * INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2)** STEP LOADED DATE - SPECIMEN NUMBER (G2)

STRESS LEVEL, KSI	TIME, HR.
150	19
175	11
200	10
225	10
250	10

SPECIMEN FAILED →

TABLE VIII - SUSTAINED LOAD - .003 NOTCH - PLATED BY BENDIX-SOUTH BEND (DALIC BRUSH) TESTED BY CONVAIR-FORT WORTH

SPECIMEN NO.	FRACTURE STRESS, KSI(2) ***SEE STEP LOADED DATA BELOW	TIME, HR.(1)
C1	225***	10.3
C2	175***	9.3
C3	175(3)	100.6**
C4	200(3)	137.9**
C5	314.4	.01*
C6	291.7	.1
C7	210	140.2**
C8	215(3)	143.5**
C9	220(3)	100.9**
C10	235	502.9**

(1) * INDICATES FAILURE ON LOADING.
** INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2)***STEP LOADED DATA - SPECIMEN NUMBER (C-1 AND C-2)

	STRESS LEVEL, KSI	TIME, HR.
SPECIMEN C-1	100	12
	125	12
	150	12
	175	12
	200	12
	225	10.3
SPECIMEN C-2	100	17.2
	125	14.7
	150	12.5
	175	9.3

(3) ON NEXT PAGE

TABLE VIII - SUSTAINED LOAD - .003 NOTCH - PLATED BY BENDIX-SOUTH BEND (DALIC BRUSH) TESTED BY CONVAIR-FORT WORTH (CONTINUED)

(3) THESE SPECIMENS, AFTER NOT FAILING AT INDICATED TIME WERE SUSTAIN LOADED AT INDICATED LEVELS AND TIME TO FAILURE OR AS NOTED

SPECIMEN NO.	STRESS LEVEL, KSI	TIME, HR.(4)
C-3	175	100.6**
	200	24.1**
	225	.01*
C-4	200	137.9**
	235	118.1**
	240	144.6**
	245	502.9**
C-7	210	140.2**
	240	119.3**
	245	35.4
C-8	215	143.5**
	225	120.9**
	235	62.6
C-9	220	100.9**
	230	115.2**
	240	44.3

(4) *INDICATES FAILURE ON LOADING

**INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

TABLE IX - SUSTAINED LOAD - .003 NOTCH - PLATED BY DOUGLAS-SANTA MONICA (DPS-9.28, K.2 CYANIDE) TESTED BY LOCKHEED MISSILES & SPACE

SPECIMEN NO.	FRACTURE STRESS, KSI (2)	TIME, HR. (1)
	**SEE STEP LOADED DATA BELOW	
E1	210**	66.3
E2	230 (3)	74.0
E3	250 (3)	30.5
E4	230	297.6*
E5	230	16.2
E6	230	185.4
E7	230	20.8
E8	230	1.2
E9	225	140.2*
E10	225	137.2*

(1) *INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2) **STEP LOADED DATA - SPECIMEN NUMBER (E-1)

STRESS LEVEL, KSI	TIME, HR.
150	10.0
160	10.0
170	10.0
180	10.0
190	10.0
200	10.0
210	6.3

SPECIMEN FAILED →

(3) THESE SPECIMENS, AFTER NOT FAILING AT INDICATED TIME, WERE SUSTAIN LOADED AT INDICATED LEVELS AND TIME TO FAILURE OR AS NOTED

(CONTINUED ON NEXT PAGE)

TABLE IX - SUSTAINED LOAD - .003 NOTCH - PLATED BY DOUGLAS-SANTA MONICA (DPS-9.28, K.2 CYANIDE) TESTED BY LOCKHEED MISSILES & SPACE
(CONTINUED)

SPECIMEN NO.	STRESS LEVEL, KSI	TIME, HR.(4)
E-2	210	10*
	220	10*
	230	54
E-3	230	10*
	240	10*
	250	10.5

(4) *INDICATES NO FAILURE - SPECIMEN REMOVED AT INDICATED TIME.

TABLE X - SUSTAINED LOAD - .003 NOTCH - PLATED BY CLEVELAND PNEUMATIC (CPT-8206) TESTED BY LOCKHEED-GEORGIA

SPECIMEN NO.	FRACTURE STRESS, KSI (2)	TIME, HR. (1)
	***SEE STEP LOADED DATA BELOW	
D1	241.5***	.01*
D2	222.0	13.3
D3	201.5 (3)	100.0**
D4	216.5	19.4
D5	211.5	118.2**
D6	214.5 (3)	100.0**
D7	216.0 (3)	113.9**
D8	231.5	64.5
D9	243.0	85.6
D10	252.0	26.2

(1) *INDICATES FAILURE ON LOADING

**INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2)***STEP LOADED DATA - SPECIMEN NUMBER (D1)

STRESS LEVEL, KSI	TIME, HR.
151	20.0
192	6.7
216.5	15.5
241.5	.01

SPECIMEN FAILED →

(3) ON NEXT PAGE

TABLE X - SUSTAINED LOAD - .003 NOTCH - PLATED BY CLEVELAND PNEUMATIC (CPT-8206) TESTED BY LOCKHEED-GEORGIA (CONTINUED)

(3) THESE SPECIMENS, AFTER NOT FAILING AT INDICATED TIME, WERE SUSTAIN LOADED AT INDICATED LEVELS AND TIME TO FAILURE OR AS NOTED.

SPECIMEN NO.	STRESS LEVEL, KSI	TIME, HR.(4)
D3	234	6.9
D6	240	144.5*
D7	219.5	22.1*
	232.5	18.0

(4)*INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

TABLE XI - SUSTAINED LOAD - .003 NOTCH - PLATED BY BOEING-RENTON (CADMIUM-TITANIUM BAC 5804) TESTED BY MARTIN-BALTIMORE

SPECIMEN NO.	FRACTURE STRESS, KSI (2)	TIME, HR. (1)
	***SEE STEP LOADED DATA BELOW	
1J	210***	.01*
2J	210	5.7
3J	190	200.0**
4J	190	187.9
5J	190	.6
6J	190	200.0**
7J	190	200.0**
8J	190	40.8
9J	190	140.2
10J	190	102.1

(1) *INDICATES FAILURE ON LOADING.

**INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2)***STEP LOADED DATA - SPECIMEN NUMBER (1-J)

STRESS LEVEL, KSI	TIME, HR.
150	23.6
170	23.6
190	23.6
210	.01

SPECIMEN FAILED →

TABLE XII - SUSTAINED LOAD- .003 NOTCH - PLATED BY GRUMMAN-BETHPAGE GAEC NON-AQUEOUS (DIMETHYL FORMAMIDE) TESTED BY BOEING-SEATTLE

SPECIMEN NO.	FRACTURE STRESS, KSI(2)	TIME, HR.(1)
	***SEE STEP LOADED DATA BELOW	
K1	240**	2.7
K2	240	2.7
K3	230	33.7
K4	220	13.9
K5	210	15.4
K6	190	309.5*
K7	180	155.4
K8	180	.3
K9	170	241.3*
K10	180	200.1*

(1) *INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2) **STEP LOADED DATA - SPECIMEN NUMBER (K1)

STRESS LEVEL, KSI	TIME, HR.
200	16.6
220	14.3
240	2.7

SPECIMEN FAILED →

TABLE XIII - SUSTAINED LOAD - .003 NOTCH - PLATED BY BENDIX, SOUTH BEND (PS 1008) TESTED BY KAMAN-BLOOMFIELD

SPECIMEN NO.	FRACTURE STRESS, KSI[2] ***SEE STEP LOADED DATA BELOW	TIME, HR.[1]
B1	180***	.01*
B2	150	79.3
B3	170	4.0
B4	160	26.5
B5	150	2.9
B6	140	1.6
B7	120	45.3
B8	110[3]	200.0**
B9	140	100.0**
B10	180	1.9

(1) *INDICATES FAILURE ON LOADING
**INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

(2)***STEP LOADED DATA - SPECIMEN NUMBER (B1)

STRESS LEVEL, KSI	TIME, HR.
85	161
90	102
95	67
100	50
105	50
110	66
120	24
130	24
140	24
150	24
160	71.3
170	24
180	.01

SPECIMEN FAILED →

(3) THIS SPECIMEN, AFTER NOT FAILING AT INDICATED TIME, WAS SUSTAIN LOADED AT INDICATED LEVEL AND TIME TO FAILURE.

SPECIMEN NO.	STRESS LEVEL, KSI	TIME, HR.
B8	160	55.6

TABLE XIV - SUSTAINED LOAD- .003 NOTCH - PLATED BY LOCKHEED, MISSILE & SPACE (PS 491G TYPE II CLASS B) TESTED BY GRUMMAN-BETHPAGE

SPECIMEN NO.	FRACTURE STRESS, KSI	TIME, HR.(1)
H1	150	17.1
H2	125	22.1
H3	100	100.8*
H4	120	58.3
H5	110	200.0*
H6	115	63.4
H7	115	215.0*
H8	120	10.9
H9	115	148.7*
H10	110	280.0*

(1)*INDICATES NO FAILURE - SPECIMEN REMOVED AT INDICATED TIME.

TABLE XV - SUSTAINED LOAD - .003 NOTCH - PLATED BY DOUGLAS (DPS - 9.28, K.3 FLUOBORATE) TESTED BY LOCKHEED MISSILES & SPACE

SPECIMEN NO.	FRACTURE STRESS, KSI	TIME, HR.(1)
F1	150	1.7
F2	150	3.2
F3	150	1.3
F4	100	.7
F5	75	56.0
F6	65	191.0*
F7	70	167.4*
F8	70	167.1*
F9	68	58.7
F10	72	145.3*

(1) *INDICATES NO FAILURE - SPECIMEN REMOVED UNFAILED AT INDICATED TIME.

TABLE XVI - DOUGLAS STRESSED RING TEST - PLATED BY BENDIX-SOUTH BEND (PS-1008) - TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD[1] TO FAILURE
240	5
240	5
240	34
210	12
210	142
210	142
170	3
170	330
170	330
130	500*
130	500*
130	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XVII - DOUGLAS STRESSED RING TESTS - PLATED BY BENDIX-SOUTH BEND (DALIC BRUSH) - TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD[(1)] TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XVIII - DOUGLAS STRESSED RING TESTS - PLATED BY BOEING-WICHITA (BAC 5718) TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD[(1)] TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XIX - DOUGLAS STRESSED RING TESTS - PLATED BY DOUGLAS-SANTA MONICA (DPS 9.28, K.2 CYANIDE) TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD[1] TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XX - DOUGLAS STRESSED RING TESTS - PLATED BY LOCKHEED, MISSILE & SPACE (PS 491G TYPE II CLASS C) TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD[1] TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XXI - DOUGLAS STRESSED RING TESTS - PLATED BY LOCKHEED, MISSILE & SPACE (PS 491G TYPE II CLASS B) TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD[1] TO FAILURE
240	192
240	216
240	216
210	90
210	186
210	254
170	173
170	360
170	501
240	92
240	124
240	124
210	357
210	500*
210	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XXII - DOUGLAS STRESSED RING TESTS - PLATED BY BOEING-RENTON (BAC 5804) CADMIUM-TITANIUM) - TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD(1) TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XXIII - DOUGLAS STRESSED RING TESTS - PLATED BY GRUMMAN-BETHPAGE (GAEC NON-AQUEOUS DIMETHYL FORMAMIDE) TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD(1) TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XXIV - DOUGLAS STRESSED RING TESTS - PLATE BY NAVAL RESEARCH LABORATORIES (TRIETHANOLAMINE) - TESTED BY DOUGLAS

APPROX. STRESS LEVEL - KSI	HOURS AT LOAD(1) TO FAILURE
240	500*
240	500*
240	500*
240	500*
240	500*

(1) * INDICATES NO FAILURE AT INDICATED TIME.

TABLE XXV - HEAT TREATMENT OF AISI 4340 STEEL
STATIC NOTCHED TENSILE SPECIMENS

TREATMENT	ATMOSPHERE	TEMPERATURE	TIME
NORMALIZING	NEUTRAL SALT	1650 ±10°F	60 MIN.
HARDNEING	NEUTRAL SALT	1525 ±10°F	30 MIN.
QUENCHING	OIL	85°F	
TEMPERING	AIR	425°F	. 2-1/2 HOURS DOUBLE TEMPERED

SUSTAINED LOAD RING SPECIMENS

TREATMENT	ATMOSPHERE	TEMPERATURE	TIME
HARDENING	NEUTRAL	1500 ±10°F	45 MIN.
QUENCHING	OIL	80 -110°F*	
TEMPERING	AIR	450 ±10°F	1 HOUR

*USUAL CONTROL, NOT RECORDED.

TABLE XXVI - CHEMICAL COMPOSITION

		CARBON	MANG.	PHOS.	SULP.	SIL.	NI	CR	MO
	MAX.	.43	.85	.040	.040	.35	2.00	.90	.30
REQUIREMENT	MIN.	.38	.65			.20	1.65	.70	.20
REPUBLIC		.40	.76	.007	.010	.32	1.78	.79	.24
BOEING		.40	.73			.32	1.90	.90	.29

APPENDIX B

ALIGNMENT CELL CALIBRATION

(NOTCHED TENSILE SPECIMEN)

The following outline is the step by step alignment procedure used by Boeing-Wichita to obtain data for percent bending curve.

STEP 1

Fixture, rods and calibration specimens were installed in creep test machine.

STEP 2

Calibration specimen was electrically connected to strain indicator.

STEP 3

The calibration specimen was loaded to a stress level of approximately 120,000 psi and percent bending was calculated (See Equation 7) and recorded.

STEP 4

The relative orientation oftest fixtures were then rotated slightly and Step 3 was repeated.

STEP 5

Step 4 was repeated until a minimum percent bending value was obtained for a certain relative orientation of the test fixtures.

STEP 6

Several values of percent bending vs. load were then obtained to ensure satisfactory alignment was obtained. (See attached percent bending curve).

