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INVESTIGATION OF THE COMPRESSIVE, BEARING AND SHEAR CREEP-RUPTURE PROPERTIES OF AIRCRAFT STRUCTURAL METALS AND JOINTS AT ELEVATED TEMPERATURES

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FOREWORD

This report was prepared by the Cornell Aeronautical Laboratory, Inc. under USAF Contract No. AF 33(616)-3456. This contract was initiated under Project No. 7360 "Materials Analysis and Evaluation Techniques", Task No. 73605 "Design Data for Metals". The work was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Messrs. K. D. Shimmin and E. L. Horne acting as project engineers.

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ABSTRACT

The establishment of the high-temperature mechanical properties of aircraft constructional materials is a prerequisite to efficient design when elevated temperature service is expected. These properties, which normally are determined from the conventional short-time tensile test and the tensile-creep test, are not necessarily applicable if stress conditions other than tension are encountered. The present program was initiated to examine the high-temperature strength characteristics of a number of aircraft structural alloys when subjected to a variety of stresses under both short and long time loading with the specific purpose of applying these high-temperature characteristics to riveted joint configurations.

This report summarizes in tabular form the high-temperature short-time strength properties of a number of test alloys in tension, compression, bearing, and shear. Data representing the bearing creep behavior of 2024-T3 aluminum alloy sheet for a number of variables associated with bearing are also included. The creep behavior of several selected joint designs undergoing bearing and shear creep are illustrated as time-deformation charts, and comparisons between the predicted and experimental performances are made.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Richard R. Kennedy

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SUMMARY

A variety of aircraft structural alloys have been tested at high temperature under short-time tension, compression, bearing, and shear stresses. Correlations of the results of these various types of loads appear to indicate that strain rate, regardless of the type of load applied, is particularly important in establishing the short-time high-temperature strength characteristics of materials.

The results of the bearing creep phase of the program, in which hole diameter, ratio of edge distance to hole diameter, and sheet thickness were investigated appear to indicate that bearing creep is sensitive to these test variables. Correlations between bearing creep strength and tensile rupture strength for constant time and temperature levels show major differences especially with variation in hole diameter. These differences in bearing creep strength seem to imply that stress concentrations, which apparently vary due to hole diameter, are more important in some cases than in others.

Three riveted joint configurations, consisting of 2024-T3 aluminum elements entirely, have been creep tested at 450°F to examine the practicability of utilizing bearing and shear creep data for this alloy in predicting the creep performance of joints. In general, the predicted performance appears to be slightly conservative from the standpoint of creep deformation and rupture for joint Types I and II. This is probably due to friction between the faying surfaces, which reduces bearing and shear stress for specific load levels. On the other hand, joint Type III experiences an accelerated rupture effect which appears to be associated with increased stress arising from joint configuration.

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INTRODUCTION

The elevated temperatures caused by aerodynamic heating of supersonic aircraft have necessitated numerous changes in design in order to meet strength and stability requirements. At these temperatures conventional aircraft materials undergo weakening to the point where creep becomes a major factor controlling useful life.

In the assembly of aircraft structural members, rivets, and other mechanical fasteners, which have been adopted as practical and acceptable methods of fabrication, are usually required to carry and transmit loads. The ability of joined members to sustain loads imposed upon them is in most cases dependent upon the strength characteristics of the elements forming the joint and in some instances upon the stress condition created in the joint area. When loads are transmitted through joints, complex and concentrated stress patterns arise which can promote failure in any of a number of ways. In spite of these stress complexities, however, determinations of shear and bearing characteristics of joints have provided sufficient guidance for satisfactory design in the range of temperature where the effects of creep are not important.

Concurrent with the structural materials problems which have arisen from high speed flight, it has become apparent that certain conventional design characteristics, heretofore regarded as controlling the usefulness of structures, cannot be applied. Instead, it has become recognized that many of these same design characteristics must be defined according to their influences on particular creep processes associated with specific stress states and temperatures. By way of illustration, Mordfin (1)* found that tensile creep data could not be used to predict the creep and rupture behavior of single riveted joints undergoing high-temperature shear and bearing creep deformation. On the other hand, Mordfin and Legate (2) were able to correlate multiple riveted joint behavior with corresponding shear and bearing creep behavior. In view of these significant observations, it appears that the compression, bearing, and shear creep characteristics of aircraft materials, along with their tensile creep characteristics, are important design criteria in modern air frame construction. In order to investigate compression, bearing and shear creep, and their relation, this study of elevated temperature characteristics was undertaken.

*See bibliography.

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TEST PROGRAM AND TEST MATERIALS

Under sponsorship of the Materials Laboratory of the Wright Air Development Center, a test program was initiated to study the strength characteristics of various aircraft structural alloys in tension, compression, bearing, and shear at elevated temperatures. The threefold objective of the program was summarized as follows:

(a) A determination of the factors affecting bearing creep-rupture strength. For this phase of the investigation, 2024-T3 aluminum alloy sheet has been selected to undergo bearing creep testing at 300, 450, and 600°F. Variables to be studied include bearing hole diameter, edge distance to hole diameter ratio and sheet thickness. Accordingly, hole diameters of 1/16, 1/8, and 3/16 inch are to be used to determine if this variable affects bearing creep and rupture strength when used in combination with 1.5 and 2.0 edge distance to hole diameter ratios and nominal sheet thicknesses of 0.064 and 0.090 inch. In all cases, the creep and rupture behaviors at the three temperature levels are to be surveyed for a number of stresses which will produce rupture in the 10 to 250 hour range.

(b) A determination of the short-time high-temperature mechanical properties of 16 test alloys under the influences of the various types of stresses to establish relationship with strength in tension. Specifically, the test alloys which have been investigated for their creep characteristics in earlier work under Air Force Contract No. AF 33(616)-190 and reported in references 3, 4, and 5 are to be tested for their short-time loading characteristics when exposed to identical types of stresses. All materials are to be tested at temperatures corresponding to those at which their creep behaviors were determined.

(c) A determination of the utility of these short-time and long-time high-temperature data obtained for the various stress conditions as applied to riveted joints for elevated temperature service. In this regard, three types of joints are to be creep-rupture tested for the specific purpose of correlating existing shear and bearing creep data with high-temperature joint behavior. This phase of the investigation is to be conducted on 2024-T3 aluminum alloy sheet and C-110M titanium alloy sheet. Joint creep-rupture testing is to be conducted at temperatures corresponding to those at which individual tension, compression, bearing, and shear creep data were determined.

All materials along with the nominal or actual chemical compositions as furnished by the suppliers are listed in Table 1. Essentailly all sheet alloys were tested in tension, compression and bearing while the bar alloys were tested in tension and shear. The schedules of test to which the alloys were exposed are summarized in Tables 2 and 3.

TEST APPARATUS

Creep Testing

All creep tests were conducted in conventional lever-loaded (10:1 ratio) creep machines of Cornell Aeronautical Laboratory design. Since these machines were primarily designed for tensile creep testing, special fixtures were necessary to adapt the equipment for bearing, shear, and joint creep testing.

Test temperature is maintained with a resistance-wound creep furnace, provided with appropriate shunts to adjust temperature distribution in the top, middle, and bottom furnace section as required. Regulation occurs through low or high voltage input to the furnace by a conventional potentiometer temperature controller. With this system of control and adjustment, the test temperature is maintained within limits of $\pm$ 3°F of the nominal test temperature over a specific gage length for the duration of the test. Temperature measurements are made at various selected positions on the test section by calibrated chromel-alumel thermocouples wired to the specimen at these positions and shielded from furnace radiation by asbestos cord. A precision potentiometer, accurate to within 0.5°F, is used to indicate the test section temperature and to serve as a guide for temperature adjustment.

In tension creep testing, strain is measured by a set of extensometers attached to a two-inch gage section. These extensometers engage cantilever beams to which resistance strain gages are cemented. The displacement of the extensometers, which is a direct measure of the creep deformation, is transmitted to the cantilever pickup system and is detected as an unbalance in an electrical bridge circuit. Precalibration of the beams together with the bridge circuit permits convenient and accurate conversion of the generated bridge unbalance to creep strain. Continuous record of the strain is made on a Dynalog type strain recorder with a long time accuracy of 0.0004 in/in/div and a sensitivity of 0.00004 inch per inch.

In applying the basic tensile creep equipment for conducting bearing creep tests, special equipment modifications were required to accommodate the bearing specimen. The modification consists essentially of a clevis of two hardened tool steel plates riveted to a spacer bar to maintain a total clearance between the clevis and bearing specimen of 0.070 inch. Two holes 1/32 inch larger than the bearing hole diameter were drilled and reamed in line through these plates. The bearing specimen was positioned between the plates and a hardened tool steel pin inserted through the plate and bearing specimen hole. The unit, when secured into the creep testing machine, with pin connected joints permits a bearing load to be applied to the specimen.

The effective bearing area is calculated as the product of the bearing hole diameter and the thickness of the sheet. Bearing hole deformation is measured by the displacement of the bearing pin with respect to the stress free corners of the bottom edge of the specimen. Two deformometer arms are attached to a stress-free area of the specimen holder above the bearing pin hole. The other pair of deformometer arms engage the bottom edge of the specimen. These four arms are used to generate a bridge signal which is conveniently converted to bearing hole deformation. The strain measuring system employed in the bearing creep program is capable of detecting deformations of 0.000016 inch.

This same scheme of strain measurement has been applied in determining the creep behavior of joints. In the case of joints, the extensometers are attached at stress free areas of the upper and lower sheets which form the joint, and the combined deformation due to shear of the rivet and extension of the bearing hole is recorded. As in bearing creep measurement, strains of 0.000016 inch can be detected.

The study on the individual creep behaviors under various types of stresses has been in progress for the past four years, and the testing techniques for determining these mechanical characteristics are essentially unchanged. The test equipment, including temperature control procedures, strain measuring techniques and specimen specifications pertinent to creep testing other than joint-creep testing, are discussed in greater length with the aid of appropriate illustrations in reference 3. Basically, the same procedures were followed in creep testing joints, with the exception that alterations in specimen grips were necessary to accommodate the various joint designs. The joint configurations examined for their creep behaviors are illustrated in Figure 1, each being defined by individual joint specifications to produce failure by shear, bearing, or a combination of both.

Short-Time Testing

The room and elevated temperature tensile characteristics of all alloys were determined in a 60,000 pound hydraulic Universal Testing Machine. The machine is equipped with a strain pacer, operating in conjunction with a pair of extensometers attached to a two-inch specimen test section, which permits stress-strain characteristics to be obtained under controlled rates of strain.

Short-time elevated-temperature bearing and shear strengths of the test alloys were determined in the creep test units, already described, using increment loading to the point of rupture. Due to the very nature of load application, no control of strain rate is possible.

The short-time compression characteristics of selected sheet alloys were determined for increment loading using compression creep units described in reference 3. As in the short-time bearing and shear portions of the program, no controlled strain rate can be applied in testing compression specimens because of the manner of loading. In general, however, the rates of strain associated with the increment loading procedure for compression as well as bearing and shear were considerably greater than the 0.5% per minute used in obtaining tensile stress-strain characteristics.

TEST RESULTS

Tensile Creep

Inasmuch as 2024-T3 aluminum alloy sheet of 0.091 inch thickness was procured for the bearing creep phase of the program, it became necessary for correlating creep behavior under various types of stresses to establish the base-line static tensile creep-rupture characteristics of this alloy in the temperature and time ranges of interest. Accordingly, the tensile creep-rupture properties of 0.091 inch thick 2024-T3 sheet were surveyed at 300, 450, and 600°F and a number of stress levels producing rupture from 10 to 300 hours. The results of these tensile creep-rupture tests are tabulated for various amounts of creep and total deformation in Table 4 and are summarized as typical stress-time design curves in Figures 2 through 4 for the 300, 450, and 600°F temperature levels, respectively.

Bearing Creep

The bearing creep-rupture characteristics of 2024-T3 aluminum alloy sheet were determined at 300, 450, and 600°F. A comprehensive study of the variables associated with bearing strength, namely, bearing hole diameter, edge distance to hole diameter ratio, and sheet thickness, were incorporated in this phase of the investigation. The bearing creep and rupture characteristics of 0.064 and 0.091 inch thick aluminum alloy sheet were systematically observed when the bearing hole diameter was varied from 1/16, 1/8, and 3/16 inch using edge distance to hole diameter ratios of 1.5 and 2.0. The results of these series of bearing creep-rupture tests are summarized in Tables 5 through 16 with each table properly identified by the variables under consideration. The creep and rupture characteristics of the two alloys are graphically presented in design type creep deformation and total deformation stress versus time charts in Figures 5 through 40 which represent the behaviors of the alloys for specific combinations of the variables at the 300, 450, and 600°F temperature levels.

Consistent with the procedures which have been employed in presenting bearing creep data in references 3, 4, and 5, correlations of bearing-creep stress to tensile-rupture stress at specific levels of bearing hole deformation through creep have been made in the time range of 1 to 500 hours. These correlations are summarized in Tables 17 through 20 which give the stress ratios as functions of the hole diameter, time, temperature and percent deformation. The correlations indicate that bearing creep is sensitive to temperature, as illustrated by the variation in the ratio for a specific bearing condition, and is also sensitive to bearing hole diameter at constant temperature. The net effect, in summarizing the bearing creep-rupture behavior of 2024-T3 aluminum, is that it appears very unlikely that a common factor can be assigned to designate both bearing creep and rupture even for a defined set of bearing conditions and temperatures.

Short-Time Tension

All test materials were short-time tensile tested at room and elevated temperature with the load being applied parallel to the direction of working. As in the creep phases of the test program, the tensile properties were determined in order to provide a base line by which the short-time compression, bearing and shear characteristics may be correlated. Table 21 summarizes the tensile properties of the 16 test alloys obtained for a constant strain rate of 0.5% per minute at the various test temperature levels.

Short-Time Compression

The sheet alloys were short-time compression tested at those temperatures at which previous compression-creep tests had been conducted. The results of this series of tests are summarized in Table 22 for the temperature levels and materials concerned. Along with a summary of the short-time compression properties determined from duplicate tests, Table 22 includes a correlation of the 0.2% average yield in compression and tension. The correlation is based upon the strength characteristics of the alloys obtained when loaded parallel to the direction of working.

Short-Time Bearing

In determining the short-time high-temperature bearing properties of the sheet alloys, all tests were conducted using a 1/8 inch diameter bearing hole and either a 1.5 or 2.0 ratio of edge distance to bearing hole diameter. The selection of the ratio of edge distance to bearing hole diameter coincided with those bearing specifications for which high temperature creep data were obtained in references 3, 4, and 5. The results of these short-time bearing tests are summarized in Table 23 as duplicate determinations for the specific temperature levels of interest. Included in Table 23 is a correlation of the average bearing strength with average tensile strength for each temperature. It is to be noted that there exists considerable variation for a specific material with changes in temperature. At the higher temperatures where creep effects are predominant, it may be noted that in general the ratio of bearing strength to tensile strength is large, perhaps 50% greater than at lower temperatures. This suggests that the bearing tests were conducted at higher rates of strain than were the tension tests. Consequently, it appears that valid correlations of the bearing characteristics, or for that matter any strength characteristics where creep is a factor, cannot be made unless these characteristics are obtained under identical strain rate conditions.

Short-Time Shear

The short-time high-temperature shear strengths of 0.187 inch thick 2024-T3 aluminum alloy sheet and of all bar materials were determined using a 1/8 inch diameter specimen loaded in double shear. Temperatures conformed to those at which shear creep characteristics were determined and reported in references 3, 4, and 5. The results of the short-time shear tests are presented in duplicate in Table 24 along with the correlations of ratio of shear strength to tensile strength at the specific test temperatures. As was the case in the correlation between bearing and tensile strength, there appears to be a general variation in the shear-tensile correlation, as indicated by the increasing ratio with increasing temperature. This observation also supports the argument that adequate correlation between short-time properties can only be made under identical and controlled rates of strain when creep effects are predominate.

Joint Creep

Riveted joints fail in a number of ways, all of which can be related to the tension, compression, bearing, and shear characteristics of the elements in the joint assembly. The procedures for predicting the type of failure at normal temperatures are generally handled by simple mechanics wherein the tension, bearing, and shear areas, based on conventional strength properties, are adjusted in designing the weakest and strongest elements in the joint. If on the other hand, circumstances exist which permit the joint to undergo creep deformation, it becomes obvious that the utility of such an assembly is time-dependent. Under these conditions, the performance of a joint must be predicted from creep behaviors rather than short-time strength characteristics.

This phase of the test program was conducted on the three joint configurations illustrated in Figure 1, of which all components were formed from 2024-T3 aluminum alloy whose creep behaviors had been established in this and earlier studies. The joints were tested in their simplest forms (i.e., the minimum number of elements required to form the component) each of which may be said to represent a single unit of a multiple riveted assembly. The study was made with the primary objective of correlating joint creep-rupture behavior with the individual creep and rupture characteristics determined in tension, compression, bearing and shear at corresponding test temperatures. In essence, the joint elements were designed to fail preferentially, in some instances by bearing hole deformation and in others by shearing of the rivet. In all cases, however, stresses were sufficiently large so that significant deformation by both bearing and shear creep would occur throughout the test. This procedure was followed in order to compare the predicted and actual performances of the joints from the standpoint of creep-rupture as well as type of rupture.

All three joint configurations were creep tested at 450°F for specific combinations of stress which permitted a survey of the joint creep behavior in the time range of 10 to 200 hours. The results of these joint creep tests are summarized in Tables 25, 26, and 27 for joint Types I through III. The 450°F creep behaviors of these joints are illustrated in Figures 41 through 43 in which total joint deformation is related to time. Based on the results of these tests, correlations were made of the predicted and experimental behaviors of the joints as shown in Tables 28 through 30. It is of interest to note that the predicted 10-hour creep values, which are the totals of the individual element deformations, are consistently larger than those recorded by test. This observation indicates that the bearing and shear stresses are somewhat less than those calculated for the areas concerned. This can be seen to be reasonable because part of the load must overcome friction between the faying surfaces of the joint, at least until the rivet loses its holding power through stress relaxation. In the case of the Type I and II joints, the friction effect appears to exert an influence on time to rupture as well as mode of rupture. It can be seen from the comparisons for these two types of joints that the experimental time to rupture is generally longer than that predicted and that the mode of failure does not necessarily follow the pattern determined by calculation.

In contrast to the Types I and II joints, for which predicted rupture behaviors appear to be conservative, the Type III joint consistently displays a pattern of accelerated rupture as shown by the comparison of the predicted and experimental values. The accelerated rupture behavior for this type of joint indicates that the stress pattern is intensified by virtue of the joint configuration.

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TABLE 1

CHEMICAL COMPOSITION OF TEST MATERIALS

Alloy	C	Si	Mn	S	P	Cr	Ni	Cu	Fe	Mo	W	V	Al	Mg	Zn	Ti	Sn	N	Other
2024-T3 Al Alloy Sheet 0.064 In. Thick		0.50	0.30-0.90			0.10		3.80-4.90	0.50				Bal.	1.20-1.80	0.10				0.15
2024-T3 Al Alloy Sheet 0.090 In. Thick		0.50	0.30-0.90			0.10		3.80-4.90	0.50				Bal.	1.20-1.80	0.10				0.15
2024-T3 Al Alloy Sheet 0.187 In. Thick		0.50	0.30-0.90			0.10		3.80-4.90	0.50				Bal.	1.20-1.80	0.10				0.15
2117-T4 Al Alloy Bar		0.80	0.20			0.10		2.20-3.00	1.00				Bal.	0.20-0.50	0.10				0.15
A-70 Ti Sheet	<0.1															Bal.		0.070	
C-110AM Ti Alloy Sheet	<0.1		6.76													Bal.		0.027	
A-110AT Ti Alloy Sheet	<0.1												5.9			Bal.	1.90	0.03	
A-110AT Ti Alloy Bar	<0.1												4.3			Bal.	2.20	0.02	
SAE 4130 Steel Sheet	0.31	0.27	0.51	0.032	0.012	0.96			Bal.	0.18									
Monel Alloy Bar	0.17	0.07	1.03	0.007			65.19	31.94	1.57										
Type 301 SS Bar	0.096	0.57	1.86	0.013	0.023	17.21	7.58		Bal.										

TABLE 1 (Contd.)

CHEMICAL COMPOSITION OF TEST MATERIALS

Alloy	C	Si	Mn	S	P	Cr	Ni	Cu	Fe	Mo	W	V	Al	Mg	Zn	Ti	Sn	N	Other
Type 321 SS Sheet	0.051	0.72	1.30	0.012	0.027	17.57	9.68		Bal.							0.060			
A-286 Alloy Sheet	0.050	0.58	1.24	0.012	0.024	14.01	24.87		Bal.	1.24		0.32	0.25			2.25			
A-286 Alloy Bar	0.042	0.66	1.44	0.016	0.026	14.64	24.95		Bal.	1.24		0.28				2.05			
19-9 DX Alloy Sheet	0.29	0.56	1.10	0.011	0.018	19.81	9.06	0.14	Bal.	1.43	1.39					0.05			
19-9 DX Alloy Bar	0.31	0.64	1.28	0.020	0.014	19.08	8.77	0.13	Bal.	1.60	1.33					0.44			

TABLE 2

SUMMARY OF SHORT-TIME TEST PROGRAM

Material	Temp. °F	Tension	Compression	Bearing	Shear
2024-T3 Aluminum Alloy Sheet 0.064 Inch Thick	80	a			
	300	a	a	a	
	450	a	a	a	
	600	a	a	a	
2024-T3 Aluminum Alloy Sheet 0.090 Inch Thick	80	a			
	300	a	a		
	450	a	a		
	600	a	a		
2024-T3 Aluminum Alloy Sheet 0.187 Inch Thick	80	a			a
	300	a			a
	450	a	a		a
	600	a	a		a
2117-T4 Aluminum Alloy Bar	80	a			a
	300	a			a
	450	a			a
	600	a			a
A-70 Titanium Sheet	80	a			
	700	a	a	a	
	800	a	a	a	
C-110M Titanium Alloy Sheet	80	a			
	600	a			
	700	a	a	a	
	800	a	a	a	
A-110AT Titanium Alloy Sheet	80	a			
	600	a			
	800	a	a	a	
	1000	a	a	a	
A-110AT Titanium Alloy Bar	80	a			
	600	a			
	800	a			a
	1000	a			a
SAE 4130 Steel Sheet	80	a			
	800	a	a	a	
	900	a	a	a	
	1000	a	a	a	
Monel Alloy Bar	80	a			a
	1000	a			a
	1200	a			a
Type 301 Stainless Steel Alloy Bar	80	a			a
	1200	a			a
	1350	a			a
Type 321 Stainless Steel Sheet	80	a			
	1000	a	a		
	1200	a	a	a	
	1350	a	a	a	

TABLE 2 (Contd.)

SUMMARY OF SHORT-TIME TEST PROGRAM

Material	Temp. °F	Tension	Compression	Bearing	Shear
A-286 Stainless Steel Sheet	80	a			
	1000	a			
	1200	a			
	1350	a			
	1500	a			
A-286 Stainless Steel Bar	80	a			
	1000	a			a
	1200	a			a
	1350				a
19-9 DX Alloy Sheet	80	a			
	1000	a			
	1200	a	a	a	
	1350	a	a	a	
	1500	a			
19-9 DX Alloy Bar	80	a			
	1000	a			a
	1200	a			a
	1350				a

a = Data presented in this report.

TABLE 3

SUMMARY OF BEARING CREEP-RUPTURE TEST PROGRAM

Material	Sheet Thickness Inch	Temp. °F	Bearing Hole Diameter Inch	Edge Distance to Hole Diameter Ratio 1.5	Edge Distance to Hole Diameter Ratio 2.0
2024-T3 Aluminum Alloy Sheet	0.064	300	1/16	a	a
			1/8	a	a
			3/16	a	a
		450	1/16	a	a
			1/8	a	a
			3/16	a	a
		600	1/16	a	a
			1/8	a	a
			3/16	a	a
2024-T3 Aluminum Alloy Sheet	0.090	300	1/16	a	a
			1/8	a	a
			3/16	a	a
		450	1/16	a	a
			1/8	a	a
			3/16	a	a
		600	1/16	a	a
			1/8	a	a
			3/16	a	a

a = Data presented in this report.

TABLE 4

TENSION CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET

Temp °F	Stress PSI	% Elong. on Loading	Time in Hours for Deformation of 0.1% C	0.1% TD	0.2% C	0.2% TD	0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	3.0% C	3.0% TD	5.0% C	5.0% TD	Fracture Hours	Time of Test Hours	Specimen
300	40,000	0.485	6.1	OL	167.0	OL	452.0	0.5	-	465.0	-	-	-	-	-	-	616.0	616.0	398-19
	47,000	1.106	0.5	OL	1.0	OL	4.0	OL	171.0	OL	-	140.0	-	-	-	-	216.0	216.0	389-9
	49,000	1.521	0.75	OL	1.75	OL	6.0	OL	-	OL	-	6.5	-	-	-	-	100.5	100.5	398-6
	53,000	2.83	0.10	OL	0.25	OL	1.0	OL	3.5	OL	-	OL	-	0.25	-	-	85.2	85.2	398-2
	58,000	8.60	0.05	OL	0.08	OL	0.20	OL	0.5	OL	1.30	OL	2.5	OL	10.2	OL	11.0	11.0	398-10
450	12,000	0.095	19.0	0.2	80.0	25.0	260.0	205.0	453.0	424.0	608.0	598.0	-	-	-	-	635.2	635.2	398-16
	15,000	0.084	4.2	0.3	65.0	10.0	128.0	112.0	196.0	190.0	224.7	224.0	238.0	238.0	-	-	244.5	244.5	398-7
	19,000	0.214	4.0	OL	28.0	OL	56.5	43.0	76.0	68.5	107.0	102.5	117.5	117.7	-	-	127.0	127.0	398-3
	22,000	0.285	1.95	OL	7.5	OL	22.5	OL	38.0	31.0	54.0	51.0	63.0	61.0	-	-	96.5	96.5	398-1
	27,000	0.285	0.30	OL	0.65	OL	2.45	0.8	4.7	3.5	-	-	-	-	-	-	5.9	5.9	398-8
600	3,000	0.066	7.0	0.6	120.0	27.0	474.0	412.0	797.0	780.0	-	-	-	-	-	-	816.0	816.0	398-17
	4,000	0.007	3.15	3.2	26.5	22.0	98.0	97.0	169.0	168.0	214.9	214.8	-	-	-	-	258.5	258.5	398-5
	5,000	0.066	5.0	0.9	13.0	8.2	44.0	41.0	66.0	63.5	95.5	94.0	109.7	108.7	121.7	121.0	140.0	140.0	398-20
	7,000	0.078	0.6	0.2	1.2	0.8	5.6	4.7	10.2	9.6	15.4	15.1	18.5	18.3	21.4	21.4	23.8	23.8	398-12

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 5

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/16 INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 1.5D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter: 0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	3.0% C	3.0% TD	5.0% C	5.0% TD	10.0% C	10.0% TD	20.0% C	20.0% TD	Fracture Hours	Time of Test Hours	Specimen 212-B
300	56,000	16.05	0.90	OL	1.10	OL	4.00	OL	16.50	OL	191.00	OL	274.0	OL	-	OL	286.0	286.0	207
	60,000	16.75	0.80	OL	0.90	OL	6.00	OL	72.00	OL	83.50	OL	217.00	OL	-	OL	195.75	195.75	157
	70,000	26.45	2.00	OL	6.00	OL	36.50	OL	57.00	OL	61.00	OL	-	OL	-	OL	60.75	60.75	161
	82,000	30.45	0.40	OL	1.20	OL	2.20	OL	7.50	OL	9.50	OL	-	OL	-	OL	20.0	20.0	160
450	19,000	2.38	1.10	OL	1.90	OL	5.50	OL	13.50	1.80	36.0	10.00	101.50	75.00	146.00	141.80	151.75	151.75	151
	22,000	2.76	0.95	OL	1.00	OL	4.00	OL	12.00	0.90	31.50	7.00	62.0	55.0	106.00	103.50	105.5	105.5	150
	25,000	2.85	0.50	OL	0.75	OL	2.00	OL	4.20	0.30	9.98	2.10	27.00	17.75	40.00	38.40	41.5	41.5	149
	30,000	5.88	0.25	OL	0.50	OL	0.95	OL	1.70	OL	2.30	OL	7.95	1.75	12.00	10.20	11.75	11.75	148
	35,000	6.65	0.20	OL	0.60	OL	0.85	OL	1.50	OL	2.00	OL	3.10	1.50	-	3.70	3.75	3.75	147
600	4,000	1.35	0.45	OL	1.00	OL	2.00	1.00	5.00	1.95	14.00	7.00	63.00	77.00	211.00	194.00	359.5	359.5	155
	5,000	2.14	0.09	OL	0.50	OL	1.75	OL	3.50	0.45	9.00	3.25	32.00	21.00	68.50	62.30	107.50	107.50	209
	6,000	1.63	0.05	OL	0.20	OL	1.10	0.15	2.00	0.30	4.10	2.00	18.00	13.80	46.00	42.00	72.8	72.8	158
	7,000	1.72	0.15	OL	0.35	OL	0.90	0.10	1.85	0.50	3.45	2.00	6.75	5.70	11.20	10.60	13.50	13.50	208
	8,000	0.598	0.30	OL	0.60	OL	1.35	0.75	2.00	1.50	3.35	2.75	6.55	6.35	11.00	10.80	14.0	14.0	156
	8,000	0.878	0.45	OL	0.55	OL	1.00	0.60	1.50	1.00	3.00	2.10	7.50	6.80	13.50	13.00	19.5	19.5	153

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 6

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/8-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 1.5D

Temp. °F	Stress P.S.I.	% Def. of Hole on Loading	Time in Hours for Deformation of Bearing Hole Diameter of														Fracture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
			1.0%		2.0%		3.0%		4.0%		5.0%		7.0%		10.0%					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
	40,000	1.84	720.	OL		3.		900.										958.	.000666	212-B58
	50,000	2.53	415.	OL		OL		20.		850.								2468.	.00111	212-B57
	62,000	4.06	120.	OL	503.	OL	580.	OL	620.	OL	652.	100.		578.			711.5	711.5	.00208	212-B63
	66,000	4.21	35.	OL	310.	OL	430.	OL	442.	OL	453.	13.	488.	420.	497.	464.	498.	498.	.00317	212-B56
	70,000	5.45	20.	OL	260.	OL	303.	OL	307.	OL	313.	OL	330.	150.	345.	310.	349.	349.	.00338	212-B60
300	74,000	5.66	5.0	OL	30.	OL	125.	OL	207.	OL	212.	OL	225.	7.		207.	237.7	237.7	.0059	212-B53
	78,000	7.44	2.0	OL	12.	OL	67.	OL	98.	OL		OL		OL		28.	112.7	112.7	.0080	212-B52
	82,000	8.85	3.5	OL	11.5	OL	70.	OL	70.5	OL	72.	OL	75.	OL		4.	75.3	75.3	.0125	212-B51
	86,000	12.8	2.5	OL	11.	OL	29.	OL	33.5	OL		OL		OL		OL	34.3	34.3	.0455	212-B49
	89,000	13.28	No Readings														25.5	25.5		212-B47
	92,000	17.68	.64	OL	1.6	OL	2.7	OL	4.0	OL	4.9	OL		OL		OL	5.5	5.5	.74	212-B55
	100,000		Fractured On Loading																	212-B54

C = Creep
TD = Total deformation
OL = On loading

TABLE 6 (Contd.)

