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PART 2

MATERIALS-PROPERTY-DESIGN CRITERIA FOR METALS

Part 2. A Study of Methods of Presenting Creep Data for Airframe Design

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FOREWORD

This report was prepared by Battelle Memorial Institute, Columbus, Ohio, under Contract No. AF 33(616)-2303. The investigation was initiated under Project No. 7360, "Materials Analysis and Evaluation Techniques", Task No. 73605, "Design Data for Metals", formerly RDO No. 614-13, "Design and Evaluation Data for Structural Metals", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center with Mr. D. A. Shinn acting as project engineer.

This report covers work conducted from October, 1954, to April, 1955.

ABSTRACT

A study was made of a number of methods of presenting creep data from the standpoint of usefulness to the designer of airframes. These methods included: stress-time graphs, stress-temperature graphs, Larson-Miller graphs, and isochronous stress-strain graphs. Consideration was given to current practices and needs of personnel in the aircraft structures field. Also, consideration was given to the use of creep data in particular problems associated with high-speed flight.

On the basis of this study, it appears that a particularly useful method of presenting creep data is that of the stress-temperature graphs (with time as a parameter). It is also believed in some applications that the isochronous stress-strain graph may be a particularly desirable presentation, since useful engineering approaches for certain high-temperature problems have been advanced based on these graphs. This latter presentation should be considered tentative pending verification of these engineering approaches by experimental studies.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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INTRODUCTION

The demands of high-speed aircraft and missiles have stimulated the need for additional data on elevated-temperature behavior of metals. While such data may be presented in many different plots, it is possible that certain methods of presentation are more useful to designers than are other methods. Accordingly, a study was made of various methods of presenting creep data from the standpoint of usefulness to the designer of airframes.

The approach to this problem involved:

(1) Contacts with personnel in aircraft companies

(2) Examination of various methods of presenting creep and related property data

(3) Examination of the use of creep data in problems associated with high-speed flight.

This report summarizes the results of the survey. Suggestions and recommendations concerning presentation of creep data are made. Also included in these suggestions are comments concerning certain areas where additional data appear warranted.

CONTACT WITH AIRCRAFT COMPANIES

Five aircraft companies were visited to determine:

(1) The extent to which designers use available creep data, such as appear (for aluminum alloys) in Bulletin ANC-5, Figures 3.1221(d) to 3.1221(m)

(2) The method of application of such data

(3) Kind of data needed and method of presentation of such data for maximum usefulness.

The companies involved were manufacturers of a wide variety of aircraft ranging from commercial aircraft to missiles.

It appears that creep data available in ANC-5 are not being used extensively at the present time. Specific reasons for this are:

(1) Evolution of design concepts to account for elevated-temperature problems in aircraft structures has not kept pace with aerodynamic- and propulsion-system achievements.

(2) Data such as are available in ANC-5 do not cover all ranges of temperature, stress, and time of practical significance to aircraft and missile designers.

(3) Data frequently do not cover materials of interest at the present time or in the near future.

(4) Current method of presenting elevated-temperature data does not appear the most useful.

With specific reference to Item 1 above, it appears that all companies are aware of the existence of problems such as creep, creep buckling, thermal stress, etc., with regard to high-speed flight. This awareness stems from the large volume of information in the literature, from observations made on tests of certain components at specific plants, and from discussions with co-workers in the aircraft structures field and allied fields. All are seeking methods to incorporate such phenomena into safe design practice. This appears to be the greatest need. It is not so much a desire to obtain exact mathematical solutions of specific problems; rather it appears that the need is the development of less rigorous techniques, which can be applied easily and used by the designer to account for elevated-temperature phenomena.

Only one aircraft company disclosed a definite design procedure to account for cumulative creep. This company used a "cumulative-creep" hypothesis similar to that described by Gerard[1]. Creep data used were obtained in the company's laboratory. These data were plotted on design stress-temperature graphs with time as a parameter. A separate graph was used for each creep criterion (0.2 per cent creep, 1 per cent creep, etc., and stress rupture).

To design a particular component, an estimate was made of its stress and temperature spectra over the expected life of the aircraft. A permissible creep criterion was selected for the component based on the best estimate of tolerable deformation. The cumulative-creep analysis then was carried out.

Other companies have not attempted to resolve the creep problem in such a manner. In two cases, the aircraft companies were designing aircraft for which the flight duration was considered so low, at conditions where creep might be a problem, that creep was not believed of major importance. In other cases, it appeared that a 0.2 per cent offset strain was considered the limiting design condition.

Most, but not all, of the companies are concerned presently with the problem of creep buckling and thermal buckling. However, there appears to be no general "feeling" as to the treatment of such problems with data as presented in ANC-5 or with other "popular" methods of presenting creep data.

Information concerning Items 2, 3, and 4 can be summarized readily. The following data are considered necessary by most of the company personnel contacted:

(1) Low values of total creep. ANC-5, in some cases, presents curves for 0.5 per cent creep. Values lower than this are considered necessary but generally are not available in published literature.

(2) Inelastic creep data.

(3) Strains resulting from thermal expansion.

(4) Creep data for low values of time as well as deformation.

(5) Data on aluminum alloys for temperatures up to 600 F.

(6) Data on other materials; for example, 17-7 PH, high heat-treated steels, and titanium alloys.

(7) Data relating the effect of elevated-temperature exposure on subsequent lower temperature or ambient-temperature mechanical properties.

(8) Specific data on shearing and bearing strength and Poisson's ratio.

In general, it appears that personnel in the aircraft companies visited believe that additional elevated-temperature data are needed in ANC-5. A specific method of presentation has not been agreed upon. Application of such data to design problems is being made by most of the companies to a variable extent. However, greater effort should be expended in evolving and demonstrating experimentally simplified analyses to account for elevated-temperature phenomena. Such work would clarify the extent of needed experimental data.

PRESENTATION OF CREEP DATA

The variables in creep behavior include: stress, temperature, time, and deformation. Creep data can be represented graphically by many different combinations of these variables. Four such methods are illustrated in this report.

Stress Versus Lifetime Graph

The most conventional plot of creep data is that illustrated in ANC-5. This is a plot of stress versus log lifetime. The parameter is creep deformation and rupture. For clarity, data on such a plot are limited usually to one specific temperature. Thus, a series of graphs is needed to illustrate the creep behavior of a particular material over its useful temperature range.

Figure 1 illustrates this method of presentation. The material, 7075-T6 (75S-T6), was selected in this case, since the data (obtained from ANC-5) included a wider range of the pertinent variables than was the case for other aluminum alloys in ANC-5. In this figure, stress is plotted as the ordinate instead of per cent room-temperature tensile strength (the customary ANC-5 ordinate). Also included on the figure is a curve representing the start of third-stage creep. This latter curve is included, since it presumably defines a limiting condition with respect to safe creep design.

Stress Versus Temperature Graph

The curves in Figure 1 and similar curves for other temperatures can be cross plotted on stress-temperature coordinates, with the parameter time for a particular creep criterion. Figure 2 shows such a plot for data obtained from Bulletin ANC-5 for 7075-T6 Alclad. The creep criterion is 0.5 per cent total creep. For clarity, such graphs should be constructed for each creep criterion of interest.

Larson-Miller Graph

A number of suggestions have been advanced concerning the possibility that creep behavior can be usefully analyzed in terms of a single variable (some function of both time and temperature). Such analysis, if justified, would provide workable means for interpolation and extrapolation of limited data to conditions of design interest.