STEP 7

Fixtures were indexed to ensure the ability of test operator to duplicate calibration test conditions.

STEP 8

Several trial test installations were repeated.

STEP 9

Step 6 was then repeated to check repeatability and reliability of test set-up and procedure. No significant change was noted.

PERCENT BENDING

Ref. - ASTM(TP31) 1-56

These calculations develop an expression for the percent bending from measurements taken about the circumference (4 places 90° apart).

ASSUMING A CONSTANT MOMENT BENDING

S_O	=	Average Stress = $\frac{\text{Load}}{\text{Area}}$
S_M	=	Maximum Bending Stress
α	=	Angular Position - Bending Plane with respect to one gage
M	=	Bending Moment
b and e	=	Perpendicular Distances from Neutral Axis to Gage position Numbers 1 and 4, respectively.
r	=	Radius of the Specimen
I	=	Moment of Inertia
K	=	$\frac{I}{r}$
B	=	Percent Bending

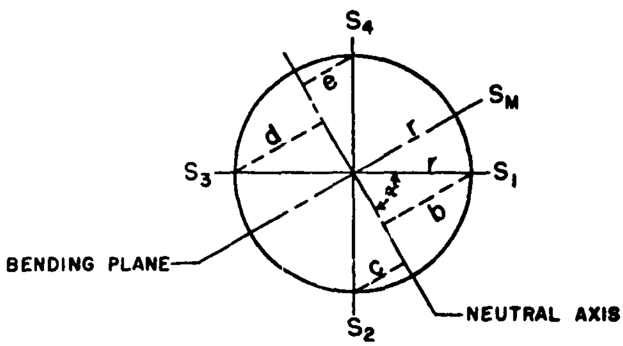

FIGURE 1

(SINGLE OR TWO GAGE)

$$S_1 = S_o + \frac{M_b}{I} = S_o + \frac{Mr \sin \alpha}{I} \quad (1)$$

$$S_4 = S_o + \frac{Me}{I} = S_o + \frac{Mr \cos \alpha}{I}$$

No Reliability Check of Gage Readings

$$S_M = S_o + \frac{Mr}{I}$$

FOUR GAGE

$$\Delta S_1 = (S_1 - S_o) = \Delta S_3 = -(S_3 - S_o) \quad (2)$$

$$\Delta S_4 = (S_4 - S_o) = \Delta S_2 = -(S_2 - S_o)$$

By averaging Δ Ss in EQS 2 Problem is treated as one of two gages located 90° apart.

$$\Delta S_{1,3} = \frac{\Delta S_1 + \Delta S_3}{2} \quad (3)$$

$$\Delta S_{4,2} = \frac{\Delta S_2 + \Delta S_4}{2}$$

Equation 1 may be rewritten in terms of:

$\Delta S_{1,3}$ and $\Delta S_{4,2}$ as follows:

$$\Delta S_{1,3} = MK \text{ SIN } \alpha$$

$$\Delta S_{4,2} = MK \text{ COS } \alpha$$

$$\Delta S_M = MK \quad (4)$$

Solving EQS 4 for $(MK)^2$

$$(MK)^2 = (\Delta S_{4,2})^2 + (\Delta S_{1,3})^2$$

$$(MK)^2 = (\Delta S_M)^2$$

$$\Delta S_M = \left[(\Delta S_{4,2})^2 + (\Delta S_{1,3})^2\right]^{1/2} \tag{5}$$

$$B = \left(\frac{\Delta S_M}{S_o}\right) 100 \tag{6}$$

Gage Readings G_1, G_2, G_3, G_4 in 10^{-6} IN/IN.

$$G_o = (G_1, + G_2, + G_3, + G_4)/4$$

THEN

$$B = \left(\frac{\Delta S_M}{S_o}\right) 100 = \left(\frac{\left[(\Delta G_{1,3})^2 + (\Delta G_{4,2})^2\right]^{1/2}}{G_o}\right) 100 \tag{7}$$

$$\Delta G_{1,3} = \frac{(G_1 - G_o) - (G_3 - G_o)}{2}$$

$$\Delta G_{4,2} = \frac{(G_4 - G_o) - (G_2 - G_o)}{2}$$

The eccentricity associated with a given percent of bending will depend on specimen diameter (2r). From EQS, I consider the expression for S_M rewritten as follows:

$$S_M - S_o = \frac{Mr}{I} \tag{8}$$

Then dividing by S_o and multiplying by 100

$$B = \left(\frac{S_M - S_o}{S_o}\right) 100 = \left(\frac{Mr}{S_o I}\right) 100$$

The bending moment (M) is produced by the tensile load (P) acting at an eccentricity (ϵ).