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064-INCH THICK 2024-T3
ALUMINUM ALLOY SHEET FOR 1/8-INCH DIAMETER BEARING HOLE
AND EDGE DISTANCE OF 1.5D

Temp. °F	Stress P.S.I.	% Def. of Hole on Loading	Time in Hours for Deformation of Bearing Hole Diameter of														Fracture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
			1.0%		2.0%		3.0%		4.0%		5.0%		7.0%		10.0%					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
	10,000	0.462	50.	11.	530.	230.		970.										1028.	.00122	212B50
	18,500	.802	40.	.50	160.	59.	295.	187.	429.	323.	523.	450.	664.	610.	804.	777.	905.	905.	.00727	212B70
	22,000	0.80	20.	0.83	70.	26.	120.	78.0	160.	130.	192.*	168.						189.	.0198	212B12
	24,000	0.93	13.	0.1	68.	22.	121.	74.	162.	126.	194.	167.	240.	222.	285.	277.	292.	292.	.0188	212B26
	25,000	1.03	8.	OL	38.	7.0	74.	38.	110.	73.	142.	110.	167.5	167.	226.	215.	251.	251.	.0278	212B21
	26,000	1.11	6.	OL	17.	3.	37.	16.	63.	36.	80.	60.	108.	93.	132.	124.	144.	144.	.0476	212B3
	28,000	1.12	7.0	OL	25.	6.0	42.	26.	59.	40.	73.	58.	89.5	81.5	102.8	98.	109.	109.	.0545	212B17
450	29,000	1.09	4.5	OL	18.5	3.5	33.5	18.	49.	32.5	59.	48.	75.5	67.6	87.	84.	93.7	93.7	.065	212B14
	30,000	1.04	2.1	OL	13.3	4.0	35.3	14.	34.0	25.0	41.0	34.	51.4	47.	59.	57.	64.0	64.0	.094	212B8
	33,000	1.19	3.0	OL	9.0	1.6	15.4	7.5	21.7	14.2	26.0	20.3	32.4	29.	37.8	36.	41.58	41.58	.156	212B6
	35,000	1.67	2.4	OL	5.9	0.3	10.3	3.0	14.7	7.5	18.3	12.0	23.3	19.4	27.7	24	30.25	30.25	.207	212B1
	37,000	1.39	1.60	OL	5.0	0.75	8.5	4.0	11.5	7.3	14.0	10.25	17.8	15.3	20.6	19.7	22.25	22.25	.276	212B7
	40,000	1.81	.70	OL	2.2	0.10	4.2	1.0	6.0	2.5	7.5	4.6	9.8	7.7	11.80	10.7	13.0	13.0	.51	212B25
	45,000	0.86	.77	.02	1.8	1.0	2.85	2.0	3.80	3.0	4.67	4.0	5.65	5.35	6.25	6.12	6.5	6.5	1.11	212B11
	50,000	1.27	.4	OL	1.0	0.25	1.53	0.80	2.05	1.4	2.42	1.8	2.88	2.6	3.22	3.1	3.83	3.83	1.85	212B20
	55,000	2.4	.04	OL	.103	OL	.19	.016	.28	.075	.36	0.15	.49	.33	.604	.53	.75	.75	10.8	212B19
	60,000	3.2	.055	OL	.125	OL	.183	OL	.23	.042	.27	0.12	.34	.22		.33	.50	.50	13.7	212B24

* Extrapolated
C = Creep
TD = Total deformation
OL = On loading

TABLE 6 (Contd.)

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064-INCH THICK 2024-T3
ALUMINUM ALLOY SHEET FOR 1/8-INCH DIAMETER BEARING HOLE
AND EDGE DISTANCE OF 1.5D

Temp. °F	Stress P.S.I.	% Def. of Hole on Loading	Time in Hours for Deformation of Bearing Hole Diameter of: 0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	3.0% C	3.0% TD	4.0% C	4.0% TD	5.0% C	5.0% TD	10.0% C	10.0% TD	Fracture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
	2,000	0.054	167.	130.	547.	515.												616.	.00095	212-B28
	3,000	0.11	9.	4.	70.	50.	950*	895.										898.	.00074	212-B42
	4,000	0.17	6.	3.	30.	15.	230.	185.		463.								499.	.00324	212-B32
	5,000	0.23	1.4	0.9	8.	4.5	40.	30.	109.	94.	172.	159.	230.	215.	452.	445.	786.	786.	.0143	212-B29
	6,000	0.36	0.9		3.0	1.2	15.	10.	42.	32.	78.	68.	98.	90.	174.	171.	294.	294.	.0268	212-B30
600	7.000	0.26	2.	.9	7.0	3.6	20.	16.	35.	31.	49.	44.	57.	54.	88.	86.	127.	127.	.060	212-B34
	8,000	0.41	1.		2.5	.85	7.2	4.7	13.5	11.	20.	17.2	25.5	23.	42.7	42.	70.	70.	.155	212-B40
	9,000	0.52	1.	OL	2.2	.54	5.0	3.5	8.8	7.0	11.3	10.4	14.3	13.	23.5	22.8	35.	35.	.285	212-B35
	10,000	0.53	0.6	OL	1.8	.44	4.2	3.0	6.7	5.5	8.7	7.7	10.5	9.5	16.2	16.0	24.3	24.3	.358	212-B39
	11,000	0.72	.90	OL	1.5	.35	3.4	2.1		3.7							13.25	13.25	.52	212-B31
	15,000	0.95	.16	OL	.32	.02	.76	.34	1.8	.78	1.32	1.08	1.52	1.33	2.16	2.07	2.95	2.95	2.1	212-B37

* Extrapolated
C = Creep
TD = Total deformation
OL = On loading

TABLE 7

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 3/16 INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 1.5D

Temp °F	Bearing Stress PSI	Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 212-F
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	65,000	3.314	1.00	OL	4.00	OL	30.00	OL	160.00	OL	188.00	15.00	205.50	196.00	-	-	210.0	210.0	190
	72,000	5.22	0.15	OL	1.5	OL	5.00	OL	21.50	OL	81.50	OL	96.00	81.00	-	-	97.75	97.75	187
	80,000	8.80	0.05	OL	0.40	OL	1.00	OL	3.00	OL	25.00	OL	26.80	1.10	-	27.00	27.25	27.25	188
	88,000	18.90	0.05	OL	0.10	OL	0.15	OL	0.35	OL	1.70	OL	-	OL	-	0.10	4.00	.4.00	189
450	21,000	0.74	1.90	OL	4.00	0.80	17.00	7.00	37.50	22.00	73.00	72.00	191.00	182.50	-	-	221.0	221.0	185
	25,000	0.938	0.95	OL	5.50	OL	19.00	5.75	34.00	20.00	62.00	49.50	93.50	90.00	-	-	102.25	102.25	183
	30,000	1.33	1.00	OL	2.00	OL	7.50	1.10	15.10	6.00	27.00	19.00	40.10	38.00	-	-	44.0	44.0	182
	40,000	1.836	0.05	OL	0.50	OL	1.00	OL	1.95	0.80	3.20	2.00	5.00	4.85	-	-	6.0	6.0	184
600	6,000	0.1975	2.00	1.00	8.00	4.00	30.00	26.00	57.00	52.00	104.00	100.00	174.00	173.50	230.00	229.50	259.5	259.5	180
	7,000	0.296	0.70	0.50	1.75	1.00	6.00	5.75	13.75	12.00	30.00	28.00	67.50	65.50	-	-	115.0	115.0	181
	8,500	0.306	1.00	0.60	2.00	1.10	5.95	5.00	9.00	8.10	14.10	13.50	-	-	-	-	29.0	29.0	179
	10,000	0.867	0.50	OL	0.90	OL	1.80	0.90	3.00	1.90	5.00	4.65	-	-	-	-	16.25	16.25	177

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 8

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/16 INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 2.0D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 212-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	80,000	12.35	0.70	OL	2.00	OL	8.00	OL	60.00	OL	167.50	OL	218.00	OL	-	205.50	241.25	241.25	170
	87,000	16.60	3.00	OL	13.00	OL	80.00	OL	138.00	OL	164.00	OL	174.00	OL	-	148.00	176.25	176.25	171
	105,000	49.99	3.20	OL	6.00	OL	19.00	OL	27.00	OL	-	OL	-	OL	-	OL	43.5	43.5	172
	108,000	47.50	0.40	OL	0.95	OL	2.10	OL	4.00	OL	9.00	OL	-	OL	-	OL	14.0	14.0	175
450	25,000	6.58	0.60	OL	1.00	OL	4.00	OL	10.00	OL	27.85	OL	72.00	13.70	-	95.75	182.5	182.5	164
	30,000	5.39	0.10	OL	0.50	OL	1.50	OL	3.00	OL	9.00	OL	33.00	7.00	66.50	56.50	84.0	84.0	162
	35,000	5.00	0.05	OL	0.20	OL	1.00	OL	2.90	OL	7.00	OL	19.00	6.95	31.90	26.50	41.0	41.0	163
	41,000	11.42	0.30	OL	0.50	OL	0.95	OL	1.50	OL	3.00	OL	5.90	OL	-	5.10	14.25	14.25	165
600	6,000	2.58	0.25	OL	0.80	OL	1.50	OL	3.30	0.25	12.00	1.80	48.00	28.80	122.00	105.00	310.0	310.0	167
	8,000	2.38	0.30	OL	1.10	OL	2.30	OL	3.80	0.95	6.50	3.40	17.10	12.00	40.90	35.00	97.75	97.75	166
	9,400	2.37	0.70	OL	1.30	OL	2.00	OL	3.95	0.75	6.60	3.30	14.60	10.50	31.00	27.30	56.0	56.0	168
	15,000	3.17	0.10	OL	0.20	OL	0.40	OL	0.50	OL	0.70	0.35	1.40	1.10	2.70	2.45	4.4	4.4	169

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 9

BEARING CREEP RUPTURE CHARACTERISTICS OF 0.064-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/8-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 2.0D

Temp. °F	Stress PSI	% Elong- on Load - ing	Time in Hours for Bearing Deformation Expressed as Percent of the Diameter														Frac- ture Time Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%					
			C	TD	C	TD	C	TD	C	TD	C	. TD	C	TD	C	TD				
	80,000	6.98	7	OL	40.	OL	335.	OL		OL		OL						405.	0.00303	212B126
	90,000	8.97	0.1	OL	2.6	OL	13.	OL		OL		OL						18.2	0.077	212B128
300	100,000	13.04		OL	0.25	OL	4.	OL	15.	OL	86.	OL		OL			99.0	99.0	0.0143	212B123
	110,000	19.28		OL	0.30	OL	0.60	OL	1.60	OL	9.6	OL		OL			24.5	24.5	0.143	212B124
	120,000		No strain measurements														4.5	4.5		212B127
	25,000	1.57	6.5	OL	29.	OL	97.	5.		60.								113.	0.015	212B110
	35,000	2.03		OL	4.	OL	12.	OL	18.	3.	29.	18.	59.	47.			109.5	109.5	0.17	212B109
450	40,000	1.95	0.4	OL	2.4	OL	4.5		8.	2.5	12.	8.	27.	20.5		46.	51.	51.	0.29	212B108
	55,000	3.37	0.04	OL	0.07	OL	0.2	OL	0.32	OL	0.62	0.15	1.76	0.95		3.2	4.0	4.0	8.3	212B107
	65,000	4.91		OL		OL		OL	0.02	OL	0.05		0.17	0.05		0.33	0.5	0.5	59.	212B106
	5,000	0.446	10.		65.	15.	217.	150.		300.								307.	0.0067	212B105
	7,000	0.62	2.	OL	7.	0.5	35.	15.	63.	45.	118.	102.						136.	0.035	212B121
600	10,000	0.87	1.	OL	2.8		6.8	3.	10.	7.	16.8	14.	35.	32.			99.	99.	0.238	212B113
	15,000	1.17	0.1	OL	0.45	OL	1.4	0.35	2.0	1.25	3.1	2.5	6.5	5.6			17.	17.	1.39	212B111
	20,000	1.86		OL	0.06	OL	0.13		0.22	0.07	0.37	0.24	0.39	0.68		1.66	2.5	2.5	10.7	212B114

C : Creep

TD : Total Deformation

OL : On Loading

TABLE 10

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 3/16 INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 2.0D

Temp °F	Bearing Stress PSI	Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 212-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	80,000	4.03	1.75	OL	15.00	OL	190.00	OL	261.00	OL	314.00	13.00	354.00	330.00	-	364.00	366.75	366.75	202
	100,000	10.62	1.00	OL	2.00	OL	8.20	OL	34.00	OL	65.90	OL	-	OL	-	-	69.5	69.5	203
	105,000	12.95	0.50	OL	1.30	OL	5.00	OL	13.50	OL	-	OL	-	OL	-	-	29.5	29.5	205
	110,000	19.50	0.05	OL	0.10	OL	0.50	OL	1.40	OL	5.75	OL	-	OL	-	OL	14.5	14.5	206
450	30,000	1.15	1.00	OL	2.00	OL	5.90	1.00	13.80	5.50	35.50	22.00	105.50	91.00	180.00	176.00	192.25	192.25	199
	34,000	1.19	1.00	OL	1.90	OL	6.10	0.98	11.60	5.60	20.60	15.00	48.40	42.20	-	-	94.0	94.0	198
	40,000	1.50	0.50	OL	1.00	OL	3.20	0.50	5.50	2.10	10.00	6.60	22.50	19.00	-	-	37.25	37.25	197
	48,000	2.06	0.10	OL	0.15	OL	0.55	OL	1.00	0.10	2.50	1.10	6.75	5.00	-	-	10.25	10.25	201
600	7,600	0.316	0.60	OL	1.90	1.00	6.10	4.00	15.10	13.0	34.90	32.40	100.00	96.00	223.00	220.00	308.5	308.5	195
	9,000	0.346	0.30	OL	0.95	0.70	5.90	4.00	7.90	7.50	19.95	17.90	48.00	46.00	96.00	95.85	148.0	148.0	194
	10,000	0.612	0.15	OL	0.75	0.50	3.50	2.00	7.50	5.00	16.00	13.90	42.00	39.00	71.75	70.00	93.75	93.75	193
	17,000	0.711	0.10	OL	0.19	0.09	0.35	0.24	0.50	0.40	0.90	0.75	2.10	2.00	2.85	2.82	4.75	4.75	196

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 11

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/16-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 1.5D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 398-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	64,000	13.30	2.50	OL	7.00	OL	97.00	OL	192.0	OL	225.6	OL	234.9	OL	-	233.0	235.2	235.2	40
	67,000	22.38	2.00	OL	5.90	OL	92.00	OL	138.3	OL	164.0	OL	-	OL	-	OL	171.8	171.8	39
	70,000	15.18	1.00	OL	3.90	OL	66.00	OL	132.5	OL	155.2	OL	-	OL	-	155.0	158.5	158.5	38
	75,000	18.76	0.60	OL	1.60	OL	8.00	OL	47.0	OL	66.1	OL	-	OL	-	-	68.0	68.0	36
	80,000	22.86	0.30	OL	0.80	OL	16.00	OL	47.2	OL	53.2	OL	-	OL	-	OL	53.7	53.7	37
450	16,000	2.68	0.20	OL	0.90	OL	3.20	OL	8.0	0.20	31.0	4.0	146.0	86.0	266.7	250.0	298.5	298.5	41
	20,000	5.90	0.17	OL	0.55	OL	2.70	OL	6.0	OL	28.0	OL	112.0	17.0	178.0	154.0	188.5	188.5	105
	22,000	6.70	0.15	OL	0.40	OL	0.80	OL	1.5	OL	11.0	OL	23.0	1.8	48.9	35.5	54.2	54.2	43
	28,000	19.09	0.09	OL	0.20	OL	0.60	OL	1.0	OL	3.0	OL	8.4	OL	13.3	0.5	14.0	14.0	42
600	4,500	2.97	0.35	OL	0.90	OL	1.60	OL	3.8	OL	20.0	1.20	120.0	9.7	240.5	214.0	314.0	314.0	102
	5,500	0.67	0.30	OL	0.75	0.30	1.30	0.75	3.9	2.00	15.0	10.0	57.0	56.5	59.2	59.0	60.0	60.0	106
	6,000	1.78	0.20	OL	0.45	OL	0.95	0.40	2.0	0.95	4.9	2.4	17.0	12.0	39.9	37.0	52.5	52.5	45
	9,000	2.97	0.05	OL	0.10	OL	0.25	OL	0.5	OL	0.9	0.2	2.0	1.3	4.9	4.0	6.7	6.7	44

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 12

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/8-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 1.5D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 398-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	70,000	7.14	1.70	OL	3.50	OL	30.0	OL	112.0	OL	146.5	OL	163.9	106.0	-	-	164.0	164.0	75
	75,000	8.94	1.65	OL	4.10	OL	34.0	OL	122.0	OL	153.0	OL	-	4.90	-	-	157.0	157.0	74
	80,000	10.85	0.50	OL	1.10	OL	2.80	OL	8.0	OL	46.3	OL	-	OL	-	-	49.7	49.7	73
	90,000	18.55	0.10	OL	0.45	OL	1.00	OL	1.8	OL	3.7	OL	-	OL	-	1.70	4.5	4.5	72
450	19,000	1.21	1.65	OL	3.00	OL	20.0	2.00	39.9	13.0	96.2	60.0	202.2	186.0	-	-	269.5	269.5	70
	23,000	1.64	1.00	OL	1.95	OL	6.0	1.00	18.0	3.0	47.0	20.0	107.0	95.0	135.9	133.8	142.0	142.0	68
	30,000	2.07	0.55	OL	1.00	OL	4.1	OL	7.0	0.95	13.1	7.0	25.2	22.0	30.6	30.1	31.5	31.5	67
	40,000	2.24	0.30	OL	0.55	OL	1.0	OL	1.4	0.45	2.6	1.4	4.3	3.7	-	-	5.25	5.25	66
600	6,000	0.32	1.80	0.50	6.00	2.00	18.0	16.00	44.0	36.0	96.0	88.0	194.0	188.0	287.0	285.0	373.0	373.0	65
	7,000	0.40	1.45	0.35	3.00	0.90	8.0	4.50	14.0	12.0	34.0	30.0	74.0	71.40	117.5	117.0	151.7	151.7	63
	8,000	0.76	1.00	OL	1.90	0.45	5.6	2.60	10.2	7.9	23.0	18.2	43.0	40.0	63.5	62.5	92.0	92.0	62
	13,000	0.86	0.35	OL	0.40	0.05	0.70	0.40	1.0	0.75	1.8	1.5	3.1	2.9	4.7	4.6	6.2	6.2	64

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 13

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 3/16-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 1.5D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter: 0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	3.0% C	3.0% TD	5.0% C	5.0% TD	10.0% C	10.0% TD	20.0% C	20.0% TD	Fracture Hrs.	Time of Test Hour	Specimen 398-B
300	75,000	5.71	7.75	OL	60.0	OL	185.00	OL	214.0	OL	-	OL	-	224.0	-	-	226.2	226.2	4
	80,000	8.78	1.60	OL	5.40	OL	91.00	OL	147.5	OL	155.6	OL	155.7	3.0	-	155.5	155.7	155.7	3
	85,000	10.77	0.25	OL	0.95	OL	4.00	OL	23.0	OL	-	OL	-	OL	-	-	57.7	57.7	2
	90,000	17.40	0.20	OL	0.95	OL	4.00	OL	8.4	OL	-	OL	-	OL	-	6.6	12.7	12.7	1
450	20,000	1.06	3.00	OL	10.00	OL	65.00	7.50	140.0	60.0	272.0	210.0	404.0	388.5	405.0	405.0	429.0	429.0	11
	25,000	1.73	2.65	OL	11.0	OL	47.00	1.00	74.5	20.0	106.0	80.0	147.0	138.0	166.0	164.7	170.5	170.5	10
	30,000	1.75	1.20	OL	2.00	OL	6.50	0.60	13.8	3.0	30.5	16.0	55.4	49.0	-	66.0	67.5	67.5	12
	35,000	2.00	0.70	OL	1.65	OL	4.50	OL	8.3	1.8	14.4	8.0	24.6	22.0	-	-	27.0	27.0	9
600	7,000	0.54	2.00	OL	6.00	1.85	26.00	13.50	50.0	37.0	104.0	90.0	180.0	174.5	230.0	229.0	266.0	266.0	5
	8,000	0.43	1.00	0.05	2.00	0.90	9.00	5.65	21.0	16.0	40.0	36.5	73.0	71.0	94.9	94.2	104.5	104.5	8
	9,000	0.81	0.85	OL	2.50	0.60	8.80	3.60	16.5	10.5	30.0	25.0	48.2	46.2	59.6	59.5	62.5	62.5	7
	12,000	0.84	0.40	OL	1.00	0.30	2.80	1.30	4.0	3.0	6.1	5.5	9.0	8.7	-	-	10.5	10.5	6

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 14

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/16-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 2.0D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 398-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	85,000	24.75	0.85	OL	1.20	OL	9.50	OL	74.00	OL	196.0	OL	247.5	OL	262.0	OL	263.2	263.2	27
	90,000	31.40	0.20	OL	0.50	OL	5.00	OL	29.00	OL	151.5	OL	180.5	OL	-	OL	185.0	185.0	26
	97,000	38.78	0.20	OL	0.85	OL	2.50	OL	9.00	OL	83.00	OL	104.5	OL	-	OL	105.5	105.5	28
	110,000	52.70	0.05	OL	0.20	OL	0.70	OL	1.25	OL	3.70	OL	11.2	OL	-	OL	12.0	12.0	29
450	26,000	5.21	0.40	OL	1.10	OL	5.00	OL	14.00	OL	40.00	OL	77.0	37.8	161.5	138.5	198.2	198.2	21
	30,000	14.37	0.35	OL	0.50	OL	1.80	OL	4.20	OL	12.50	OL	42.1	OL	74.0	16.6	92.5	92.5	97
	35,000	15.80	0.30	OL	0.50	OL	1.00	OL	2.45	OL	6.90	OL	17.6	OL	29.5	6.1	37.0	37.0	96
	48,000	11.83	0.20	OL	0.40	OL	0.90	OL	1.50	OL	2.95	OL	6.4	OL	9.3	5.3	10.0	10.0	18
600	6,000	0.594	0.30	OL	0.50	0.35	1.60	1.00	3.00	2.10	11.95	8.30	70.0	60.1	191.8	185.9	408.0	408.0	92
	7,500	2.14	0.10	OL	0.40	OL	0.80	OL	1.00	0.10	3.20	0.50	25.2	11.9	82.9	74.2	163.5	163.5	93
	8,000	3.35	0.07	OL	0.30	OL	0.90	OL	1.95	OL	7.90	0.60	36.0	16.0	80.9	69.0	148.5	148.5	30
	9,000	3.27	0.05	OL	0.10	OL	0.50	OL	0.90	OL	2.90	0.40	14.6	5.5	39.0	32.5	70.7	70.7	94
	10,000	3.27	0.05	OL	0.10	OL	0.50	OL	0.90	OL	2.70	0.40	8.9	4.9	16.4	14.5	22.0	22.0	91

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 15

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 1/8-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 2.0D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 398-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	80,000	5.83	2.00	OL	9.50	OL	15.50	OL	85.00	OL	347.5	OL	462.0	282.5	528.5	507.5	533.0	533.0	77
	90,000	9.58	0.50	OL	1.00	OL	3.40	OL	17.00	OL	108.0	OL	172.0	.3	187.0	174.5	187.5	187.5	87
	100,000	11.21	0.30	OL	0.55	OL	1.00	OL	2.75	OL	20.0	OL	101.0	OL	-	94.5	111.0	111.0	90
	110,000	26.20	0.90	OL	1.80	OL	4.40	OL	10.00	OL	10.4	OL	-	OL	-	OL	12.5	12.5	88
	120,000	37.50	1.60	OL	3.10	OL	3.80	OL	4.00	OL	-	OL	-	OL	-	OL	4.0	4.0	78
450	25,000	1.45	2.50	OL	7.00	OL	29.00	3.00	56.00	17.50	108.0	70.0	232.0	193.5	449.0	433.5	505.7	505.7	81
	30,000	1.59	2.10	OL	5.00	OL	17.00	2.00	27.00	12.00	43.0	30.0	85.0	72.0	155.0	148.0	179.0	179.0	79
	35,000	1.61	1.40	OL	1.90	OL	6.75	1.30	11.90	3.80	22.0	14.0	45.8	38.0	76.8	75.0	77.0	77.0	80
	46,000	3.16	0.20	OL	0.35	OL	0.65	OL	0.95	OL	1.5	0.6	2.6	2.0	4.3	3.8	5.5	5.5	82
600	9,000	0.819	0.60	OL	2.20	0.95	5.95	3.10	10.00	6.10	20.1	15.40	49.0	43.9	131.0	126.0	217.0	217.0	85
	10,000	1.08	0.55	OL	1.75	OL	3.85	1.70	6.00	3.80	11.0	8.0	32.0	25.0	78.4	75.0	135.0	135.0	84
	12,000	1.07	0.40	OL	0.95	OL	2.00	0.95	2.95	1.95	4.9	3.9	11.5	9.9	24.0	23.1	33.0	33.0	86
	15,000	1.26	0.25	OL	0.30	OL	0.50	0.25	0.95	0.45	1.8	1.1	4.9	4.0	-	-	18.5	18.5	83

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 16

BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091-INCH THICK 2024-T3 ALUMINUM ALLOY SHEET FOR 3/16-INCH DIAMETER BEARING HOLE AND EDGE DISTANCE OF 2.0D

Temp °F	Bearing Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen 398-B
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
300	90,000	9.53	3.70	OL	12.00	OL	130.00	OL	190.0	OL	242.5	OL	273.0	3.65	-	280.0	305.0	305.5	49
	92,000	9.88	3.30	OL	9.00	OL	118.00	OL	174.0	OL	212.5	OL	240.0	1.60	-	245.0	260.0	260.0	50
	95,000	11.88	3.35	OL	7.70	OL	90.00	OL	178.0	OL	213.0	OL	229.0	OL	-	226.0	232.0	232.0	58
	98,000	13.50	1.80	OL	3.00	OL	6.50	OL	31.0	OL	128.5	OL	172.0	OL	-	149.0	176.0	176.0	47
	100,000	12.14	1.00	OL	2.95	OL	10.50	OL	32.9	OL	34.5	OL	-	OL	-	34.8	35.0	35.0	46
450	30,000	1.68	1.75	OL	2.60	OL	9.50	1.10	25.0	4.0	52.5	30.0	96.5	84.0	189.0	176.0	250.5	250.5	52
	35,000	2.00	1.00	OL	2.00	OL	6.00	OL	13.0	1.9	25.3	13.0	47.0	38.9	84.0	78.0	109.0	109.0	53
	40,000	2.20	0.55	OL	0.95	OL	2.75	OL	5.0	0.8	10.4	4.5	21.5	16.6	-	39.3	56.5	56.5	51
	50,000	2.45	0.25	OL	0.45	OL	1.00	OL	1.8	0.3	2.6	1.5	4.5	3.5	8.3	7.5	10.0	10.0	54
600	8,000	0.48	1.85	OL	3.65	1.50	11.00	6.00	21.0	16.0	41.0	36.0	88.5	84.0	187.0	182.0	360.0	360.0	57
	9,000	0.68	2.70	OL	6.50	2.45	14.00	9.00	20.9	17.0	32.1	28.7	58.0	54.7	105.0	102.0	186.0	186.0	59
	10,000	0.714	1.00	OL	1.90	0.90	3.90	2.00	6.5	4.0	11.8	10.0	23.6	22.0	46.6	45.0	78.5	78.5	55
	12,000	0.714	0.55	OL	1.00	0.40	1.40	1.40	3.2	2.6	5.7	5.0	10.4	9.8	20.0	18.75	34.0	34.0	56

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 17

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 1.5

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
1/16 Inch	300	10	0.090	1.18	1.45		1.61*
		50		0.98*	1.28		1.36
		100		0.95	1.22		1.30
		200			1.16		1.26
		500					1.11
	450	1	0.67	0.88	1.00*	1.14*	1.14*
		10		0.61*	0.90	1.03	1.11
		50			0.88	1.05	1.12
		100			0.86*	1.02	1.15
		200				0.99*	1.17
		500					1.21*
	600	1	0.36	0.62	0.98*		
		10			0.65	0.98	1.27*
		50				0.84	1.22
		100				0.76*	1.03
		200					1.15
		500					1.10*
1/8 Inch	300	1	1.42	1.55*			1.60*
		10	1.30	1.46			1.60
		50	1.22	1.41			1.56
		100	1.22	1.42			1.54
		200	1.17	1.46			1.54
		500	1.03	1.38			1.48
	450	1	1.12	1.39	1.47		1.51
		10	0.94	1.14	1.40		1.50
		50		1.08	1.33		1.49
		100		1.08	1.36		1.53
		200		1.00	1.37		1.58
		500		0.90	1.62		1.84
	600	1	1.06	1.24			1.44*
		10	0.66	0.99			1.63
		50	0.64	1.02			1.61
		100	0.62	1.00			1.60
		200	0.61	1.01			1.60
		500	0.60	1.01			1.59

TABLE 17 (Contd.)

