NASA TECHNICAL NOTE

NASA TN D-3883

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by I. E. Figge

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Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1967

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SUMMARY

An empirical relation has been developed to predict the fatigue limit of axially loaded unnotched specimens as a function of mean stress. Both the ultimate tensile strength and the fatigue limit at zero mean stress are required in the basic equation. An ancillary equation was developed to represent the fatigue limit at zero mean stress as a function of the ultimate tensile strength. Comparisons demonstrating the improvement of the proposed relations over the Gerber and Goodman relations are presented for five major material classes: bare aluminum, clad aluminum, low alloy steels, stainless steels and superalloys, and titanium alloys.

The proposed method predicted that it was possible to obtain a fatigue limit equal to the ultimate strength of the material. Various materials tested at approximately the stress levels predicted by the method had not failed after 2.5×10^6 or more cycles.

INTRODUCTION

Over the years numerous fatigue tests have been conducted to study the effects of mean stress on the fatigue limit. Nevertheless, designers often find that data at a specific value of mean stress are not available and must be obtained either by conducting additional fatigue tests or by extrapolating from data at some other value of mean stress. The latter method is obviously more practical; however, it does require a knowledge of the fatigue behavior as a function of mean stress.

Various equations have been proposed to represent the fatigue limit as a function of mean stress; of these the Gerber parabola and the Goodman straight-line relationships are probably the most widely used. (See appendix A and refs. 1 to 3.) However, for some materials the Gerber equation produces a substantially better fit to the data than the Goodman equation, whereas for other materials the converse is true. In some instances, both equations produce essentially the same agreement to the data. A problem arises in that no way is available for predetermining the appropriate equation to use for a specific material. Also, neither equation fits the data well at high values of mean stress and the predictions obtained by using the Gerber equation are not applicable for compressive mean stresses. The fatigue limit obtained with the Gerber or Goodman relationships approaches the ultimate tensile strength (along a parabola or straight line, respectively) as the mean stress approaches the ultimate strength. However, as will be shown, the experimental fatigue limit approaches the ultimate strength at values of mean stress substantially below the ultimate strength.

In an attempt to overcome these difficulties an empirical equation was developed relating the fatigue limit to the mean stress. This equation is applicable to axially loaded unnotched specimens (sheet and bar) over the entire range of mean stress (compressive ultimate to tensile ultimate) for a wide variety of materials. Application of the equation requires knowledge of the ultimate strength of the material and of the fatigue limit at zero mean stress. Both the Gerber and Goodman relations require the same information. An ancillary equation was developed to predict the fatigue limit at zero mean stress as a function of the ultimate strength. Sets of constants required in this equation have been obtained for each of five major material classes: bare aluminum, clad aluminum, low alloy steels, stainless steels and superalloys, and titanium alloys.

Comparisons are presented which demonstrate the improvement of the proposed relation over the Gerber and the Goodman relations to fit sets of data obtained from the literature for a wide variety of materials.

SYMBOLS

The units used for the physical quantities defined in this paper are given both in U.S. Customary Units and in the International System of Units, SI (ref. 4). Appendix B presents factors relating these two systems of units.

A to F — constants used in equations

S_a — alternating stress, kips per inch^2 (meganewtons per meter^2)

S_f — experimental fatigue limit[1] for a given mean stress other than zero (maximum stress (algebraic) within cycle), kips per inch^2 (meganewtons per meter^2)

S_m — mean stress, kips per inch^2 (meganewtons per meter^2)

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[1]For the purpose of this paper, the fatigue limit is defined as the stress below which failure will not occur in 10^6 cycles.

S_o experimental fatigue limit at zero mean stress (maximum stress (algebraic) within cycle), kips per inch^2 (meganewtons per meter^2)

S_p predicted fatigue limit for a given mean stress (maximum stress (algebraic) within cycle), kips per inch^2 (meganewtons per meter^2)

σ_u ultimate tensile strength, kips per inch^2 (meganewtons per meter^2)

BACKGROUND

As noted in the introduction, the Gerber equation is useful for predicting the fatigue limit of some materials whereas the Goodman equation is useful for others. Also, these equations do not adequately define the fatigue limit over the entire range of mean stress, particularly in the range where the mean stress approaches the ultimate strength. Examples for various materials are presented in figure 1. The same sets of data are presented in each of two plots: in the left-hand plots the Gerber and Goodman predictions are presented and in the right-hand plots the predictions obtained using the proposed equations are presented. The latter curves are discussed in the section "Agreement Between Experimental and Predicted Fatigue Limits."

In figures 1(a) and 1(b) both the Gerber and the Goodman equations produce essentially the same agreement. In figure 1(d) the Gerber equation produces a substantially better fit to the data than the Goodman equation, whereas in figures 1(c) and 1(e) the Goodman equation produces the better fit. The weakness of the Gerber equation to predict the results of tests conducted at negative mean stresses is shown in figure 1(e).

In figures 1(c), 1(d), and 1(e) the trend of the data is to approach the 45° straight line (representing $S_f = \sigma_u$) at values of mean stress substantially below the ultimate; this is particularly evident in figure 1(d). Special tests were conducted at combinations of S_m and S_a such that $S_f \approx \sigma_u$. The results of these tests are discussed in the section "Special Tests."

Based on the foregoing observations, it was apparent that an equation applicable to a wide variety of materials over the entire range of mean stress would be useful.