$$\text{Where } I = \frac{\pi r^4}{4}$$

$$B = \frac{400 P \epsilon}{S_o \pi r^3}$$

Considering $S_o = P/\pi r^2$

Then $P = S_o \pi r^2$

$$B = \frac{400\epsilon}{4}$$

Solving for Eccentricity

$$\epsilon = \frac{Br}{400}$$

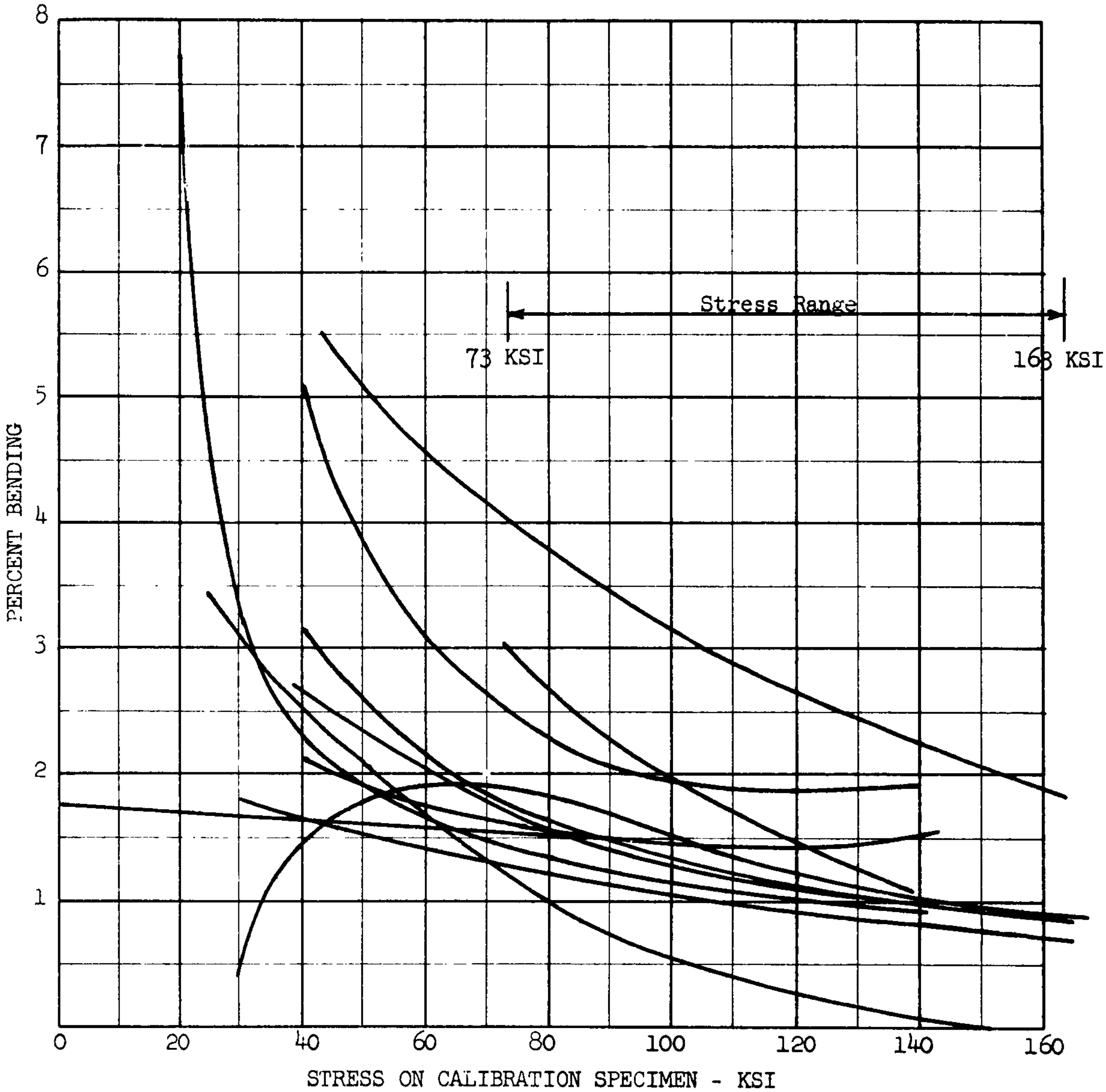

FIGURE 1 - A COMPILATION OF THE RESULTS OF PERCENT BENDING VERSUS STRESS OF THE CALIBRATION TEST CELL USED TO ALIGN CREEP-RUPTURE MACHINES FOR TESTING

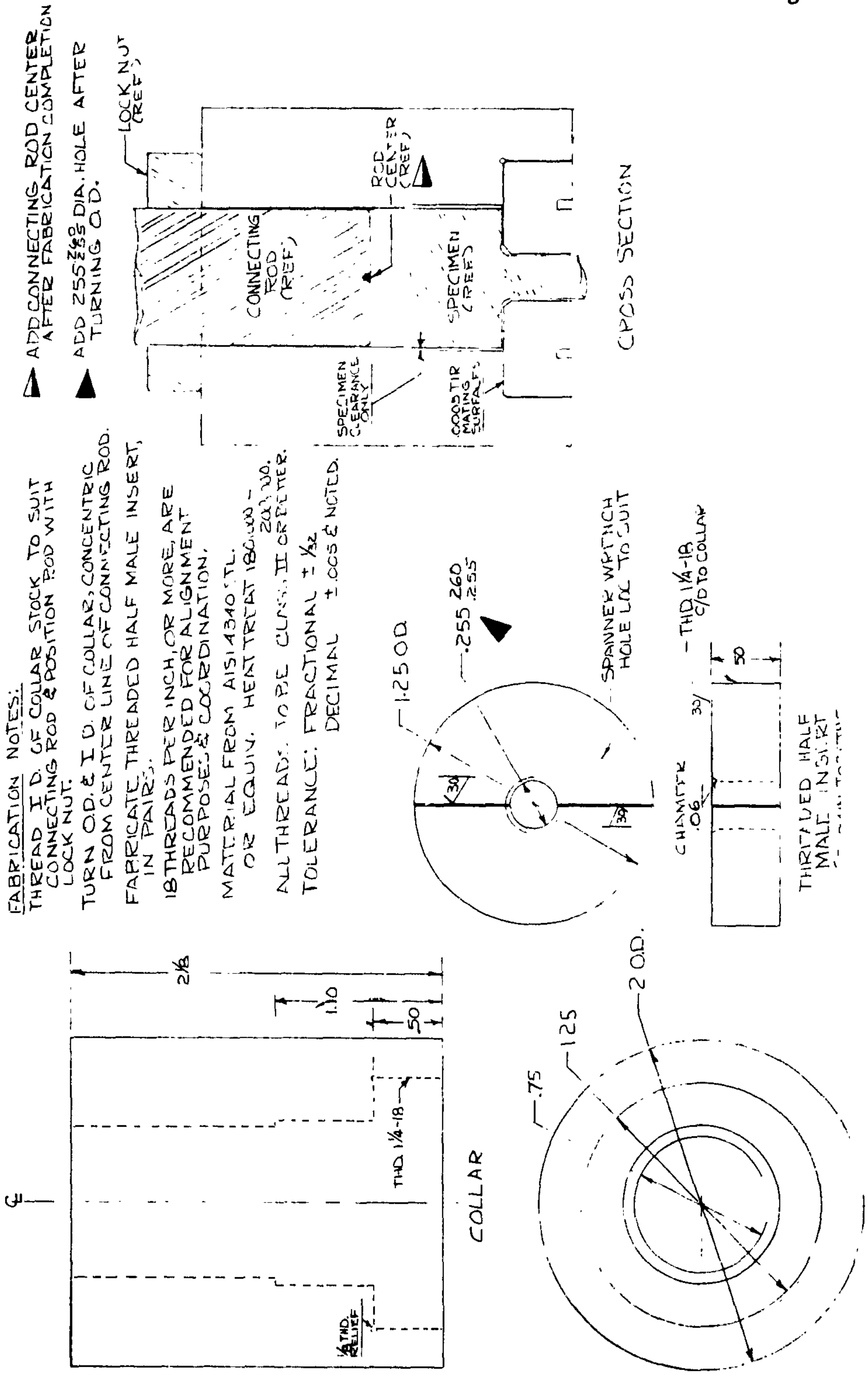

FIGURE 2 - NOTCHED TENSILE SPECIMEN GRIP ADAPTER ASSEMBLY

APPENDIX C

DESCRIPTION OF PLATING

PROCEDURE SELECTED FOR EVALUATION

BOEING BAC 5718 HIGH EFFICIENCY CYANIDE PLATING PROCEDURE (ABRASIVE CLEANING METHOD)

A. Vapor degrease. (Trichloroethylene)

B. Abrasive dry sand blast lightly with 80 grit sand.

C. Within 10 minutes immerse in cyanide holding bath to a maximum of 4 hours of the following composition:

Sodium Cyanide	4-5 oz/gal
Sodium Hydroxide	1-2 oz/gal
Temperature	70°-85°F

D. Without rinsing immerse in plating bath and plate at 50 amps/ft^2 in a bath of the following composition:

Cadmium Oxide	7.50 oz/gal
Sodium Cyanide	23.5 oz/gal
Cadmium (metal)	6.5-7.5 oz/gal
Sodium Carbonate	8.0 oz/gal maximum
Sodium Hydroxide	3.5-5.0 oz/gal
Free Sodium Cyanide (Total NaCN-1.75 X Cd)	9-15 oz/gal
Water (Deionized)	Maintain Volume
Sulfide	1 PPM Maximum
Temperature	70°-80°F

E. Cold water rinse to five minute maximum--maintain rinse not to exceed 750 PPM above incoming tap water.

F. Within 30 minutes bake 23 hours at 375°F ±25°F.

THE CADMIUM-TRIETHANOLAMINE (TEA) PLATING BATH

Description By: Simon W. Strauss
U.S. Naval Research Laboratory
Washington, D.C.