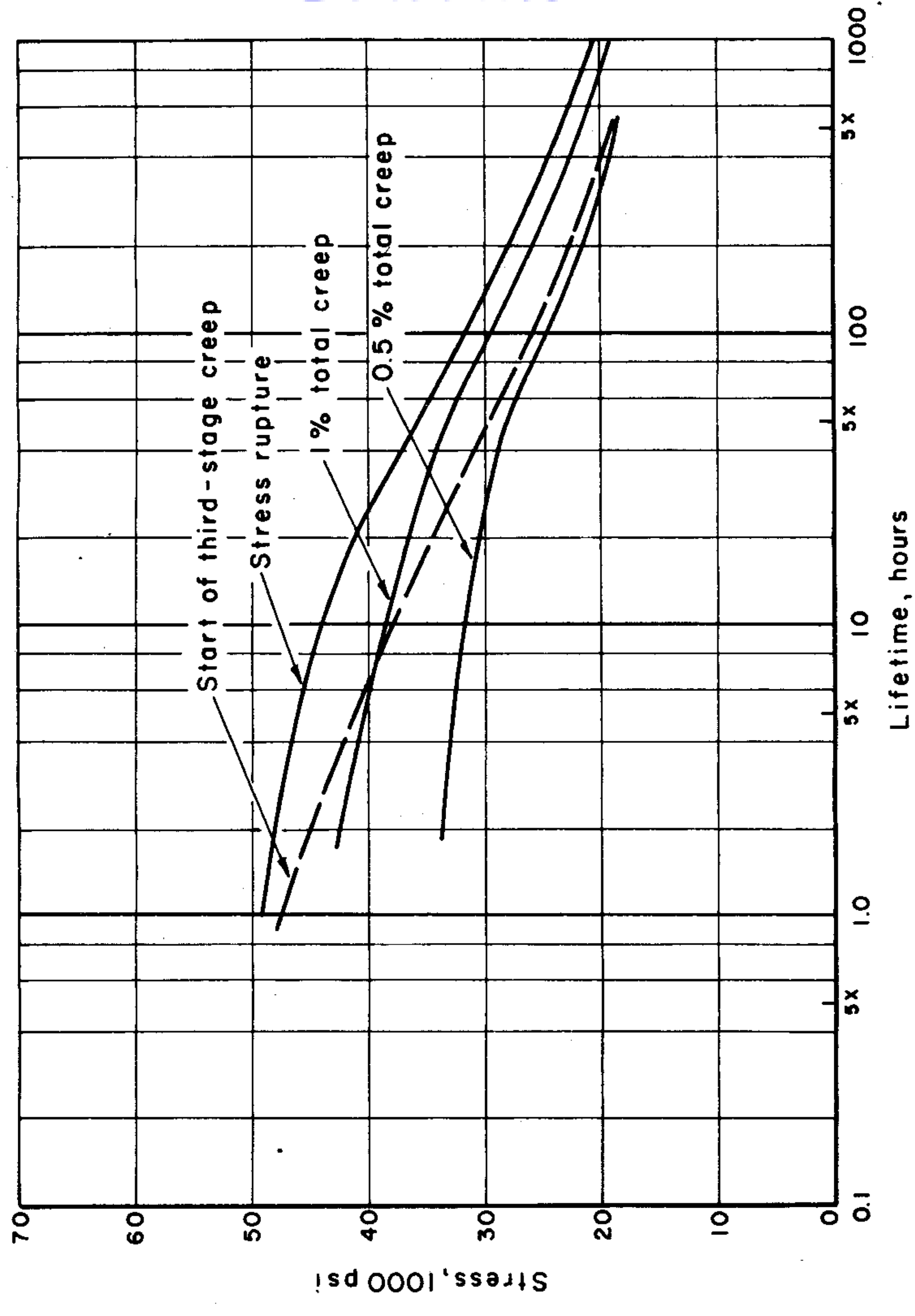

FIGURE 1 CREEP BEHAVIOR OF 7075-T6 ALCLAD AT 300 F

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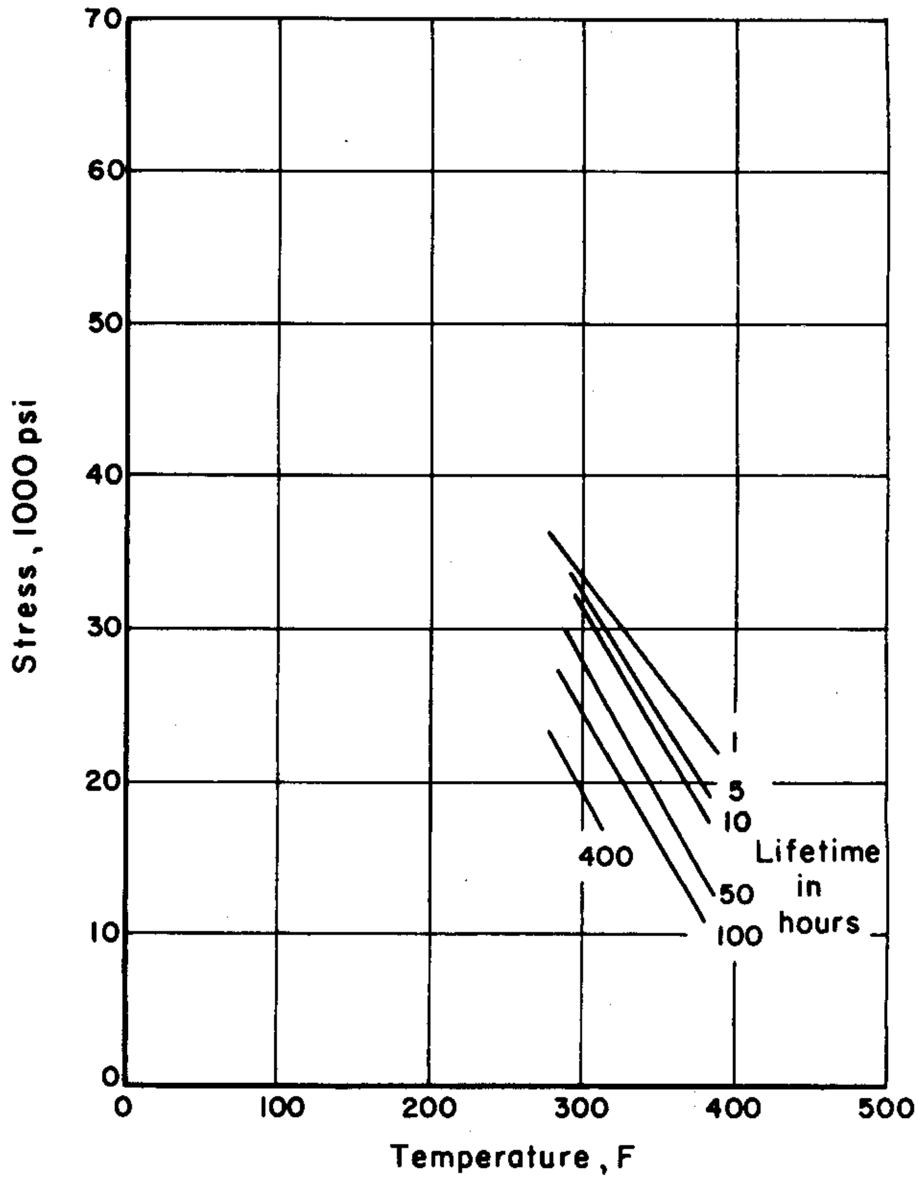

FIGURE 2. STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 7075-T6 ALCLAD FOR 0.5 PER CENT TOTAL CREEP

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Among suggestions of this nature, that of Larson and Miller[2] has been of wide interest. They suggest that temperature and time influence behavior mainly in such a combination as

$$\theta = T\ (20 + \log t)$$

where

T = temperature, degrees Rankine

t = time of exposure,

and that observations (such as stress for 0.5 per cent deformation or stress for stress rupture, etc) be plotted against θ. Use of such a plot would necessitate only one graph for each material if the pertinent creep criteria were included on the graph.

This type of plot is illustrated in Figure 3 for 7075-T6 Alclad for data obtained from ANC-5. The creep criteria in this figure for which curves are drawn include 0.5 per cent total deformation and stress rupture. Data representing initiation of third-stage creep also are plotted; however, the scatter of points is such that construction of a representative curve would be difficult.

Isochronous Stress-Strain Graph

Basic creep data frequently are plotted on rectangular coordinates of strain and time for constant values of stress. From curves through such data, cross plots can be made to show stress versus strain for constant values of time. These curves have the appearance of conventional stress-strain curves. They have been called isochronous stress-strain curves[3, 4].

Figure 4 shows typical isochronous stress-strain curves for 7075-T6 Alclad at 300 F. As with previous figures, these curves were constructed from information obtained from Bulletin ANC-5, Figures 3.1221 (h, i, and j). The initial modulus is equal to the room-temperature modulus factored by the appropriate percentage from Table 3.1221(b) of ANC-5 for 300 F. In this figure, the configuration of the various curves in the region of the modulus line is conjectural. The reason for this is that deformation curves in ANC-5 at this temperature are given for 0.5, 1.0, and 5 per cent total creep. Had smaller values of total creep been available, particularly for lower stress tests, it would have been possible to better characterize these curves.

The construction of isochronous stress-strain curves also has been approached by Carlson and Manning[5] and by Micks[6] by obtaining from creep-test data an equation representing the creep behavior of particular

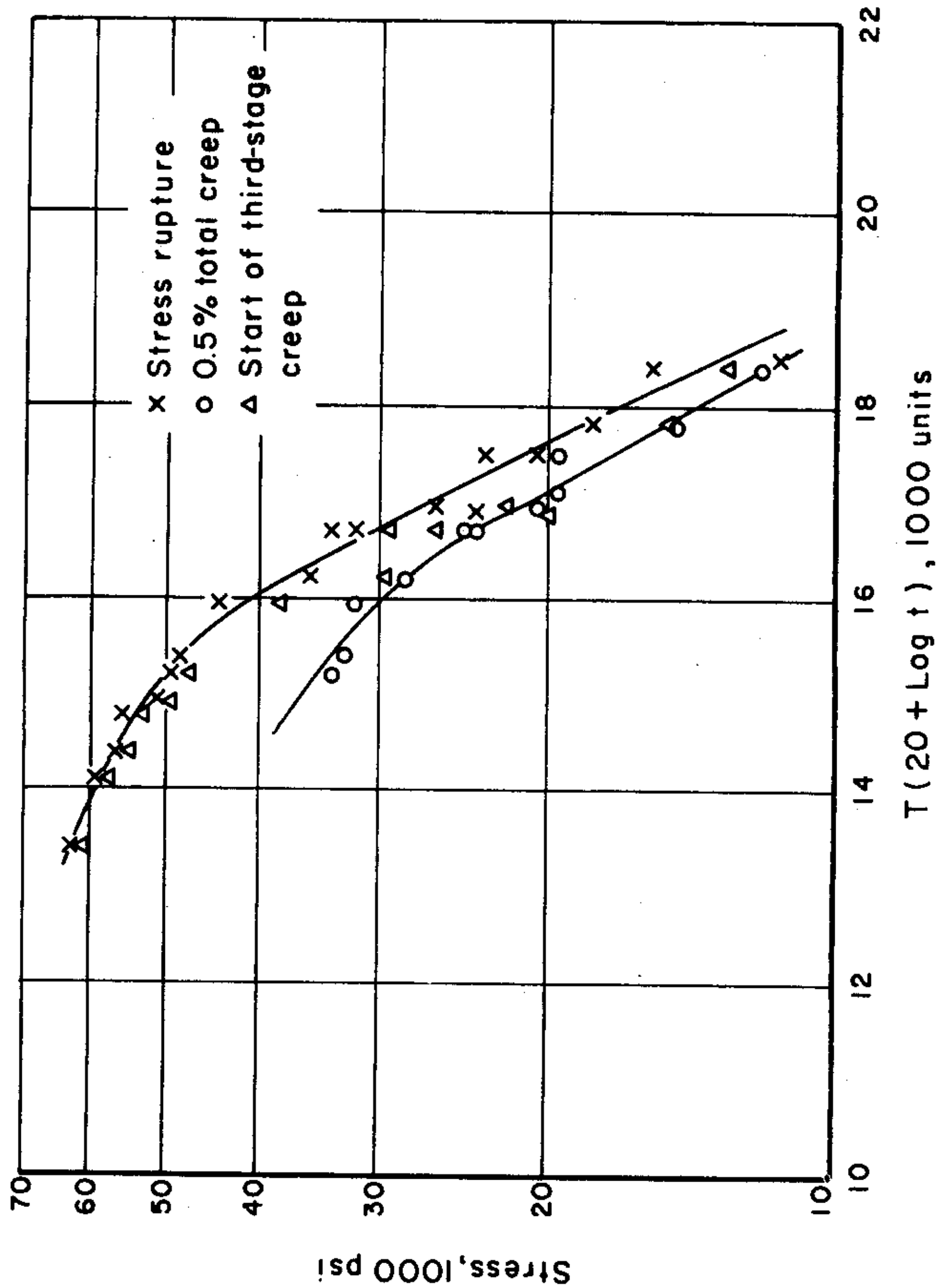

FIGURE 3. LARSON-MILLER PLOT FOR 7075-T6 ALCLAD FOR VARIOUS CREEP CRITERIA

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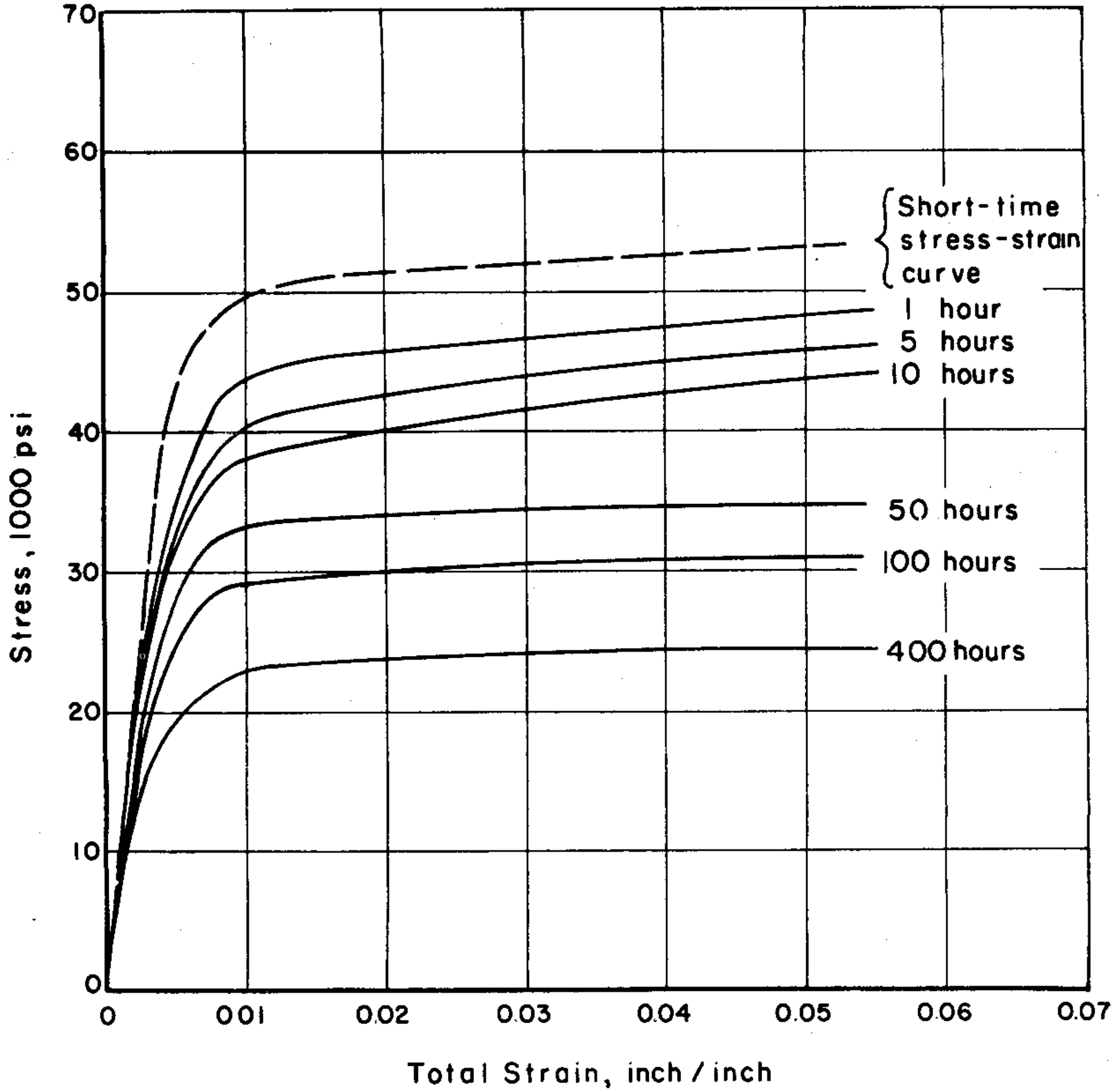

FIGURE 4 ISOCHRONOUS STRESS-STRAIN CURVES FOR 7075-T6 ALCLAD AT 300 F

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materials. This equation then is used to construct the curves over a suitable range of conditions.

It is fairly obvious that for each temperature of interest a set of such curves would be needed. For clarity, each set of curves should be plotted on a separate graph.