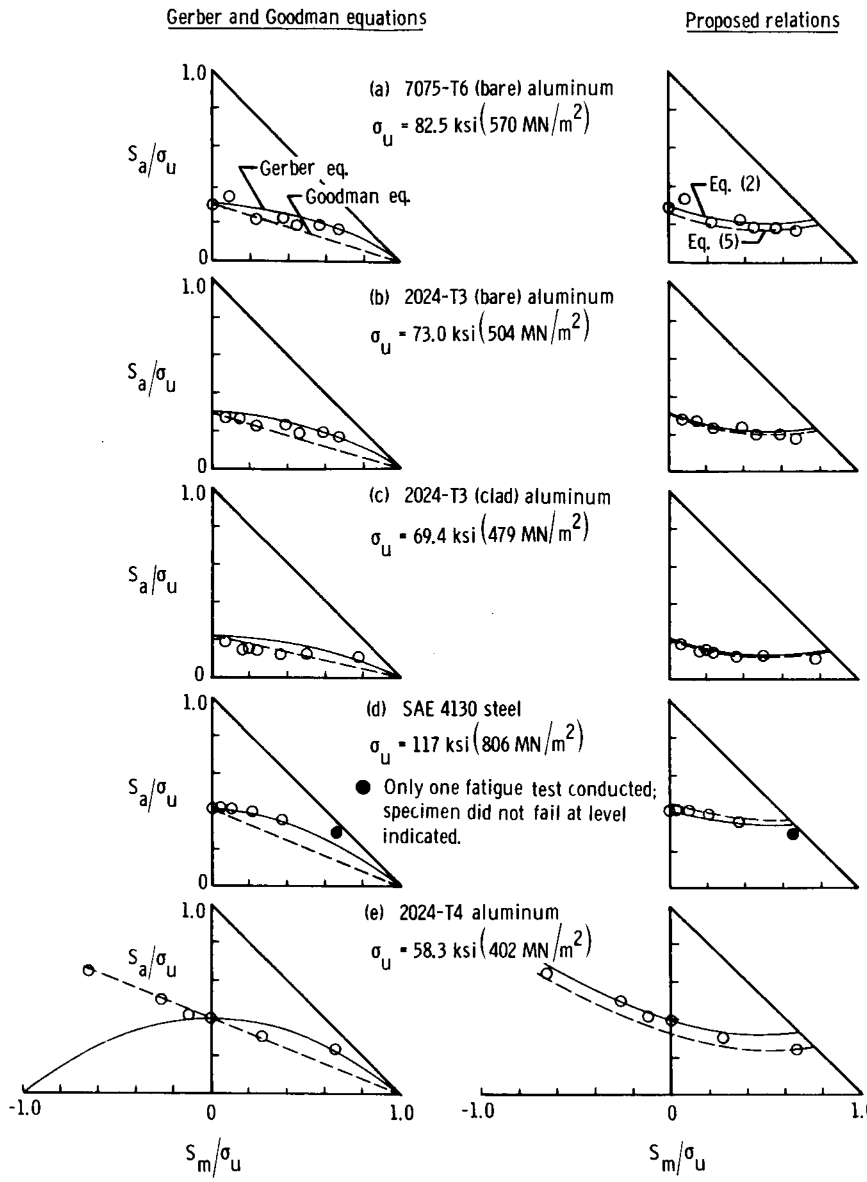


Figure 1.- Fatigue limit predictions obtained by using Gerber, Goodman, and proposed relations.

RELATION BETWEEN S_f AND S_m

In order to facilitate the development of an empirical equation, the data were replotted as the log of S_f against S_m. Two examples are presented in figure 2. Data of the form shown can be represented by an equation of the form:

$$S_p = Ae^{BS_m} - C \tag{1}$$

By assuming various values of C, sets of the constants A and B in equation (1) were evaluated by using least-squares techniques. A reasonable fit was obtained for each set of data when

$A \approx \sigma_u$

$B \approx \frac{0.693}{\sigma_u}$

$C \approx \sigma_u - S_o$

Substituting these values into equation (1) produced the following expression:

$$S_p = \sigma_u e^{0.693 S_m/\sigma_u} - \sigma_u + S_o \qquad (2)$$

As mentioned previously, the fatigue limit approaches the ultimate strength at values of mean stress substantially below the ultimate strength. Substituting a value of the fatigue limit equal to σ_u in equation (2) and solving for S_m results in the following equation:

$$S_m = \frac{\sigma_u}{0.693} \log_e\left(\frac{2\sigma_u - S_o}{\sigma_u}\right) \qquad (S_p = \sigma_u) \qquad (3)$$

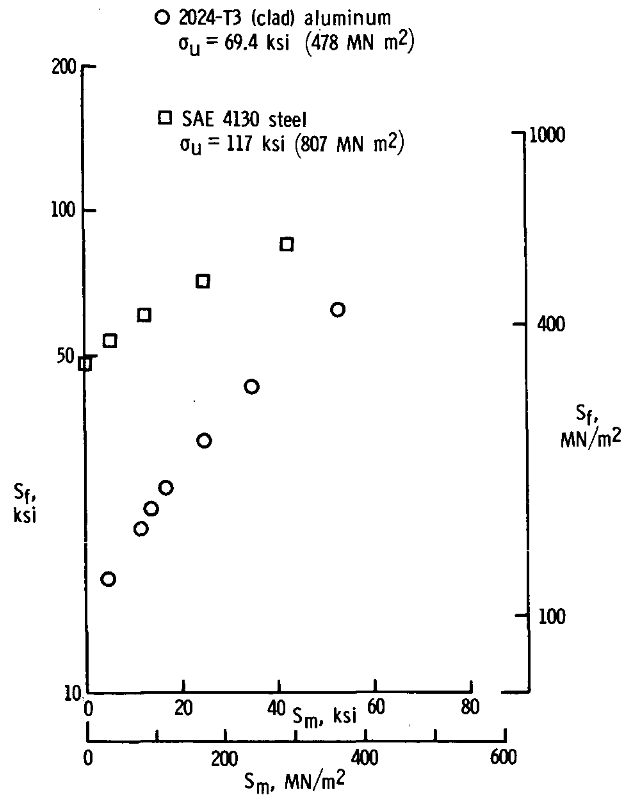


Figure 2.- Plots of fatigue limit against mean stress.

For values of S_m greater than those calculated by using equation (3), the calculated values of S_p from equation (2) are greater than σ_u. However, since there is no evidence to indicate that such fatigue limits are actually obtainable, it is recommended that calculated values of S_p greater than σ_u be set equal to σ_u.