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 1.5

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
3/16 Inch	300	1	1.24	1.34	1.51*		1.56*
		10	1.09*	1.24	1.47		1.50
		50		1.18*	1.40		1.45
		100			1.39		1.42
		200			1.33		1.38
		500					1.29*
	450	1	0.96	1.11	1.30	1.37*	1.42*
		10	0.65*	0.97	1.24	1.29	1.35
		50		0.77*	1.16	1.32	1.37
		100			1.11	1.29	1.34
		200			1.05*	1.27	1.33
		500					
	600	1	0.87	1.00*	1.17		
		10	0.76	0.99	1.23		1.47*
		50		1.00*	1.27	1.40*	1.54
		100			1.27	1.41	1.54
		200			1.30*	1.45	1.58
		500				1.48*	1.58*

* = Ratio calculated from extrapolated stress values

TABLE 18

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 2.0

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
1/16 Inch	300	1	1.80				
		10	1.60	1.58	1.90		1.97*
		50		1.62	1.74		1.95
		100		1.59	1.73		1.86
		200			1.66		1.77
		500					
	450	1	0.70	0.99	1.38*		
		10		0.70*	1.11	1.37	1.58
		50			1.01*	1.28	1.56
		100				1.24	1.53
		200				1.20*	1.52
		500					1.75*
	600	1	0.80	1.00	1.24	1.44	1.71*
		10			0.93	1.34	1.79
		50				1.13	1.84
		100				1.02	1.74
		200					1.68
		500					1.55*
1/8 Inch	300	1	1.46	1.74			2.10*
		10	1.57	1.66	1.94		2.05
		50	1.54	1.64	1.91		1.95
		100	1.56	1.68	1.92		1.97
		200		1.73			2.00*
		500					
	450	1	1.21	1.28	1.44	1.58	1.70
		10	1.08	1.26	1.47	1.62	1.74
		50	1.04*	1.27	1.46	1.65	1.85
		100		1.32	1.50*	1.70*	1.90
		200					1.91*
		500					
	600	1	1.11	1.39	1.56	1.75	2.05*
		10	1.05	1.34	1.64	1.86	2.24
		50	1.00	1.30	1.60	1.75	2.22
		100	0.99*	1.26	1.54	1.70*	2.15
		200		1.25	1.55*		2.12*
		500					

TABLE 18 (Contd.)

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 2.0

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of				
			1.0%	2.0%	5.0%	10.0%	Rupture
3/16 Inch	300	1	1.76	1.81	1.95*		
		10	1.50	1.75	1.93		1.99
		50	1.32*	1.65	1.88		1.93
		100		1.64	1.84		1.88
		200		1.66	1.79		1.83
		500			1.68*		1.74*
	450	1	1.11	1.25	1.47*		
		10		1.00*	1.44	1.62	1.72
		50			1.36	1.60	1.76
		100			1.38*	1.61	1.81
		200				1.63*	1.82
		500					
	600	1	0.82	1.16	1.49	1.75*	
		10		0.90*	1.51	1.76	2.07
		50			1.23	1.77	2.11
		100				1.65	2.12
		200				1.57*	2.07
		500					1.99*

* = Ratio calculated from extrapolated stress values.

TABLE 19

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 1.5

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
1/16 Inch	300	1	1.34				
		10		1.54			
		50		1.39	1.55		1.61
		100		1.34	1.48		1.51
		200		1.28*	1.35		1.38
		500			1.35*		1.43*
	450	1	0.50	0.72	1.03		
		10		0.53	0.89	1.03	1.12
		50			0.62*	0.95	1.03
		100				0.95	1.07
		200				0.83*	1.16
		500					1.00*
	600	1		0.46	0.75	0.86*	
		10			0.68	0.86	1.02
		50			0.61*	0.81	0.97
		100				0.82	0.97
		200				0.85*	1.01
		500					1.10*
1/8 Inch	300	1	1.39	1.51	1.65*		
		10	1.27*	1.48	1.61		1.65
		50		1.43	1.55		1.58
		100		1.38*	1.50		1.55
		200			1.50		1.52
		500					
	450	1	0.94	1.23	1.47*	1.56*	
		10		1.10	1.20	1.34	1.39
		50		0.67*	1.01	1.14	1.21
		100			0.93	1.15	1.22
		200			0.92*	1.13	1.23
		500				1.09*	1.20*
	600	1	0.79	0.94	1.17	1.28*	
		10	0.63*	0.85	1.16	1.29	1.49
		50		0.70*	1.08	1.24	1.43
		100			1.08	1.24	1.43
		200			1.11	1.29	1.49
		500				1.42*	1.62

TABLE 19 (Contd.)

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 1.5

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
3/16 Inch	300	1	1.50	1.58			
		10	1.53	1.64			1.75
		50	1.49	1.61			1.71
		100	1.48*	1.61			1.70
		200		1.57			1.62
		500					1.60*
	450	1	1.14	1.40*			
		10	0.88	1.12	1.48	1.57*	1.66*
		50		0.94	1.24	1.33	1.40
		100		0.86*	1.25	1.32	1.40
		200			1.25	1.37	1.45
		500			1.29*	1.40*	1.49
	600	1	0.96	1.20*			
		10	0.71*	1.21	1.34	1.48	1.50
		50		0.93*	1.29	1.42	1.50
		100			1.30	1.42	1.52
		200			1.34*	1.50	1.61
		500					

* = Ratio calculated from extrapolated stress values.

TABLE 20

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 2.0

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
1/16 Inch	300	1	1.50	1.83	2.00*		
		10		1.61	2.02		2.12
		50			1.98		2.04
		100			1.91		1.99
		200			1.78		1.85
		500			1.76*		1.86*
	450	1	0.72	1.40			
		10			1.30	1.66	1.86
		50			0.93	1.25	1.52
		100				1.20	1.47
		200				1.19	1.54
		500					
	600	1	0.46	0.57	0.96		
		10			0.78	1.21	1.34*
		50				1.07	1.47
		100				0.98*	1.57
		200					1.60
		500					1.59*
1/8 Inch	300	1	1.58	1.74	2.09*		
		10	1.38*	1.65	2.02	2.11	2.16
		50		1.53*	1.95	2.04	2.09
		100			1.92	2.02	2.09
		200			1.77	1.85	1.92
		500			1.74	1.83	1.88
	450	1	1.18	1.35	1.50*	1.59*	
		10	0.95	1.24	1.47	1.57	1.69
		50		1.03*	1.28	1.50	1.61
		100			1.25	1.47	1.68
		200			1.30*	1.53	1.75
		500				1.62*	1.92
	600	1	0.91	1.08	1.35*		
		10	0.81*	0.99	1.29	1.59	1.97*
		50			1.19	1.46	1.90
		100				1.48*	1.91
		200					2.04
		500					

TABLE 20 (Contd.)

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURE USING VARIOUS BEARING HOLE DIAMETERS AND A CONSTANT EDGE DISTANCE TO HOLE DIAMETER RATIO OF 2.0

Bearing Hole Diameter	Temp. °F	Time in Hours	Stress Ratio for Bearing Creep Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
3/16 Inch	300	1	1.81*				
		10	1.78	1.89	1.96*		2.02*
		50		1.90	1.94		2.04
		100		1.90	1.95		2.04
		200					2.04
		500					2.00*
	450	1	1.25	1.53	1.81*		
		10	0.84	1.16	1.59	1.74	1.97
		50			1.32	1.52	1.78
		100			1.29	1.49	1.80
		200				1.54*	1.87
		500					2.00*
	600	1	0.96	1.20*			
		10	0.75*	1.00	1.36	1.51	1.78*
		50			1.23	1.45	1.77
		100			1.20*	1.44	1.81
		200				1.52	1.93
		500					2.16

* = Ratio calculated from extrapolated stress values.

TABLE 21

SUMMARY OF SHORT-TIME TENSILE CHARACTERISTICS OF TEST ALLOYS

Material	Temp. °F	0.2% Yield Strength PSI	Ultimate Tensile Strength PSI	% Elongation in 2 Inches
2024-T3 Aluminum Alloy Sheet 0.064 Inch Thick	80	51,400 51,400	69,400 69,700	18.5 17.5
	300	47,400 46,900	59,300 60,000	22.5 20.0
	450	35,600 36,100	37,400 38,800	9.0 10.5
	600	16,720 15,400	17,390 17,610	9.5 12.5
2024-T3 Aluminum Alloy Sheet 0.091 Inch Thick	80	55,900 54,700	73,300 71,100	15.0 - *
	300	44,700 45,700	60,100 60,400	20.5 20.0
	450	42,200 40,500	42,900 40,800	9.0 13.0
	600	19,350 17,900	20,100 18,500	16.5 17.5
2024-T3 Aluminum Alloy Sheet 0.187 Inch Thick	80	55,500 56,200	71,300 71,200	15.0 17.0
	300	50,700 46,700	58,400 57,800	23.5 21.5
	450	39,400 42,900	41,700 43,300	11.5 10.0
	600	17,710 16,250	18,600 17,620	13.0 14.0
2117-T4 Aluminum Alloy Bar	80	27,100 27,600	50,000 50,000	28.5 - *
	300	21,300 22,100	36,000 38,300	18.5 26.0
	450	21,200 23,300	22,300 23,700	16.5 11.5
	600	7,170 5,820	7,310 5,930	16.5 18.0
A-70 Titanium Alloy Sheet Annealed	80	75,800 75,800	93,900 93,100	26.5 25.0
	700	22,900 24,000	33,400 34,600	23.0 18.0
	800	22,600 23,600	34,300 32,300	8.0 10.5

TABLE 21 (Contd.)

SUMMARY OF SHORT-TIME TENSILE CHARACTERISTICS OF TEST ALLOYS

Material	Temp. °F	0.2% Yield Strength PSI	Ultimate Tensile Strength PSI	% Elongation in 2 Inches
C-110M Titanium Alloy Sheet	80	137,300 137,000	150,000 150,500	21.5 19.5
	600	64,100 67,000	92,300 95,500	13.5 14.0
	700	66,800 62,400	92,800 90,400	18.0 15.0
	800	69,900 66,200	75,700 75,400	30.5 33.0
A-110AT Titanium Alloy Sheet Annealed	80	127,000 -	138,900 -	17.5 -
	600	67,700 61,900	84,300 85,300	20.5 19.5
	800	61,000 73,400	81,400 82,700	21.5 19.5
	1000	52,800 55,200	64,600 65,000	52.0 52.0
A-110AT Titanium Alloy Bar Annealed	80	115,000 115,500	131,000 131,000	13.0 12.5
	600	80,700 83,600	93,600 92,400	9.0 9.0
	800	78,400 78,900	88,700 90,400	16.5 13.5
	1000	51,200 44,900	53,000 50,100	44.0 47.0
SAE 4130 Alloy Steel Sheet Normalized	80	74,000 74,000	99,000 98,000	17.0 16.0
	800	52,800 52,900	76,700 75,000	17.0 19.0
	900	50,000 51,400	63,000 61,700	22.5 24.5
	1000	41,300 42,700	48,400 48,600	32.5 27.0
Monel Alloy Bar Annealed	80	22,000 -	80,500 81,400	51.0 51.0
	1000	19,400 19,550	41,000 40,900	41.5 44.0
	1200	16,350 15,550	26,400 26,100	28.5 28.0

TABLE 21 (Contd.)

SUMMARY OF SHORT-TIME TENSILE CHARACTERISTICS OF TEST ALLOYS

Material	Temp. °F	0.2% Yield Strength PSI	Ultimate Tensile Strength PSI	% Elongation in 2 Inches
Type 301 Stainless Steel Bar	80	50,000 47,000	112,000 115,000	54.0 52.0
	1200	37,900 29,100	45,900 42,200	20.0 29.0
	1350	25,100 25,200	30,300 27,500	28.0 32.0
Type 321 Stainless Steel Sheet Annealed	80	40,000 45,300	89,500 87,400	56.5 51.5
	1000	28,700 26,900	59,700 60,200	28.5 30.5
	1200	27,500 25,500	43,600 41,900	25.0 26.0
	1350	25,400 24,500	29,500 28,700	37.5 45.5
A-286 Stainless Steel Alloy Sheet Annealed	80	- -	- -	- -
	1000	31,300 31,000	76,200 76,700	44.5 44.5
	1200	51,000 49,800	76,600 65,300	21.0 14.5
	1350	71,600 63,700	71,800 64,700	6.0 6.0
	1500	37,000 -	37,100 -	30.0 -
A-286 Stainless Steel Alloy Sheet Age Hardened	80	112,000 -	156,000 -	22.0 -
	1000	101,000 99,400	132,800 135,000	16.0 17.5
	1200	102,400 101,400	107,900 103,000	8.5 7.5
	1350	77,900 75,900	78,300 76,400	5.0 4.5
	1500	35,600 36,000	35,900 37,000	27.0 27.0
A-286 Stainless Steel Alloy Bar Annealed	80	- -	- -	- -
	1000	52,000 46,200	78,600 75,100	31.0 33.5
	1200	64,000 65,600	83,200 83,400	29.5 34.0
	1350	73,400 -	73,900 -	- * -
	1500	- -	- -	- -

TABLE 21 (Contd.)

SUMMARY OF SHORT-TIME TENSILE CHARACTERISTICS OF TEST ALLOYS

Material	Temp. °F	0.2% Yield Strength PSI	Ultimate Tensile Strength PSI	% Elongation in 2 Inches
A-286 Stainless Steel Alloy Bar Age Hardened	80	111,000 114,000	149,100 149,000	18.0 - *
	1000			
	1200			
	1350			
	1500			
19-9 DX Stainless Steel Alloy Sheet Annealed	80	80,600 74,600	117,200 110,600	31.0 32.0
	1000	33,300 30,300	74,300 73,500	28.0 30.5
	1200	27,400 28,900	49,300 48,600	46.5 40.0
	1350	23,900 22,900	30,900 29,100	60.0 63.0
	1500	17,000 14,410	18,400 15,300	60.0 74.5
19-9 DX Stainless Steel Alloy Bar Hot Rolled - Stress Relieved at 1250°F	80	99,500 101,000	128,800 128,500	26.0 24.0
	1000	75,400 74,700	86,800 88,300	13.0 12.5
	1200	65,300 60,700	66,800 65,000	18.0 18.5
	1350	53,600 52,400	54,900 52,800	- * 32.5
	1500	32,900 28,900	34,200 34,100	69.0 - *

*Specimen ruptured outside test section.

TABLE 22

SUMMARY OF SHORT-TIME COMPRESSION CHARACTERISTICS OF SHEET ALLOYS

Material	Temp. °F	0.2% Compression Yield Strength PSI	Avg. Compression Yield Strength PSI	Avg. Compression Yield / Avg. Tensile Yield
2024-T3 Aluminum Alloy Sheet 0.064 Inch Thick	300	39,500 39,300	39,400	0.84
	450	37,300 38,100	37,700	1.05
	600	20,800 21,200	21,000	1.30
2024-T3 Aluminum Alloy Sheet 0.091 Inch Thick	300	37,000 39,800	38,400	0.85
	450	37,200 39,000	37,600	0.91
	600	16,800 18,400	17,600	0.95
2024-T3 Aluminum Alloy Sheet 0.187 Inch Thick	300			
	450	39,100 38,400	38,750	0.94
	600	16,100 17,500	16,800	0.99
A-70 Titanium Sheet Annealed	700	26,600 27,600	27,100	1.15
	800	26,400 25,700	26,050	1.12
C-110M Titanium Alloy Sheet	700	67,600 65,400	66,500	1.02
	800	64,700 66,200	65,450	0.96
A-110AT Titanium Alloy Sheet Annealed	800	59,800 63,200	61,500	0.92
	1000	51,600 52,700	52,050	0.96
SAE 4130 Steel Sheet Normalized	800	57,200 60,600	58,900	1.11
	900	55,200 53,300	54,250	1.07
	1000	48,300 46,900	47,600	1.13

TABLE 22 (Contd.)

SUMMARY OF SHORT-TIME COMPRESSION CHARACTERISTICS OF SHEET ALLOYS

Material	Temp. °F	0.2% Compression Yield Strength PSI	Avg. Compression Yield Strength PSI	Avg. Compression Yield / Avg. Tensile Yield
Type 321 Stainless Steel Sheet	1000	28,000 -	28,000	1.01
	1200	25,800 25,400	25,600	0.97
	1350	25,700 23,400	24,550	0.99
19-9 DX Stainless Steel Sheet Annealed	1200	24,400 26,100	25,250	0.90
	1350	23,500 24,600	24,050	1.03

TABLE 23

SUMMARY OF SHORT-TIME BEARING CHARACTERISTICS OF TEST ALLOYS

Material	Temp. °F	Ratio (1) ED/HD	2.0% Bearing Yield Strength PSI	Ultimate Bearing Strength PSI	Average Ultimate Bearing Strength PSI	Avg. Bearing Strength / Avg. Tensile Strength
2024-T3 Aluminum Alloy Sheet 0.064 Inch Thick	300	1.5	71,000 71,500	96,200 97,800	97,000	1.62
		2.0	87,500 84,000	131,800 125,000	128,400	2.15
	450	1.5	49,800 45,500	67,000 61,000	64,000	1.68
		2.0	61,000 59,300	72,800 71,800	72,300	1.90
	600	1.5	31,700 29,000	41,600 38,100	39,850	2.27
		2.0	33,500 30,000	42,800 41,400	42,100	2.40
A-70 Titanium Sheet Annealed	700	1.5	45,000 49,000	66,900 69,200	68,050	2.00
	800	1.5	45,200 45,300	63,000 59,400	61,200	1.83
C-110M Titanium Alloy Sheet	700	1.5	109,000 125,500	152,800 154,200	153,500	1.68
	800	1.5	93,000 104,000	127,500 128,200	127,850	1.69
A-110AT Titanium Alloy Sheet Annealed	800	2.0	106,000 112,000	161,700 163,300	162,500	1.97
	1000	2.0	97,000 98,000	147,200 153,800	150,500	2.32
SAE 4130 Alloy Steel Sheet Normalized	800	1.5	100,500 102,300	141,300 140,800	141,050	1.86
		2.0	115,500 199,500	192,600 183,500	188,050	2.48

TABLE 23 (Contd.)

SUMMARY OF SHORT-TIME BEARING CHARACTERISTICS OF TEST ALLOYS

Material	Temp. °F	Ratio (1) ED/HD	2.0% Bearing Yield Strength PSI	Ultimate Bearing Strength PSI	Average Ultimate Bearing Strength PSI	Avg. Bearing Strength / Avg. Tensile Strength
SAE 4130 Alloy Steel Sheet Normalized (Contd.)	900	1.5	92,000 94,800	123,700 127,400	125,550	2.02
		2.0	102,000 108,000	156,500 161,800	159,150	2.56
	1000	1.5	86,200 80,200	106,500 103,000	104,750	2.16
Type 321 Stainless Steel Sheet	1200	1.5	47,500 49,000	83,900 81,000	82,450	1.92
	1350	1.5	45,000 46,000	74,500 72,500	73,500	2.52
		2.0	49,200 51,600	90,300 91,200	90,750	3.11
19-9 DX Stainless Steel Alloy Sheet Annealed	1200	2.0	66,500 -	133,000 133,800	133,400	2.72
	1350	2.0	57,000 57,800	106,600 110,000	108,300	3.60

(1) Ratio - Edge Distance to Bearing Hole Diameter

TABLE 24

SUMMARY OF SHORT TIME SHEAR CHARACTERISTICS OF TEST MATERIALS

Material	Temp. °F	Shear Strength PSI	Average Shear Strength PSI	Shear Strength / Tensile Strength
2024-T3 Aluminum Alloy Sheet 0.187 Inch Thick	80	42,800 43,000	42,900	0.61
	300	41,520 40,950	41,235	0.71
	450	25,570 24,790	25,180	0.59
	600	10,210 10,520	10,365	0.57
2117-T4 Aluminum Alloy Bar	80	32,600 32,100	32,350	0.65
	300	26,475 26,425	26,450	0.71
	450	17,350 17,670	17,510	0.76
	600	7,030 7,220	7,125	1.08
A-110AT Titanium Alloy Bar Annealed	800	65,500 61,100	62,800	0.67
	1000	36,800 47,800	42,300	0.82
Monel Alloy Bar Annealed	80	51,750 53,000	52,375	0.65
	1000	42,300 41,400	41,850	1.02
	1200	30,070 30,000	30,065	1.16
301 Stainless Steel Bar	80	90,300 91,400	90,850	0.80
	1200	39,800 40,500	40,150	0.91
	1350	30,090 30,080	30,085	1.04
A-286 Stainless Steel Alloy Bar Annealed	80			
	1000	53,800 53,000	53,400	0.70
	1200	59,500 54,000	56,750	0.67
	1350	51,800 50,500	51,150	0.69

TABLE 24 (Contd.)

SUMMARY OF SHORT TIME SHEAR CHARACTERISTICS OF TEST MATERIALS

Material	Temp. °F	Shear Strength PSI	Average Shear Strength PSI	Shear Strength / Tensile Strength
19-9 DX Stainless Steel Alloy Bar Hot Rolled Stress Relieved at 1250°F	80			
	1000	54,900 58,500	56,700	0.65
	1200	49,400 49,700	49,550	0.75
	1350	41,800 42,600	42,200	

TABLE 25

SUMMARY OF JOINT CREEP-RUPTURE CHARACTERISTICS FOR TYPE I JOINT

Temp. °F	Bearing Stress PSI	Shear Stress PSI	Deformation on Loading Inch	Time in Hours for Deformation of 0.001 Inch C	0.001 Inch TD	0.002 Inch C	0.002 Inch TD	0.005 Inch C	0.005 Inch TD	0.010 Inch C	0.010 Inch TD	0.020 Inch C	0.020 Inch TD	0.030 Inch C	0.030 Inch TD	0.040 Inch C	0.040 Inch TD	Fracture Hours	Time of Test Hours	Specimen 212-J
450	28,000	9,000	0.00268	1.40	OL	4.40	OL	25.0	5.9	70.0	45.0	154.0	135.0	-	.	-	-	181.5	181.5	13-14
	32,000	10,250	0.0033	0.80	OL	1.80	OL	12.2	1.5	46.0	23.0	83.9	82.0	-	83.9	-	-	84.0	84.0	17-18
	35,000	11,210	0.0036	0.35	OL	0.75	OL	3.2	0.5	11.8	5.0	29.3	23.3	39.7	37.0	43.3	42.2	43.5	43.5	15-16
	38,000	12,175	0.0055	0.18	OL	0.35	OL	1.1	OL	1.6	1.1	-	10.8	-	-	-	-	13.0	13.0	5-6

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 26

SUMMARY OF JOINT CREEP-RUPTURE CHARACTERISTICS FOR TYPE II JOINT

Temp. °F	Max. Bearing Stress PSI	Shear Stress PSI	Deformation on Loading Inch	Time in Hours for Deformation of 0.001 Inch C	0.001 Inch TD	0.002 Inch C	0.002 Inch TD	0.005 Inch C	0.005 Inch TD	0.010 Inch C	0.010 Inch TD	0.020 Inch C	0.020 Inch TD	0.030 Inch C	0.030 Inch TD	0.040 Inch C	0.040 Inch TD	Fracture Hours	Time of Test Hours	Specimen 398-J
450	31,000	9,600	0.0018	2.00	OL	5.00	0.10	22.0	11.0	45.4	40.0	85.0	80.0	108.0	105.9	126.9	125.5	146.5	146.5	2
	33,000	10,220	0.0021	0.90	OL	2.20	OL	12.9	5.0	32.0	24.0	60.0	55.6	80.9	76.8	95.6	93.2	106.5	106.5	3
	35,000	10,850	0.0023	0.40	OL	1.30	OL	5.7	2.0	14.7	10.5	33.5	30.0	44.0	42.0	-	47.6	48.5	48.5	4
	40,000	12,400	0.0031	0.30	OL	1.00	OL	4.6	1.0	9.8	6.9	18.0	15.7	-	-	-	-	23.0	23.0	1

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 27

SUMMARY OF JOINT CREEP-RUPTURE CHARACTERISTICS FOR TYPE III JOINT

Temp. °F	Bearing Stress PSI	Shear Stress PSI	Deformation on Loading Inch	Time in Hours for Deformation of														Fracture Hours	Time of Test Hours	Specimen 212-J
				0.001 Inch		0.002 Inch		0.005 Inch		0.010 Inch		0.020 Inch		0.030 Inch		0.040 Inch				
				C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
450	18,550	8,000	0.0060	0.6	OL	2.8	OL	29.5	OL	110.0	15.0	165.0	160.0	169.0	168.7	-	-	169.5	169.5	33
	20,900	9,000	0.0063	0.7	OL	3.0	OL	28.0	OL	52.0	14.5	85.0	70.0	91.5	90.0	-	91.6	92.0	92.0	37
	23,200	10,000	0.0081	0.5	OL	1.0	OL	7.5	OL	17.0	1.0	27.5	20.5	28.7	28.0	-	28.9	29.0	29.0	31
	26,000	11,200	0.0115	0.4	OL	0.9	OL	4.8	OL	12.0	OL	21.0	10.0	-	21.5	-	-	22.0	22.0	29

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 28

COMPARISON OF PREDICTED AND EXPERIMENTAL JOINT CREEP-RUPTURE CHARACTERISTICS OF TYPE I JOINT

Temp. °F	Bearing Stress PSI	Shear Stress PSI	Joint Creep in 10 Hours Inch		Time for Joint Rupture Hours		Type of Failure	
			Predicted	Experimental	Predicted	Experimental	Predicted	Experimental
450	28,000	9,000	0.0035	0.0032	120	181	Bearing	Bearing
	32,000	10,250	0.0070	0.0047	50	84	Bearing	Bearing
	35,000	11,210	0.0105	0.0077	30	43	Bearing	Bearing
	38,000	12,175	0.0162	0.0141	17	13	Bearing or Shear	Bearing

TABLE 29

COMPARISON OF PREDICTED AND EXPERIMENTAL JOINT CREEP-RUPTURE CHARACTERISTICS OF TYPE II JOINT

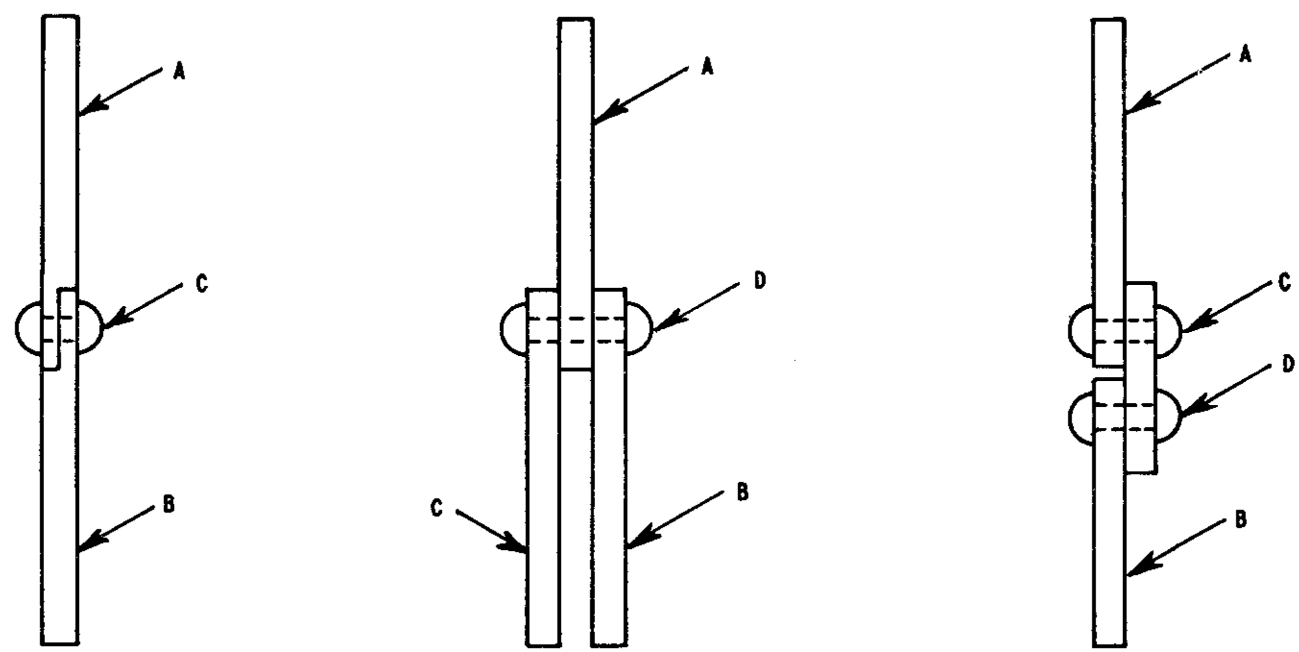
Temp. °F	Bearing Stress PSI		Shear Stress PSI	Joint Creep in 10 Hours Inch		Time for Joint Rupture Hours		Type of Failure	
	A	B & C	D	Predicted	Experimental	Predicted	Experimental	Predicted	Experimental
450	31,000	22,250	9,600	0.0077	0.0030	170	146.5	Shear	Bearing in A
	33,000	23,700	10,220	0.0094	0.0044	80	106.5	Shear	Bearing in A
	35,000	25,150	10,850	0.0115	0.0074	45	48.5	Shear	Shear in D
	40,000	28,750	12,400	0.0195*	0.0100	15	23.0	Shear	Shear in D

*Estimated Value

TABLE 30

COMPARISON OF PREDICTED AND EXPERIMENTAL JOINT CREEP-RUPTURE CHARACTERISTICS OF TYPE III JOINT

Temp. °F	Bearing Stress PSI	Shear Stress PSI	Joint Creep in 10 Hours Inch		Time for Joint Rupture Hours		Type of Failure	
			Predicted	Experimental	Predicted	Experimental	Predicted	Experimental
	18,550	8,000	0.0061	0.0035	240	169.5	Shear	Shear
450	20,900	9,000	0.0073	0.0035	190	92.	Shear	Shear
	23,200	10,000	0.0096	0.0064	77	29.	Shear	Shear
	26,000	11,200	0.0131	0.0084	35	22.	Shear	Shear