PREPARATION OF PLATING SOLUTION

A. Dissolve 256.5 gms (1/3 formula weight) of $3CdSO_4 \cdot 8H_2O$ in 500 ml of distilled water.

B. To this solution add 199 ml of TEA; the solution should be kept cold and should be continuously agitated. The precipitate which forms during the first addition of TEA will dissolve as more TEA is added, and the resulting solution should be perfectly clear.

C. Dilute the solution with distilled water to a volume of one liter.

PREPARATION OF SPECIMENS

A. The specimens were sandblasted (80 grit), rinsed with water and then with methyl alcohol prior to plating.

PLATING PROCEDURE

A. Using slowly rotating cathodes, the specimens were plated at a current density of about 19 A.S.F. to approximately .0005 inch.

B. Rinse in water followed by methyl alcohol.

C. Dry.

D. No bake.

THE CADMIUM-TRIETHANOLAMINE (TEA) PLATING BATH

Description By: Simon W. Strauss
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B. Rinse in water followed by methyl alcohol.

C. Dry.

D. No bake.

LOCKHEED PS 491g TYPE II CLASS C CYANIDE PLATING PROCEDURE

A. Anodic alkaline clean. (Lac PS 170)

B. Rinse in clean running water.

C. Dry in a clean air blast.

D. Abrasive clean with 160-200 grit dry sand.

E. Rinse in clean running water.

F. Etch 30 seconds maximum in 50% by volume commercial muriatic acid at room temperature to 100°F maximum.

G. Rinse in clean running water.

H. Immediately immerse in plating bath, plate for two minutes at an average current density in excess of 60 amperes per square foot in a bath of the following composition and condition:

Cadmium Oxide	3-5 oz/gal
Sodium Cyanide	11.4-12.8 oz/gal
Sodium Hydroxide	1.5-3.5 oz/gal
Sodium Carbonate	2-8 oz/gal

NOTE: The use of addition agents or brightners is not permitted.

Temperature	Room to 95°F maximum

I. Rinse in clean running water.

J. Immerse in 3-7% (by weight) chromic acid solution for 30-60 seconds.

K. Rinse in hot water (above 170°F) and dry in clean air blast.

L. Within 30 minutes bake 8 hours at 375°F +25°F.

PROCEDURE EMPLOYED IN CADMIUM PLATING

10 Notched Tensile by the DALIC* Process

A. Stress relieve 4 hours at 375-380°F.

B. Sandblast lightly with 100-120 mesh sand to remove thermal stress relief color.

C. Anodic electroclean** at 12 volts with DALIC cleaning and deoxidizing solution code 1010.

D. Rinse with distilled water.

E. Wet test bars with plating solution prior to application of current.

F. Plate with DALIC alkaline cadmium solution code 2021. Current 0.2 amperes, voltage -12, time 10-15 minutes. Thickness on barrel of test bars approximately .0003-.0005 inch.

G. Rinse in distilled water.

H. No bake.

* Performed by Bendix, South Bend.

** Test bars were revolved on centers at 100-150 RPM during electrocleaning and subsequent rinsing and plating operations.

PROCEDURE EMPLOYED IN CADMIUM PLATING

15 Douglas Rings by the DALIC* Process

A. Stress relieve 4 hours at 375°F.

B. Sandblast lightly all over to remove temper color.

C. Place thin steel strip around O.D. for electrical contact. Connect to positive terminal of rectifier.

D. Electroclean I.D. using DALIC cleaning and oxidizing solution, code 1010. Current: 2-3 amperes. Time: 60 seconds. Rinse.

E. Cadmium plate using DALIC alkaline plating solution code 2021. An R-5 electrode was employed. Current ranged between 2 and 3 amperes, for a total of .32 ampere hours. Rinse and dry.

F. Place ring over a rubber stopper attached through a shaft in its center to a variable speed motor. Make electrical contact to I.D. of ring with copper wire. Rotate piece at 100-150 rpm.

G. Electroclean anodically as in Step D above. Rinse.

H. Place special conforming anode in position. (See Note 1 below).

I. Cadmium plate using DALIC alkaline cadmium solution code 2021 and special electrode as well as PR-5 electrode. Current was 2.5-3.0 amperes for a total of 0.35 ampere hours. Rinse and dry.

NOTE:

1. In preliminary tests using an old Douglas ring, we found it difficult to obtain more than 1 ampere. This would have required 20 minutes plating time for .0005" of cadmium. The basic reason for this was that if sufficient pressure on the anode was employed to get higher currents, this stopped the motor at the slow speeds we were employing. A special conforming carbon electrode was constructed which contacted approximately 25% of the O.D. By using this electrode along with the P.R-5 electrode, 2.5-3.0 amperes could be obtained.

* Performed by Bendix, South Bend.

DOUGLAS DPS 9.28 - K.2 CYANIDE CADMIUM PLATING PROCEDURE

A. Vapor degrease. (Trichloroethylene)

B. Hand clean with Ajax Cleanser.

C. Rinse in clean tap water.

D. Immerse in a solution containing 4-6 oz/gal of sodium cyanide.

E. Without rinsing immerse in plating solution, immediately apply current and plate at 60 amps/ft^2 to a thickness of 0.0003" in a bath of the following composition:

Cadmium Oxide	2.9-5.5 oz/gal
Sodium Cyanide	12-20 oz/gal
Sodium Carbonate	2.0-8.0 oz/gal
Ratio NaCN-CdO	2.8-6.0
pH	Above 12
Temperature	70°-90°F
Free Caustic Soda	1.0-3.2 oz/gal

F. Rinse in clean tap water.

G. Immerse in a chromic acid solution (8 oz/gal) for 60 seconds.

H. Rinse in tap water.

I. Hot water rinse and dry.

J. Within 30 minutes bake 23 hours at 395°F ±15°F.

CLEVELAND PNEUMATIC TOOL COMPANY CPT 8206
CADMIUM CYANIDE PLATING PROCEDURE

A. Vapor degrease.(Trichloroethylene)

B. Abrasive dry blast clean with 80 grit AL_2O_3 or SiO_2.

C. Blow off excess grit with clean filtered air.

D. Immerse in plating bath and apply current at an average current density of 70 amps/ft^2 in a bath of the following composition:

Cadmium (as cadmium oxide)	2.9-5.5 oz/gal
Total Sodium Cyanide (NaCN)	12.0-20.0 oz/gal
Sodium Carbonate (Na_2CO_3)	2.0-8.0 oz/gal
Ratio NaCN-CdO	2.8-6.0
pH	Above 12
Temperature	70°F-90°F
Free Caustic Soda (NaOH)	1.0-3.2 oz/gal

Brighteners are prohibited.