Comments on Stress-Temperature-Time Graphs

Four methods of plotting creep data have been illustrated, each involving some combination of the four variables, stress, temperature, time, and creep criteria. Only the Larson-Miller-type graph includes all four variables on one graph. However, some uncertainties in this approach (the assumption of a "constant", 20, in the index, the observed scatter about the average line, etc.) suggest limitations in its general utility. The remaining methods of presentation require a family of graphs to represent the creep behavior of a material over the useful temperature range.

PROBLEMS IN ELEVATED-TEMPERATURE DESIGN

It is realized that from any one set of graphs relating stress, temperature, time, and creep criteria, it is possible to cross plot such information to produce any of the types of plots illustrated in the previous section. However, for maximum utility in aircraft structures design, it appears that the method of presentation should be compatible with current or expected design philosophy. In view of the complexity of the problem of designing structures for high-speed flight, it may be necessary to show more than one type of plot to cover various aspects of such design.

Information available in the open literature focuses attention upon specific design problems related to high-speed flight. Among others, these include: cumulative creep damage, creep buckling, thermal stresses, thermal buckling, etc. It appears profitable to examine some of these specific design problems to determine parameters that might suggest useful methods of plotting creep data.

Cumulative Creep Damage

The mission of a typical high-speed aircraft is such that it will encounter variable stress (gust loads and maneuver loads) and variable temperature (normal cruising versus maneuver temperatures). Rational design of such aircraft must account for creep damage accumulated over the lifetime of the aircraft resulting from load and temperature spectra.

A specific design philosophy to account for such cumulative creep damage is not in general use. One aircraft company visited disclosed an approach to this problem. The elements of the approach are similar to that suggested by Gerard[1]. Experimental verification of the hypothesis with regard to structural behavior is not generally available.

The cumulative creep hypothesis is based upon two assumptions:

(1) Total creep is the summation of creep obtained at each stress and temperature increment during the life of the aircraft

(2) The order of load application (stress and temperature) is unimportant.

The justification for these assumptions stems from the following observations:

(1) Elevated-temperature fatigue studies have shown for many materials that creep behavior is not affected materially by superimposing a small alternating stress upon mean stresses.[7]

(2) If stresses are applied intermittently for finite time periods, the total creep has been found to be the sum of creep obtained at each stress level to a first approximation.[8]

The effect of temperature variations on creep behavior has not been studied to an extent necessary to generalize material behavior. It is possible that temperature variations may accelerate creep. If so, the hypothesis being discussed would need modification. It is believed, however, for purposes of examining the usefulness of graphical presentations of creep data that this is of secondary importance.

On the basis of these assumptions, it can be considered for a given creep criterion (0.5 per cent total deformation, etc.) that

$$\sum_i \sum_j \frac{t_{ij}(f_i, T_j)}{t_{a_{ij}}(f_i, T_j)} = 1 ,$$

where t_{ij} is the total time spent at a particular stress (f_i) and temperature (T_j) increment during the lifetime of the aircraft, and $t_{a_{ij}}$ is the time at stress (f_i) and temperature (T_j), which results in the pertinent creep criterion.

In the design of a particular aircraft component, it is assumed that the following quantities can be estimated on the basis of expected performance: (1) service loads and stresses (straight and level flight, gusts, and maneuvers), (2) temperature variations, (3) a permissible creep criterion, and (4) service lifetime of component or of aircraft.

The determination of a feasible design on the basis of cumulative creep can be made most readily from data plotted as shown in Figure 2 (stress versus temperature, parameter is time) or as shown in Figure 3 (Larson-Miller presentation). A simple example will illustrate the usefulness of these graphs.

In this example, the following operating and design conditions are assumed:

(1) Aircraft has expected life in the temperature range 300 to 375 F of 400 hours

(2) Material, 7075-T6; F_{tu} at 375 F, 50 ksi

(3) Temperature spectrum

(a) 277 hours at 300 F
(b) 79 hours at 350 F
(c) 44 hours at 375 F

(4) Stress spectrum

Stress, ksi	Hours Exposed at Indicated Temperatures 300 F	350 F	375 F
4.5	250	60.0	22
9.0	24	12.0	11
13.5	3	4.0	7
18.0	--	2.5	3
22.5	--	0.5	1

(5) 1 g design stress based on load factor 7.5 x 1.5 is approximately 4.5 ksi

(6) Contribution of gust loads greater than 1 g ± 1 g is negligible. Stress spectrum results from maneuvers

(7) Creep criterion, 0.5 per cent total deformation.

Cumulative Creep Analysis,
Stress-Temperature Graph

On the basis of the above information, the following tabulation shows the cumulative creep analysis, employing information contained in the single graph in Figure 2:

Temperature, F	Stress, ksi	t_i, hours	t_{ai},* hours	t_i/t_{ai}
300	4.5	250.0	>>1000	--
	9.0	24.0	>>1000	--
	13.5	3.0	400	0.007
	18.0	--	--	--
	22.5	--	--	--
350	4.5	60.0	1000	0.060
	9.0	12.0	450	0.027
	13.5	4.0	200	0.020
	18.0	2.5	60	0.042
	22.0	0.5	15	0.033
375	4.5	22.0	400	0.055
	9.0	11.0	250	0.044
	13.5	7.0	60	0.117
	18.0	3.0	20	0.150
	22.5	1.0	3	0.333

$$\sum_i \sum_j \frac{t_{ij}}{t_{a_{ij}}} = 0.888$$

*From Figure 2.

In this analysis, $\sum_i \sum_j t_{ij}/t_{a_{ij}}$ is less than 1.0. The configuration of the particular component apparently would be considered satisfactory.

Cumulative Creep Analysis,
Larson-Miller Graph

In this analysis T(20 + log t) values are obtained from the graph in Figure 3. Values of t_{a_i} are then obtained from the nomograph in Figure 5 for pertinent temperatures and T(20 + log t).

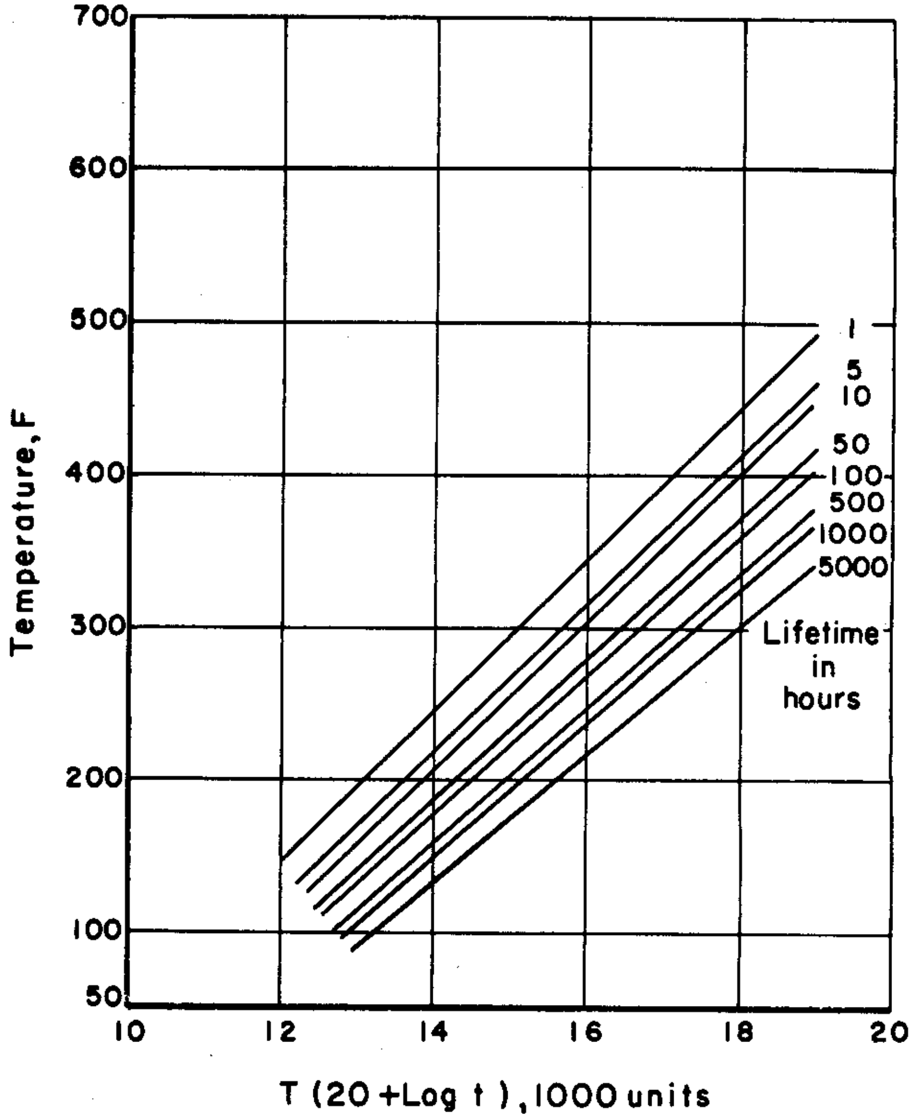

FIGURE 5. NOMOGRAPH FOR TEMPERATURE AND THE LARSON-MILLER INDEX FOR VARIOUS LIFETIMES

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Temperature, F	Stress, ksi	T(20 + log t), 1000 units	t_{ai}, hours	t_i, hours	t_i/t_{ai}
300	4.5	--	--	250.0	--
	9.0	19.0*	>>1000	24.0	--
	13.5	18.1	>>1000	3.0	--
	18.0	17.4	--	--	--
	22.5	16.95	--	--	--
350	4.5	--	--	60.0	--
	9.0	19.0*	>>1000	12.0	--
	13.5	18.1	200	4.0	0.020
	18.0	17.4	35	2.5	0.072
	22.5	16.95	9	0.5	0.055
375	4.5	--	--	--	--
	9.0	19.0*	500	11.0	0.022
	13.5	18.1	50	7.0	0.140
	18.0	17.4	7	3.0	0.430
	22.5	16.95	2	1.0	0.500

$$\sum_i \sum_j t_{ij}/t_{a_{ij}} = 1.239$$

*Estimated.

On the basis of the analysis using the Larson-Miller graph, it appears that the component is not safe.

The two methods of presenting data do not give similar results with regard to the cumulative damage hypothesis. Examination of the plotted points on Figure 3 (obtained from curves in Bulletin ANC-5) suggests a possible reason for the discrepancy. Points on the figure representing 0.5 per cent total creep show considerable scatter about the faired curve. Thus, some "averaging" might be expected in the creep analysis.

To explore this discrepancy somewhat further, data from ANC-5 for 2024-T86 (24S-T86) alloy were plotted on graphs similar to Figures 2 and 3. These are shown in Figures 6 and 7. As noted, the creep criterion is 1 per cent total creep. A similar problem was set up for this material and creep criterion; however, in this case, the temperature range was 250 F to 375 F. The following tabulation illustrates the results of the analysis in terms of $\sum_i \sum_j t_{ij}/t_{a_{ij}}$:

Stress-temperature graph	0.727
Larson-Miller graph	1.385

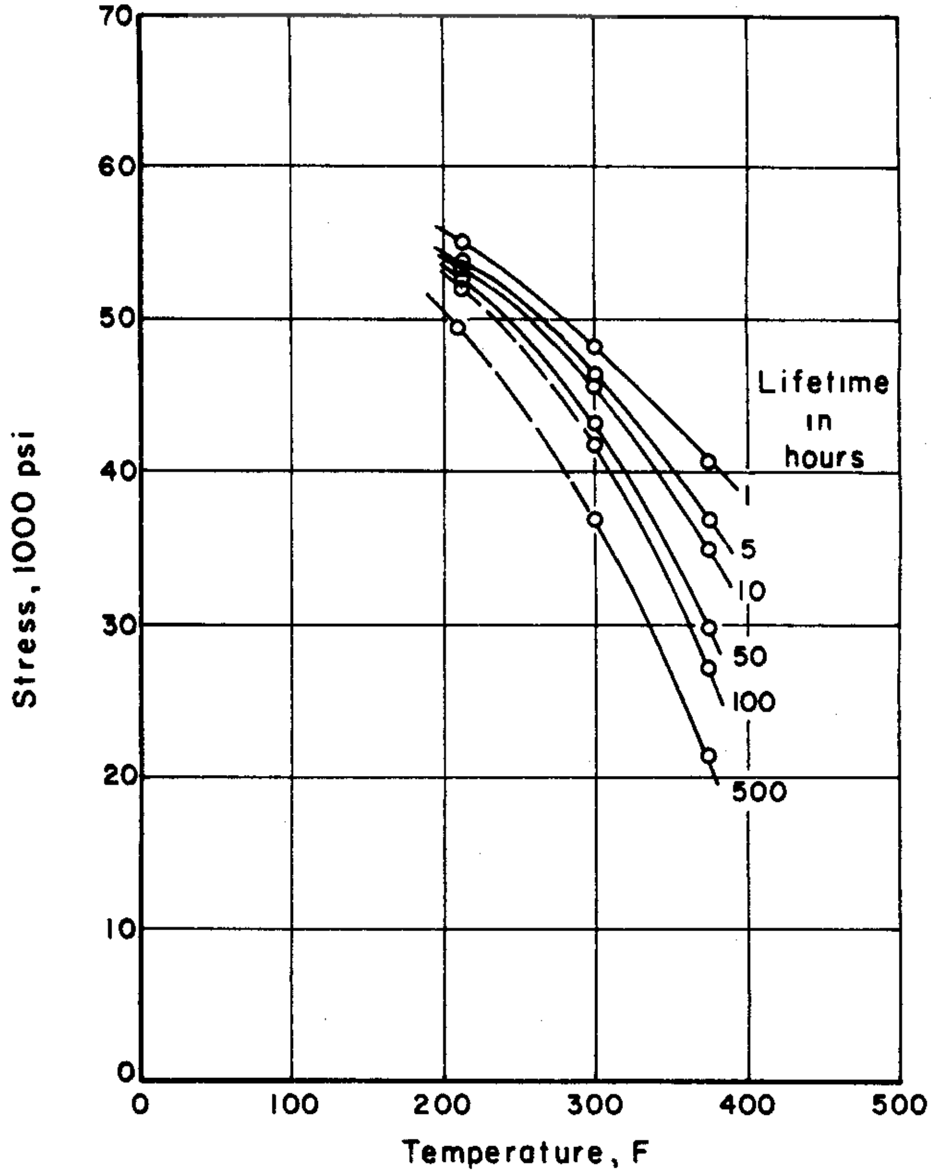

FIGURE 6 STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T86 FOR 1 PER CENT TOTAL CREEP

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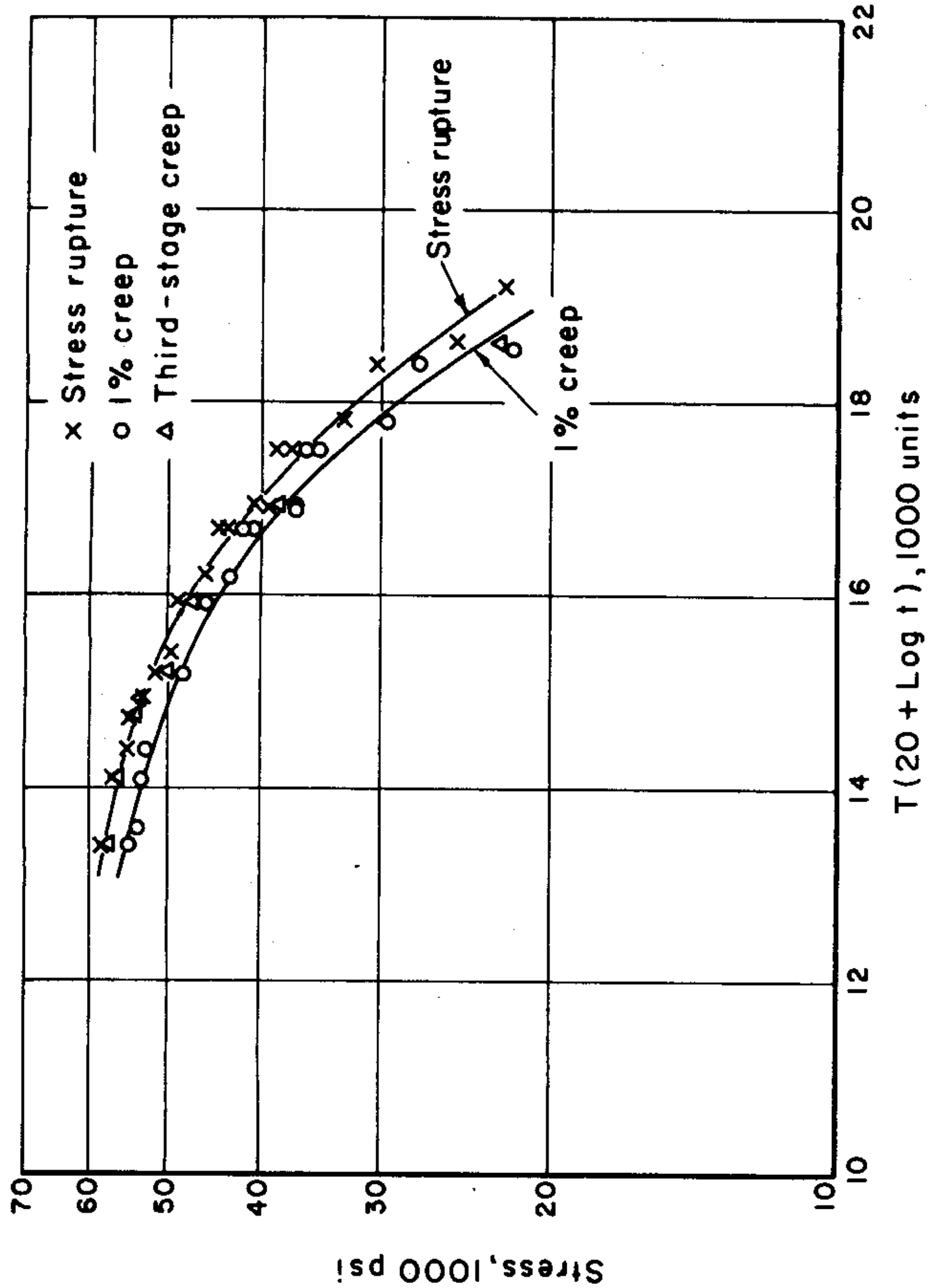

FIGURE 7. LARSON-MILLER PLOT FOR 2024-T86 ALCLAD FOR VARIOUS CREEP CRITERIA

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Here again is evidence that the two methods of presentation do not give compatible results. Examination of Figure 7 also discloses the scatter in plotted data, which was exhibited in the Larson-Miller graph of Figure 3. On the basis of Figures 2 and 6, it would appear that this scatter is not so much a reflection of the data as it may be a reflection of the assumptions involved in the use of the parameter, T(20 + log t), with regard to creep behavior.

Comments on Use of the Two Graphical Presentations

The use of two possible methods of presenting creep data from the standpoint of cumulative creep damage has been investigated in this section. It should be emphasized that the creep hypothesis employed may not represent the best possible approach. At the present time, it represents a feasible engineering approach to a complex problem. Research on structural behavior is necessary to substantiate the simplified analysis.

More important, regardless of the type of cumulative creep analysis which can be demonstrated to approximate structural behavior, this section suggests that of the two methods of presenting creep data, the stress-temperature graph is the better approach.

For example, the problem involving 2024-T86 alloy showed a summation of $t_{ij}/t_{a_{ij}}$ of 1.39 for the Larson-Miller analysis and of 0.73 for the analysis based on stress-temperature graphs. The Larson-Miller graph involves fairing a curve through points which exhibit considerable scatter (note Figures 3 and 7). Thus, the faired curve represents an approximation which, in this problem, resulted in significant error in the summation. In other situations, the error might be less or greater and possibly might be in a different direction (less value of the summation for the Larson-Miller method). The point is that results of summation calculations of this kind may be sensitive to the type of "averaging" of data that is done in the Larson-Miller plot.

The constant C = 20 in the index is of itself an approximation, which represents a "best fit" to current data on many materials. Yet, values of C ranging from 15 to 25 have been shown to provide "better fit" for certain materials. This suggests that to provide a reliable value of C for any material, considerable creep testing must be done. These data readily can be plotted on stress-temperature coordinates without the "averaging" necessary in the Larson-Miller graph (see Figures 2 and 6).

Creep Buckling

Compression members in an aircraft structure operating at high speed may shorten because of creep deformation. On the other hand, such compression members may fail by creep buckling. This latter behavior may be particularly detrimental if the buckled component comprises a part of the aerodynamic surface. Considerable study has been made of creep buckling of columns; less work has been done on plates and stiffened panels. A study of some of these sources of information has been made. This study permits some speculation concerning useful methods of presenting creep data for the problems of creep buckling.

There have been two general approaches to the problem of creep buckling in columns. The first of these approaches involves the assumption of constant stress creep laws (for example, References 9, 10, 11, and 12). The laws, in general, are either equations developed from creep investigations on specific materials, or more generalized equations considered representative of temperature-dependent inelastic behavior of metals. These equations together with equilibrium equations (force and moment) and equations relating strain with column deflection represent the basic equations for these analyses. Reduction of the basic equations to the final form usually is straightforward. Solutions usually are given in parametric form from which critical buckling times can be determined for a range of variables (stress, temperature, and initial straightness). The merit of such solutions stems from a clarification of the variables pertinent to the creep-buckling problem. Since the solutions frequently deal with ideal columns and generally entail considerable computations, they may not appear practical to designers of aircraft.

Another approach to the creep-buckling problem has, in general, more practical implications to the aircraft designer. This approach has been discussed with various degrees of complexity by Shanley(4), Higgins(13), Carlson and Manning(5), Micks(6), and others. A discussion of Shanley's arguments concerning column buckling serves to outline the method.

Shanley postulates that the behavior of a column under compressive load at elevated temperature might be deduced with the aid of isochronous stress-strain curves. Such a column (with initial out-of-straightness) will have higher compressive stresses on the concave side than on the convex side. Thus, during a given time increment, greater creep strain occurs on the concave side. This, in turn, causes a higher compressive stress on that side of the column with unloading on the convex side. He presents a step-by-step graphical solution of the problem, which employs the isochronous stress-strain curve to predict buckling time of the column. Shanley then suggests that the Engesser equation for column buckling also might be useful for determining allowable buckling stresses for time-dependent buckling. This equation is:

$$f = \frac{\pi^2 E_t}{(\ell/r)^2} ,$$

where ℓ/r is the slenderness ratio of the column, and E_t is the isochronous tangent modulus. The "critical time" associated with buckling using the Engesser equation gives a low estimate of total life of the column compared to the step-by-step procedure. However, Shanley demonstrates that the allowable stress (f) is not very sensitive to time except for short lifetimes; thus, the procedure may be useful as an actual tool in design.

Carlson and Manning(5) simplify the step-by-step graphical procedure suggested by Shanley and thus bring the problem of computing allowable buckling loads somewhat closer to the simple Engesser equation. They demonstrate that it is possible to estimate allowable load capacities for any time t_i without making the step-by-step calculations for times prior to t_i. To do this, the isochronous stress-strain curve for time t_i is considered a real stress-strain curve. With a trial-and-error method, an average-stress versus column-deflection curve is determined. The maximum stress of the curve represents the highest allowable safe stress up to time t_i. If this procedure is carried out for a range of slenderness ratios, and t_i, design curves showing allowable average stress versus slenderness ratio for various t_i can be constructed.

These authors also discuss the use of the Engesser relationship for determining allowable stresses. They point out that if initial imperfections are small, the Engesser equation may be useful. However, if imperfections are large, the results of such calculations may not be conservative. This factor is not important in the case of their simplified approach, since initial imperfections can be accounted for in the analysis.

Figures 8 and 9 give test results obtained by these authors on columns fabricated from 2024-T4 alloy (as received) tested at 350 F and 450 F, respectively. On these graphs also are curves obtained by the simplified analysis and points (at 10 hours) computed from the Engesser equation. It is noted in all cases that the simplified analysis gives conservative results; whereas, the Engesser equation resulted in some nonconservative values. The authors discuss the apparent overconservatism of the simplified analysis at 350 F. This analysis was made with tension creep data. They point out that at this temperature compression creep curves diverged from tensile creep curves to a greater extent than at 450 F. Hence, the overconservatism would be expected.

This suggests that one of the areas of interest, with regard to the creep-buckling phenomena, involves research to evaluate compressive creep properties.