TYPE I

A & B - 0.064 IN. THICK SHEET
BEARING HOLE DIAMETER 1/8 IN.
ED/HD = 1.5
C - 1/8 IN. DIAMETER RIVET

TYPE II

A - 0.090 IN. THICK SHEET
BEARING HOLE DIAMETER 3/16 IN.
ED/HD = 2.0

B & C - 0.064 IN. THICK SHEET
BEARING HOLE DIAMETER 3/16 IN.
ED/HD = 1.5

D - 3/16 IN. DIAMETER RIVET

TYPE III

A & B - 0.064 IN. THICK SHEET
BEARING HOLE DIAMETER 3/16 IN.
ED/HD = 1.5

C & D - 3/16 IN. DIAMETER RIVET

ALL JOINT ELEMENTS 2024-T3 ALUMINUM

FIG. 1 JOINT CONFIGURATIONS FOR CREEP TESTING AT ELEVATED TEMPERATURE

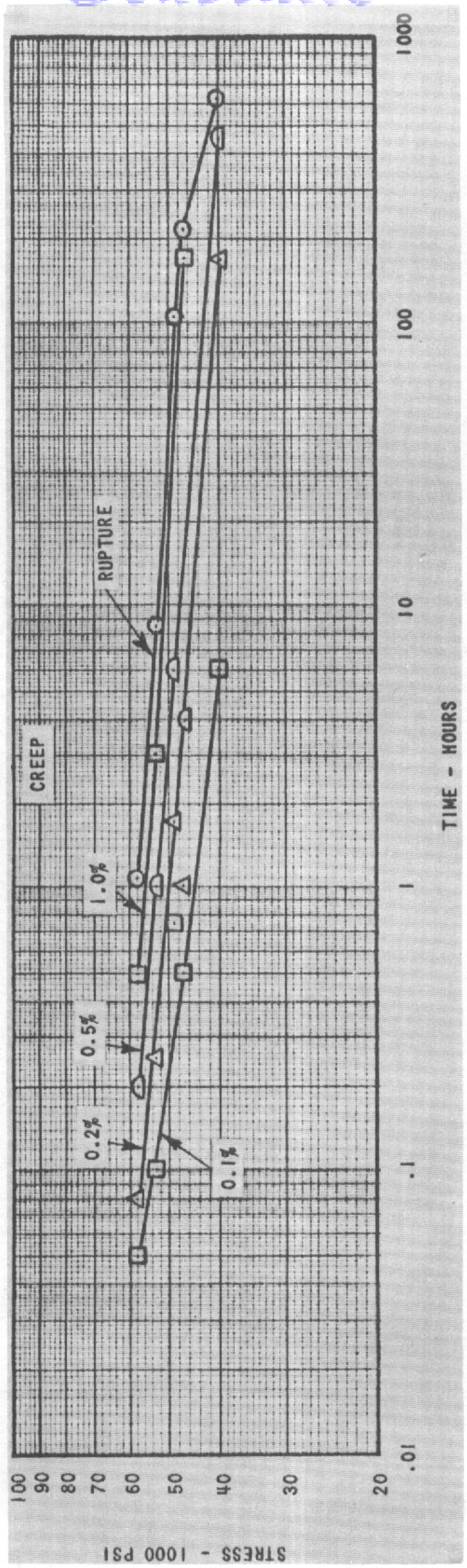


FIG. 2 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F

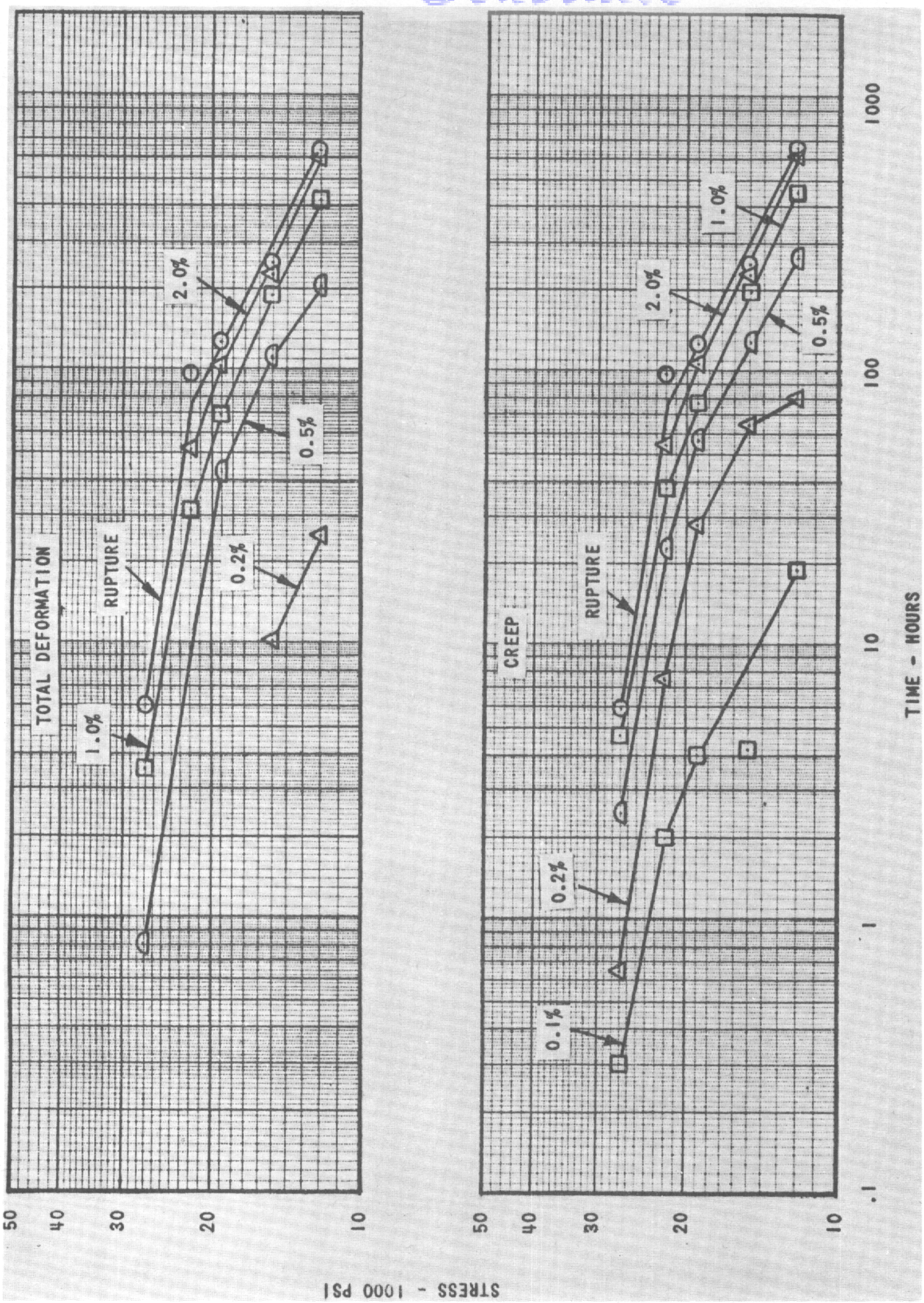


FIG. 3 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F

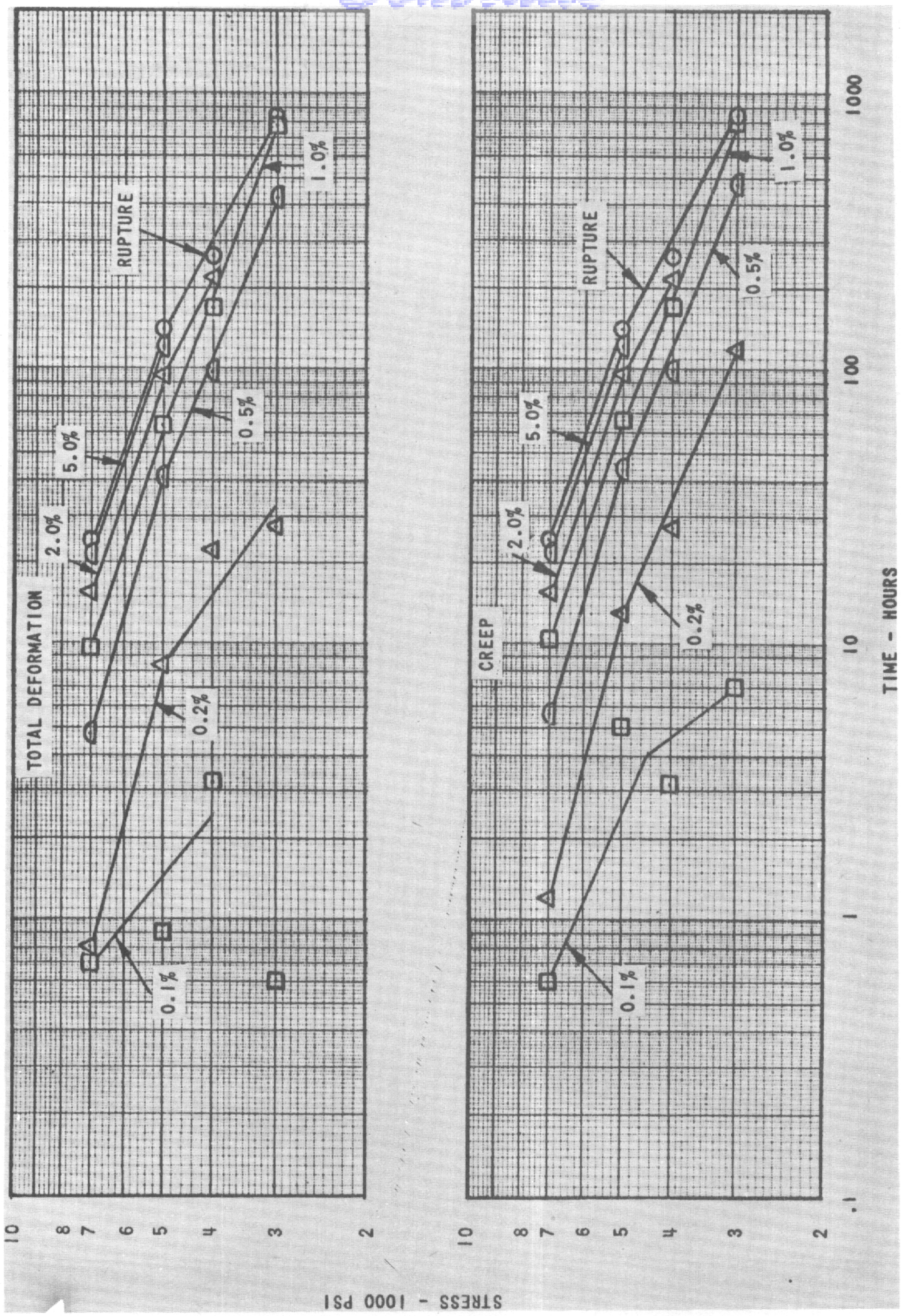


FIG. 4 TENSION CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F

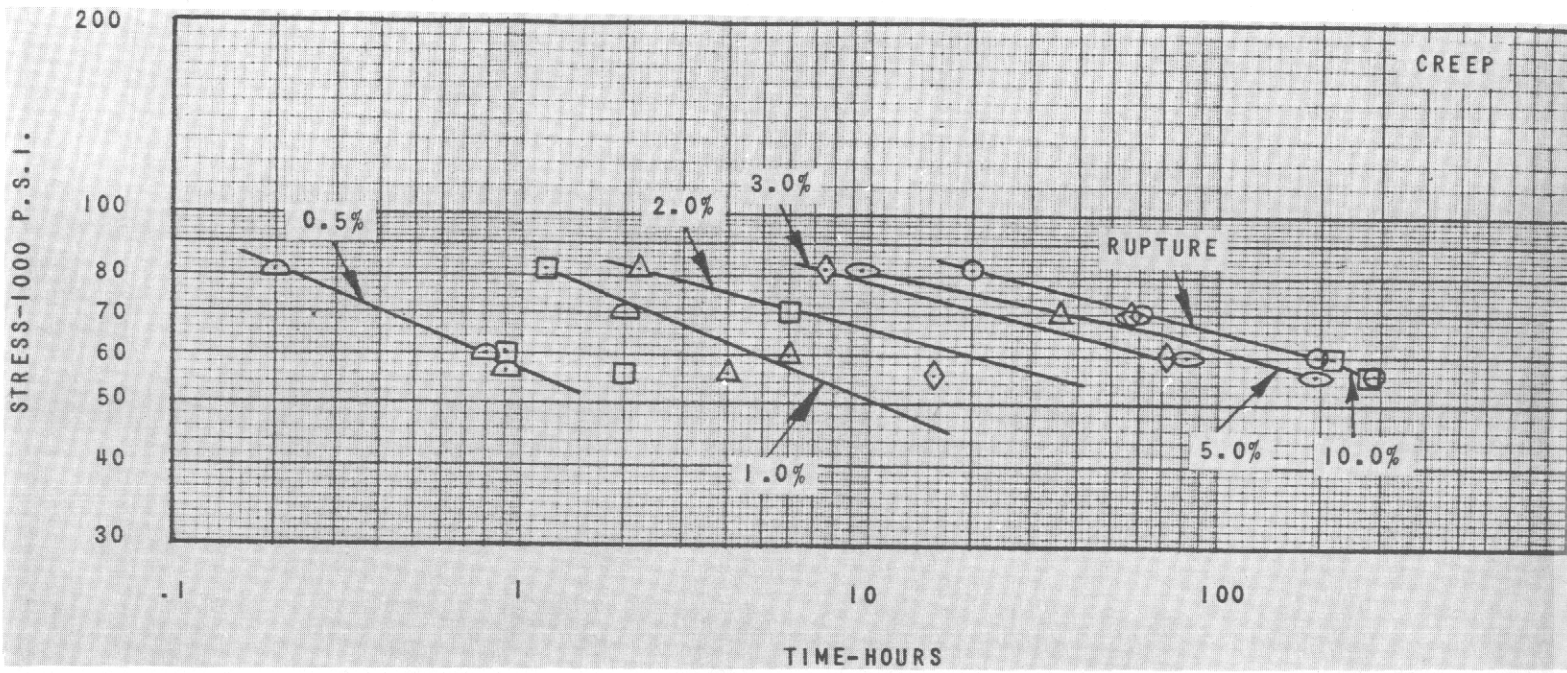


FIG. 5 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 1.5 D.

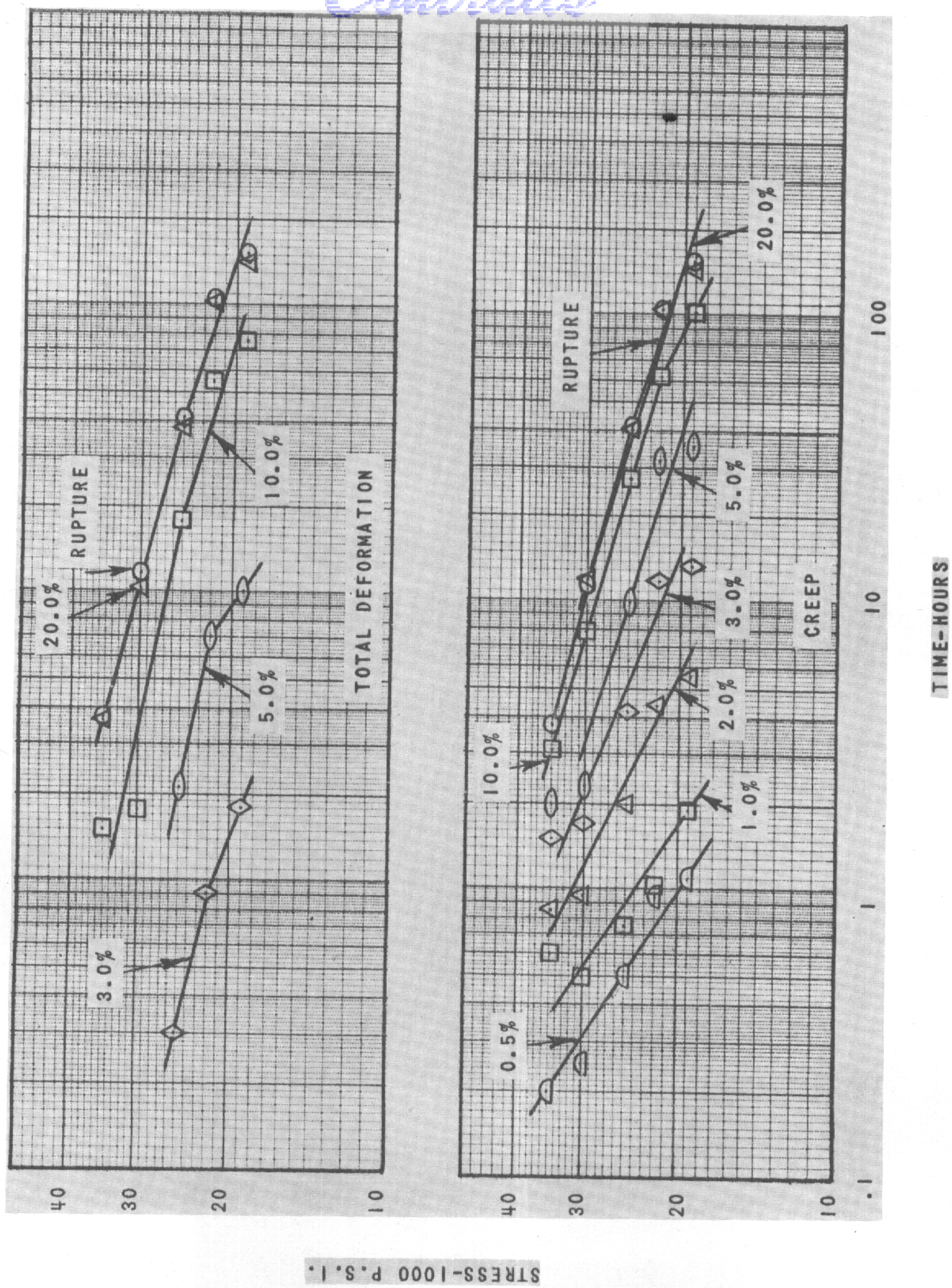


FIG. 6 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 1.5 D.

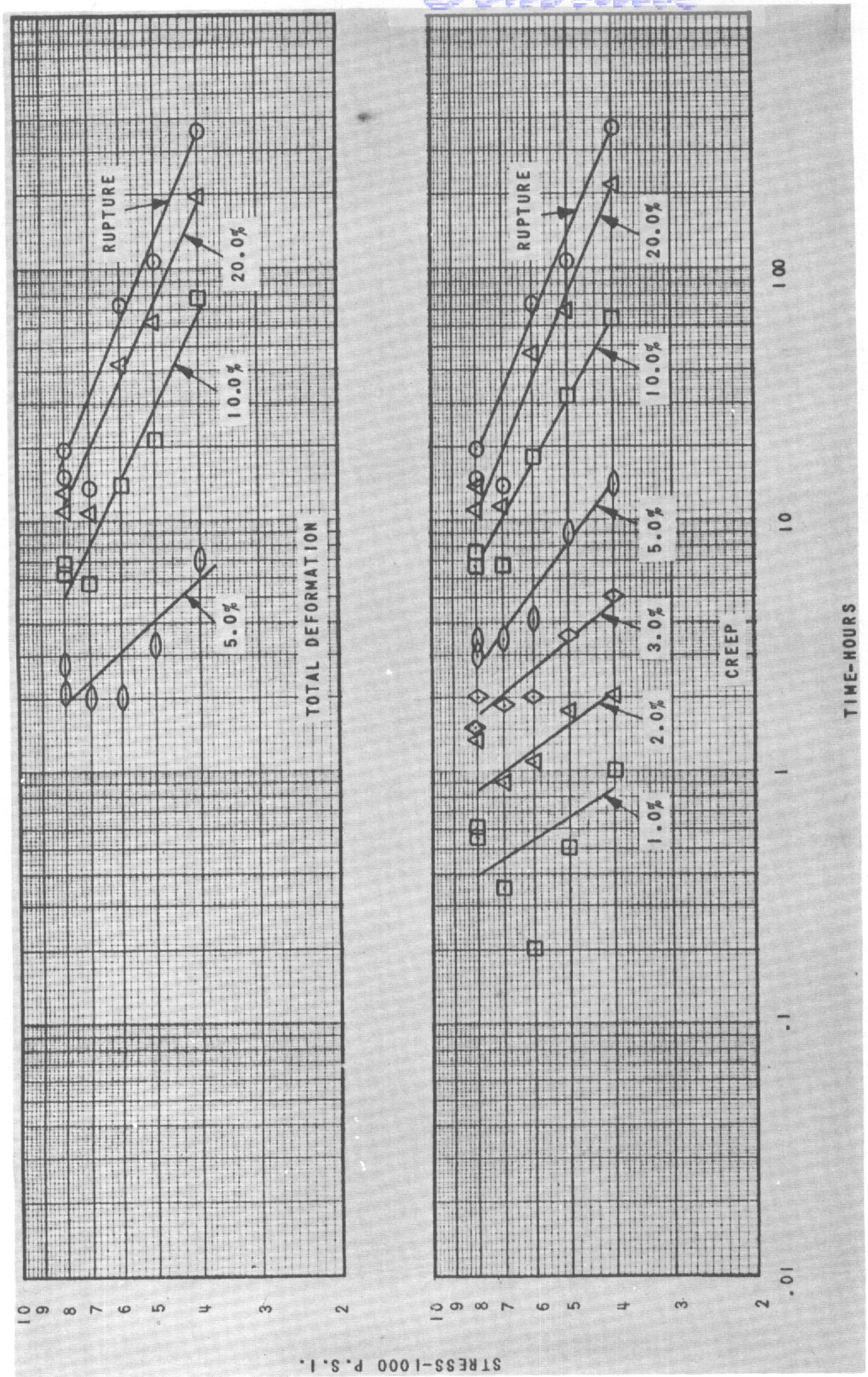


FIG. 7 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 1.5 D.

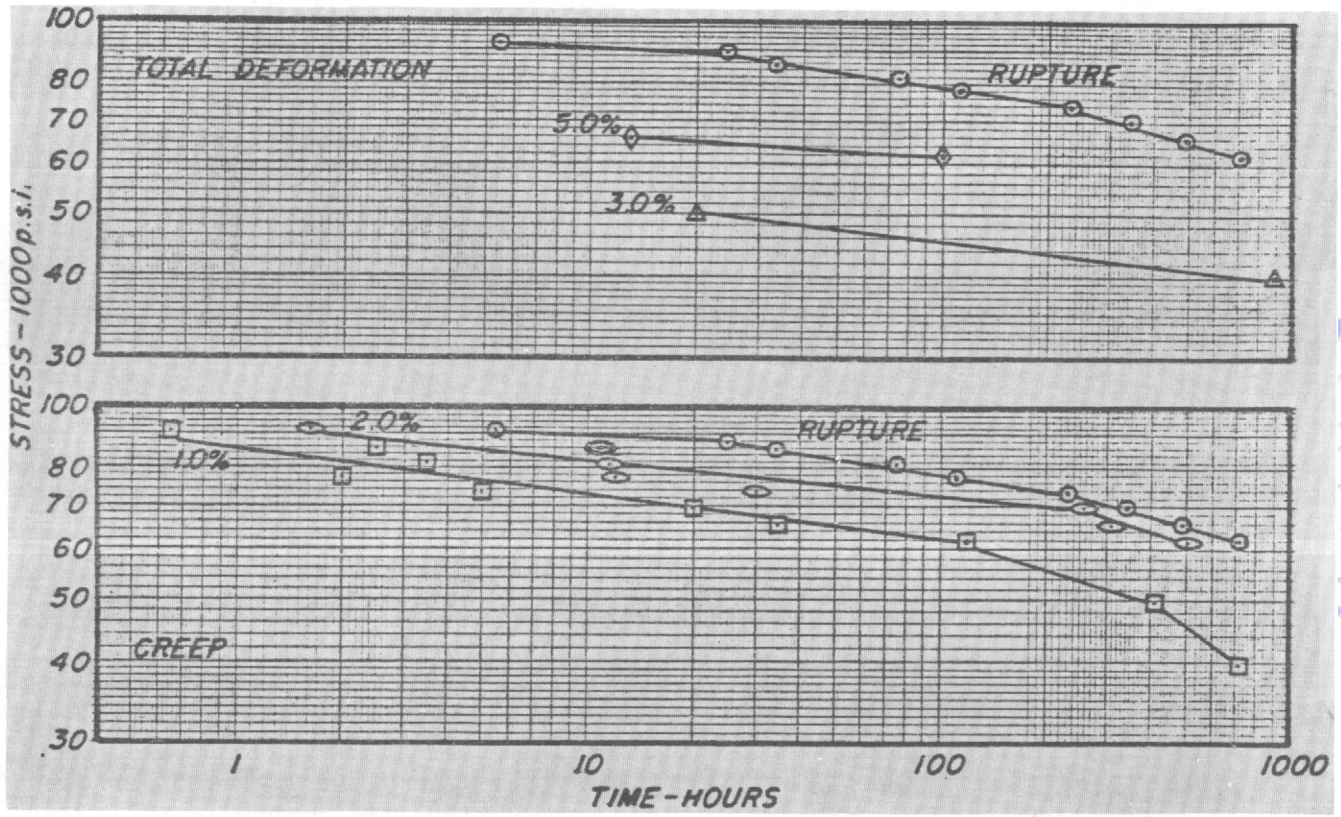


Figure 8 Bearing Creep-Rupture Characteristics of 0.064-Inch Thick 2024-T3 Aluminum Alloy Sheet at $300^{o}F$ for Bearing Hole Diameter of 1/8-Inch and Edge Distance of 1.5D

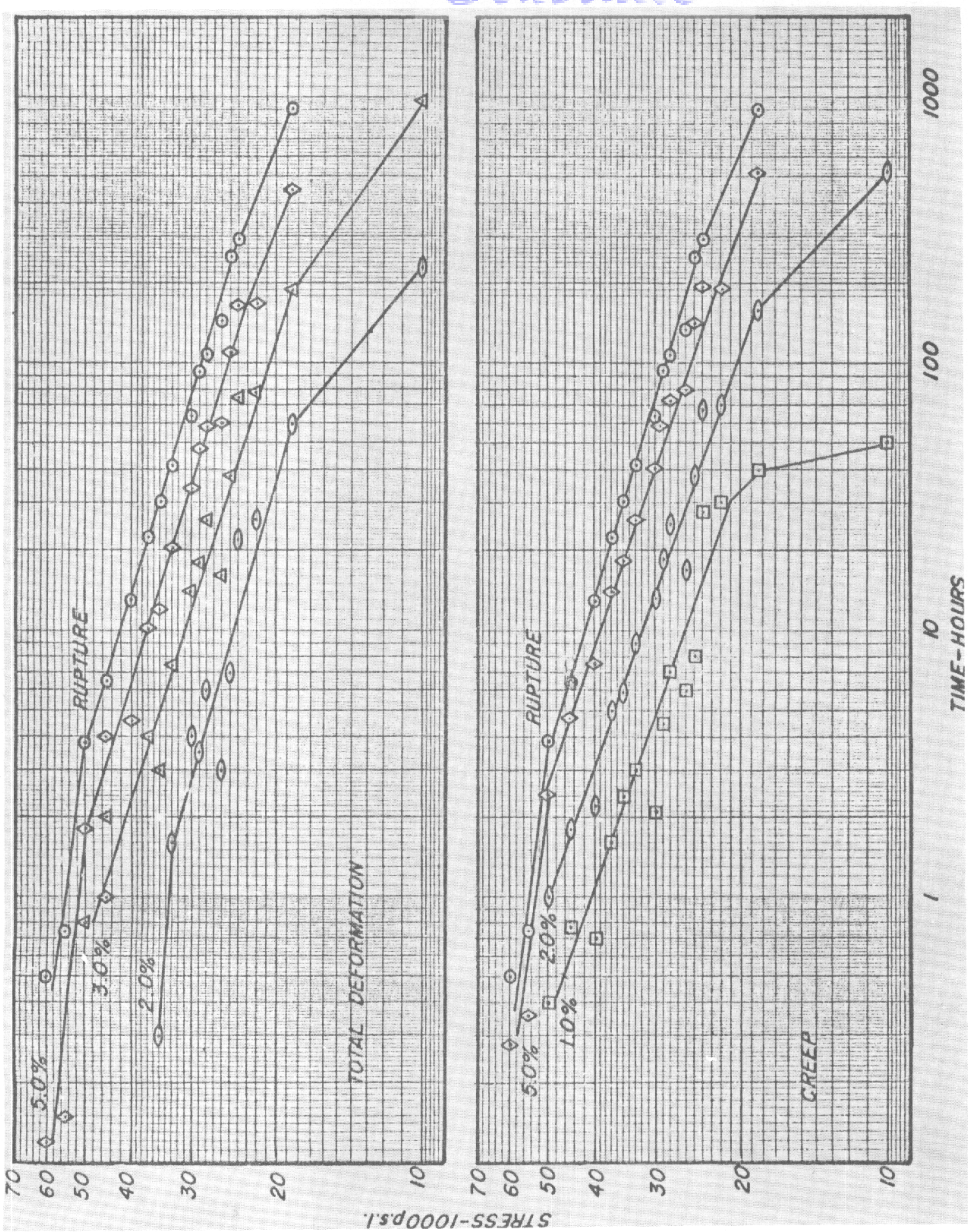


Figure 9 Bearing Creep-Rupture Characteristics of 0.064-Inch Thick 2024-T3 Aluminum Alloy Sheet at 450°F for Bearing Hole Diameter of 1/8-Inch and Edge Distance of 1.5D

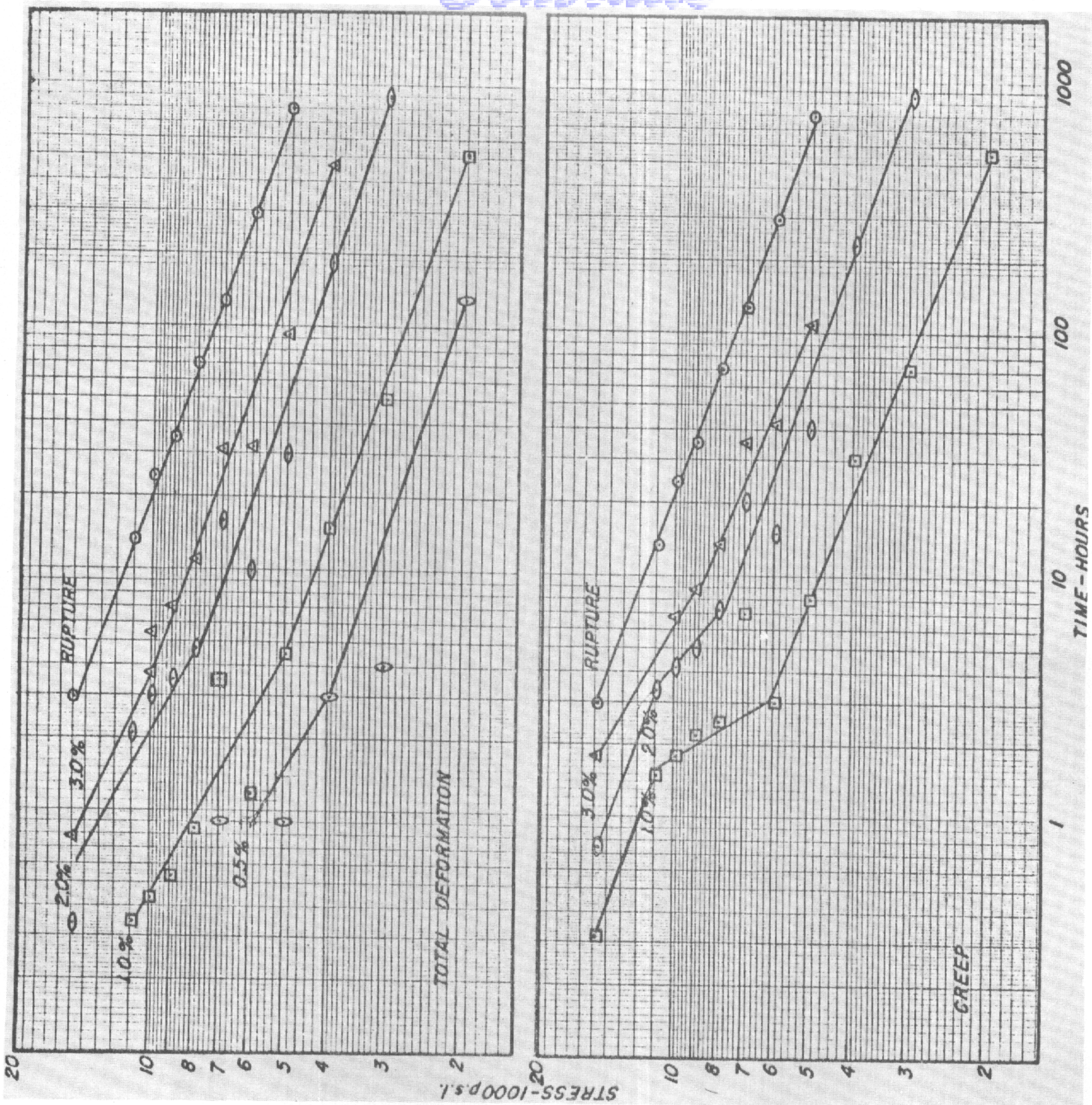


Figure 10 Bearing Creep-Rupture Characteristics of 0.064-Inch Thick 2024-T3 Aluminum Alloy Sheet at 600°F for Bearing Hole Diameter of 1/8-Inch and Edge Distance of 1.5D