RELATION BETWEEN S_o AND σ_u

In order to avoid the need for an experimental value of S_o in equation (2), an equation was developed to correlate S_o with σ_u. Plotting the log of $\sigma_u - S_o$ against σ_u for each material class (aluminum, steel, titanium, etc.) resulted in continuous curves that could be represented by an equation of the same general form as equation (1). In this case,

$$S_o = \sigma_u - De^{\sigma_u/E} + F \qquad (4)$$

Substitution of equation (4) into equation (2) results in the following general equation for the fatigue limit at any mean stress

$$S_p = \sigma_u e^{0.693 S_m/\sigma_u} - De^{\sigma_u/E} + F \qquad (5)$$

By assuming various values of F, sets of the constants D and E in equation (5) were evaluated for each material class by means of least-squares techniques. The Gaussian closeness of fit criterion

$$\frac{\sum (\text{Observed value - Calculated value})^2}{(\text{Number of data points - Number of constants})} = \text{Minimum}$$

was used to determine the best combinations of D, E, and F.

The constants which produced the best agreement for each material class are presented in the following table:

Material class	D		E		F	
	ksi	MN/m^2	ksi	MN/m^2	ksi	MN/m^2
Bare aluminum	223.0	1539	310.6	2143	229.5	1584
Clad aluminum	45.8	316	109.3	754	31.1	215
Low alloy steel	322.5	2225	584.8	4035	329.5	2274
Stainless steel and superalloys	180.4	1245	396.8	2738	169.9	1172
Titanium	241.7	1668	444.4	3066	235.2	1623

AGREEMENT BETWEEN EXPERIMENTAL AND PREDICTED FATIGUE LIMITS

All fatigue data have inherent scatter. Factors such as test technique, material variations, specimen preparation, cyclic speed, testing machine, temperature, humidity, and possibly other conditions can all have a significant influence on the test results. In general, the fatigue limits obtained under nominally identical test conditions fall within a ±5 ksi (35 MN/m^2) scatter band. The proposed methods were developed by correlating the observed trends of the available data. Thus, the accuracy of the method is, at best, only equal to the scatter in the test data. Therefore, predictions within ±5 ksi of the experimental fatigue limits were considered satisfactory. Values of the fatigue limits used in this report were obtained from the literature (refs. 5 to 24). Only S-N curves (stress against cycles curves) with a sufficient number of points to define the fatigue limit adequately were used. Each S-N curve was faired in order to obtain a reasonably consistent fit. All values of the fatigue limits quoted in this paper were estimated at the maximum number of cycles at which the tests were conducted which was 10^6, or more, cycles.

To evaluate properly the usefulness of the Gerber, Goodman, or proposed equations requires that data which cover the range of mean stress from compressive ultimate to tensile ultimate be available for a wide variety of materials. However, this condition rarely, if ever, is satisfied. Thus a proper evaluation of the superiority of one equation over the other is impossible with the existing data. However, there are limited data available covering a reasonable range of mean stress which give some evidence of the superiority of the proposed equations. These data are presented in figure 1; the predictions obtained using either equation (2) or equation (5) are presented in the right-hand plots. For all five materials the fit using either equation (2) or equation (5) was quite good over the range of mean stress, whereas the Gerber or Goodman predictions (left-hand plots) only fit the data for some materials and not others.

Considerably more data were available which were obtained from tests conducted at only one or several values of mean stress. These data are compared with the predicted fatigue limits obtained by using the Gerber, Goodman, and proposed methods for the following three cases:

Case 1: The value of S_o was adjusted for the Gerber equation, Goodman equation, or equation (2) to obtain the best possible fit for each set of data (a set consisted of two or more values of the fatigue limit obtained from tests in which the only parameter varied was the mean stress).

Case 2: The experimental value of S_o was used in the Gerber equation, Goodman equation, or equation (2) to calculate the fatigue limits for each set of data in which S_o was available or could be reasonably extrapolated from existing data. For comparison equation (5) was also used to obtain predictions for the same data.

Case 3: The constants D, E, and F (table on page 6) were used in equation (5) to calculate the fatigue limits for all the available data in each material class.

The predicted fatigue limits obtained for each case along with the experimental data are presented in tables I and II. For convenience, the experimental fatigue limits and the calculated fatigue limits obtained by using equation (5) are presented in figure 3 for each material class. The solid line in the figure represents perfect agreement, and the dashed lines represent the ±5-ksi (35 MN/m^2) scatter band previously discussed. The zero mean stress data are shown as square symbols. In general, the agreement using equation (5) was within the ±5-ksi scatter band.

Comparisons between the various equations of the predicted and experimental fatigue limits from tables I and II can become quite tedious. Thus in an attempt to summarize the results of tables I and II, the average of the differences between the predicted and experimental fatigue limits for each material class in cases 1 to 3 are presented in