E. Rinse in cold running water.

F. Immerse in 5-7% (by weight) chromic acid solution to a maximum of 30 seconds.

G. Rinse in cold running water.

H. Rinse in clean hot water.

I. Blow dry.

J. Within 4 hours bake at 380°F-400°F for 23 hours.

BOEING BAC 5804 LOW HYDROGEN EMBRITTLEMENT CADMIUM TITANIUM ALLOY PLATING PROCEDURE

A. Vapor degrease. (Trichloroethylene)

B. Abrasive clean with aluminum oxide or silica 100-180 grit.

C. Within 10 minutes immerse in cyanide holding bath to a maximum of 4 hours of the following composition:

Sodium Cyanide	4-5 oz/gal
Sodium Hydroxide	1-2 oz/gal
Temperature	70°F-85°F

D. Without rinsing immerse in plating bath and strike at 40 a.s.f. for 15 seconds and then plate at 15-30 a.s.f. for 24-12 minutes respectively, in a bath of the following composition:

Cadmium Metal	2.8-3.5 oz/gal
Total Cyanide (as NaCN)	13-17 oz/gal
Sodium Hydroxide	2.5-3.6 oz/gal
Sodium Carbonate	5.0 oz/gal
Titanium	40-80 ppm
Total Cyanide to cad. ratio	$\frac{4}{1}$ - $\frac{5}{1}$
pH of Solution	13 min.

E. Rinse in cold water, 5 minutes maximum.

F. Within 30 minutes bake 12 hours at 375°F ±25°F.

GRUMMAN GAEC NONAQUEOUS (DIMETHYL FORMAMIDE) PLATING PROCEDURE

A. Vapor degrease. (Trichloroethylene)

B. Vapor blast lightly with 140 quartz grit.

C. Alkaline clean in Oakite 90 at 160°F to 180°F for five minutes.

D. Cold running water rinse and blow dry immediately.

E. Dimethyl Formamide Dip.

F. Make judicious cathode connection. No voltage applied.

G. Immerse in tank, start cathode bar agitation and plate at 4-10 amp/ft^2.

Cadmium Iodide	70-130 gm/liter
Cadmium (by analysis)	22-42 gm/liter
CA - Chelating Agent - Cadmium Molar Ratio	2-1
Solvent	Dimethyl Formamide
Temperature	130°F max. (80°F +10°F preferred)
Agitation-Cathode Bar	180 ft/hour maximum
Anode-Cathode Area Ratio	1.5 - 1 minimum
Anodes	Cadmium
Filtration and Voltage	As necessary

H. Pressure rinse very thoroughly to remove iodides.

I. Apply chromate conversion coating. Not performed.

J. Blow dry.

K. No bake.

BENDIX PS 1008 PLATING PROCEDURE

10 Notched Tensile Specimens Per P.S. 1008

A. Vapor degrease. (Trichloroethylene)

B. Stress relieve 4 hours at 375° - 380°F.

C. Sand blast all over lightly. (Size 100 - 120)

D. Rinse to remove loose grit.

E. Immerse in plating solution, agitate at start of plating and plate at 20 amps/ft^2 for 18 minutes in a bath of the following composition:

Cadmium Metal	3.9 oz/gal
Free Sodium Cyanide*	8.5 oz/gal
Sodium Hydroxide	2.9 oz/gal
Sodium Carbonate	8.0 oz/gal maximum
Cadalyte Brightner	0.7 oz/gal
Temperature	70" - 90°F

*Free sodium cyanide is considered the excess sodium cyanide above that required to form $Na\,Cd\,(CN)_3$.

F. Rinse in clean running water.

G. Immerse in 3-5% chromic acid solution for 3-5 seconds.

H. Rinse and blow dry.

I. Within 30 minutes bake 23 hours at 375° - 380°F.

PROCEDURE EMPLOYED IN CADMIUM PLATING

15 Douglas Rings per P.S. 1008

A. Stress relieve 4 hours at 375°F.

B. Sandblast lightly all over to remove temper color.

C. Plate 5 rings on plating rack. Rinse and place in cyanide cadmium solution. (See note below for composition).

D. Plate at 10-11 amperes for 20 minutes. Rings were rotated approximately 60° three times during the 20 minutes.

E. Rinse and neutralize 5-10 seconds in 5% chromic acid solution.

F. Cold rinse, hot rinse, and blow dry.

G. Bake 23 hours at 375°F.

NOTE: COMPOSITION OF CADMIUM PLATING SOLUTION

Cd (as metal)	3.75
Free NaCN	9.0
NaOH	2.6 oz/gal
Cadalyte Brightener	0.33 oz/gal approx.

LOCKHEED PS 491g TYPE II CLASS B MODIFIED CYANIDE PLATING PROCEDURE

A. Anodic alkaline clean. (Lac PS 170)

B. Rinse in clean running water.

C. Dry in a clean air blast.

D. *Abrasive clean with 160-200 grit dry sand. (If necessary to remove excessive scale).

E. Rinse in clean running water.

F. Dry in a clean air blast.

G. Electrohone (anodic electropolish) at 75 amps/ft^2 for 15 minutes in a solution containing Batelle Electropolishing Solution #2 at room temperature to 120°F maximum, or use Electro-Gleam #55 operated at 160-180°F with 8 volts for one minute. (The Electro-Gleam Solution was used on the specimens). Agitate parts during electrohoning.

H. Rinse immediately in clean running water.

I. Immediately immerse in plating bath for 15 minutes without current and then plate to a thickness of .0003-.0005 inch at 50-100 amps/ft^2 in the following bath:

Sodium Cyanide	18-22 oz/gal
Cadmium Oxide	12-17.5 oz/gal
Sodium Hydroxide	4-12 oz/gal
Sodium Carbonate	9 oz/gal
Sodium Nitrate	3.5-9.5 oz/gal
Lac C-5 Additive	.016-.034 oz/gal
Temperature	Room to 100°F maximum
Filtration	Continuous
Agitation	Solution and part. Air agitation shall not be used.

(Continued on next page)

LOCKHEED PS 491g TYPE II CLASS B MODIFIED CYANIDE PLATING PROCEDURE

(Continued)

J. Rinse in clean running water.

K. Immerse in 3-7% (by weight) chromic acid solution for 30-60 seconds.

L. Rinse in hot water (above 170°F) and dry in clean air blast.

M. No bake.

*NOTE: The specimens will be sandblasted.