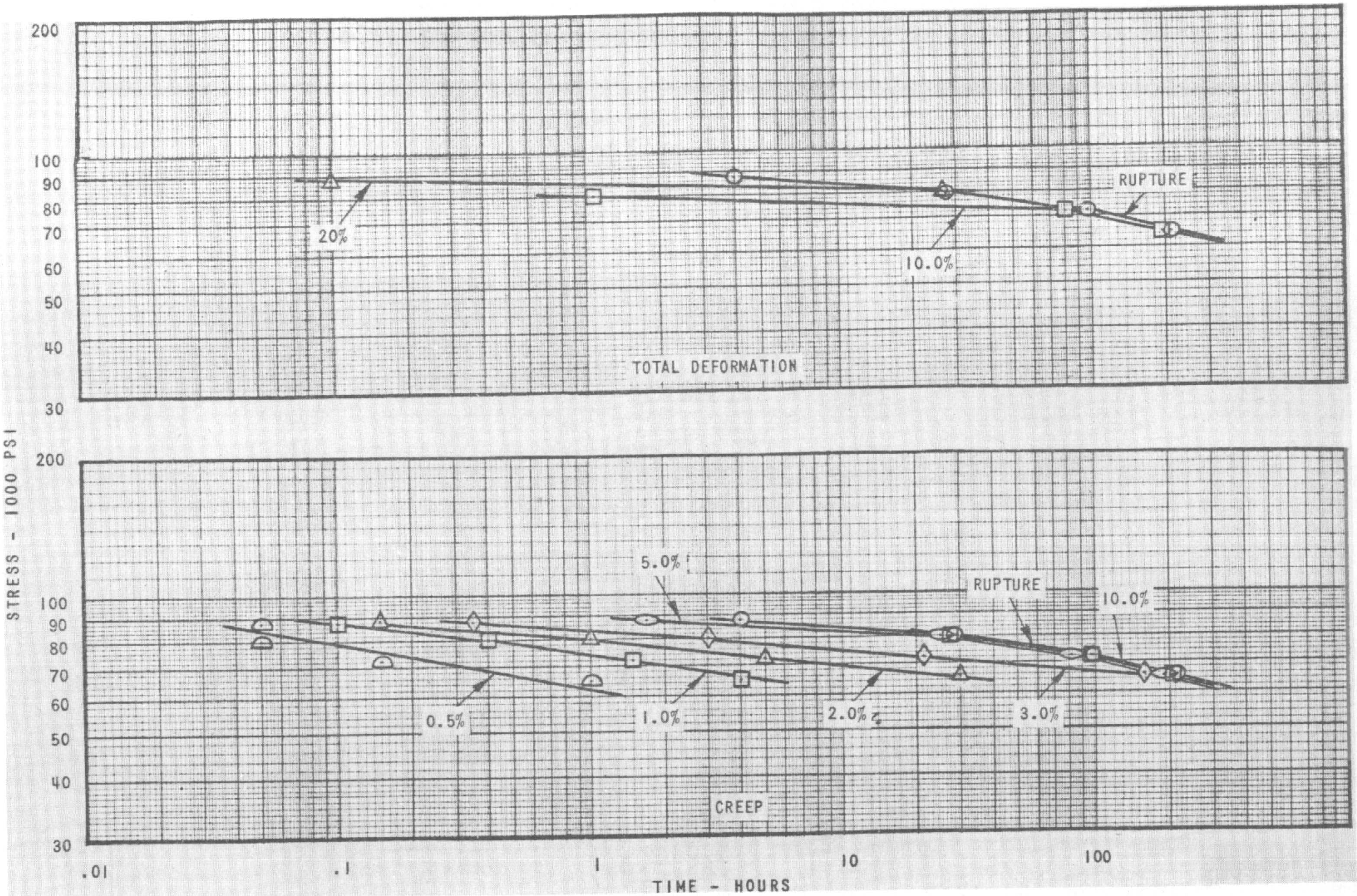


FIG. 11 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 1.5 D.

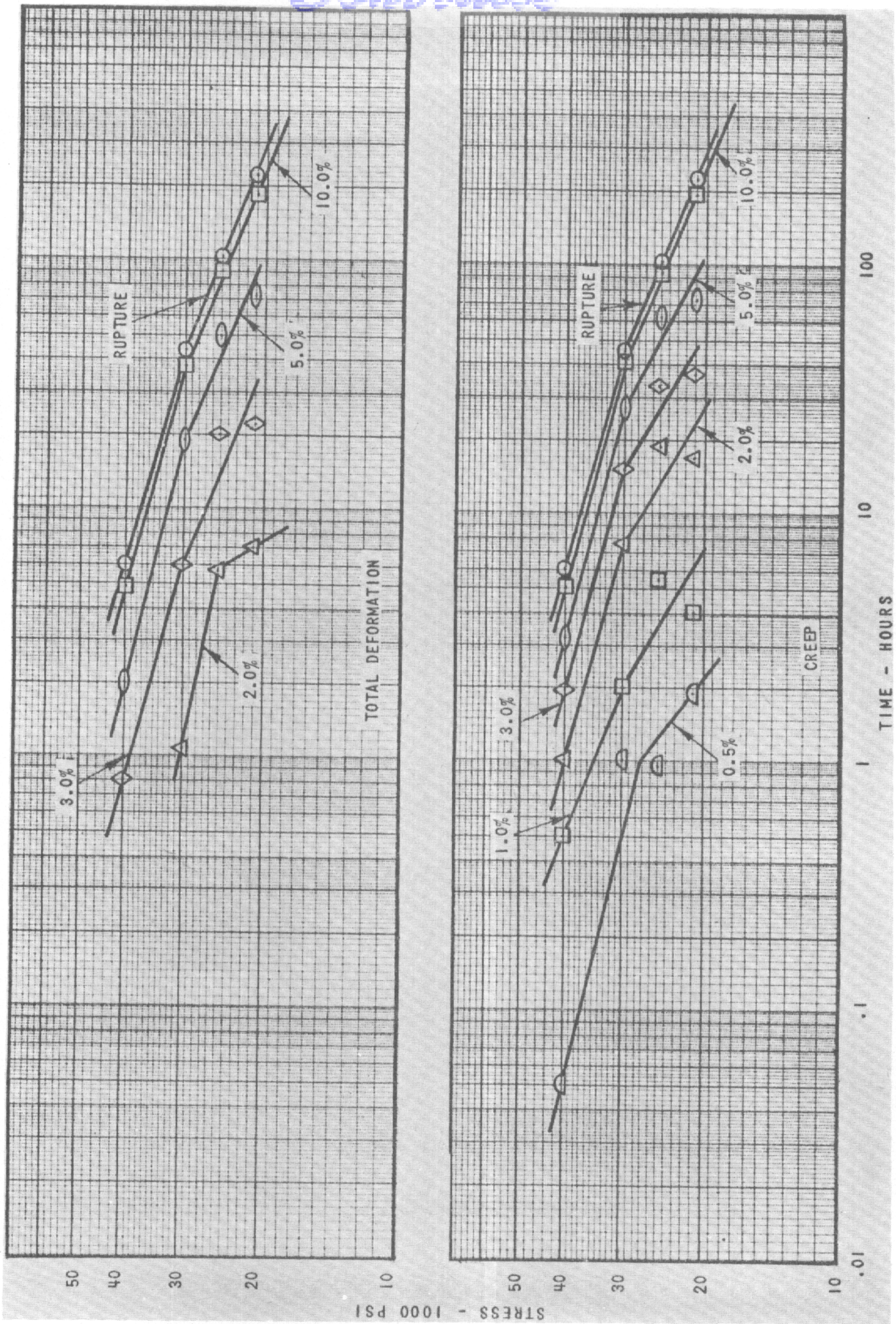


FIG. 12 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 1.5 D.

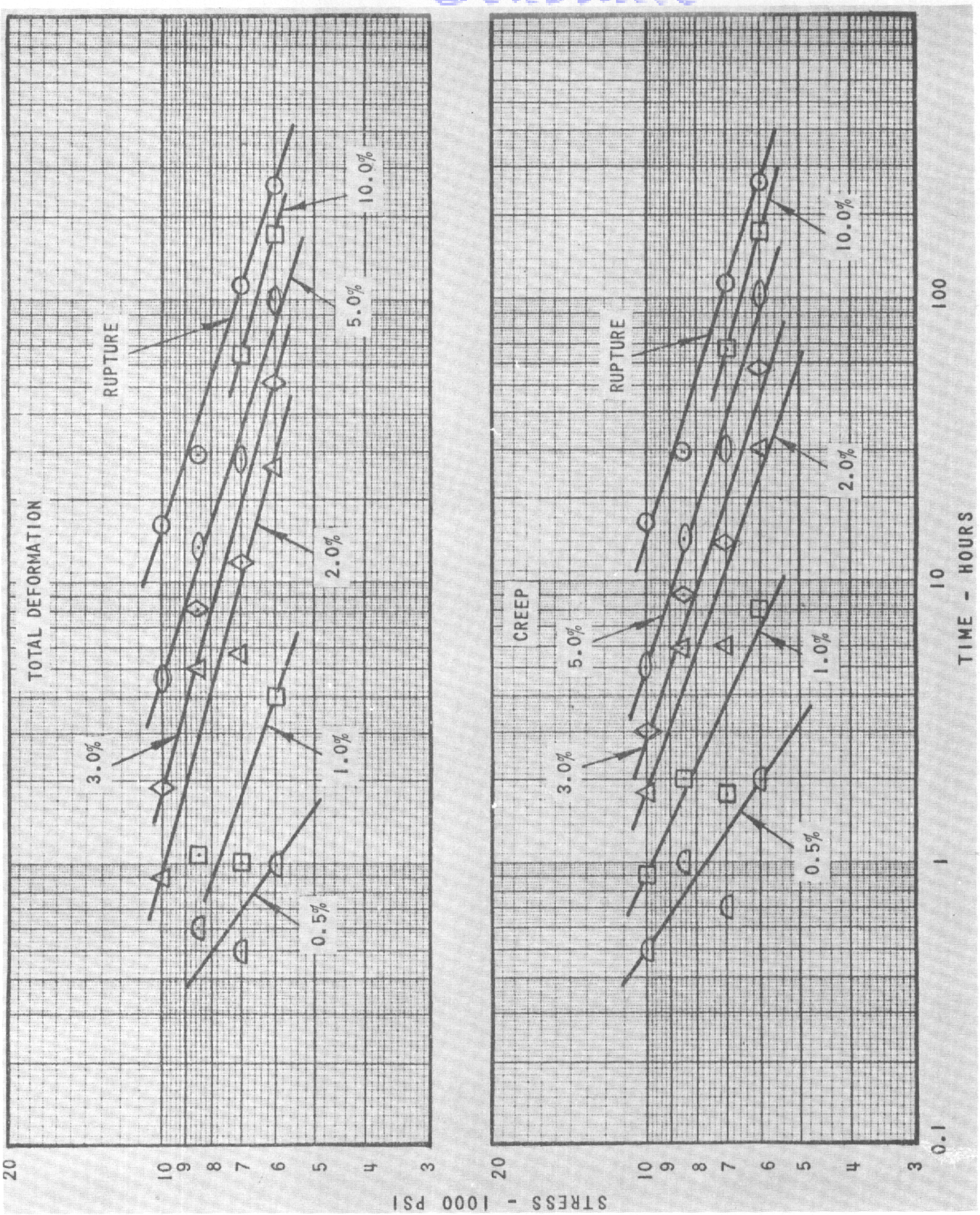


FIG. 13 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 1.5 D.

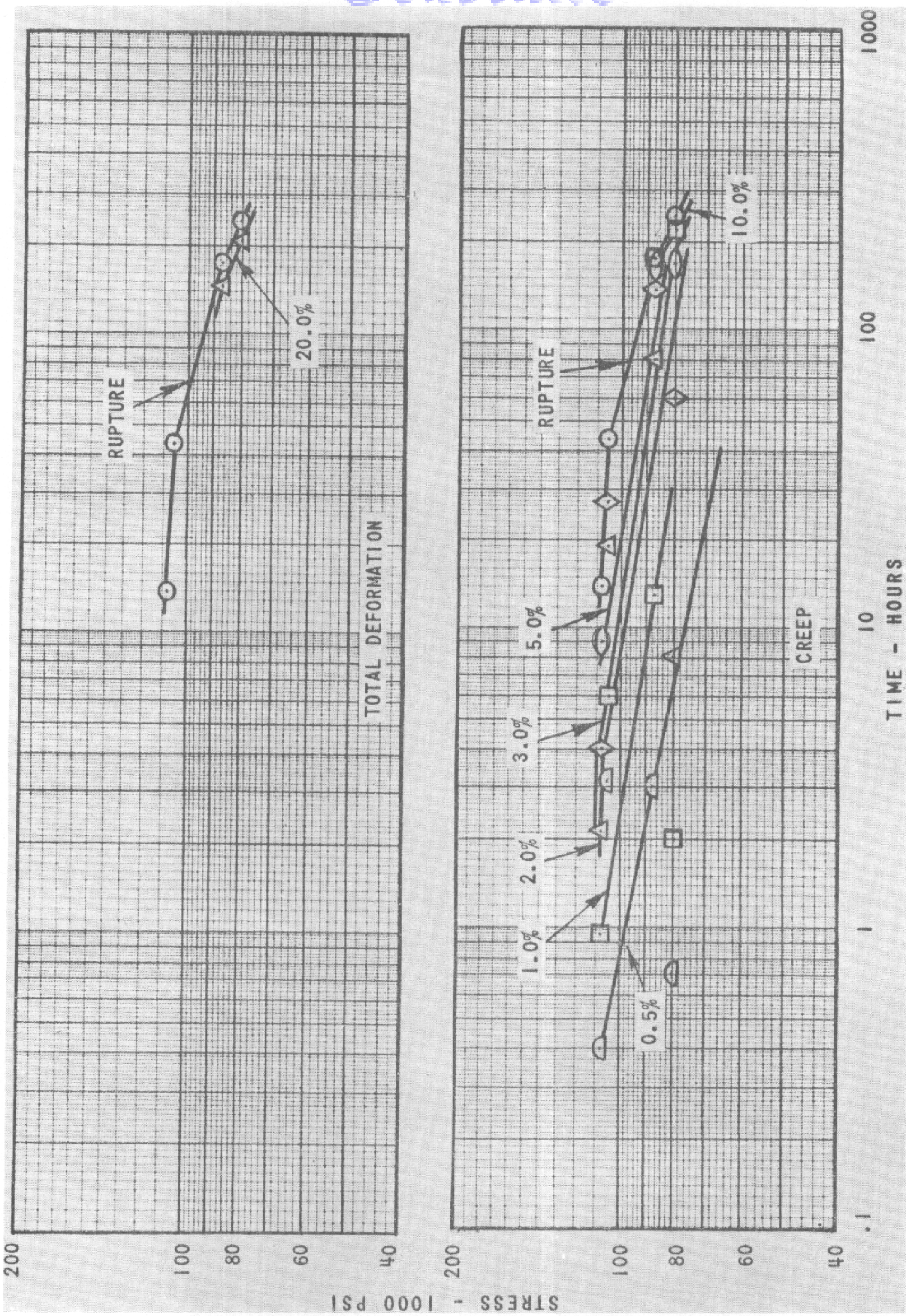


FIG. 14 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 2.0 D.

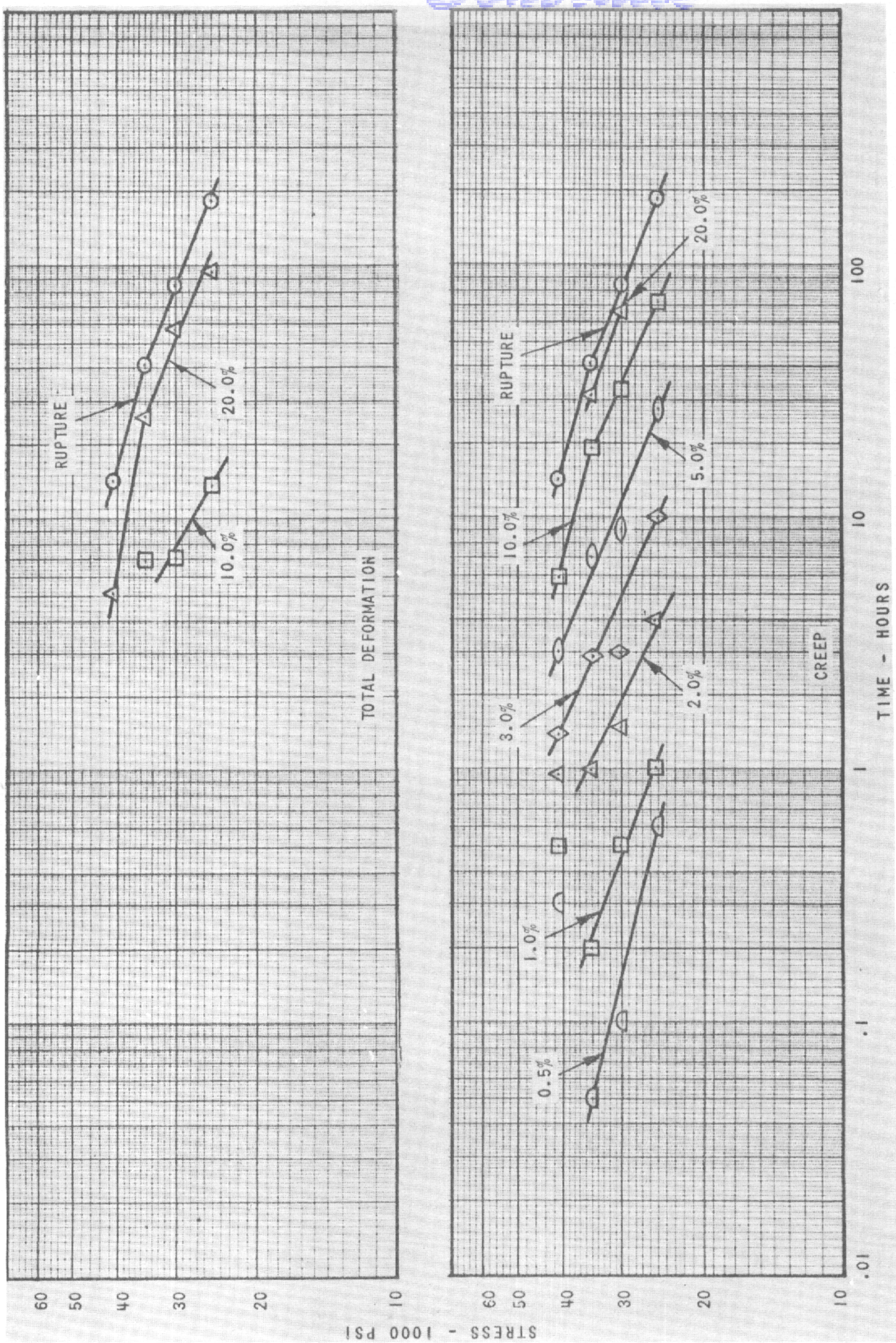


FIG. 15 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 2.0 D.

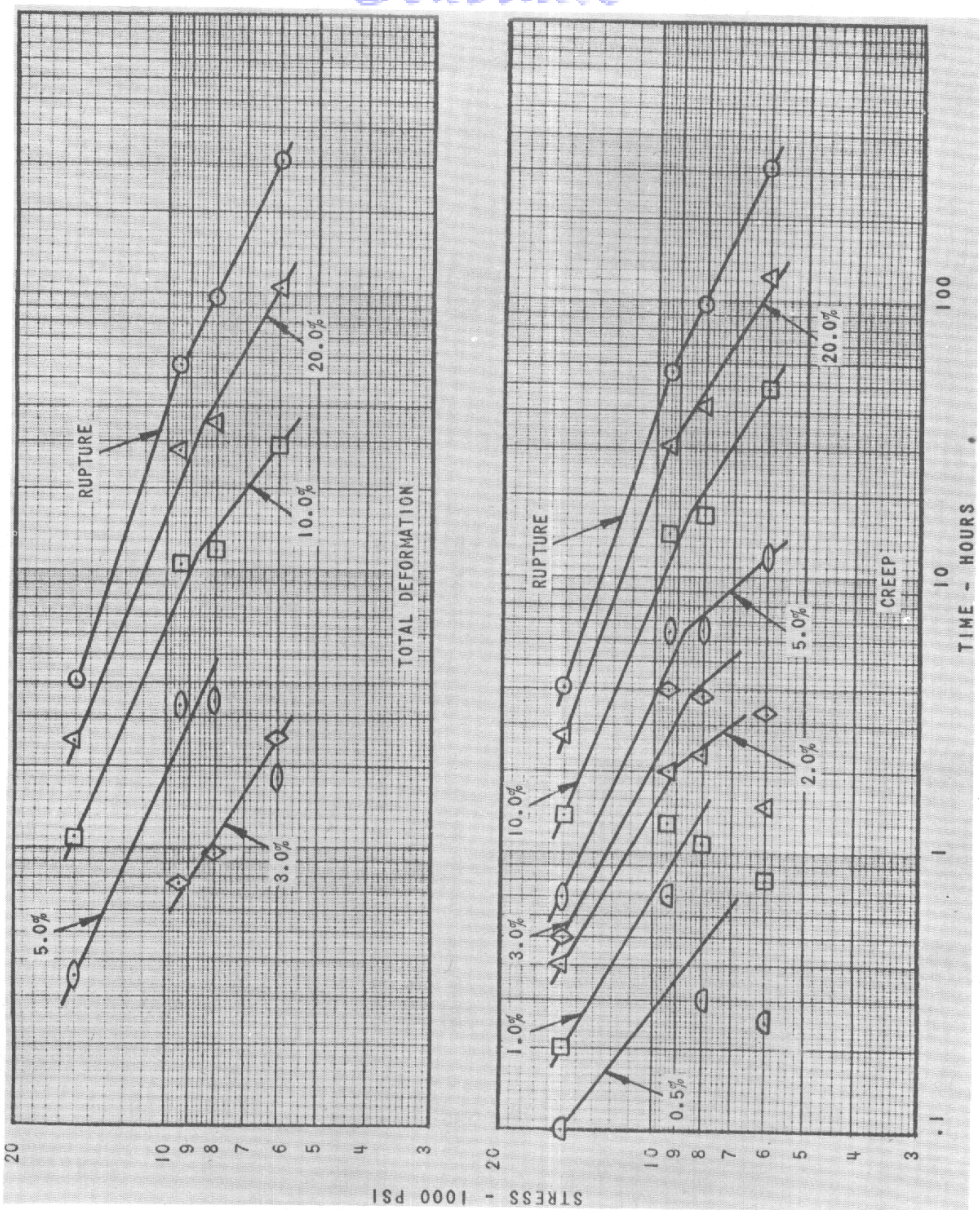


FIG. 16 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 2.0 D.

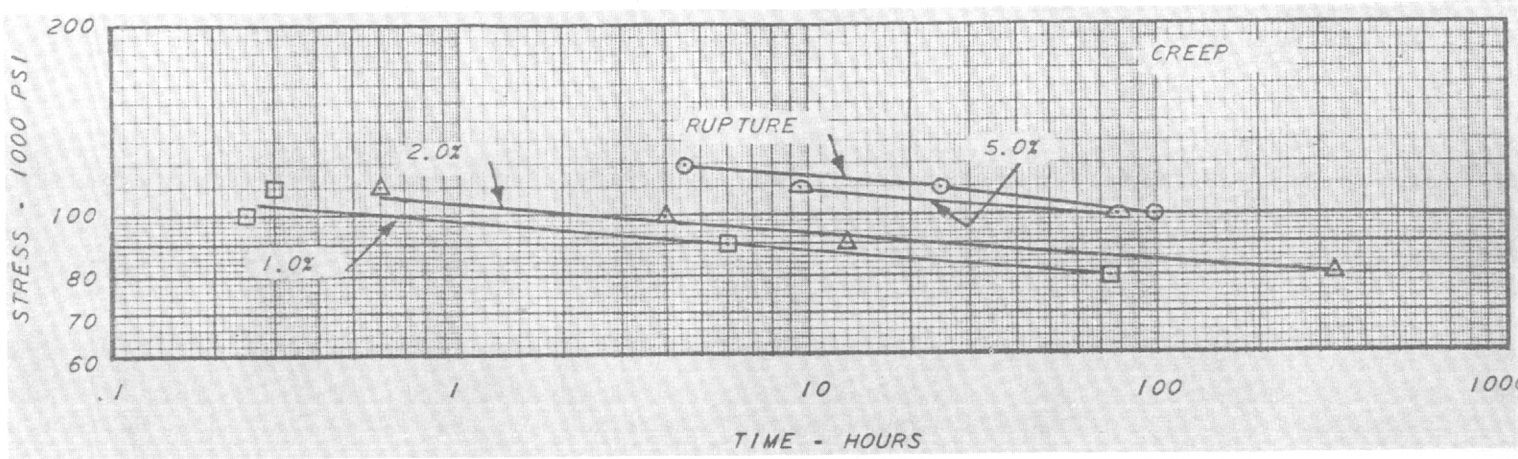


FIG. 17 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 2.0 D.

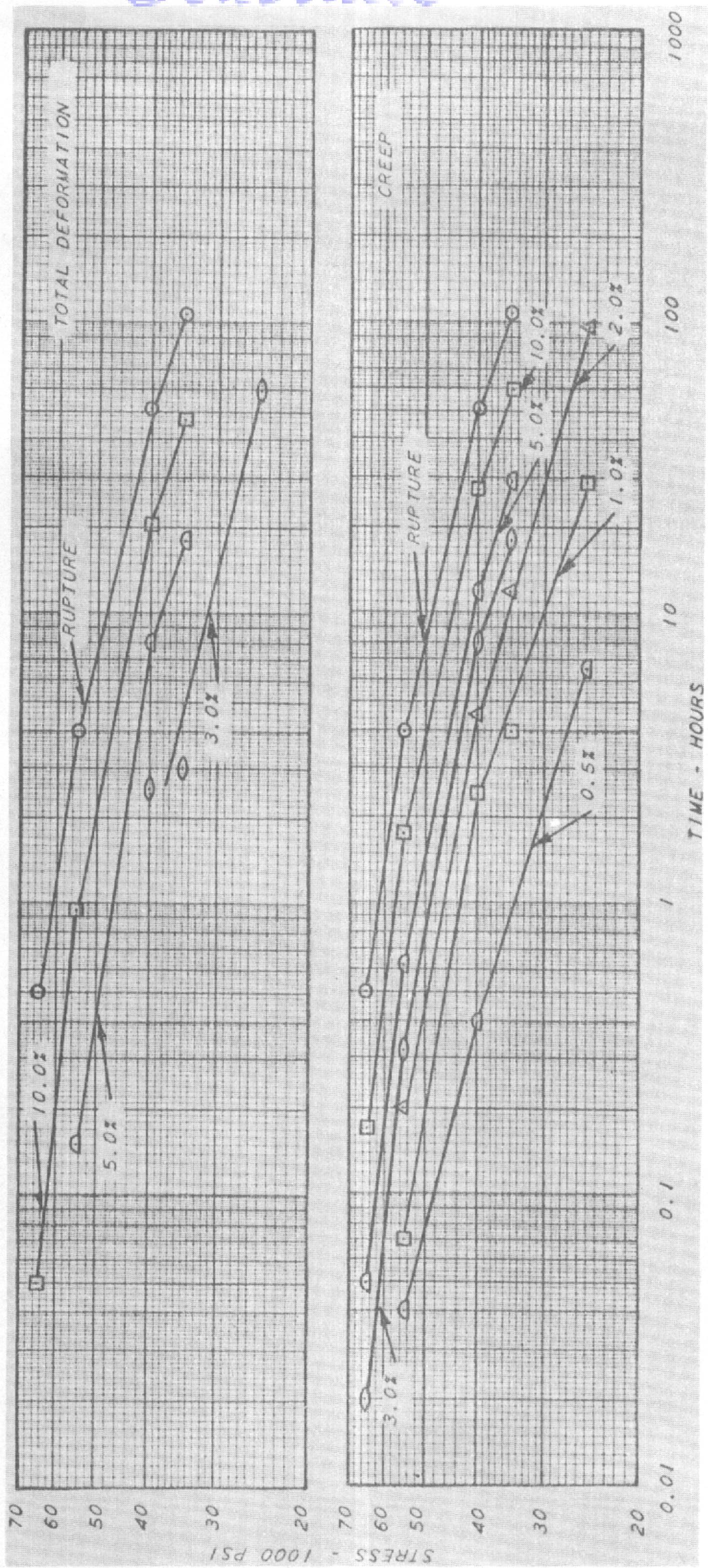


FIG. 18 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 2.0 D.