Micks(13) covers the use of the Engesser relationship, with regard to creep buckling of columns using isochronous tangent modulus curves. He

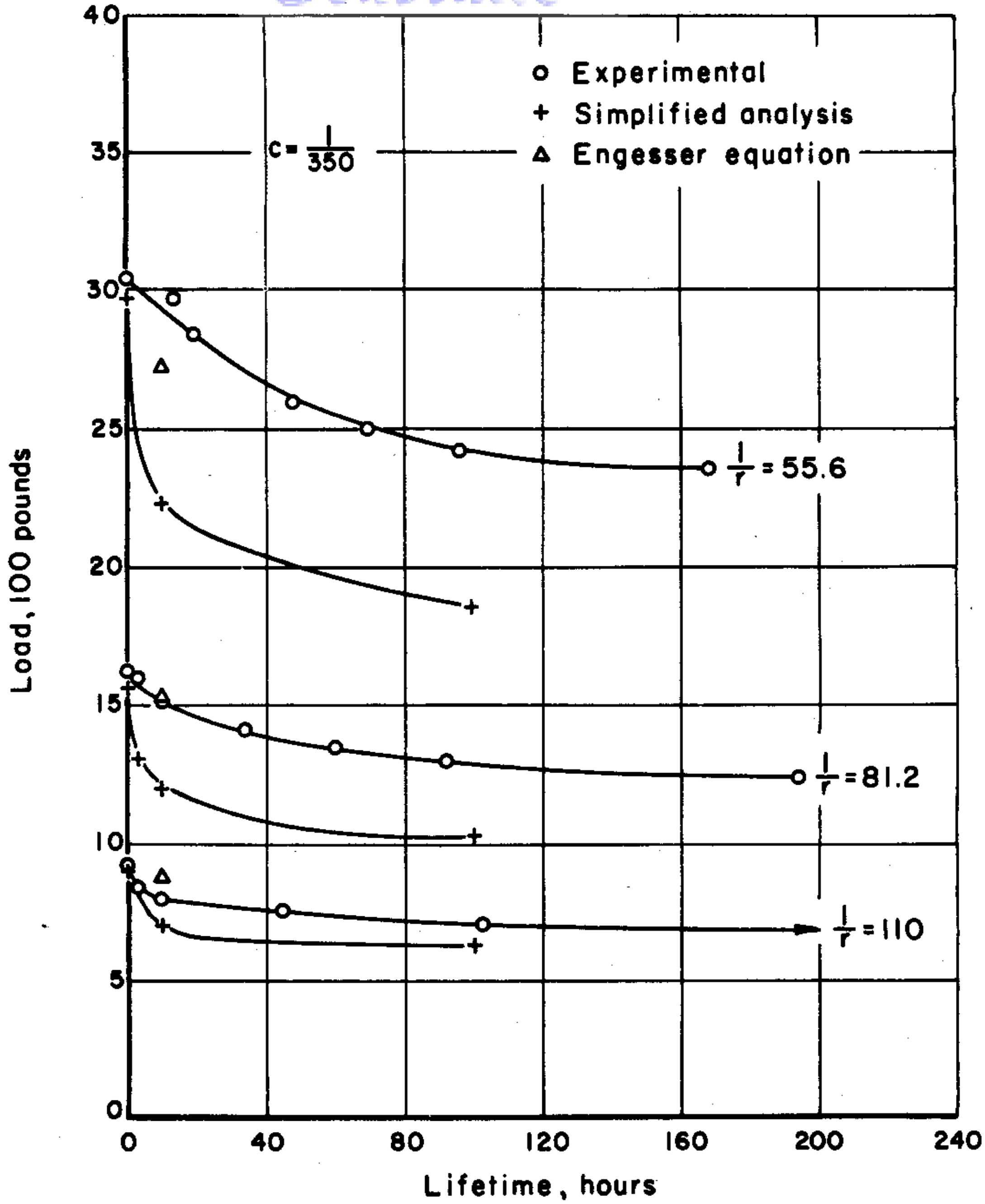

FIGURE 8. EXPERIMENTAL AND CALCULATED LOAD-LIFETIME-SLENDERNESS-RATIO RELATIONSHIPS FOR CREEP BUCKLING OF COLUMNS AT 350 F

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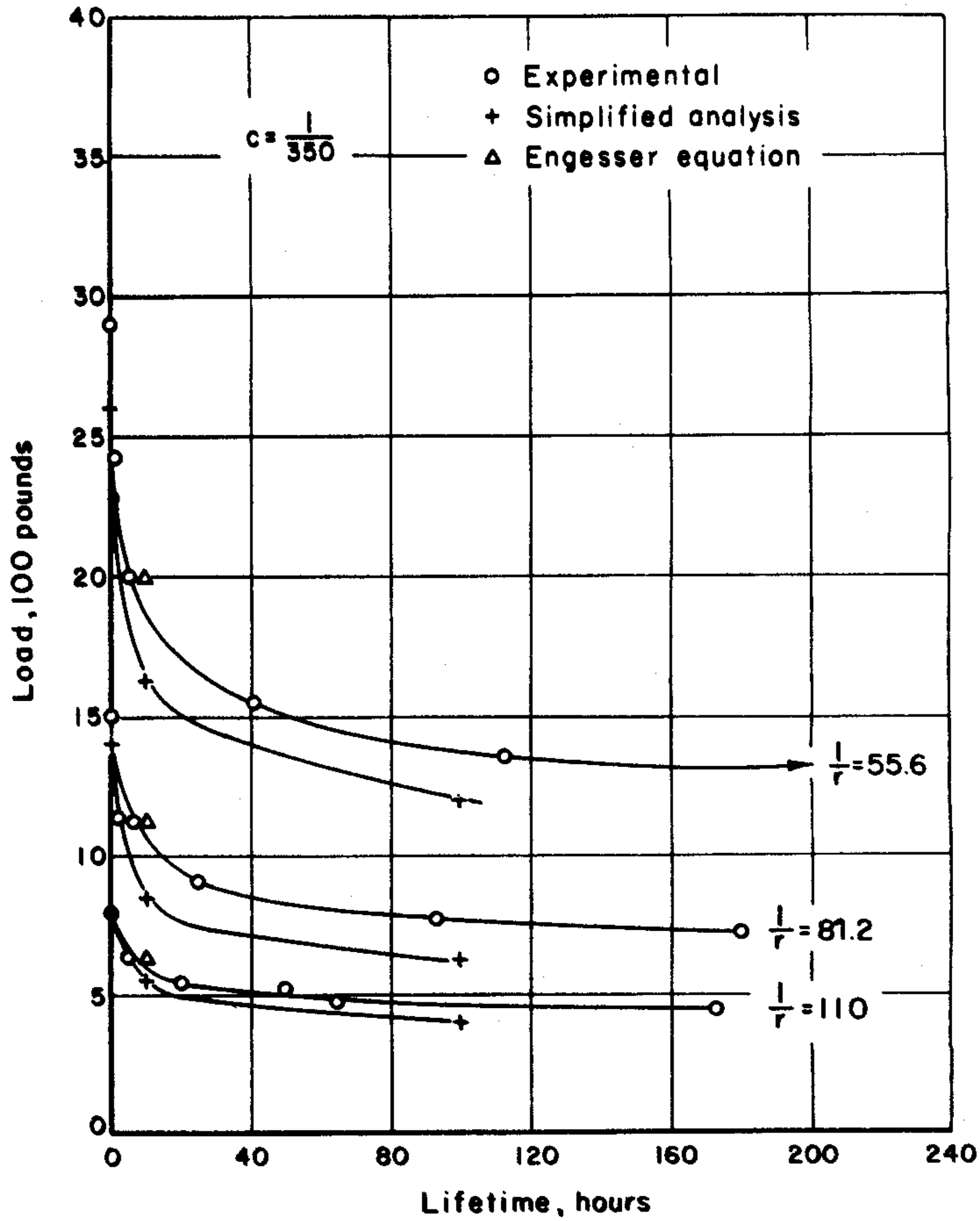

FIGURE 9. EXPERIMENTAL AND CALCULATED LOAD-LIFETIME-SLENDERNESS-RATIO RELATIONSHIPS FOR CREEP BUCKLING OF COLUMNS AT 450 F

A-14919

extends this argument to include creep buckling of plates and shows the development of allowable creep-buckling stress versus structural index curves for plates. Later, he combines the column and plate problems and shows how isochronous stress-strain curves can be employed to construct allowable creep-buckling stress versus structural index curves for sheet-stiffener panels.

The plate and sheet-stiffener applications admittedly suffer the same uncertainties with regard to initial straightness as was pointed out for columns. It cannot be denied, however, that this approach has a familiar "look" to the aircraft designer. From the standpoint of conservatism, the simplified approach of Carlson and Manning might prove useful in these two cases; however, experimental study is needed not only of this latter approach but also of Mick's approach.

One interesting feature of any of these latter approaches to the buckling problem is illustrated in Figure 9. It is observed that with the exception of very short times, the allowable stress is not very sensitive to column lifetime. This suggests that the design approach is not one of designing to a particular failure lifetime but rather that of assuring that stresses are low enough to prevent the occurrence of creep buckling.

It appears that considerable progress analytically has been made with regard to creep-buckling phenomena. However, the status with regard to experimental verification is not so well grounded. However, if experimental work verifies the feasibility of analyses similar to those proposed by Shanley, Carlson and Manning, and Micks, it appears that isochronous stress-strain curves may be quite useful as a design tool.

CONCLUSIONS

On the basis of this study, it appears that the following conclusions are warranted:

(1) The method of presenting elevated-temperature data, particularly creep data, (such as shown in ANC-5, Figures 3.1221(d) to 3.1221(m) for aluminum alloys) may not be the most useful from the standpoint of aircraft structural design.

(2) It is suggested that a more useful method of presenting such data is the stress-temperature plot (with time as a parameter) for a number of pertinent creep criteria. Figures 10 through 20 show such plots for materials now appearing in ANC-5 (2024-T3 Alclad, 7075-T6 Alclad, and 2024-T86 Alclad). Creep criteria are those appearing

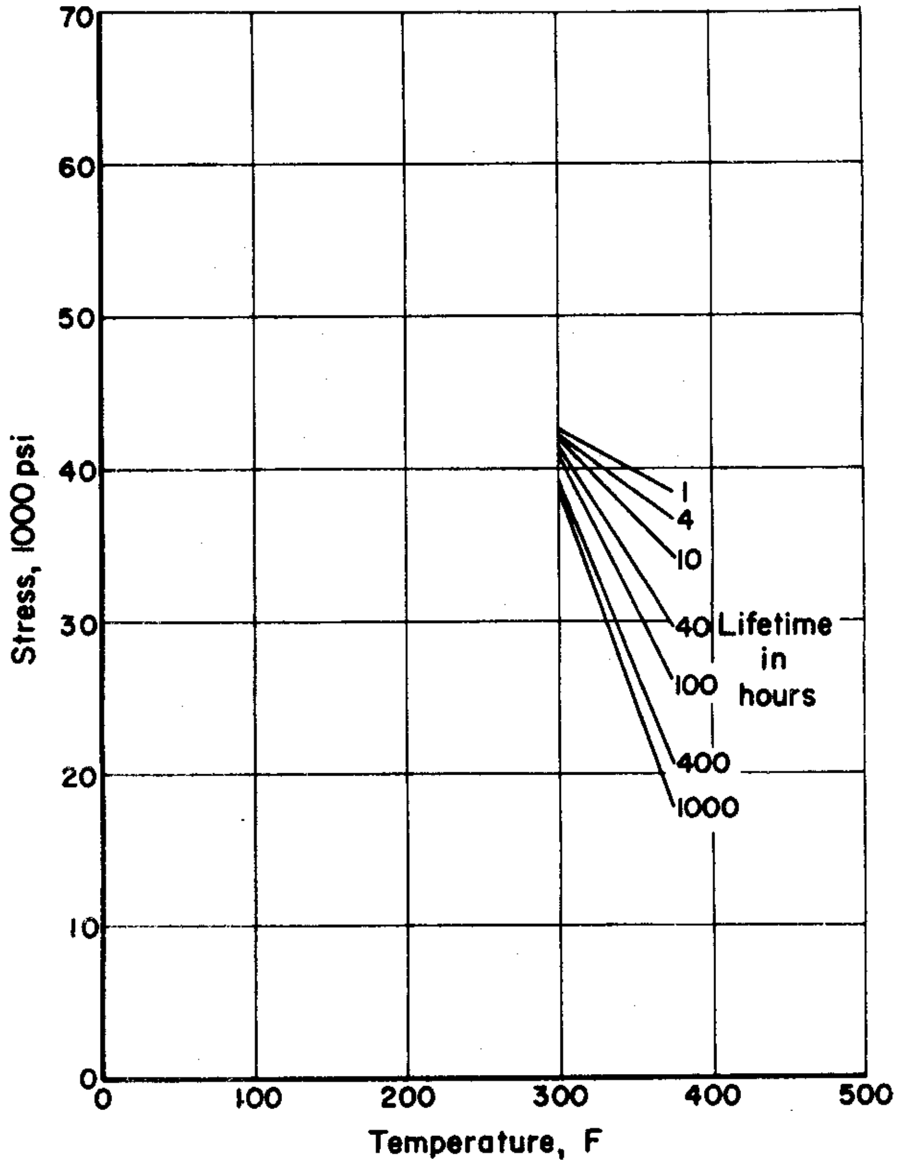

FIGURE 10. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T3 ALCLAD FOR 1.0 PER CENT TOTAL CREEP