DOUGLAS DPS 9.28 - K.3 FLUOBORATE CADMIUM PLATING PROCEDURE

A. Vapor degrease. (Trichloroethylene)

B. Hand clean with Ajax Cleanser.

C. Rinse in clean tap water.

D. Immerse in plating solution, immediately apply current and plate at 20 amps/ft^2 to a thickness of 0.0003" in a bath of the following composition:

Cadmium Fluoborate	35-38 oz/gal
Ammonium Fluoborate	11-13 oz/gal
pH (Hydrion or Precision pH paper or Colorimetrically)	2.8-3.4
Temperature	70°F-85°F
Brightner	As Recommended

E. Rinse in clean tap water.

F. Immerse in a chromic acid solution (8 oz/gal) for 60 seconds.

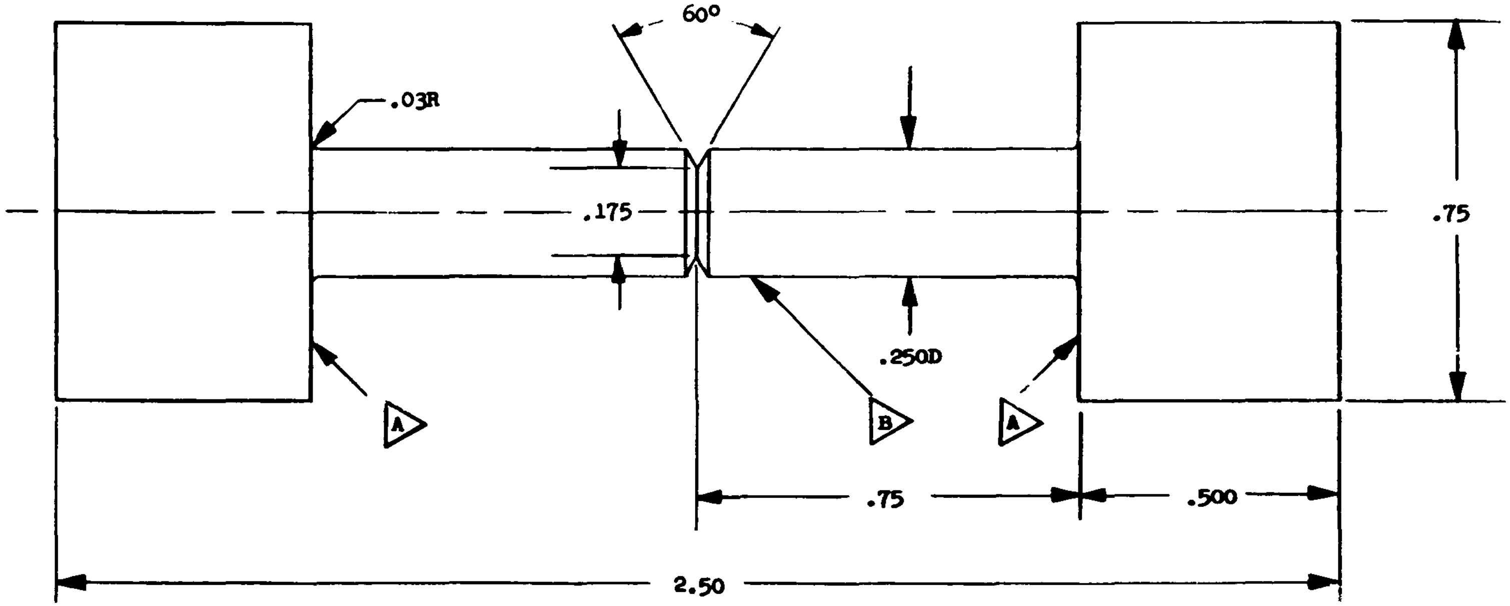
G. Rinse in clean tap water.