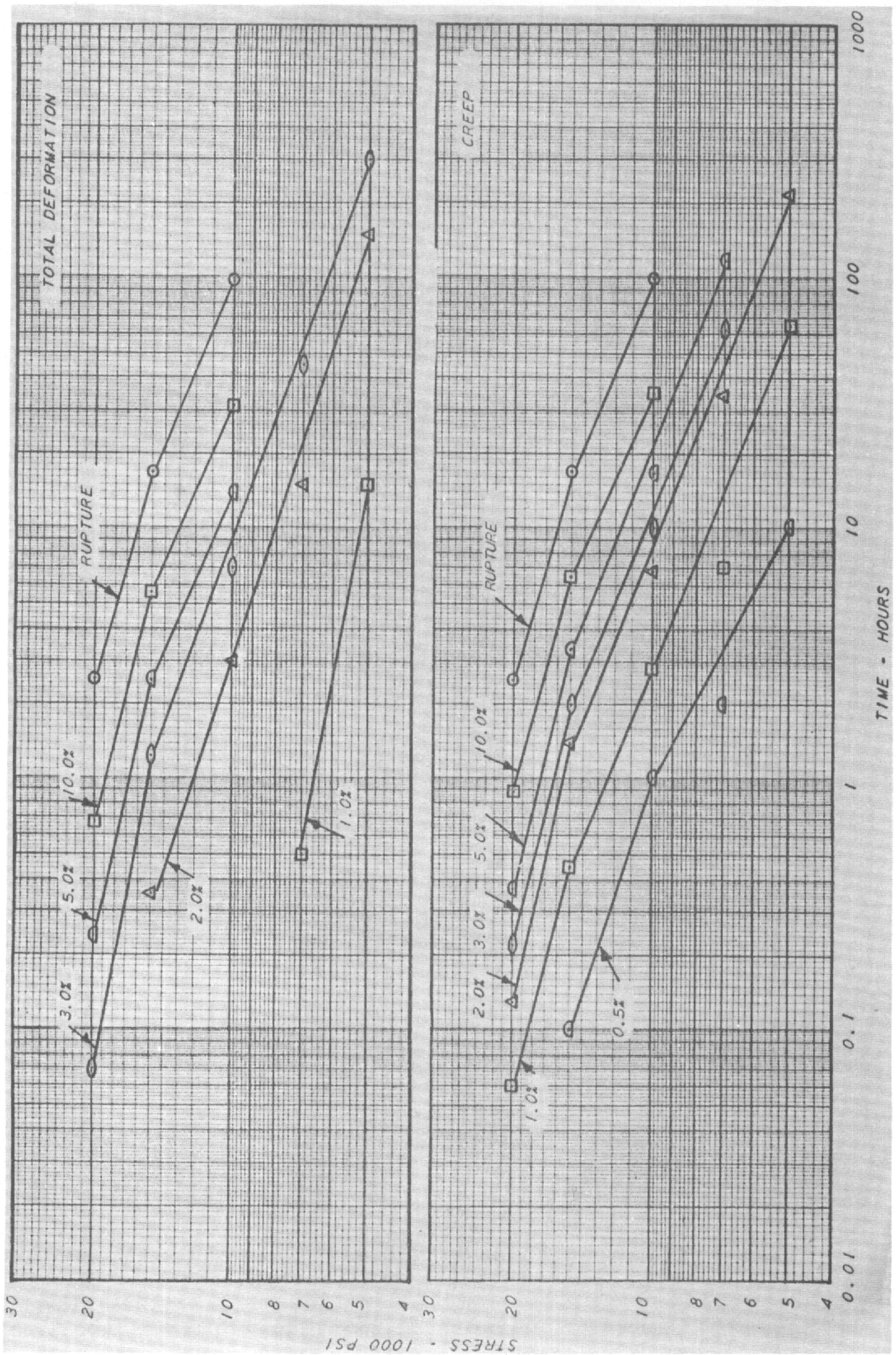


FIG. 19 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 2.0 D.

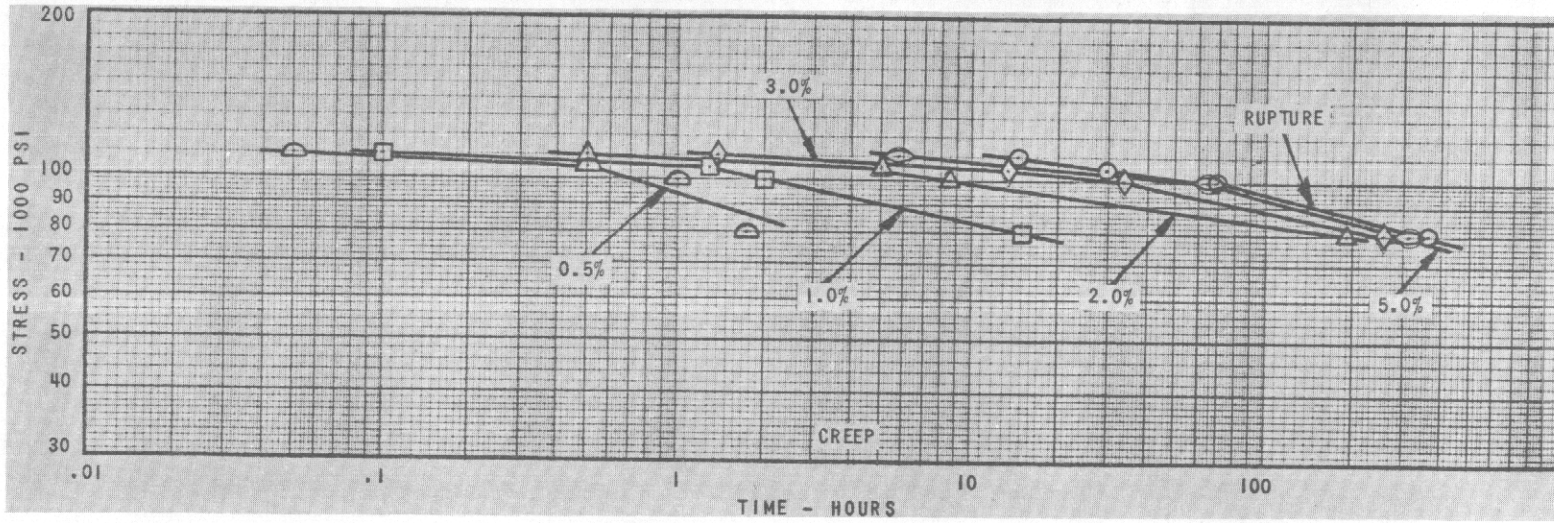


FIG. 20 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 2.0 D.

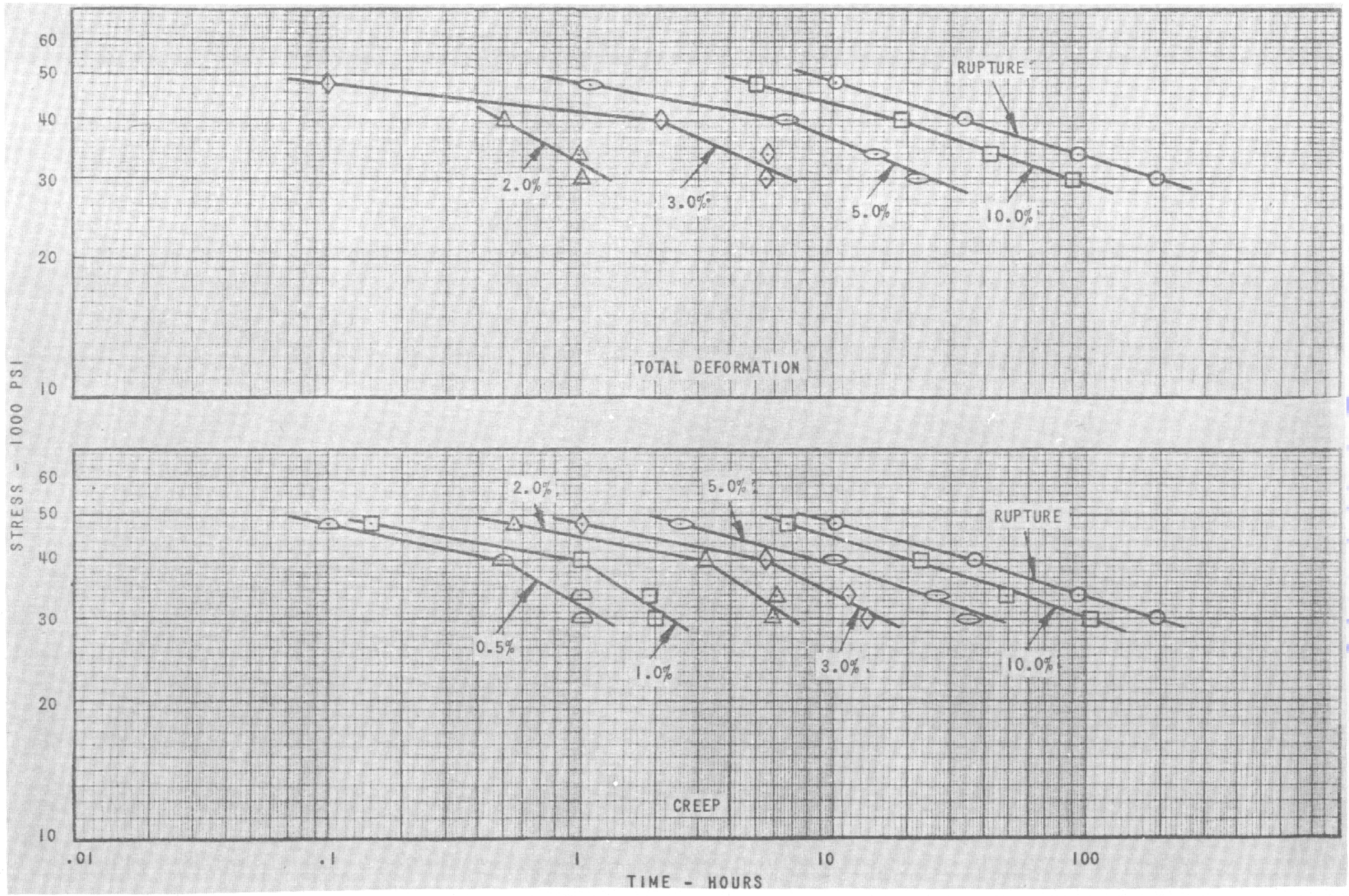


FIG. 21 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 2.0 D.

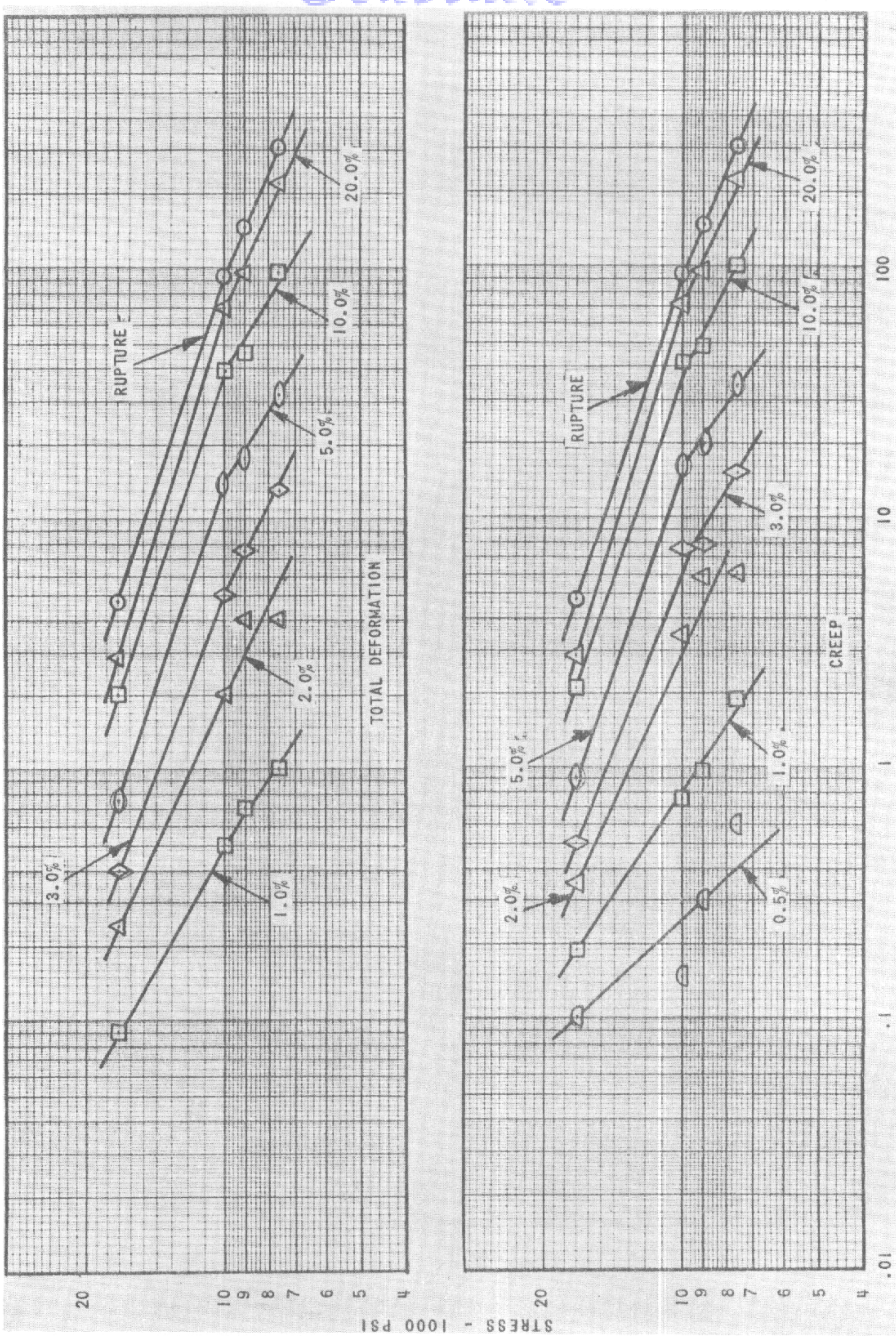


FIG. 22 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.064 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 2.0 D.

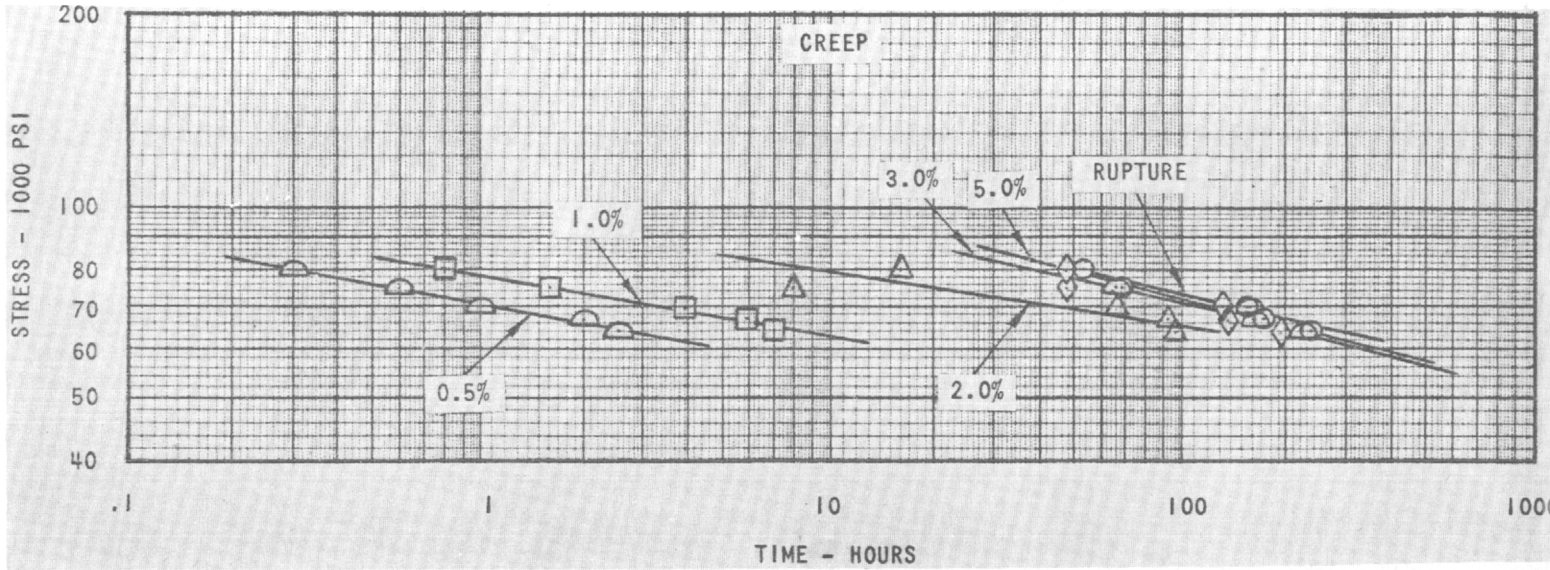


FIG. 23 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 1.5 D.

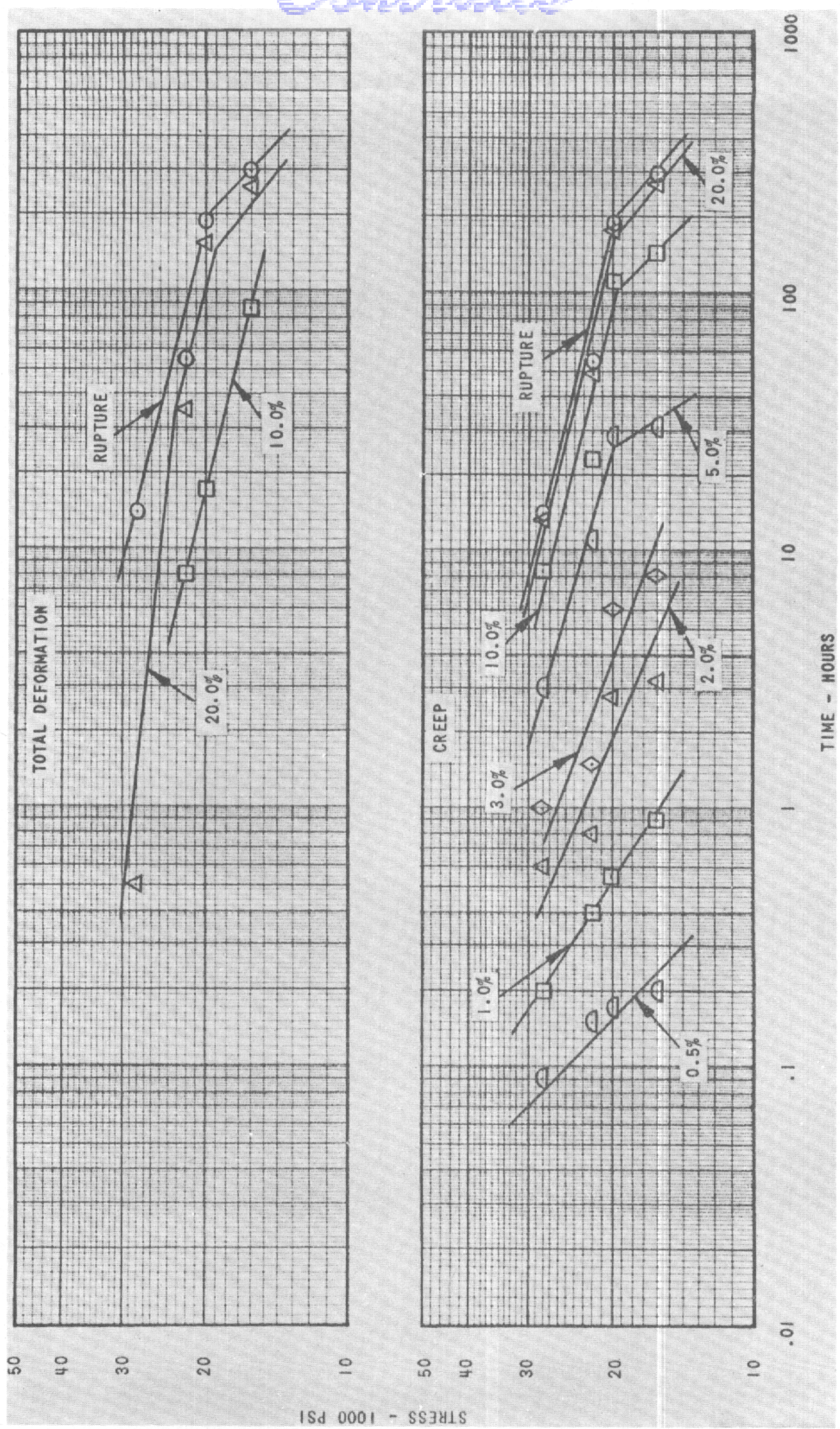


FIG. 24 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 1.5 D.

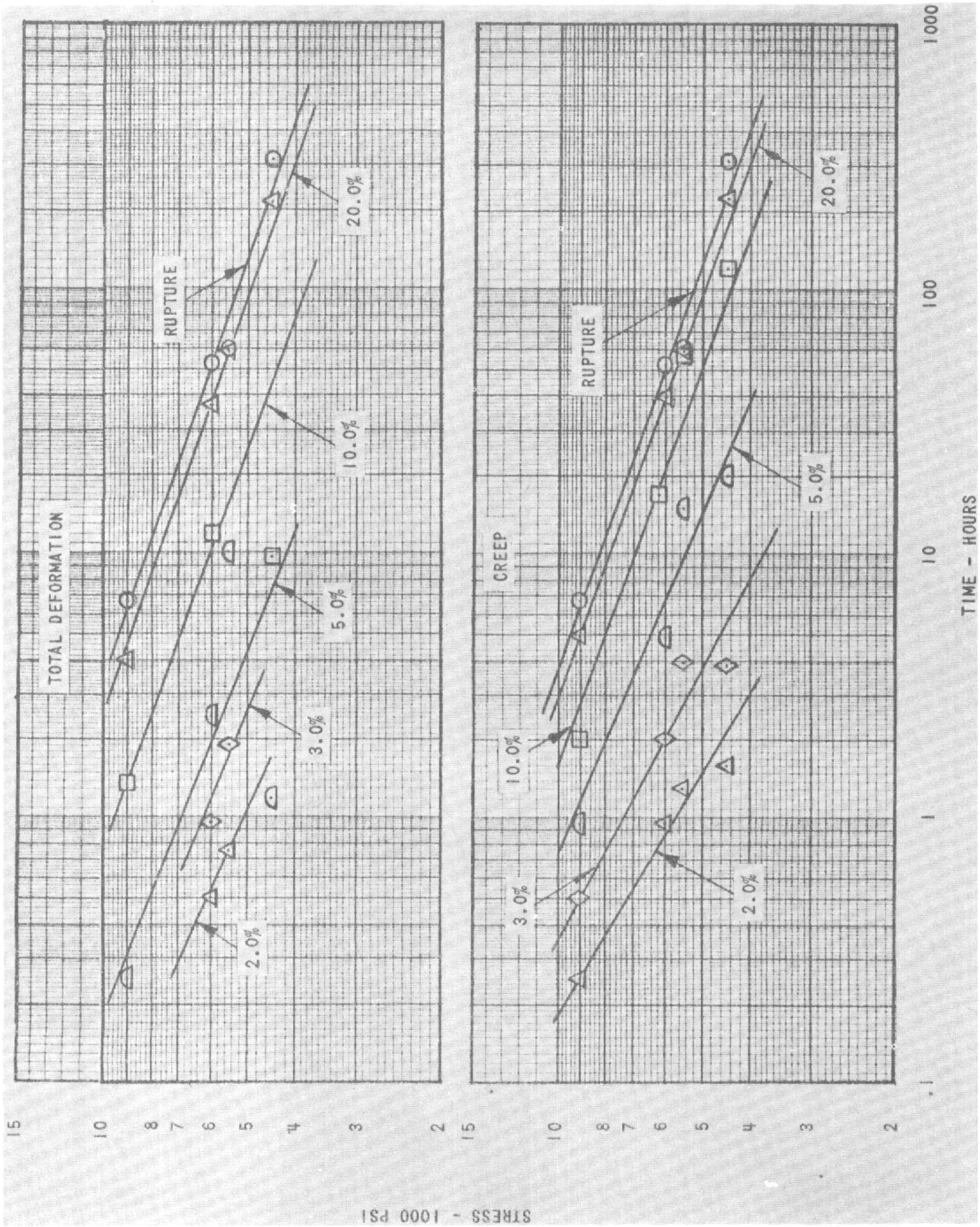


FIG. 25 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 1.5 D.

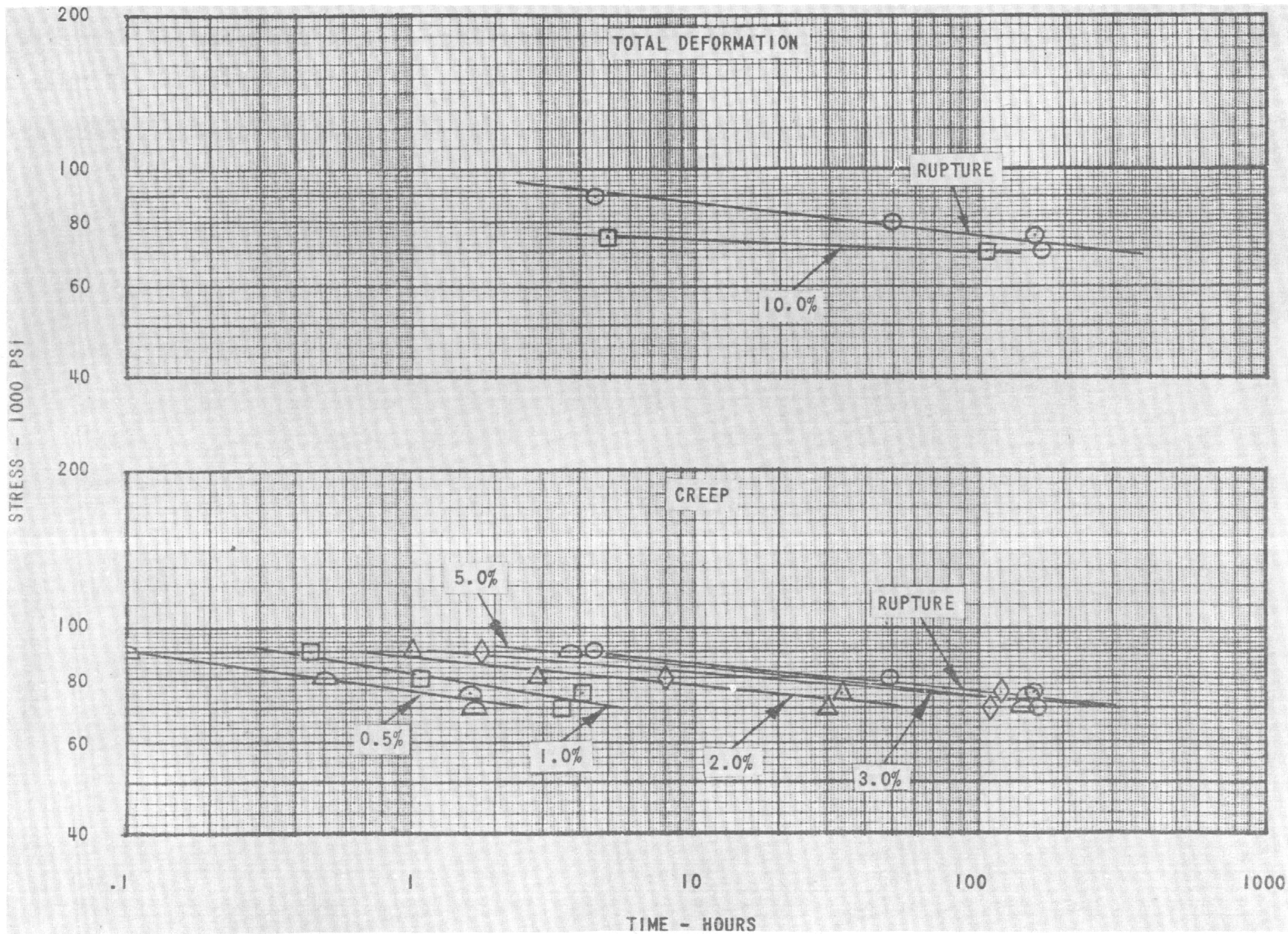


FIG. 26 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 1.5 D.

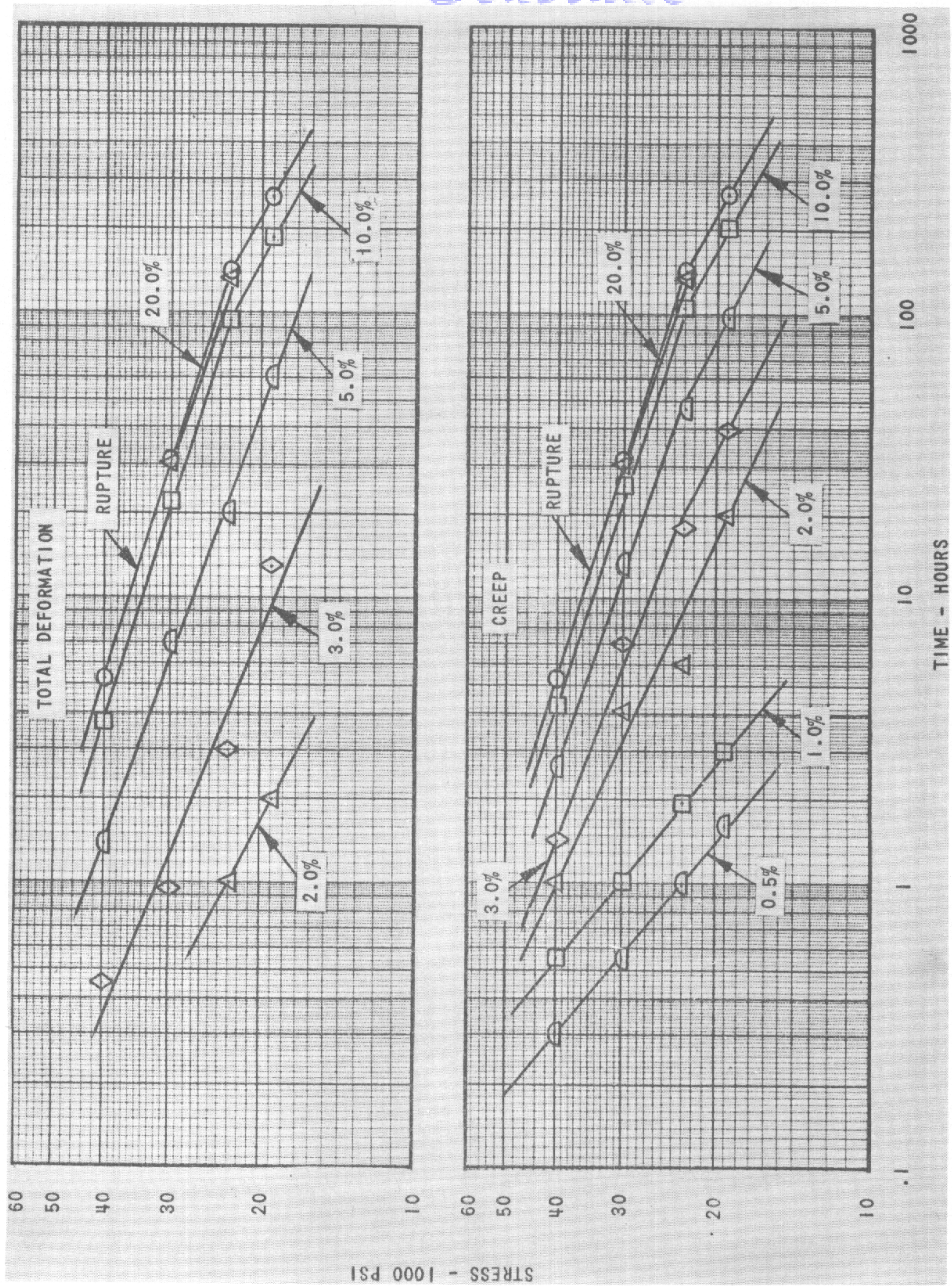


FIG. 27 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 1.5 D.