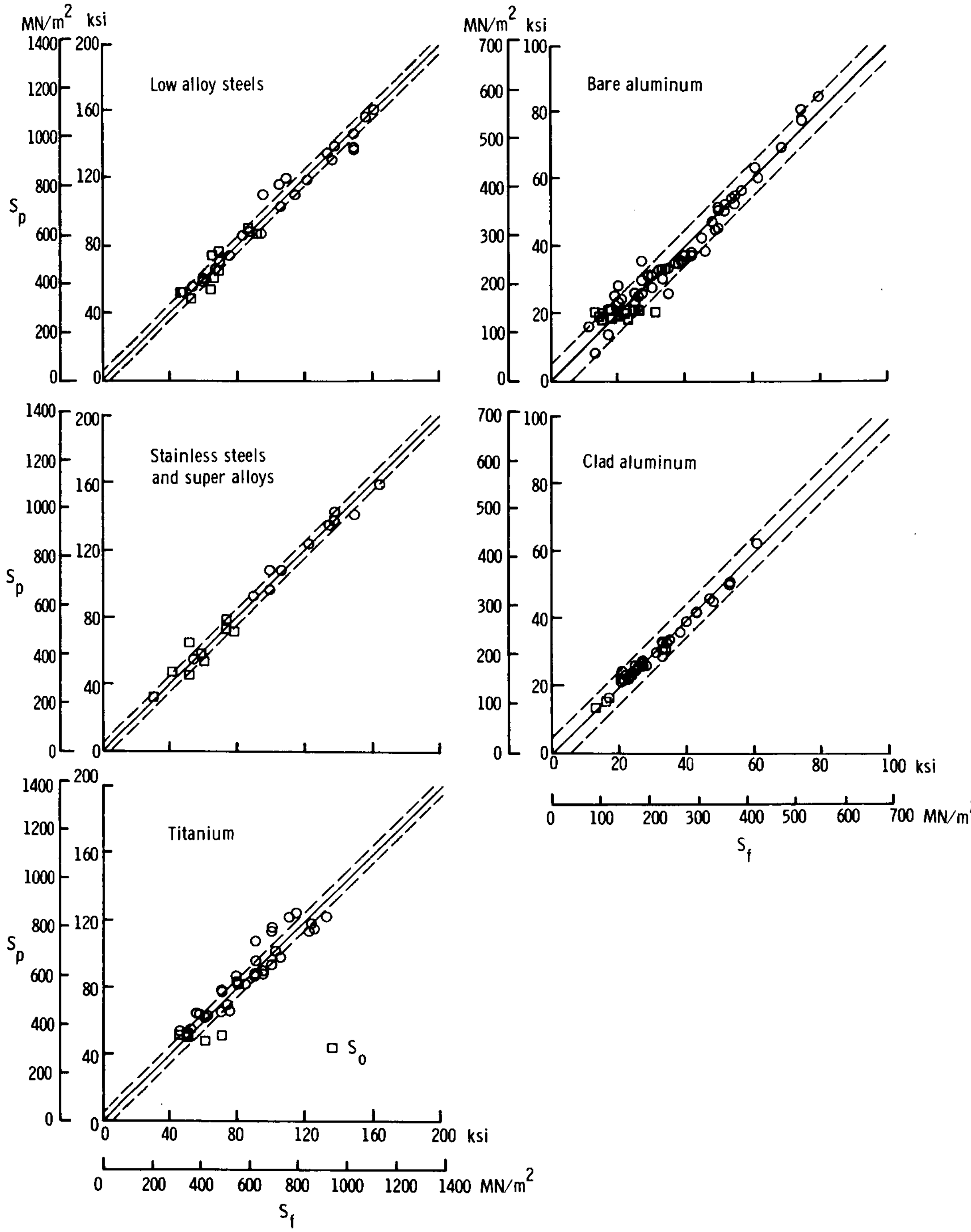


Figure 3.- Experimental fatigue limits and predicted fatigue limits using equation (5) for five major material classes.

the following table. For convenience the lowest values have been underlined in cases 1 and 2 for each material class. Direct comparisons of the results in this table indicate the average agreement but not necessarily the most appropriate equation.

Equation used	Bare aluminum Δ, ksi (MN/m^2) (a)	Clad aluminum Δ, ksi (MN/m^2) (a)	Low alloy steel Δ, ksi (MN/m^2) (a)	Stainless steel and superalloys Δ, ksi (MN/m^2) (a)	Titanium Δ, ksi (MN/m^2) (a)
Case 1: "Adjusted" S_o used in equations; for test series conducted at two or more values of S_m					
Equation (2)	1.7 (11.7)	0.6 (4.1)	2.4 (16.6)	3.0 (20.7)	4.7 (32.4)
Gerber equation	2.4 (16.6)	0.8 (5.5)	3.5 (24.2)	4.5 (31.1)	5.7 (39.3)
Goodman equation	2.4 (16.6)	1.8 (12.4)	6.1 (42.1)	6.6 (45.5)	2.3 (15.9)
Number of points	64	25	31	7	25
Case 2: Experimental S_o used in equations; for test series with tests conducted at $S_m = 0$					
Equation (2)	3.0 (20.7)	1.3 (9.0)	4.3 (29.7)	4.8 (33.1)	6.8 (46.9)
Gerber equation	3.9 (26.9)	3.4 (23.5)	5.7 (39.3)	7.8 (53.8)	11.1 (76.6)
Goodman equation	2.7 (18.6)	2.9 (20.0)	9.2 (63.5)	6.5 (44.9)	3.1 (21.4)
Equation (5)[b]	2.9 (20.0)	0.6 (4.1)	3.6 (24.8)	2.9 (20.0)	7.4 (51.1)
Number of points	35	7	20	5	13
Case 3: Master constants D, E, and F used in equation (5); all available data					
Equation (5)	2.6 (17.9)	1.0 (6.9)	5.1 (35.2)	3.9 (26.9)	6.2 (42.8)
Number of points	83	41	34	21	44

$$^{a}\Delta = \frac{\sum \left| S_f - S_p \right|}{\text{No. pts.}}.$$

[b]Master constants D, E, and F used in equation (5).

Considering the results in this table, figure 1 and tables I and II, there does appear to be a reasonable indication that the proposed methods (eq. (2) or (5)), in general, produced a better fit to the data than either the Gerber or Goodman equation for all the material classes with the exception of the titanium alloys. For this class, the Goodman equation produced the best fit. Less reliance probably should be put on the results for this material class since the scatter in the experimental fatigue data was often greater than for the other materials.

It is important to note the limited amount of data available for some material classes at zero mean stress (for example, see tables I(b) and II(b)) and thus the limited number of predictions obtainable with the use of equation (2) or the Gerber or Goodman equations (see last three columns of tables I(b) and II(b)). Thus, equation (5) which requires knowledge of only σ_u has the decided advantage of being capable of predicting the fatigue limit at any mean stress with reasonable accuracy without requiring that fatigue tests be conducted.