A-14920

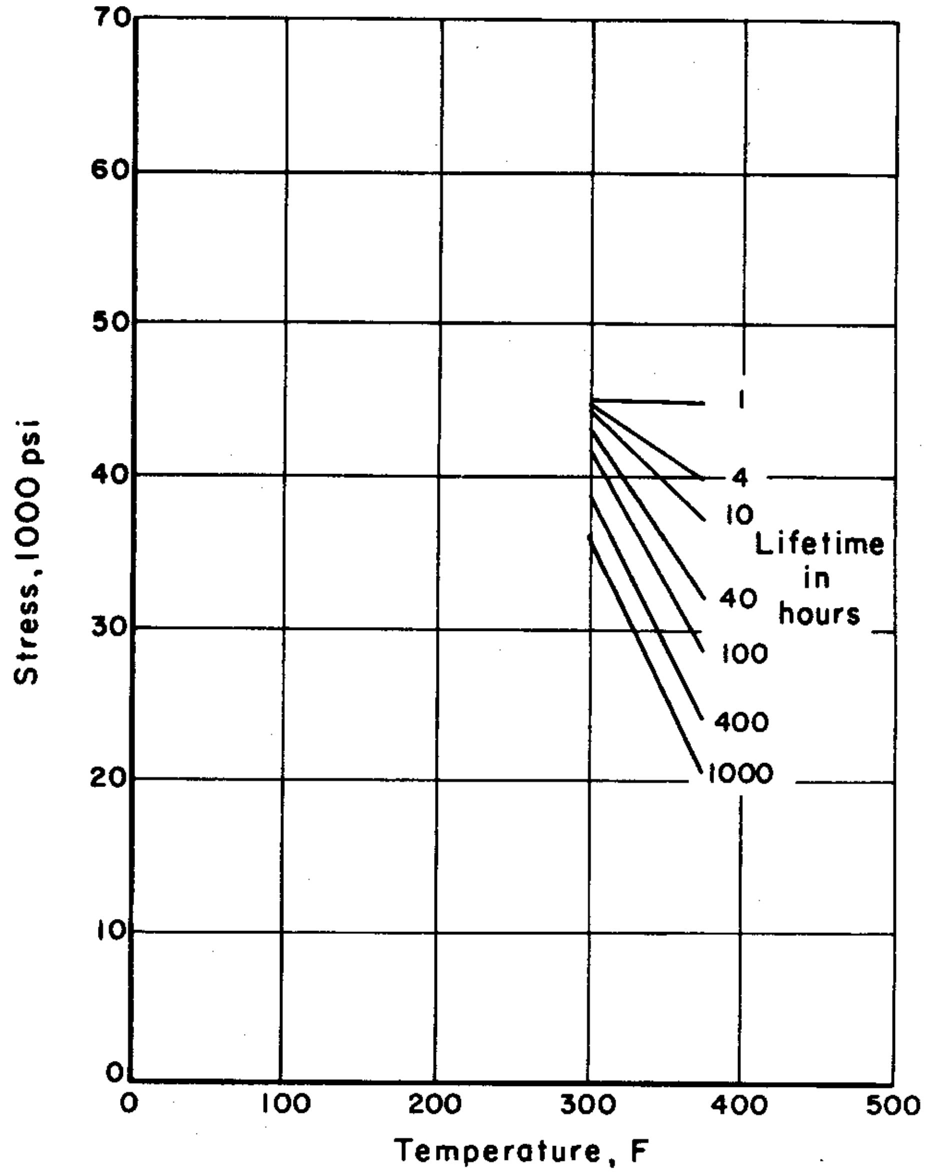

FIGURE 11. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T3 ALCLAD FOR 2.0 PER CENT TOTAL CREEP

A-14921

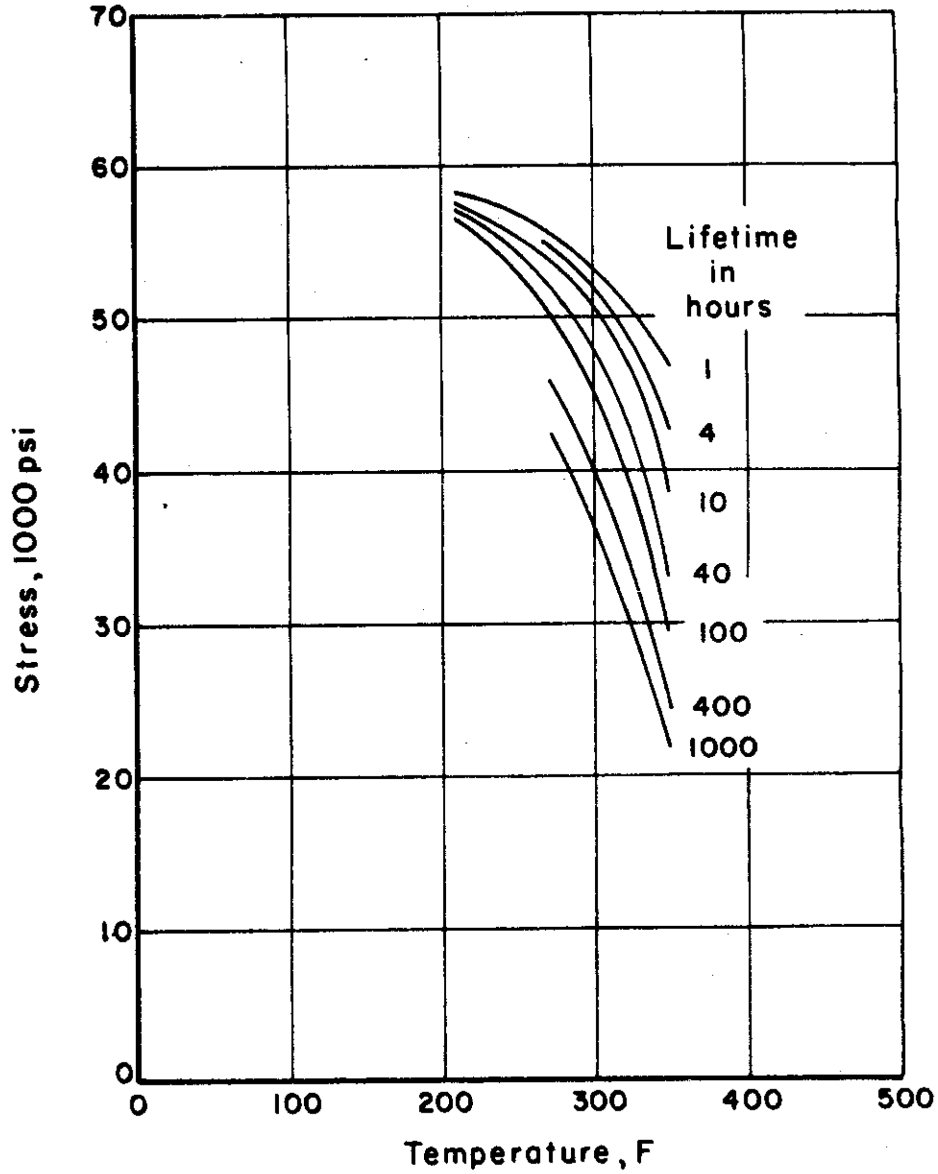

FIGURE 12. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T3 ALCLAD FOR STRESS RUPTURE