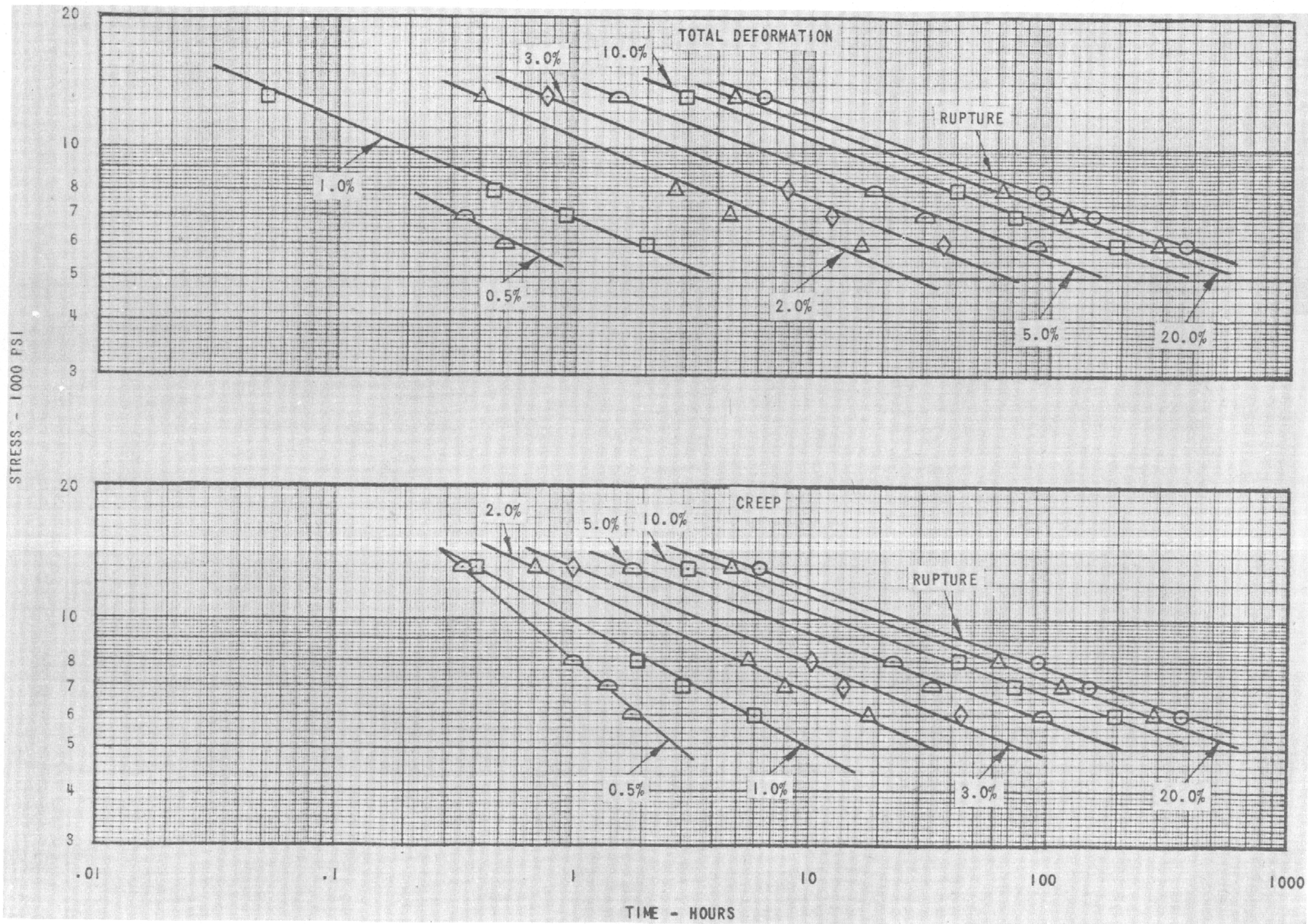


FIG. 28 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 1.5 D.

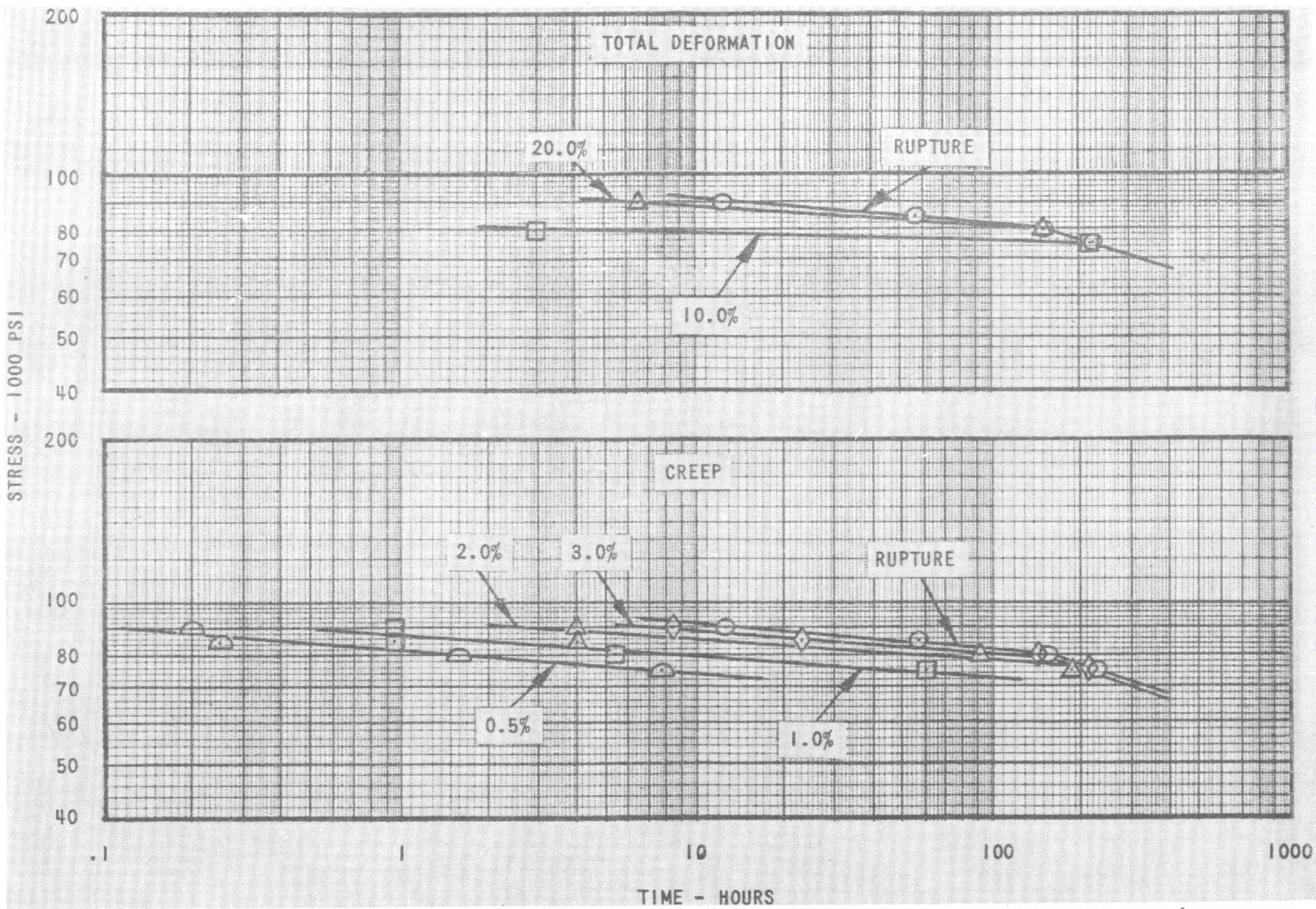


FIG. 29 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 1.5 D.

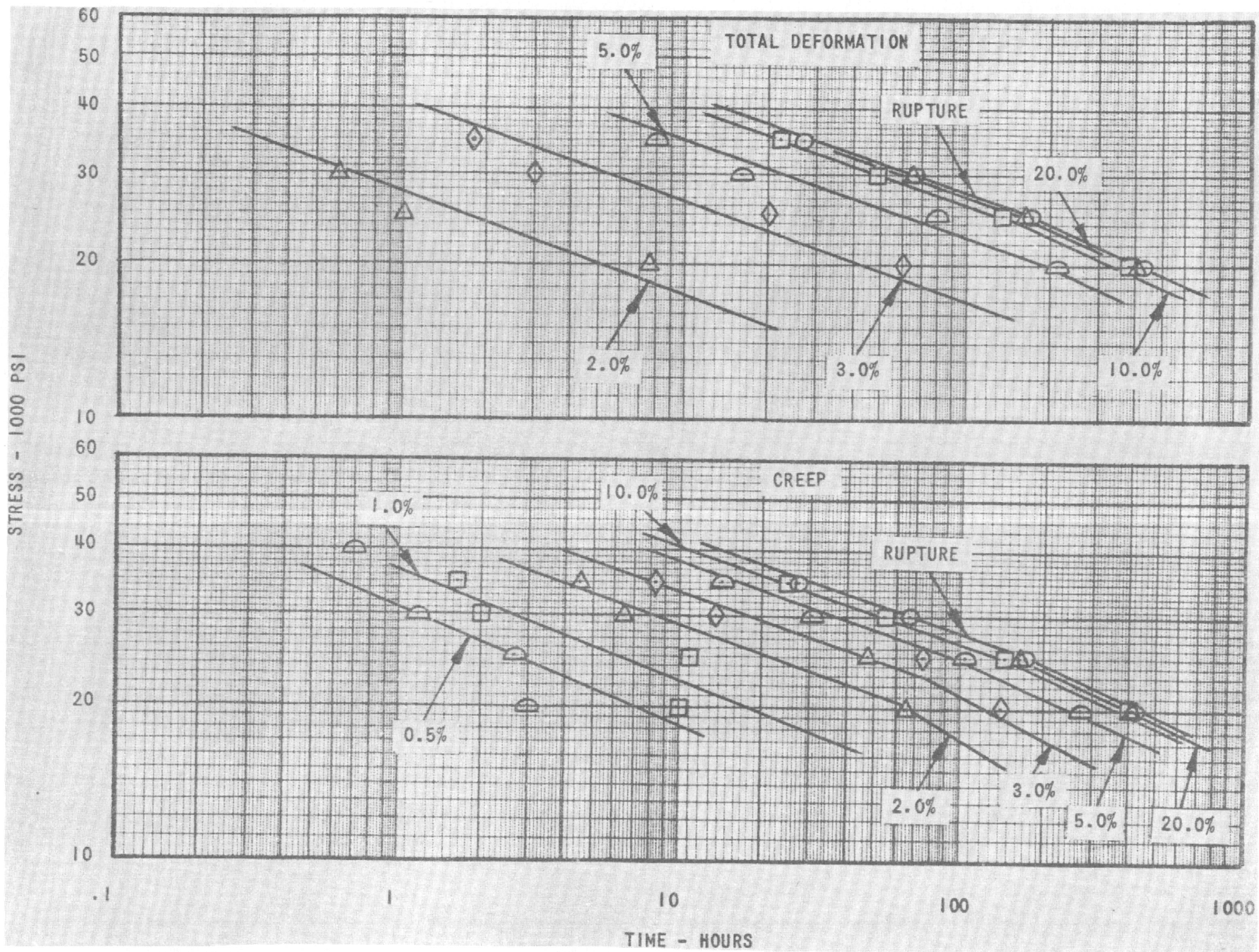


FIG. 30 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 1.5 D.

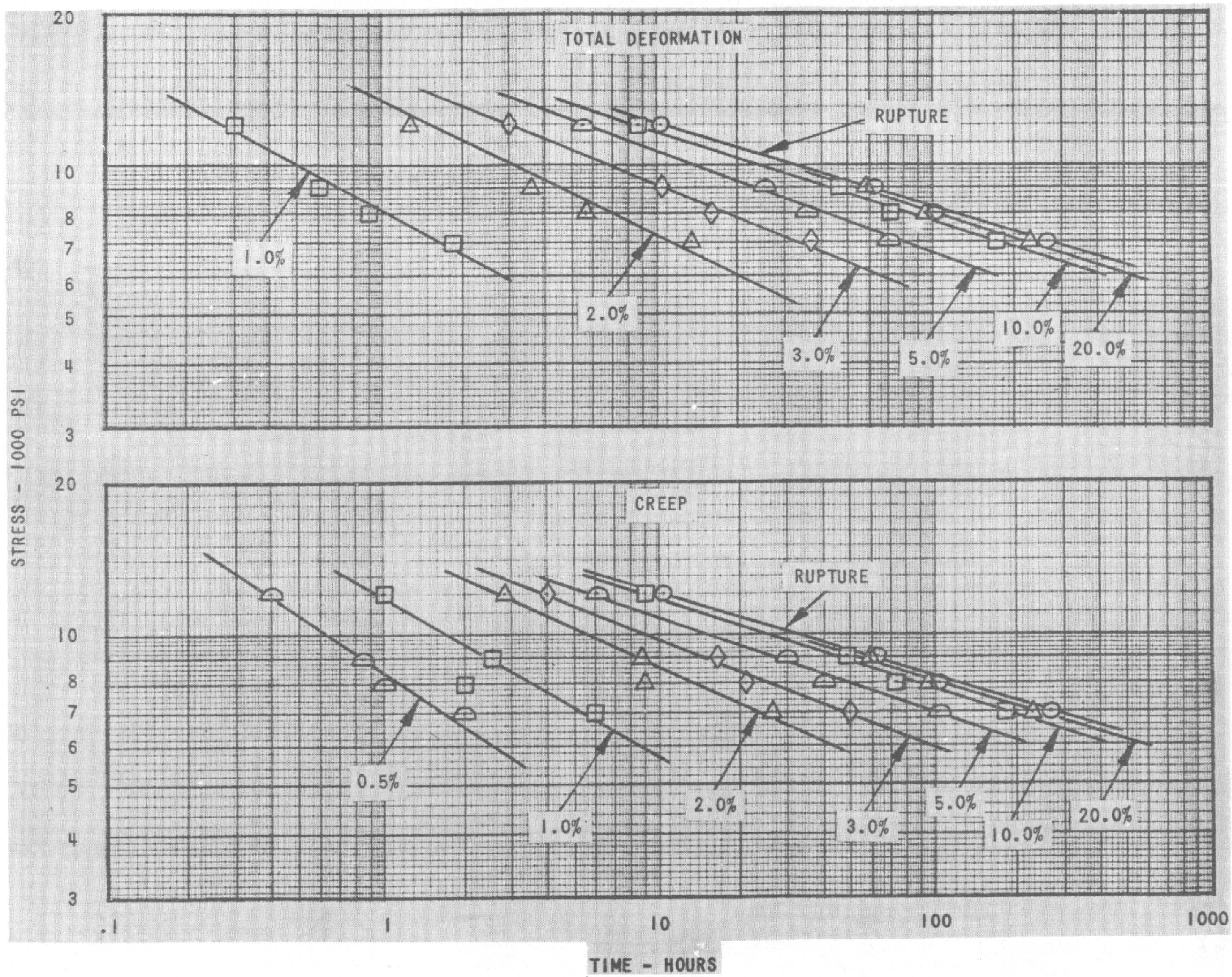


FIG. 31 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 1.5 D.

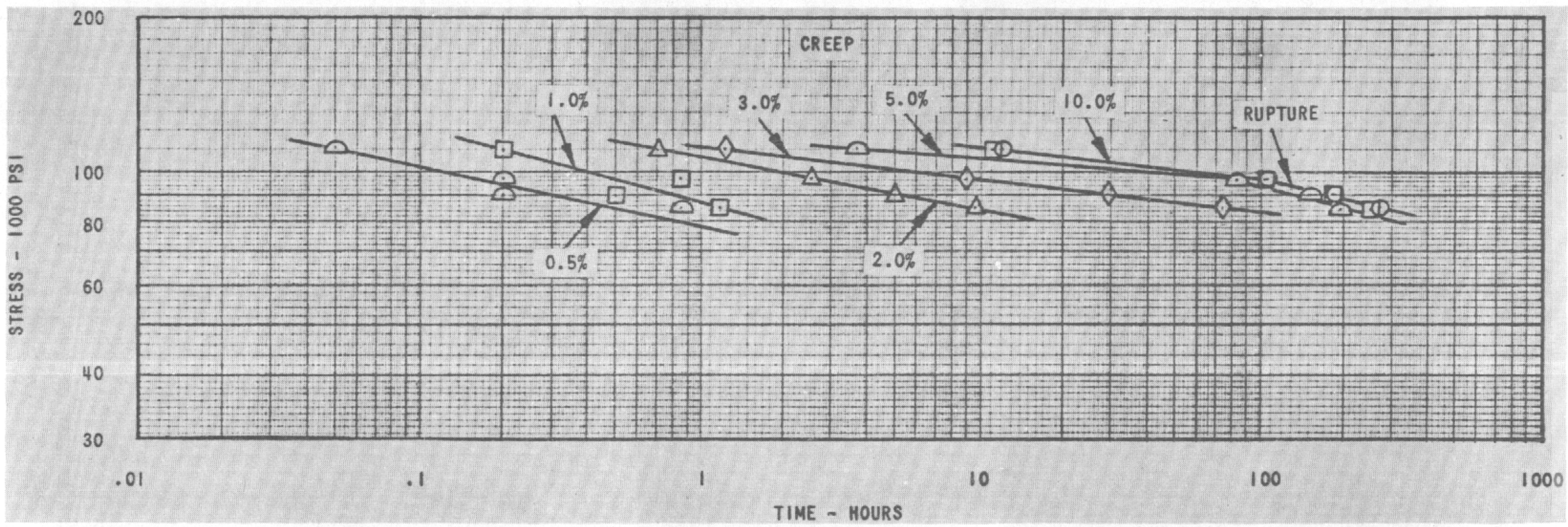


FIG. 32 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF OF 2.0 D.

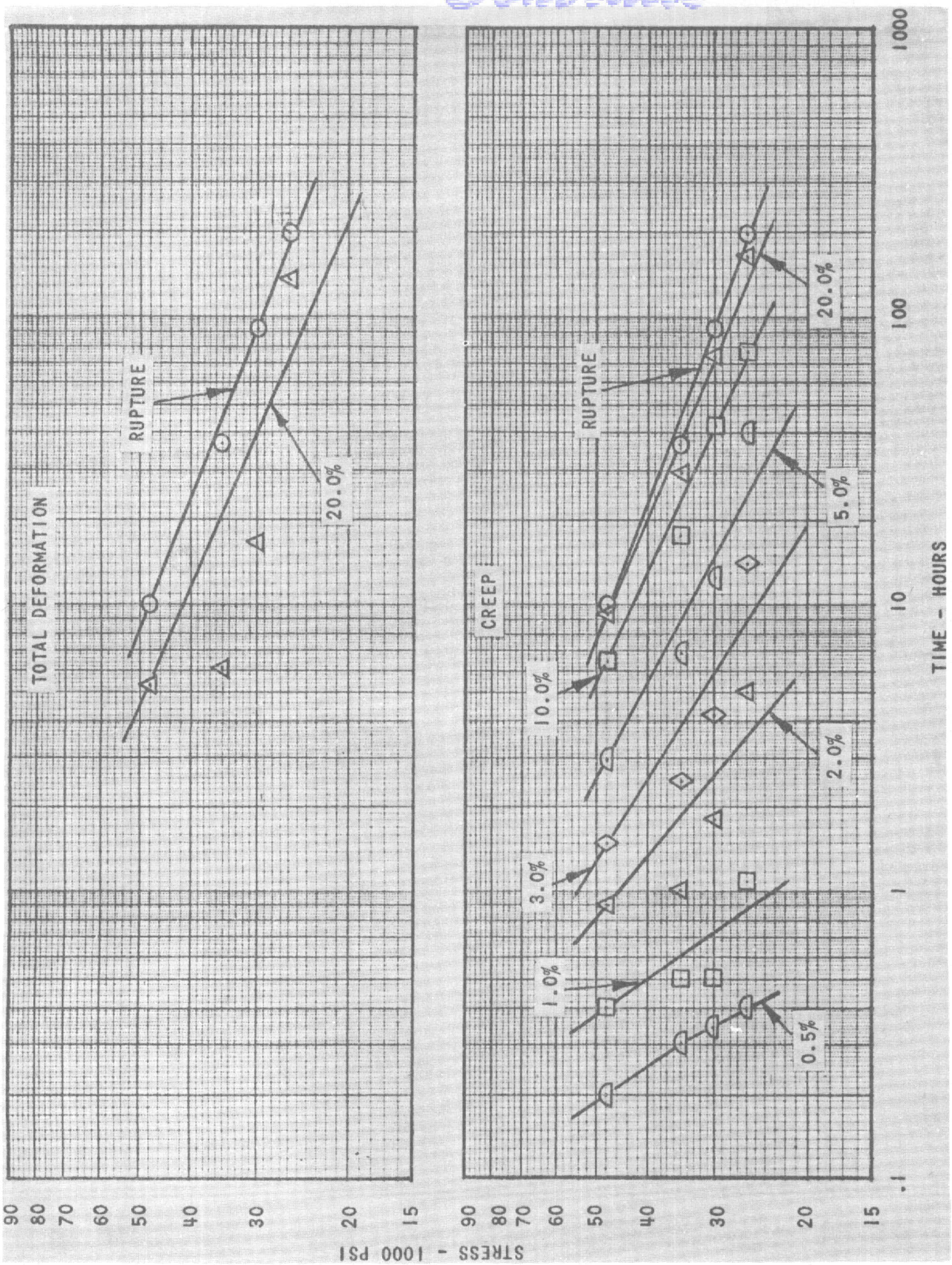


FIG. 33 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 2.0 D.

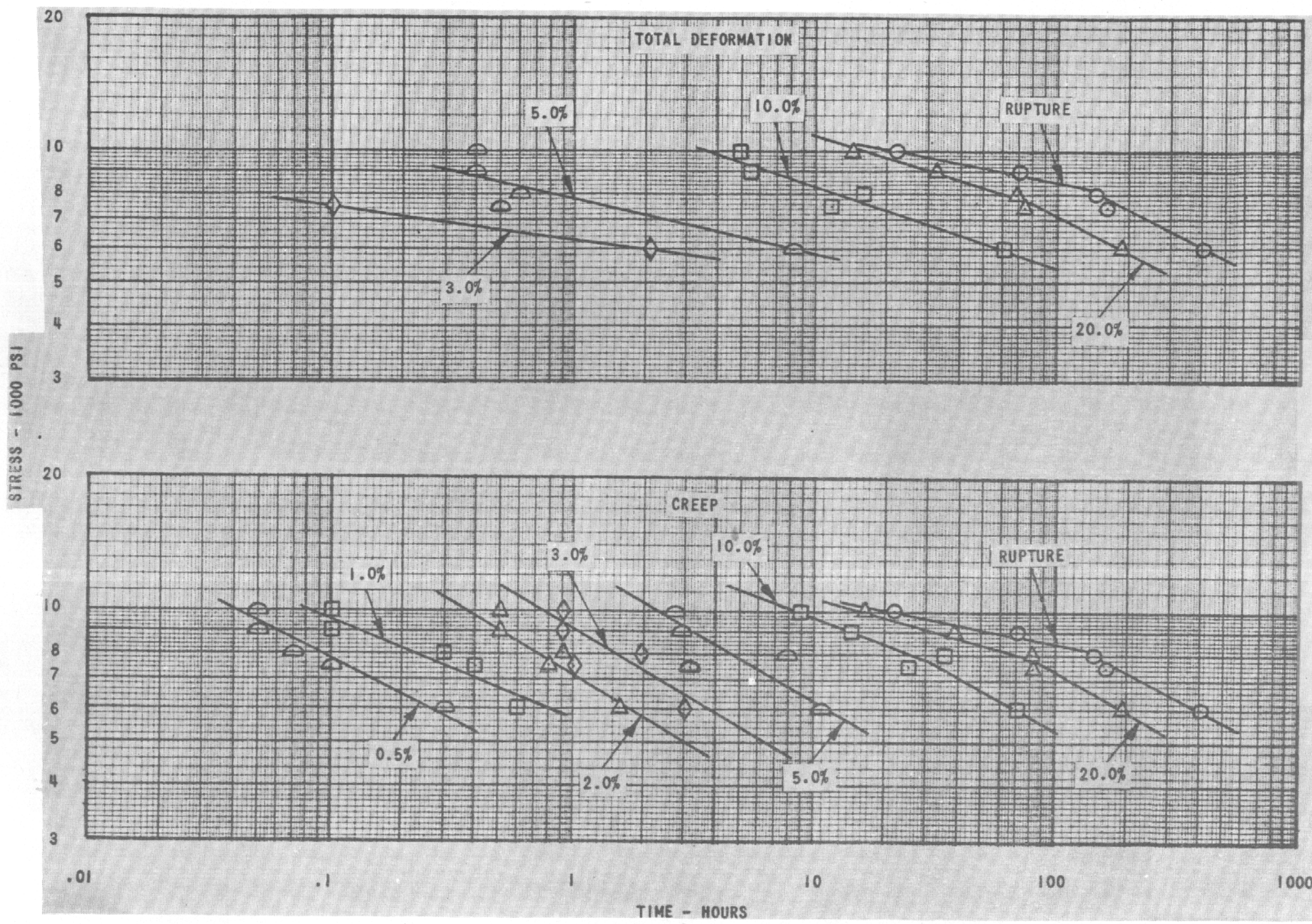


FIG. 34 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T-3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/16 INCH AND EDGE DISTANCE OF 2.0 D.

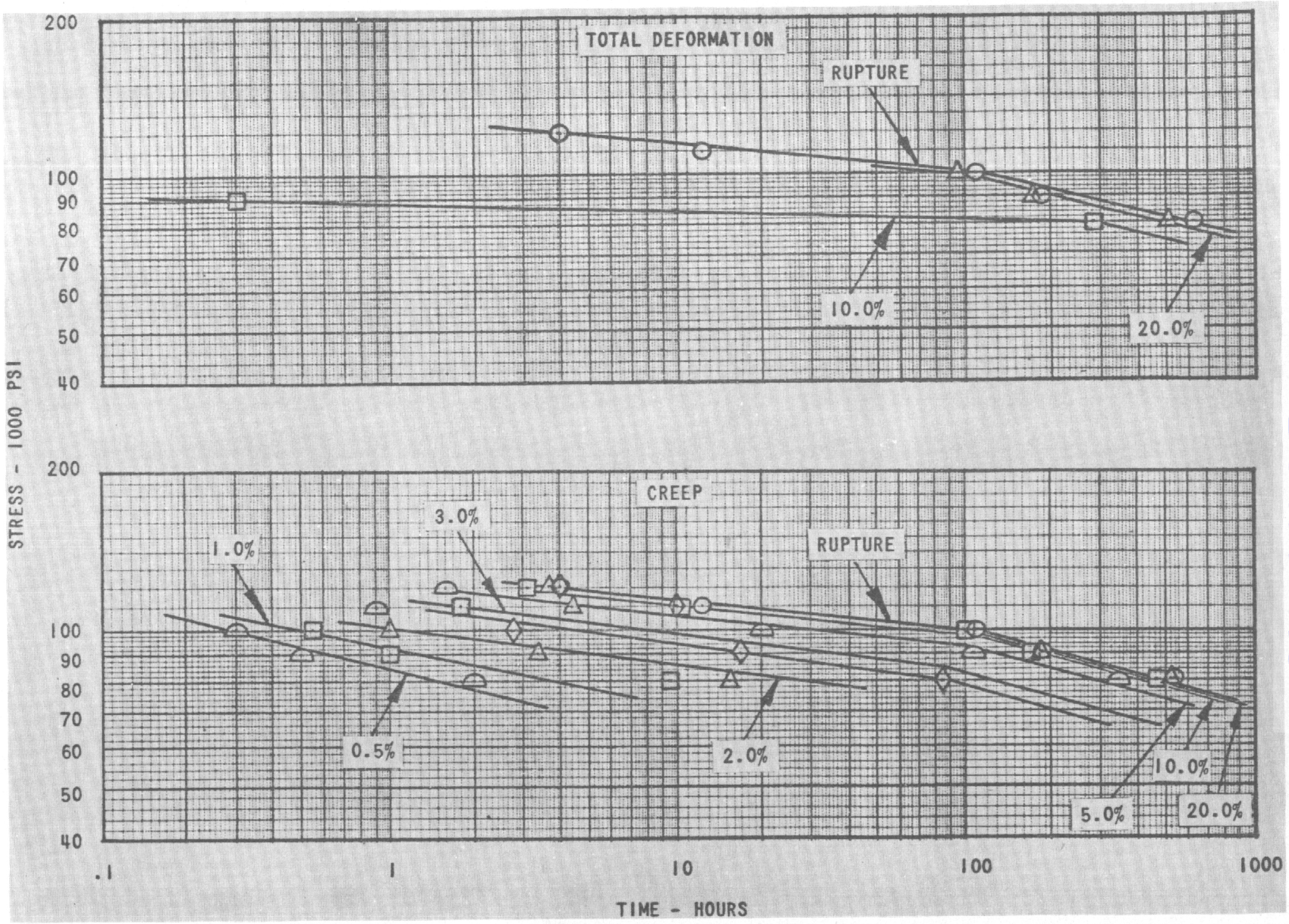


FIG. 35 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 2.0 D.