It is possible in all three equations (Gerber, Goodman, and eq. (2)) to compute a value of the fatigue limit at any mean stress if at least one fatigue limit is available. However, in the Gerber and Goodman relations, any inherent errors in the fatigue limit at a given mean stress result in proportionately larger errors when used to compute fatigue limits at lower values of mean stress; conversely, proportionately smaller errors are obtained when used to compute values at higher mean stresses.

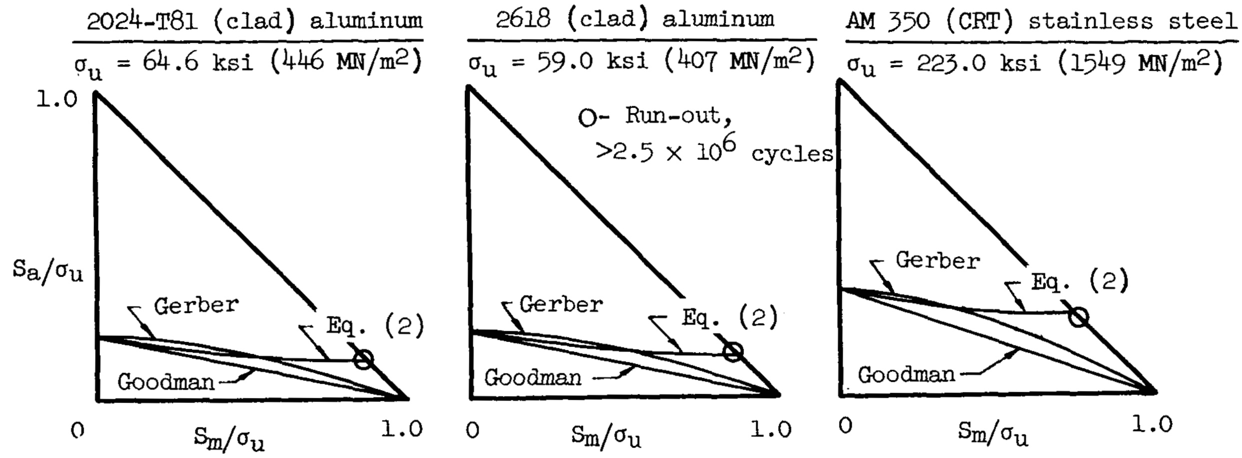
Thus, in order not to introduce additional errors in the predictions obtained by using the Gerber or Goodman equation requires that a value of the fatigue limit be available at the lowest value of mean stress of the range of mean stresses in which predictions are to be made. However, such data are often not available. Equation (2) offers the feature of being capable of making predictions over the entire range of mean stress without introducing additional errors regardless of the mean stress at which the data are available.

SPECIAL TESTS

Several fatigue tests were conducted at room temperature on unnotched sheet specimens (see ref. 16 for specimen configuration) of various materials to determine whether fatigue tests could be conducted at the combinations of mean and alternating stress predicted by equation (3) such that the maximum stress approximately equaled the nominal ultimate strength of the material. The tests were conducted in a closed-loop hydraulic testing machine which maintained the minimum and maximum load constant throughout the test (including first load cycle).

The results of these tests along with the predictions obtained by using the Gerber, Goodman, and proposed (eq. (2)) relations are presented in sketch 1; the data are also presented in table III.

The values predicted by equation (2) are in excellent agreement with the data; the values predicted by the Gerber and Goodman relations are in poor agreement. These results, although limited, indicate that it is possible to obtain a fatigue limit approximately equal to the ultimate strength of the material (as predicted by eq. (3)) and further substantiate the fact that the fatigue limit approaches the ultimate strength at values of mean stress less than the ultimate strength.



Sketch 1

Run-outs occurring at a maximum stress equal to the nominal ultimate strength can probably be explained by the fact that the values of σ_u were obtained from tests conducted at low strain rates, whereas the fatigue tests were at comparatively high rates. Ultimate strength tests conducted at the strain rates equal to the rates achieved in fatigue tests probably would have resulted in ultimate strengths higher than those quoted. Thus, in reality the maximum cyclic stresses were probably below the comparable ultimate strength of the material.

CONCLUDING REMARKS

An empirical method has been developed to represent the fatigue limit of axially loaded specimens as a function of mean stress. Predictions made by using this method indicate that reasonably good agreement with test data can be obtained over the entire range of mean stresses for a variety of materials and specimen configurations. In general, the method produces better agreement than the Gerber or Goodman relations.

The proposed method predicted that it was possible to obtain a fatigue limit equal to the ultimate strength of the material. Specimens of various materials tested at approximately the stress levels predicted by the method had not failed after 2.5×10^6 or more cycles.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., November 18, 1966,
126-14-03-08-23.

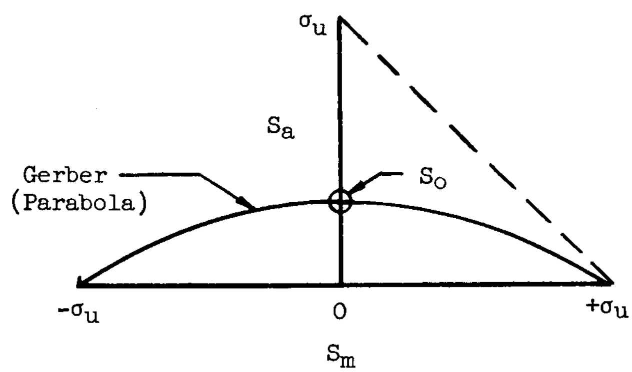
APPENDIX A

GERBER AND GOODMAN EQUATIONS

The Gerber equation (refs. 1 and 2) is

$$S_p = S_m + S_o\left[1 - \left(\frac{S_m}{\sigma_u}\right)^2\right]$$

A graphic representation of this equation is shown in sketch 2:

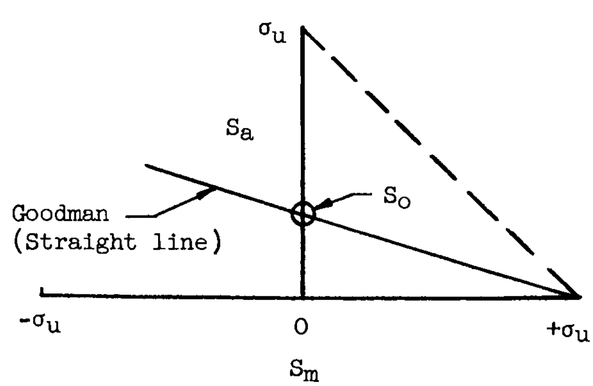


Sketch 2

The Goodman equation (refs. 1 and 3) is:

$$S_p = S_m + S_o\left(1 - \frac{S_m}{\sigma_u}\right)$$

A graphic representation of this equation is shown in sketch 3:



Sketch 3

APPENDIX B

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference of Weights and Measures, Paris, October 1960, in Resolution No. 12 (ref. 4). Conversion factors for the units used herein are given in the following table:

To convert from U.S. customary units	Multiply by –	To obtain SI units
in.	2.54×10^{-2}	meter (m)
ksi	6.894757	meganewton/meter^2 (MN/m^2)

Prefixes and symbols to indicate multiples of units are as follows:

Multiple	Prefix	Symbol
10^{-2}	centi	c
10^{6}	mega	M

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TABLE I.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS

[U.S. Customary Units]

(a) Bare aluminum

Material	Specimen dimensions and type, in. (a)	σ_u, ksi	S_m, ksi	S_f, ksi	Calculated fatigue limit, Sp, ksi — Case 3 — Eq. (5)	Case 1 — Best fit; adjusting S_o — Eq. (2)	Case 1 — Gerber eq.	Case 1 — Goodman eq.	Case 2 — Using experimental S_o — Eq. (2)	Case 2 — Gerber eq.	Case 2 — Goodman eq.	Reference
2014-T6 (Formerly 14S-T6)	0.40 diam. B	78.8	61.5	75	77.4	81.2	72.1	70.2	[b]78.8	73.6	68.3	10
↓	↓	↓	22.8	42	38.3	42.2	47.6	51.1	48.5	51.3	44.9	↓
			0	31	20.8	24.7	27.0	39.8	31.0	31.0	31.0	
2014-T6	0.10 × 0.375 S	71.0	0	15	20.2	----	----	----	-----	-----	-----	8
2014-T6	0.40 diam. B	73.9	36.5	50	50.6	52.5	54.7	47.8	53.9	54.7	48.7	6
↓	↓	↓	8.5	27	26.6	28.6	29.6	28.4	38.6	32.3	29.6	↓
			0	24	20.4	22.4	21.4	22.5	24.0	24.0	24.0	
2020-T6	0.09 × 0.375 S	82.6	0	18	21.1	----	----	----	-----	-----	-----	6
2024-T3 (Formerly 24S-T3)	0.09 × 1.0 S	73.0	48.8	61	63.4	63.9	59.6	57.9	64.7	60.9	56.1	5
↓	↓	↓	42.8	57	56.9	57.9	55.6	54.1	59.1	57.2	51.9	↓
			33.6	48	47.8	48.3	49.1	48.4	49.5	51.0	45.5	
			28.1	45	42.7	43.3	44.8	44.9	44.6	47.0	41.7	
			17.3	34	33.4	34.0	35.8	38.2	34.6	38.0	34.0	
			10.5	30	28.0	28.6	29.7	33.9	29.7	32.1	29.4	
			5.0	25	23.9	24.5	24.5	30.5	[c]25.7	[c]26.9	[c]25.0	
2024-T3 (Formerly 24S-T3)	0.032 × 0.5 S	72.0	0	22	20.3	----	----	----	-----	-----	-----	7
2024-T3	0.032 × 0.5 S	71.7	0	21	20.2	----	----	----	-----	-----	-----	6
2024-T3	0.032 × 0.5 S	72.6	0	21	20.3	----	----	----	-----	-----	-----	6
2024-T3	0.032 × 0.5 S	71.5	0	20	20.2	----	----	----	-----	-----	-----	6
2024-T3	0.032 × 0.5 S	71.5	0	20	20.2	----	----	----	-----	-----	-----	6
2024-T3	0.040 × 1.0 S	73.7	42.7	57	56.9	58.9	56.6	55.1	-----	-----	-----	6
↓	↓	↓	38.5	55	52.6	54.6	53.7	52.5	-----	-----	-----	↓
			30.6	49	45.0	47.1	47.9	47.8	-----	-----	-----	
			19.4	38	35.2	37.2	38.9	41.0	-----	-----	-----	
			6.5	26	25.1	27.1	27.3	32.2	-----	-----	-----	
2024-T3	0.064 × 0.5 S	71.6	0	20	20.2	----	----	----	-----	-----	-----	6
2024-T3	0.090 × 1.0 S	72.0	15.0	30	31.5	30.1	31.7	30.0	29.8	33.2	30.0	6
↓	↓	↓	0	19	20.3	18.9	17.4	19.0	19.0	19.0	19.0	↓
2024-T4	0.295 diam. B	58.3	-38.4	-1	-2.7	0.2	-22.8	4.3	1.4	-25.2	-0.2	6
↓	↓	↓	-15.6	13	8.8	11.7	10.0	17.0	13.1	5.8	13.6	↓
			-7.1	17	14.0	16.8	20.0	21.8	18.3	15.7	18.7	
			0	23	18.7	21.6	27.6	25.7	23.0	23.0	23.0	
			15.6	33	30.6	33.4	41.2	34.4	35.2	37.0	32.4	
			38.4	52	52.4	55.3	54.0	47.2	57.1	51.3	46.2	
2024-T4	0.16 diam. B	85.3	41.2	55	55.2	58.7	58.1	56.3	-----	-----	-----	6
2024-T4	0.16 diam. B	85.3	23.0	46	38.8	42.3	43.4	44.2	-----	-----	-----	6
2024-T4	0.16 diam. B	77.9	37.5	50	51.6	51.4	51.0	49.6	-----	-----	-----	6
↓	↓	↓	17.5	35	33.9	33.6	34.2	35.6	-----	-----	-----	↓
2024-T4	0.20 diam. B	71.3	13.5	27	30.2	----	----	----	-----	-----	-----	6
2024-T4	0.20 diam. B	70.5	13.5	27	30.1	26.3	28.6	26.7	26.8	29.8	27.2	6
↓	↓	↓	5.0	20	23.7	19.8	20.6	20.1	20.6	21.9	20.8	↓
			0	17	20.1	16.3	15.7	16.3	17.0	17.0	17.0	

[a]B means bar; S means sheet.