H. Hot water rinse and dry.

I. Within 30 minutes bake 23 hours at 395°F ±15°F.

APPENDIX D

DESCRIPTION OF TEST SPECIMENS AND TEST APPARATUS



NOTES: (A) THESE SURFACES PERPENDICULAR TO CENTER AXIS WITHIN .001

(B) CONCENTRIC TO CENTER AXIS WITHIN .001

32 FINISH ON ENTIRE SURFACE

TOLERANCES: ±5° FOR ANGLE
±.001 FOR THREE DECIMAL PLACES
± .005 FOR TWO DECIMAL PLACES

ROOT RADIUS AS SPECIFIED

FIGURE 1 - STATIC NOTCHED TENSILE TEST SPECIMEN CONFIGURATION

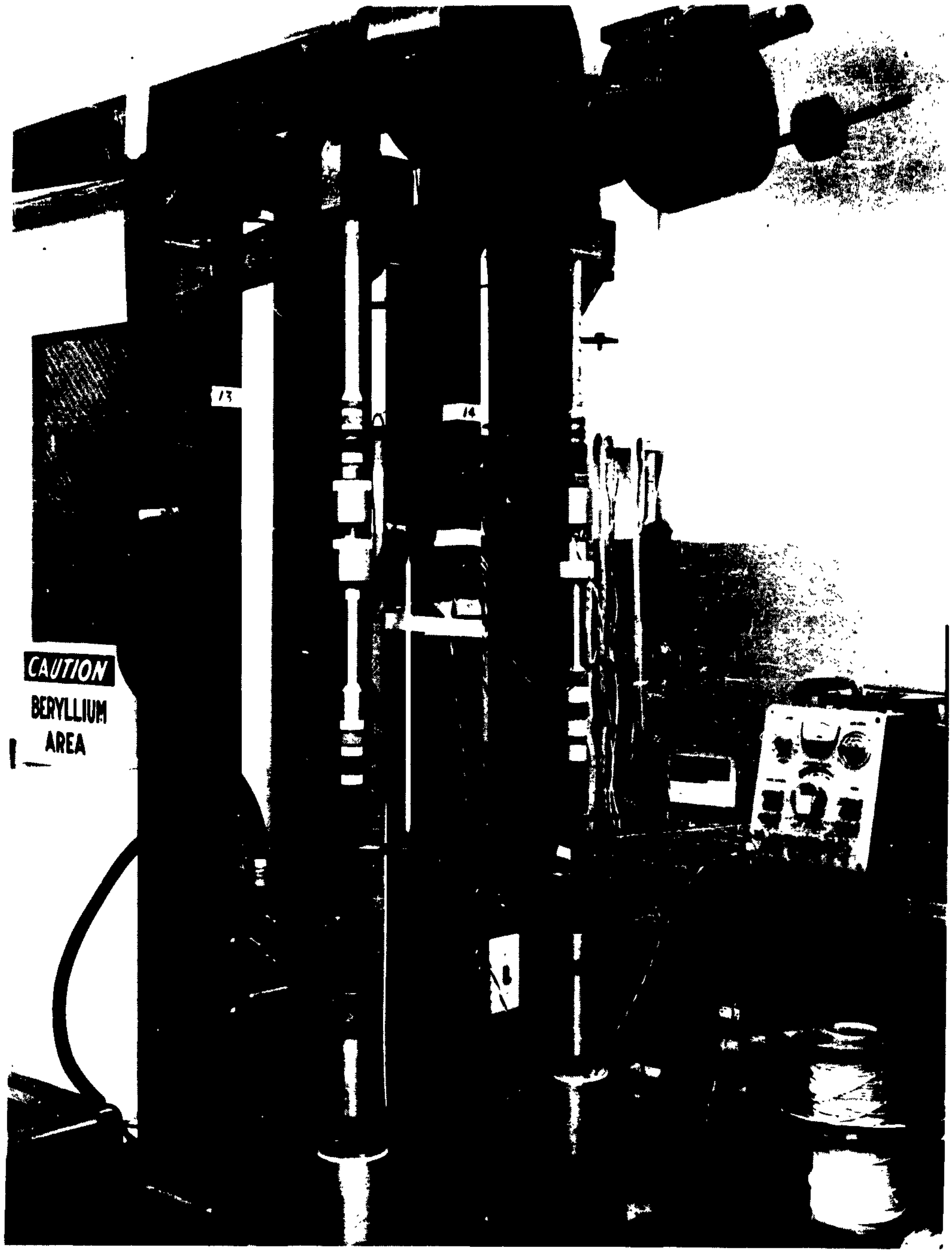
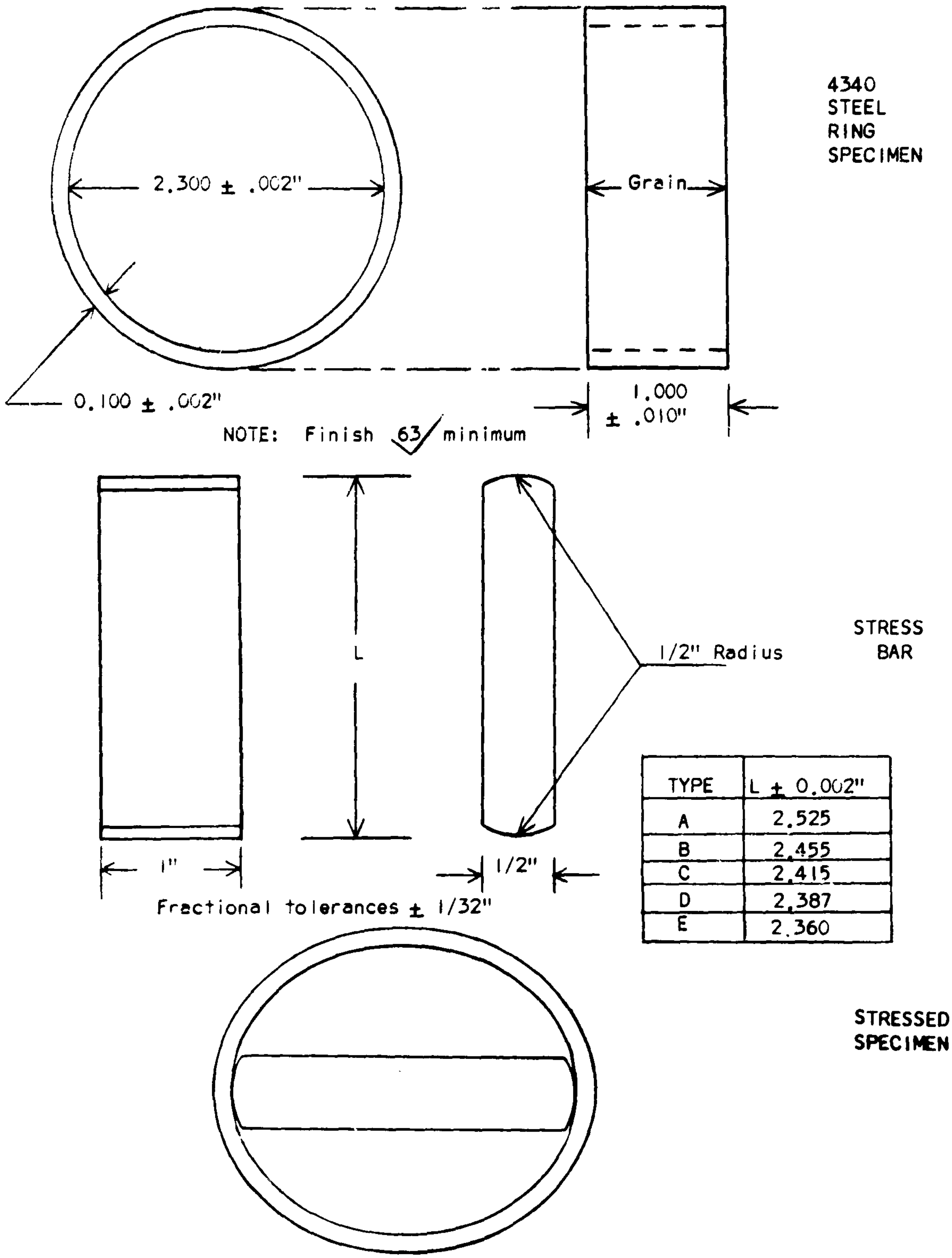


FIGURE 2 - TEST APPARATUS WITH NOTCHED SPECIMEN LOADED IN MACHINE AT LEFT AND CALIBRATION SPECIMEN LOADED IN MACHINE AT RIGHT
PHOTO COURTESY OF LOCKHEED AIRCRAFT CORPORATION



TYPE	L ± 0.002"
A	2.525
B	2.455
C	2.415
D	2.387
E	2.360

FIGURE 3 - DETAILED DRAWING OF DOUGLAS RING TEST SPECIMEN

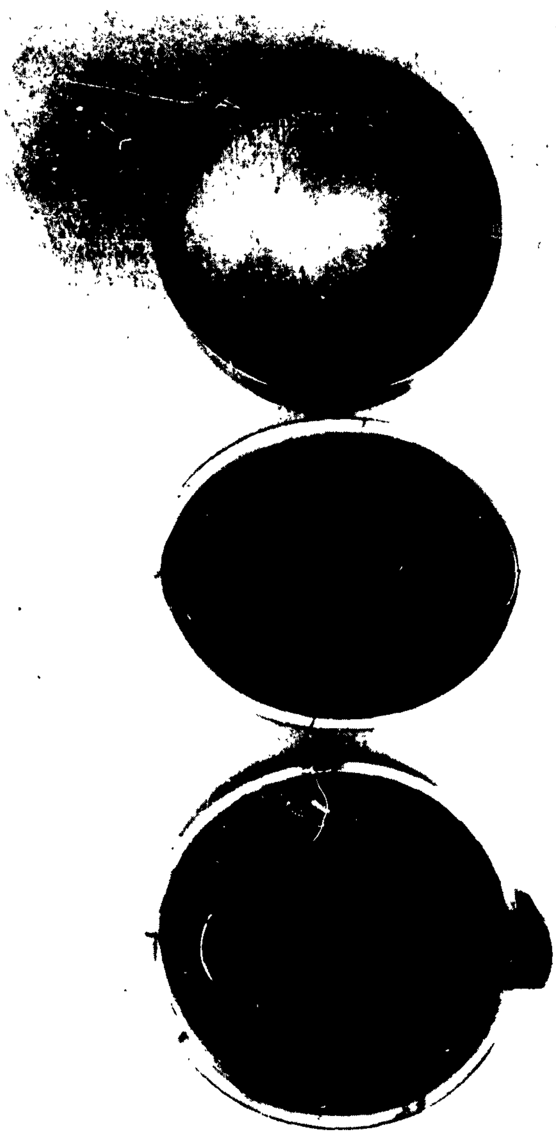


FIGURE 4 - DOUGLAS RING SPECIMENS
(PHOTO COURTESY OF DOUGLAS AIRCRAFT CORPORATION)