A-14922

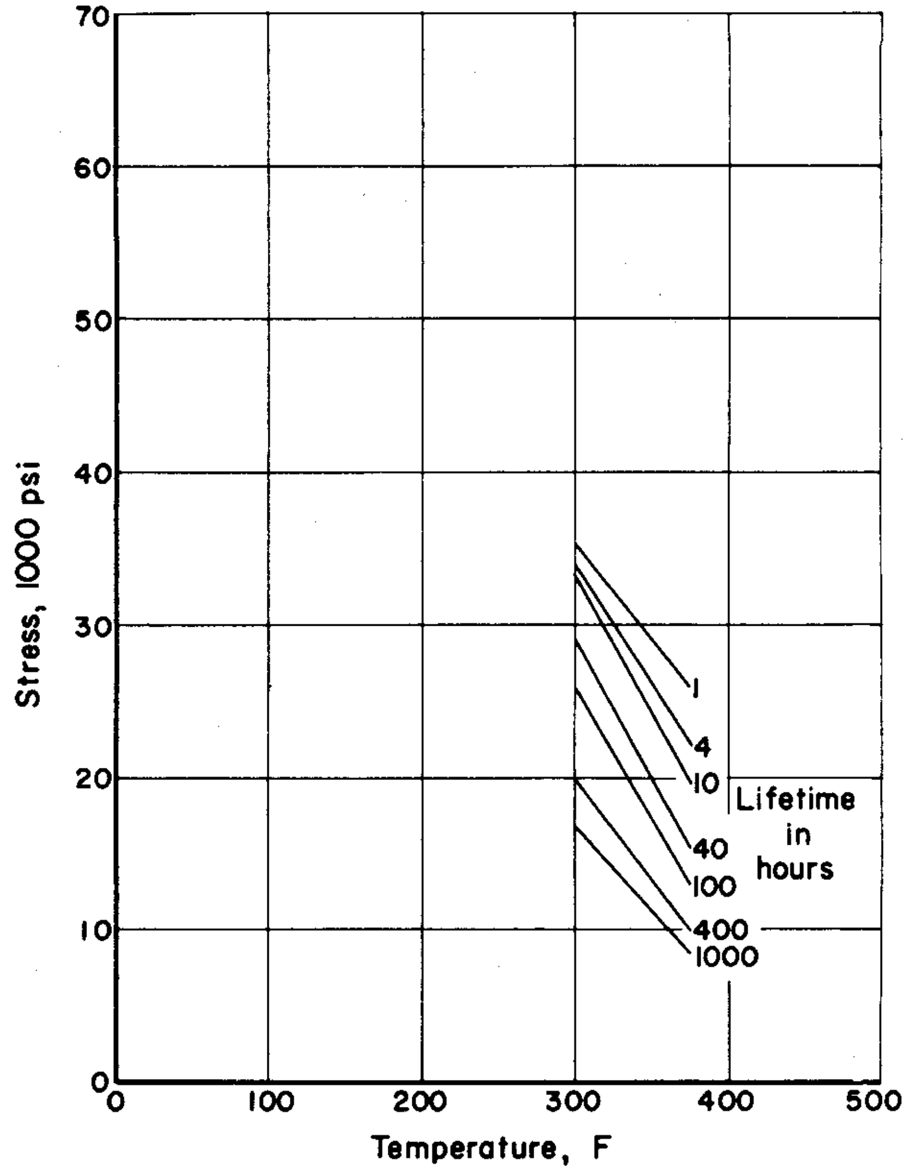

FIGURE 13. TYPICAL STRESS—TEMPERATURE—TIME RELATIONSHIP FOR 7075-T6 ALCLAD FOR 0.5 PER CENT TOTAL CREEP

A-14923

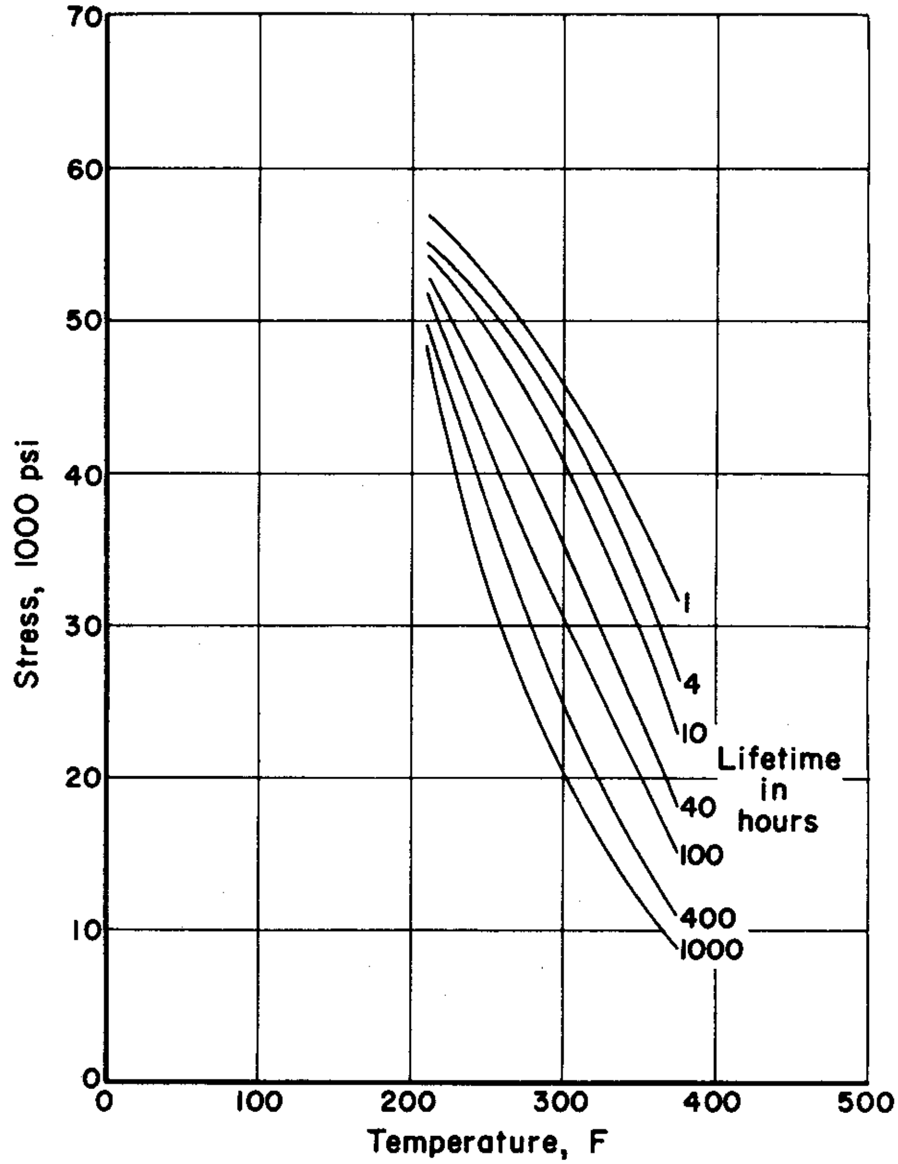

FIGURE 14. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 7075-T6 ALCLAD FOR 1.0 PER CENT TOTAL CREEP

A-14924

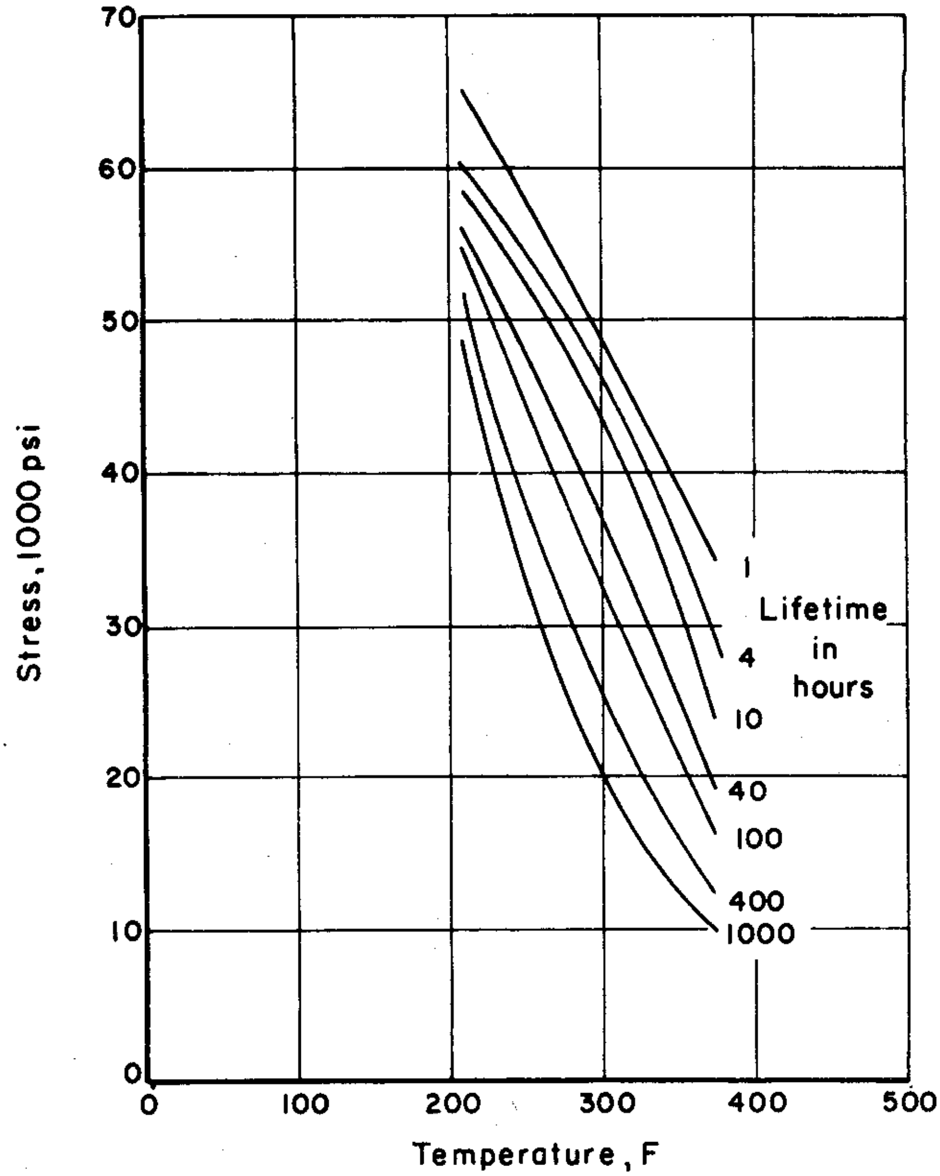

FIGURE 15. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 7075-T6 ALCLAD FOR 2.0 PER CENT TOTAL CREEP

A-14925

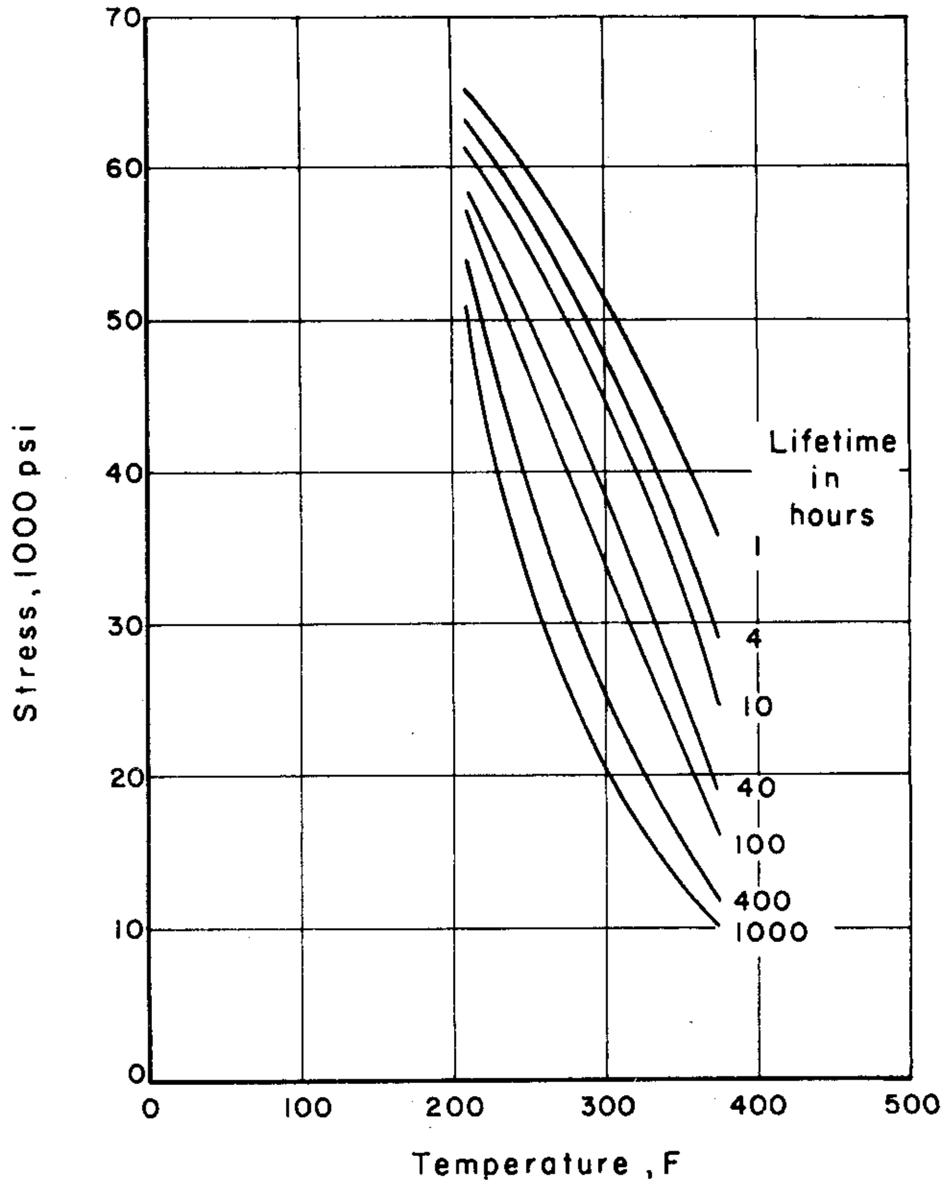

FIGURE 16. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 7075-T6 ALCLAD FOR STRESS RUPTURE

A-14926

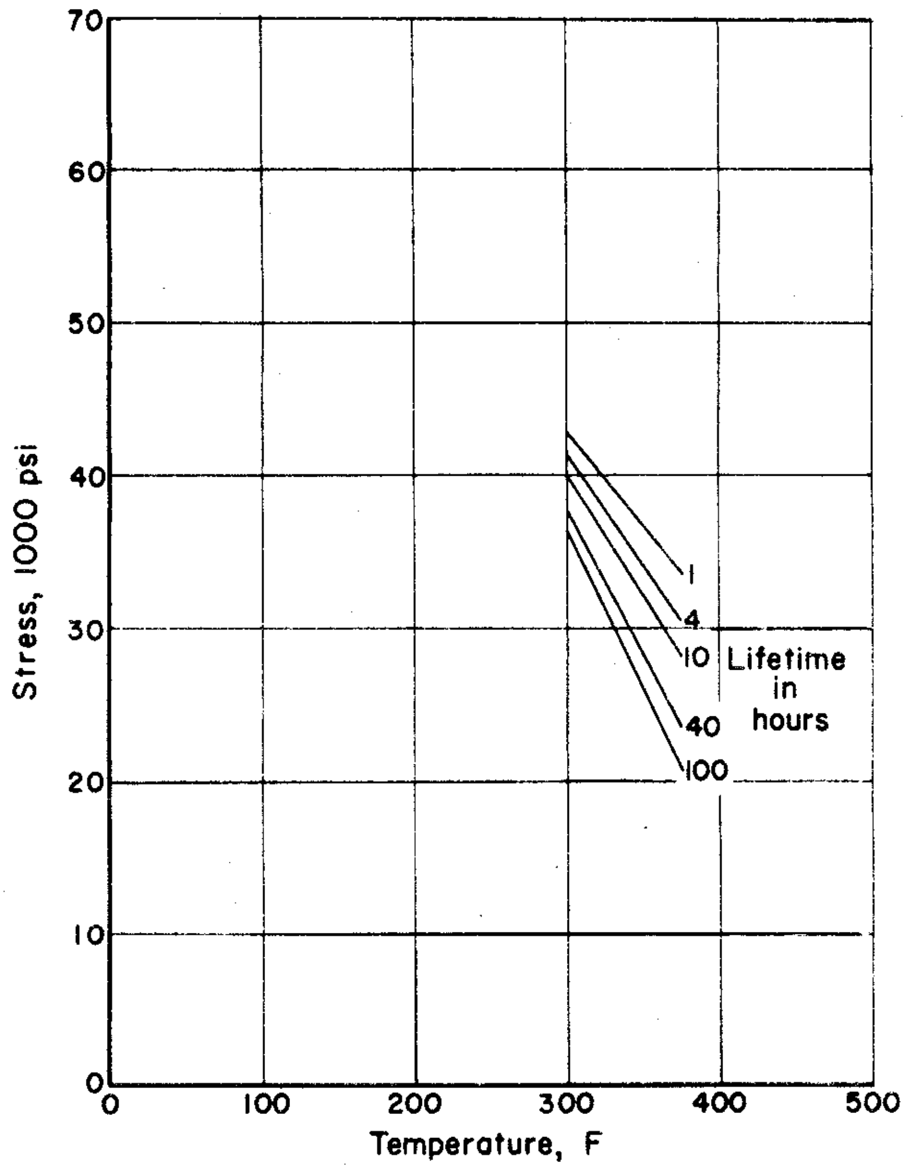

FIGURE 17. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T86 ALCLAD FOR 0.5 PER CENT TOTAL CREEP