[b]Calculated S_p above σ_u; $S_p = \sigma_u$ used.

[c]Estimated S_o = 22 ksi.

TABLE I.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[U.S. Customary Units]

(a) Bare aluminum – Concluded

Material	Specimen dimensions and type, in. (a)	σ_u, ksi	S_m, ksi	S_f, ksi	Calculated fatigue limit, S_p, ksi							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
2024-T4	0.40 diam. B	86.8	-5.5	11	16.4	12.6	10.1	12.1	13.5	11.4	12.9	10
(Formerly 24S-T4)												
			65.2	75	80.6	81.2	75.3	72.7	85.3	76.6	71.7	
			21.2	40	37.4	37.9	42.9	43.9	42.1	45.6	41.0	
			0	26	21.3	21.9	23.1	30.1	26.0	26.0	26.0	
2024-T4	0.282 diam. B	86.1	16.0	32	33.1	----	----	----	----	----	----	12
2219-T87	0.10 × 0.375 S	66.7	0	20	19.7	----	----	----	----	----	----	8
2219-T6	0.10 × 0.375 S	58.9	0	18	18.8	----	----	----	----	----	----	8
5456-H343	0.10 × 0.375 S	56.6	0	15	18.5	----	----	----	----	----	----	8
6061-T6	0.125 × 1.0 S	46.0	12.5	25	26.4	----	----	----	----	----	----	9
(Formerly 61S-T6)												
7039-T6	0.10 × 0.375 S	64.1	0	18	19.4	----	----	----	----	----	----	8
7075-T6	0.10 × 0.375 S	78.8	0	13	20.8	----	----	----	----	----	----	8
7075-T6	0.090 × 1.0 S	82.5	55.2	69	69.8	72.6	67.9	65.3	72.2	68.4	63.1	5
(Formerly 75S-T6)												
			46.5	62	60.5	63.3	62.2	59.8	63.4	63.1	57.1	
			36.4	52	50.6	53.4	54.9	53.4	54.0	55.8	49.8	
			31.2	50	45.9	48.7	50.9	50.2	48.5	51.8	46.1	
			18.9	37	35.3	38.1	40.7	42.4	38.4	41.7	37.4	
			7.0	35	26.1	28.9	29.8	34.9	29.1	30.9	29.1	
			0	24	21.1	23.9	23.0	30.5	24.0	24.0	24.0	
7075-T6	0.40 diam. B	95.2	69.5	80	84.3	84.9	80.1	77.4	88.3	81.3	76.3	10
(Formerly 75S-T6)												
			21.0	40	37.4	37.9	42.5	43.9	40.4	44.8	40.5	
			0	25	21.7	22.2	22.6	29.4	25.0	25.0	25.0	
7075-T6	0.032 × 1.0 S	85.0	0	18	21.2	----	----	----	----	----	----	6
7075-T6	0.090 × 1.0 S	83.0	0	18	21.1	----	----	----	----	----	----	6
7075-T6	0.16 diam. B	94.9	21.0	42	37.4	39.7	39.9	41.0	----	----	----	6
			41.2	55	55.0	57.3	57.4	55.7	----	----	----	
7075-T6	0.16 diam. B	87.0	40.5	54	54.5	55.2	55.0	53.5	----	----	----	6
			18.5	37	35.2	35.8	36.2	37.7	----	----	----	
7075-T6	0.20 diam. B	81.3	14.5	29	31.7	28.4	30.8	28.9	----	----	----	6
7075-T6	0.20 diam. B	81.3	5.2	21	24.7	21.4	22.0	21.6	----	----	----	6
			-6.5	13	16.6	13.3	10.2	12.4	----	----	----	
7075-T6	0.20 diam. B	83.8	16.5	33	33.4	33.8	36.7	33.9	----	----	----	6
			6.7	27	26.0	26.4	27.6	26.6	----	----	----	
7075-T6	0.20 diam. B	86.5	19.5	39	36.0	37.8	39.7	37.8	37.1	40.4	36.4	6
			0	22	21.3	23.2	21.3	23.6	22.0	22.0	22.0	
7075-T6	0.20 diam. B	83.8	0	22	21.2	21.6	21.0	21.6	22.0	22.0	22.0	6
			-8.0	16	15.8	16.2	12.8	15.7	16.1	13.8	16.2	
7075-T6	0.20 diam. B	81.3	0	19	21.0	----	----	----	----	----	----	6
7075-T6	0.40 diam. B	82.3	19.7	27	35.9	29.1	31.2	29.7	33.2	36.6	33.4	6
			10.6	20	28.8	22.0	22.6	22.0	25.7	28.2	26.3	
			6.1	19	25.4	18.6	18.2	18.2	22.2	24.0	22.8	
			0	18	21.1	14.3	12.2	13.1	18.0	18.0	18.0	

[a]B means bar; S means sheet.