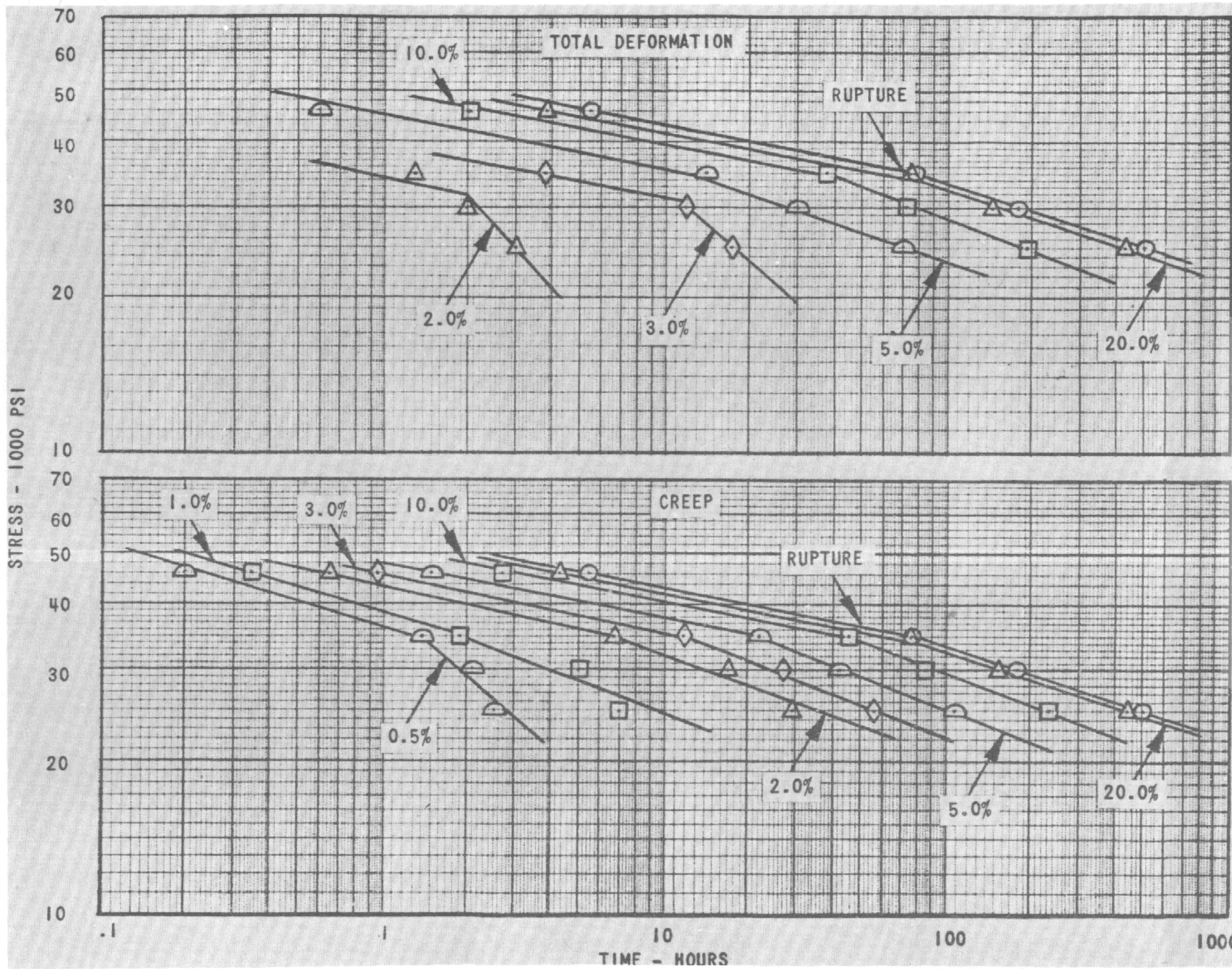


FIG. 36 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 2.0 D.

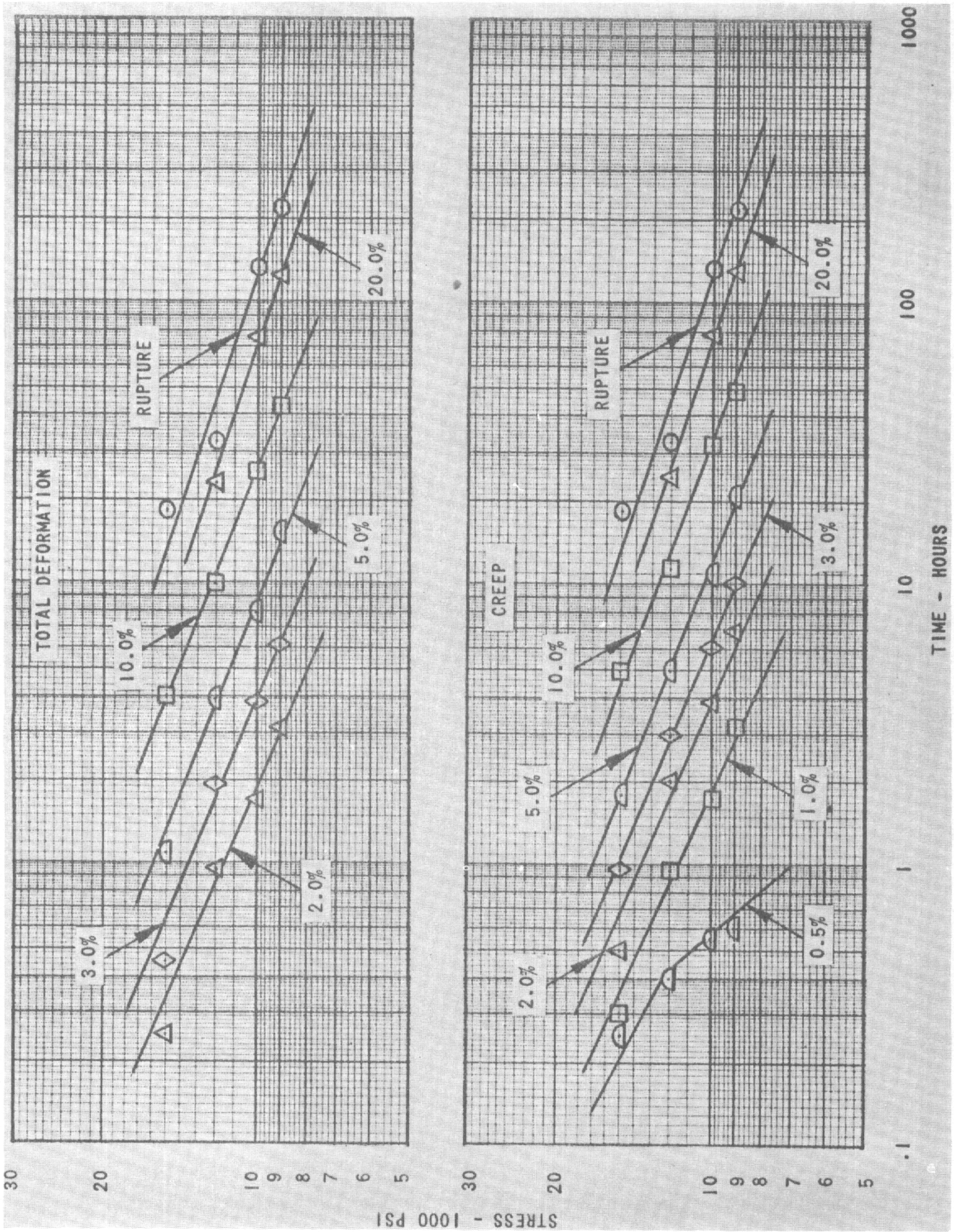


FIG. 37 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 1/8 INCH AND EDGE DISTANCE OF 2.0 D.

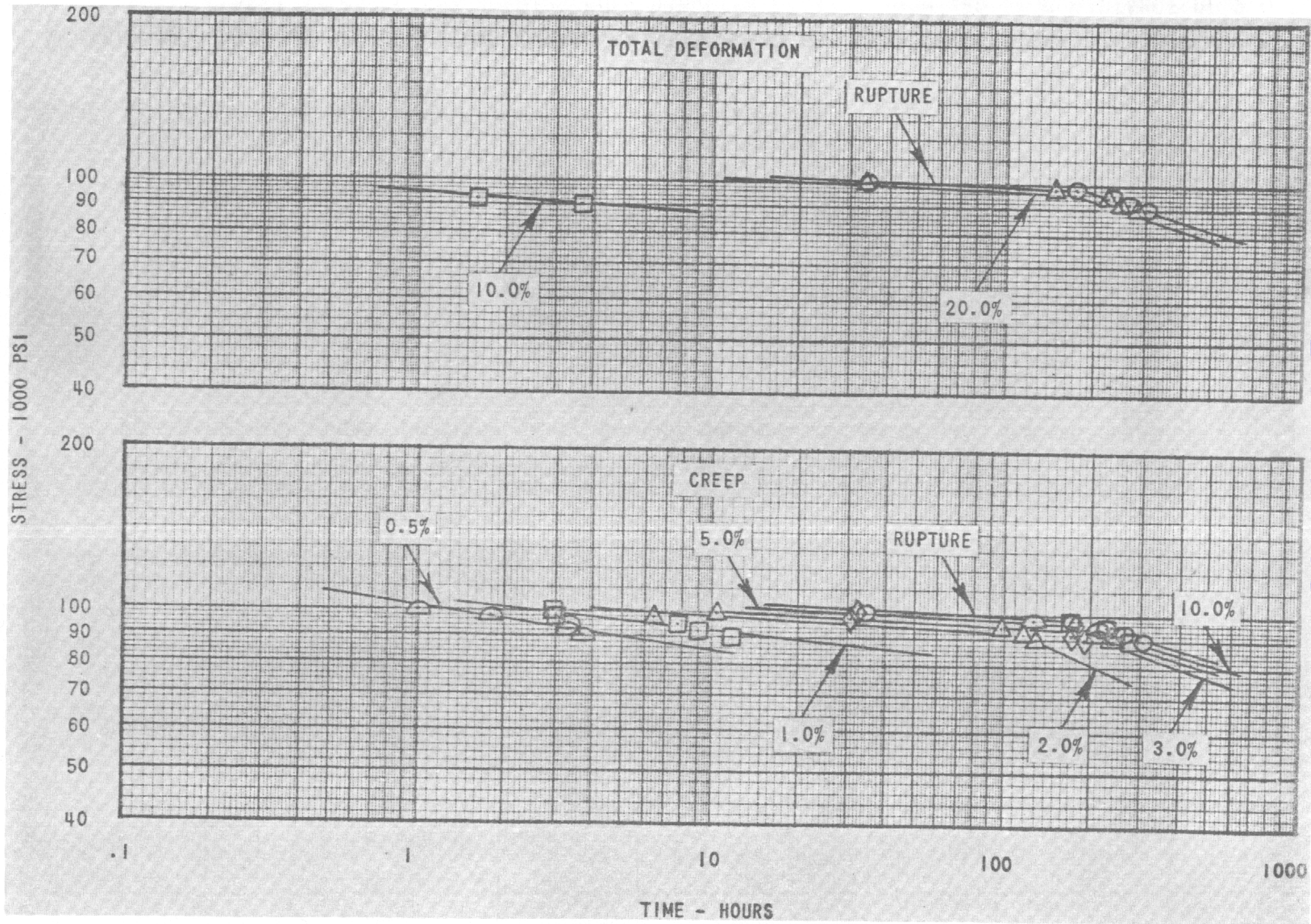


FIG. 38 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 300°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 2.0 D.

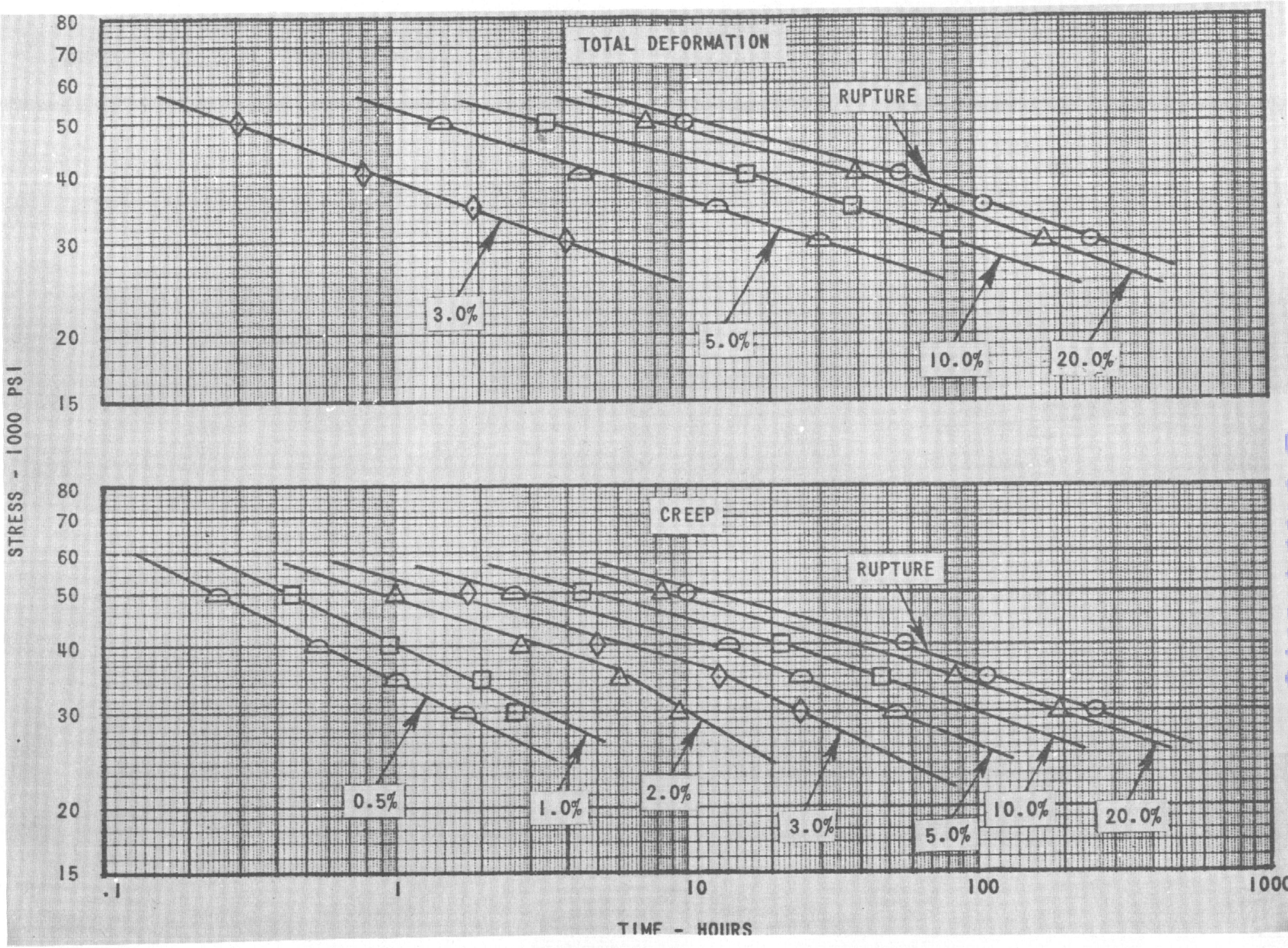


FIG. 39 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 450°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 2.0 D.

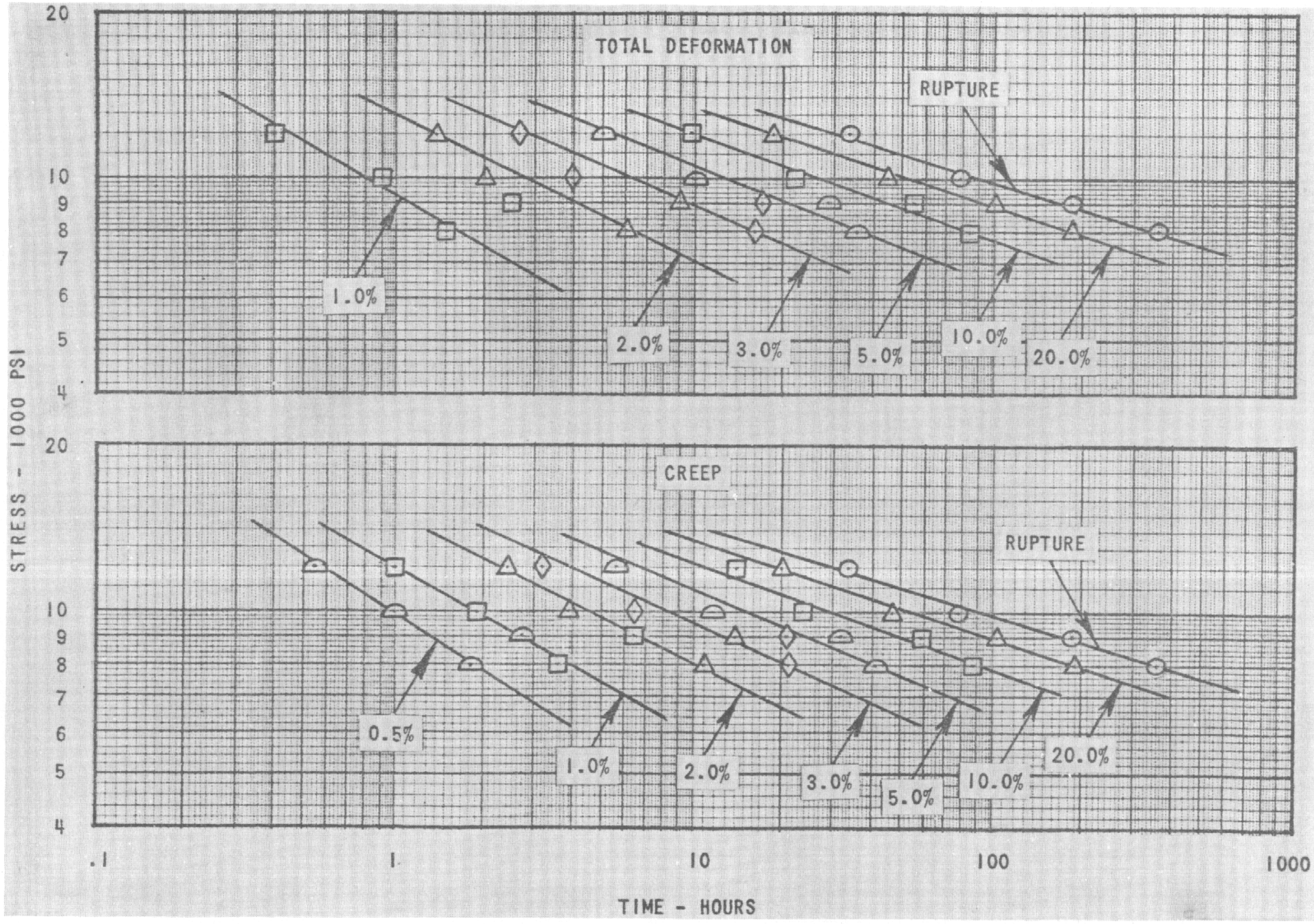


FIG. 40 BEARING CREEP-RUPTURE CHARACTERISTICS OF 0.091 INCH THICK 2024-T3 ALUMINUM ALLOY SHEET AT 600°F FOR BEARING HOLE DIAMETER OF 3/16 INCH AND EDGE DISTANCE OF 2.0 D.

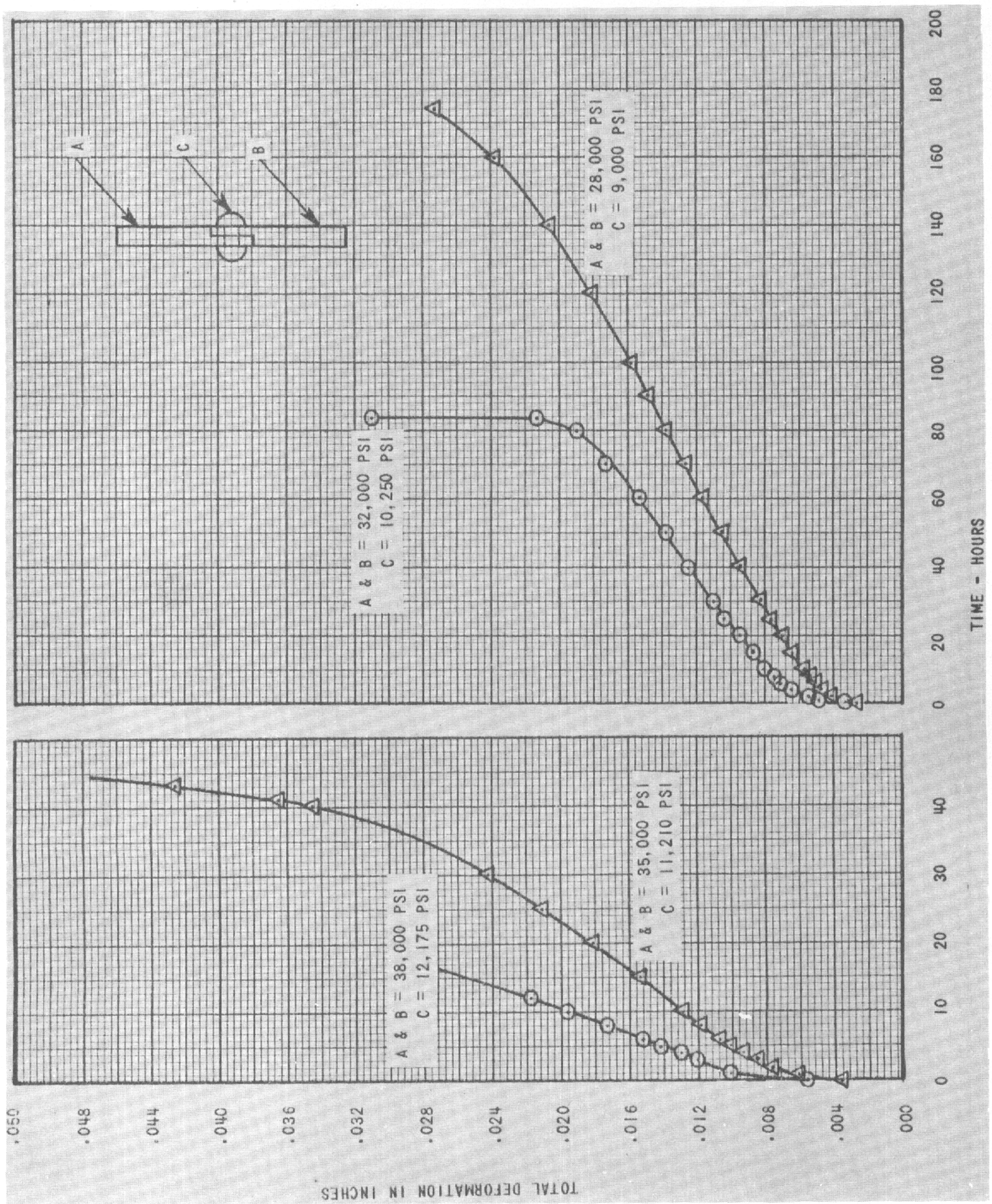


FIG. 41 TIME-TOTAL DEFORMATION CHARACTERISTICS OF TYPE I JOINT AT 450°F

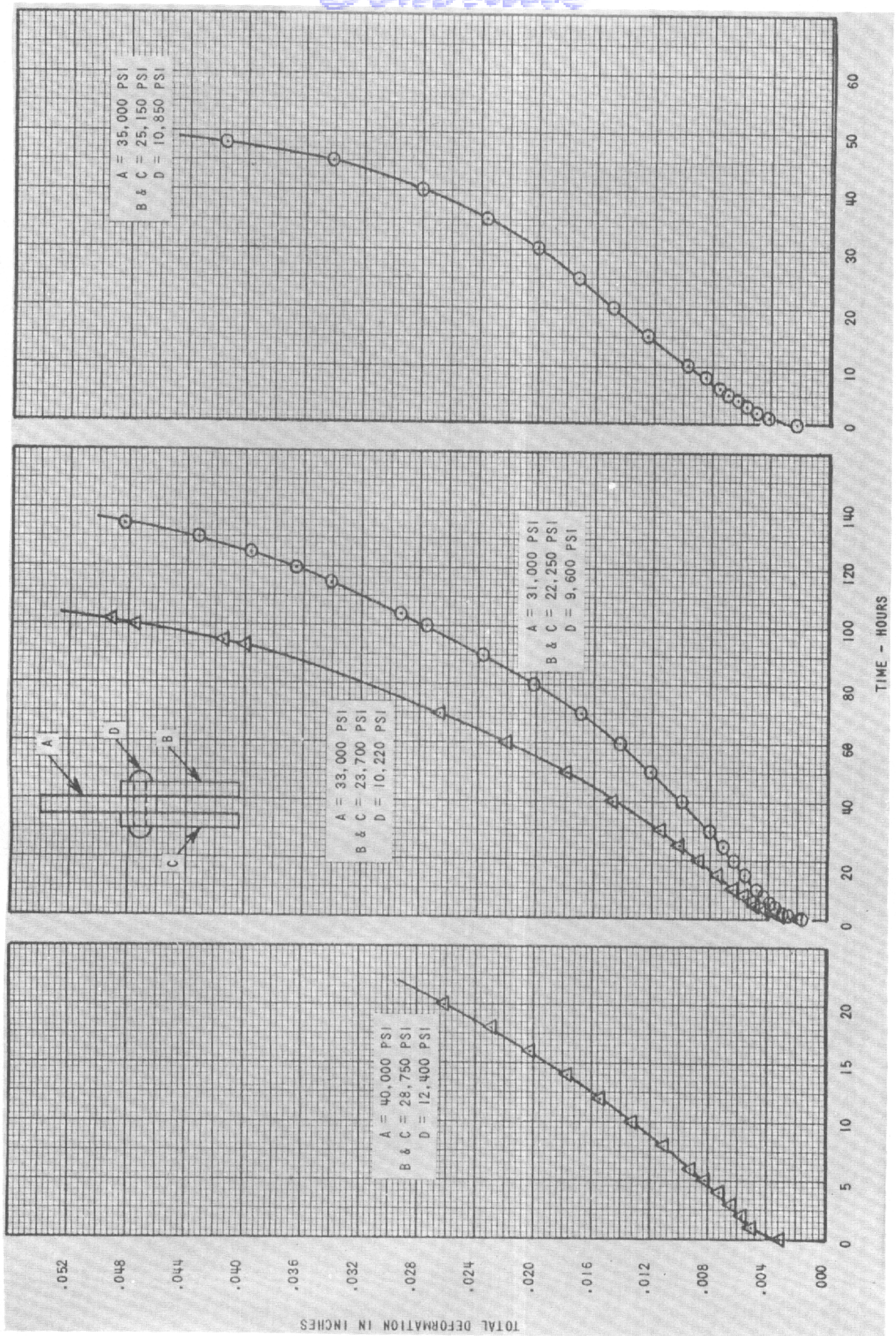


FIG. 42 TIME-TOTAL DEFORMATION CHARACTERISTICS OF TYPE II JOINT AT 450°F

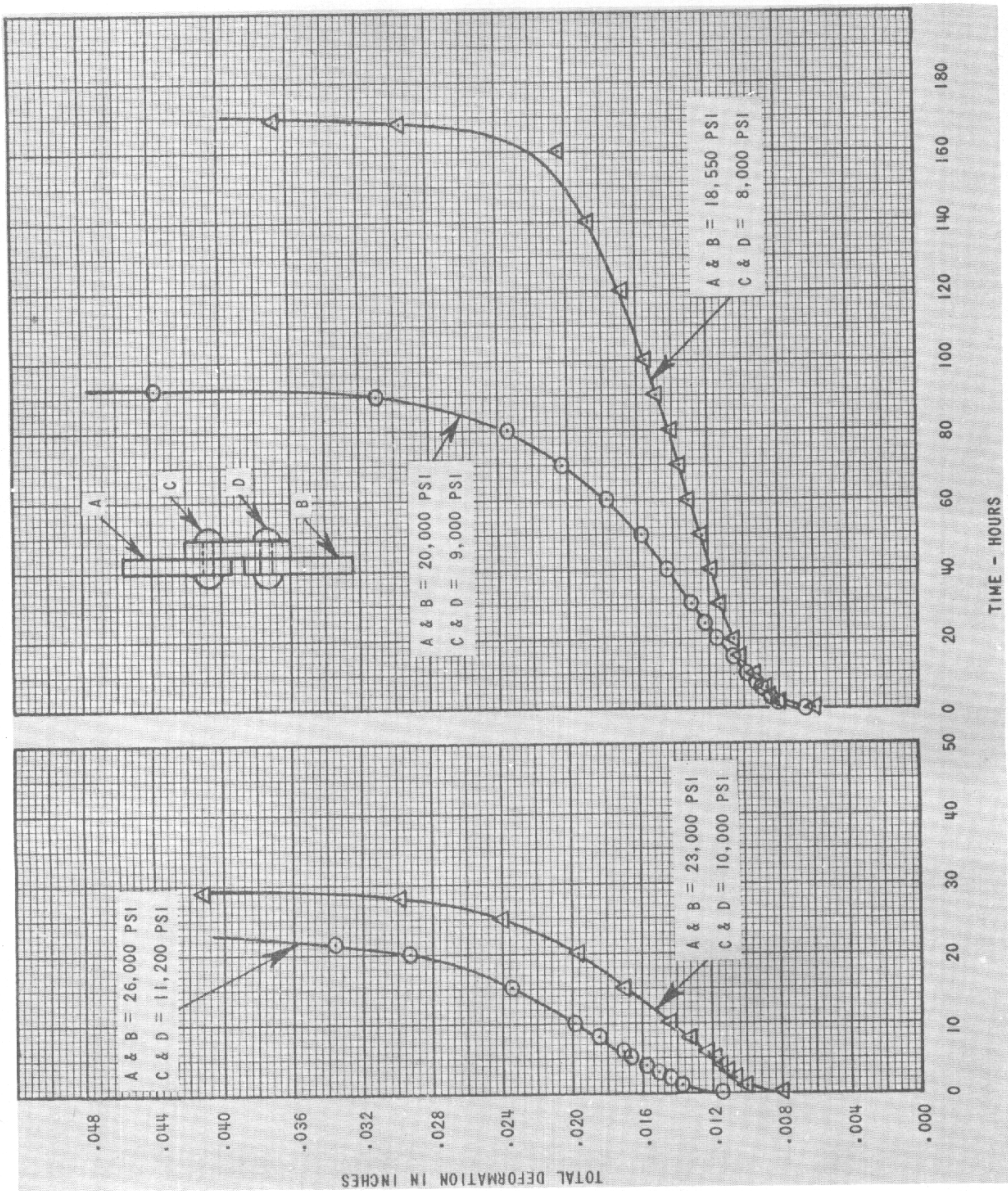


Fig. 43 TIME-TOTAL DEFORMATION CHARACTERISTICS OF TYPE III JOINT AT 450°F