A-14927

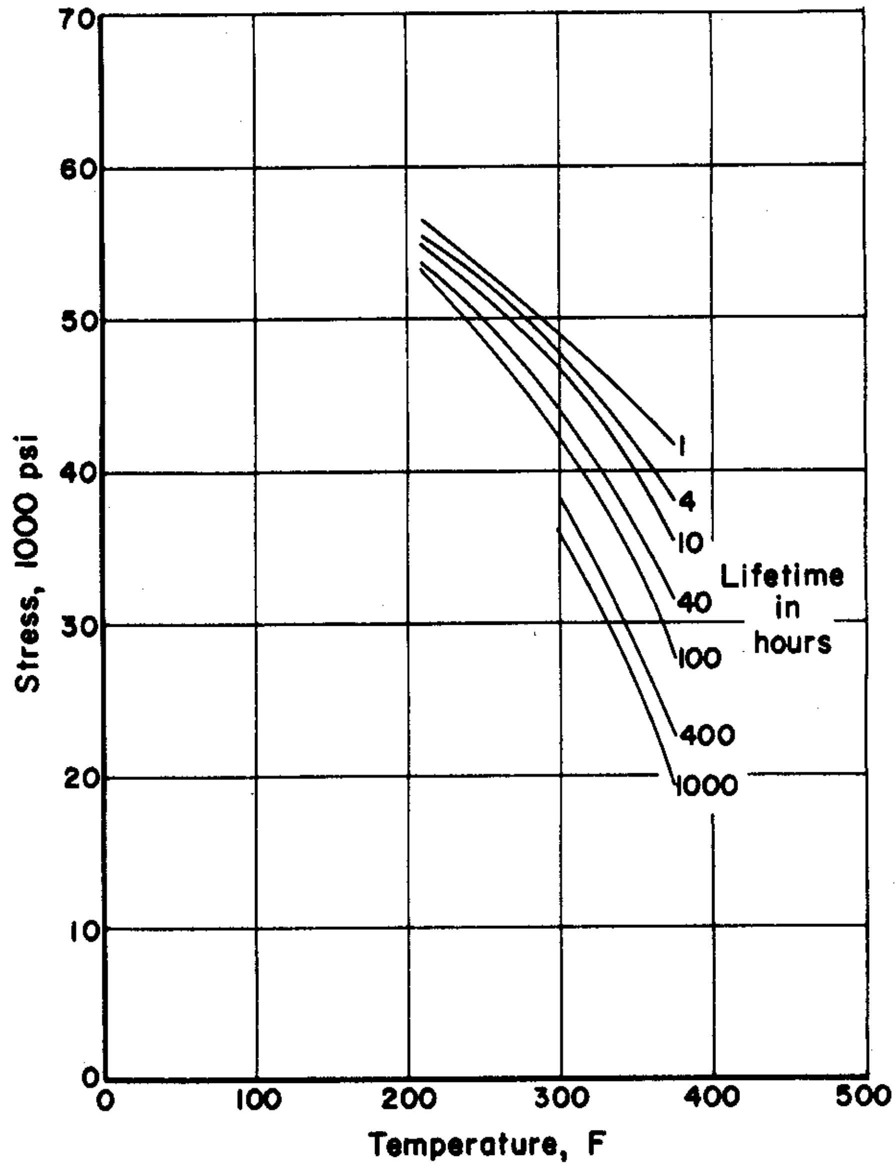

FIGURE 18. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T86 ALCLAD FOR 1.0 PER CENT TOTAL CREEP

A-14928

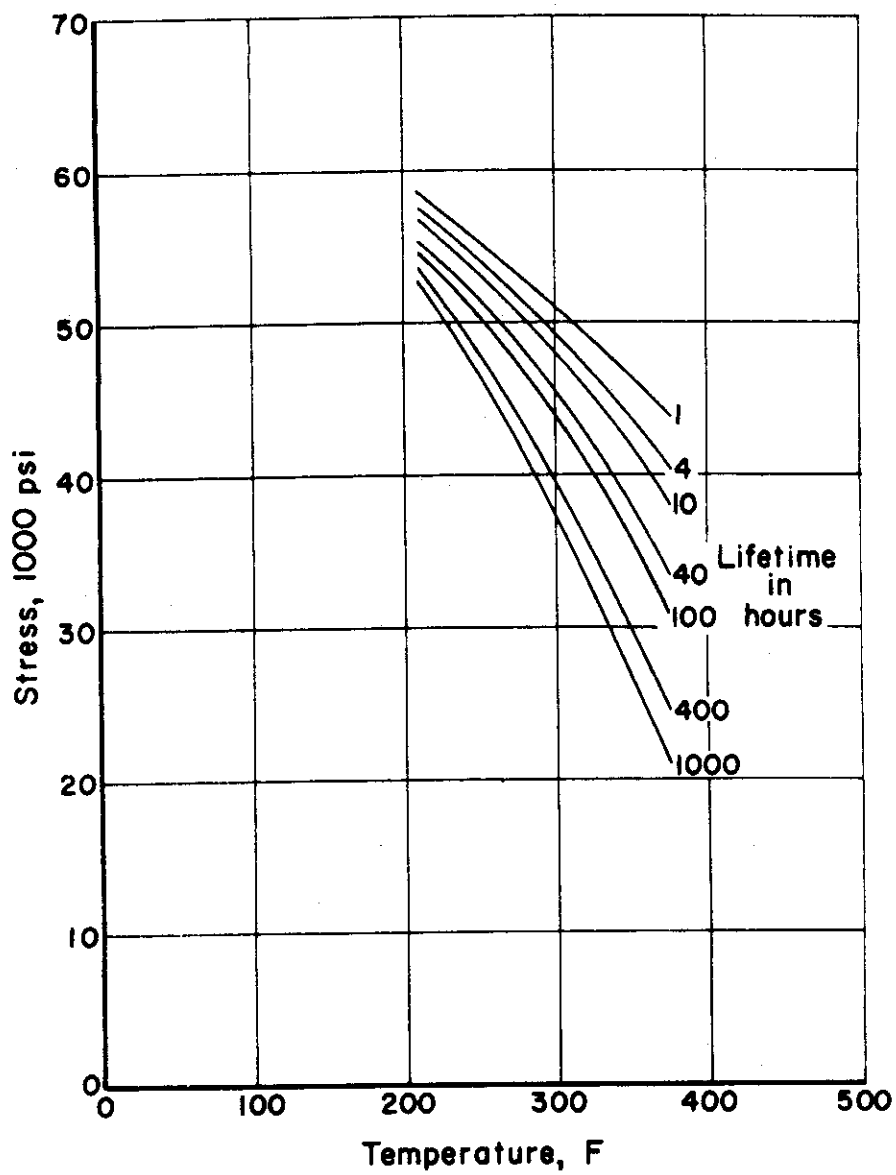

FIGURE 19. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T86 ALCLAD FOR 2.0 PER CENT TOTAL CREEP

A-14929

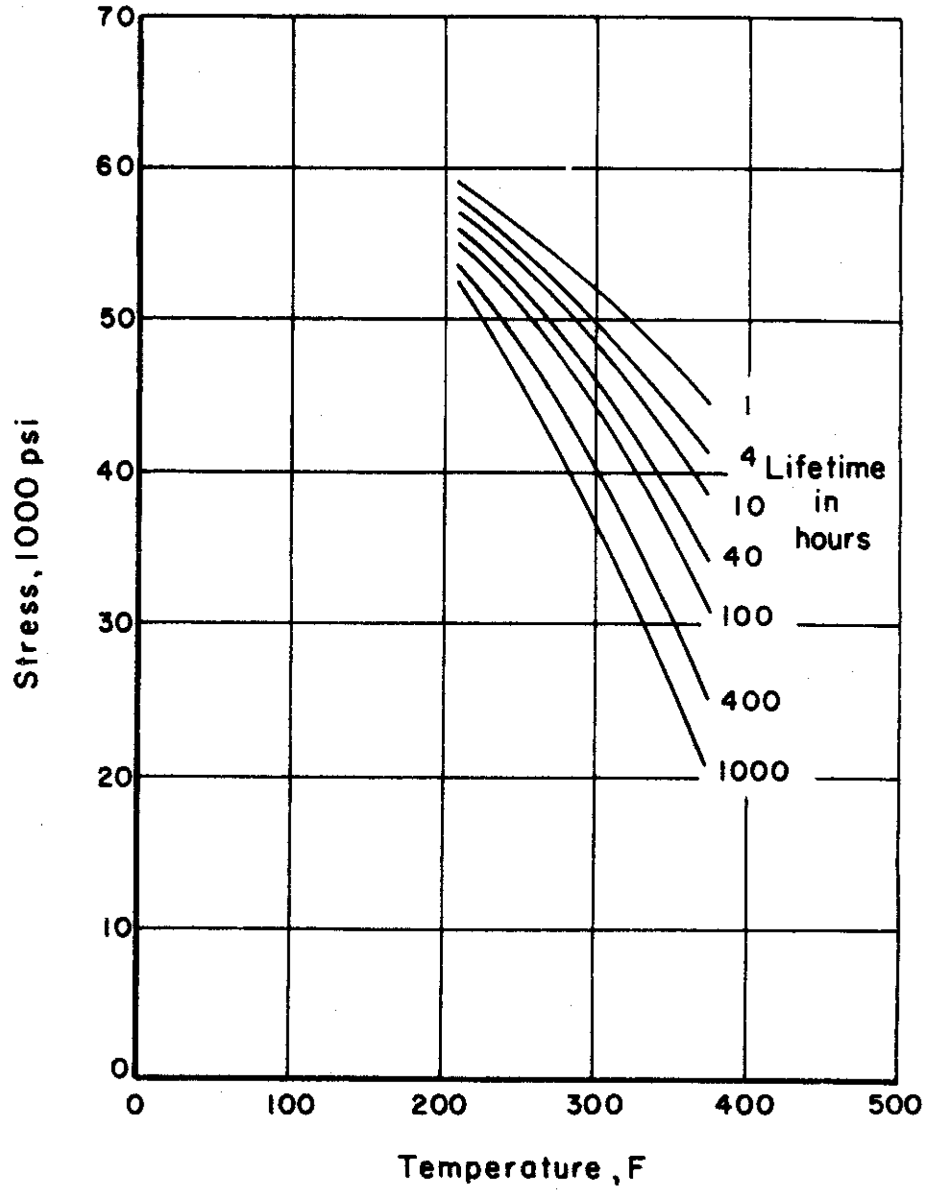

FIGURE 20. TYPICAL STRESS-TEMPERATURE-TIME RELATIONSHIP FOR 2024-T86 ALCLAD FOR STRESS RUPTURE

A-14930

in ANC-5, but the data used are from reference (14), upon which ANC-5 values are based. These values are considered typical for these alloys.

(3) It is believed that some design applications may require inelastic creep criteria rather than total creep as shown in Figures 10 to 20. Graphs corresponding to such plots have not been constructed, since data in Reference 14 (the original source of ANC-5 data) did not include initial deformation values.

(4) In order to provide inelastic deformation curves, as suggested above, additional experimental work is needed. It is suggested that such studies be designed to provide (for each material) data upon which to base design allowables to temperatures up to 600 F. This implies multiple specimen tests on various heats of each material. Such programs should include compressive creep tests as well as tension creep tests and should provide thermal-expansion data.

(5) In some applications, the isochronous stress-strain curve may be useful. Thus, some consideration (in the future) might have to be given for developing families of such curves for pertinent aircraft structural materials. The necessary experimental studies to verify the engineering approach using such curves, of course, will have to be carried out.

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