TABLE I.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[U.S. Customary Units]

(b) Clad aluminum

Material	Specimen dimensions and type, in. (a)	σ_u, ksi	S_m, ksi	S_f, ksi	Calculated fatigue limit, S_p, ksi							Reference
					Case 3	Case 1			Case 2			
					Eq. (5)	Best fit; adjusting S_o			Using experimental S_o			
						Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
2024-T3 (Formerly 24S-T3)	0.032 × 0.5 S	67.4	0	13	13.6	----	----	----	-----	-----	-----	11
2024-T3	0.016 × 1.0 S	66.2	42.4	53	50.4	53.5	51.2	50.9	-----	-----	-----	6
↓	↓	↓	20.6	33	29.3	32.5	34.2	37.0	-----	-----	-----	↓
2024-T3	0.020 × 0.5 S	62.1	14.4	24	23.2	----	----	----	-----	-----	-----	6
2024-T3	0.020 × 0.5 S	66.1	13.2	22	23.2	----	----	----	-----	-----	-----	6
2024-T3	0.020 × 0.5 S	66.3	12.6	21	22.7	----	----	----	-----	-----	-----	6
2024-T3	0.020 × 0.5 S	62.8	13.8	23	22.9	----	----	----	-----	-----	-----	6
2024-T3	0.040 × 1.0 S	67.4	32.0	40	39.9	40.1	40.0	39.3	-----	-----	-----	6
↓	↓	↓	23.1	33	31.7	31.9	32.2	32.3	-----	-----	-----	↓
↓	↓	↓	15.0	24	24.9	25.1	24.8	25.9	-----	-----	-----	↓
2024-T3	0.040 × 1.0 S	69.4	53.4	61	62.9	62.5	58.0	57.2	63.6	59.6	56.9	6
↓	↓	↓	34.4	43	42.5	42.1	42.9	42.7	43.1	45.7	41.9	↓
↓	↓	↓	24.7	33	33.5	33.1	34.6	35.3	34.7	37.8	34.3	↓
↓	↓	↓	16.2	26	26.3	25.9	26.9	28.8	27.1	30.5	27.8	↓
↓	↓	↓	13.2	24	23.9	23.4	24.0	26.5	24.6	27.6	25.4	↓
↓	↓	↓	10.7	21	21.9	21.5	21.7	24.6	23.1	25.4	23.5	↓
↓	↓	↓	4.2	17	17.1	16.6	15.4	19.6	[b]17.8	[b]19.1	[b]18.3	↓
2024-T3	0.040 × 1.0 S	69.0	34.4	43	42.5	42.8	42.5	41.9	-----	-----	-----	6
↓	↓	↓	26.2	35	34.8	35.1	35.5	35.5	-----	-----	-----	↓
↓	↓	↓	16.9	27	26.7	27.1	27.0	28.1	-----	-----	-----	↓
2024-T3	0.040 × 1.0 S	66.4	25.5	34	33.7	33.7	34.0	33.5	-----	-----	-----	6
↓	↓	↓	15.6	25	25.2	25.3	25.0	25.6	-----	-----	-----	↓
2024-T3	0.040 × 1.0 S	66.7	17.5	28	26.8	----	----	----	-----	-----	-----	6
2024-T3	0.040 × 1.0 S	66.2	15.6	25	25.1	----	----	----	-----	-----	-----	6
2024-T3	0.040 × 0.5 S	64.2	13.8	23	23.2	----	----	----	-----	-----	-----	6
2024-T3	0.040 × 0.5 S	61.5	13.2	22	22.1	----	----	----	-----	-----	-----	6
2024-T3	0.040 × 0.5 S	68.8	15.6	25	25.7	----	----	----	-----	-----	-----	6
2024-T3	0.064 × 1.0 S	73.2	16.9	27	27.5	----	----	----	-----	-----	-----	6
2024-T3	0.091 × 1.0 S	69.3	13.3	22	23.9	----	----	----	-----	-----	-----	6
2024-T3	0.102 × 1.0 S	69.7	16.2	26	26.4	----	----	----	-----	-----	-----	6
7075-T6	0.040 × 1.0 S	81.2	42.4	53	51.4	52.9	52.2	51.5	-----	-----	-----	6
↓	↓	↓	36.0	48	45.2	46.7	46.8	46.6	-----	-----	-----	↓
↓	↓	↓	26.6	38	36.7	38.2	38.6	39.4	-----	-----	-----	↓
↓	↓	↓	19.4	31	30.6	32.1	32.1	33.8	-----	-----	-----	↓
7075-T6	0.064 × 0.5 S	77.8	0	16	15.6	----	----	----	-----	-----	-----	6
7075-T6	0.064 × 1.0 S	76.0	30.0	40	39.2	38.6	39.0	38.6	-----	-----	-----	6
↓	↓	↓	15.6	25	26.9	26.4	25.9	26.9	-----	-----	-----	↓
7075-T6	0.091 × 1.0 S	75.5	13.3	21	25.0	----	----	----	-----	-----	-----	6
7075-T6	0.040 × 1.0 S	80.2	37.6	47	46.7	46.5	46.4	46.0	-----	-----	-----	6
↓	↓	↓	23.1	33	33.6	33.5	33.5	34.3	-----	-----	-----	↓
7178-T6	0.125 × 0.5 S	79.0	16.9	27	28.3	----	----	----	-----	-----	-----	6

[a]B means bar; S means sheet.

[b]Estimated S_o = 15 ksi.

TABLE I.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[U.S. Customary Units]

(c) Low alloy steel

Material	Specimen dimensions and type, in. (a)	σ_u, ksi	S_m, ksi	S_f, ksi	Calculated fatigue limit, S_p, ksi							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
SAE 2330	0.30 diam. B	123.1	44.0	88	89.2	93.3	95.0	86.0	100.0	100.6	85.6	14
	0.30 diam. B		0	65	54.6	54.7	55.4	69.2	65.0	65.0	65.0	
SAE 4130	0.075 × 1.0 S	117.0	77.0	110	[b]117.0	116.7	104.7	98.2	116.4	103.9	93.3	5
			42.8	84	86.4	82.9	85.2	82.2	81.2	84.1	73.0	
			24.8	71	71.2	67.7	71.5	73.7	67.0	70.9	62.7	
			12.0	60	61.2	57.7	60.4	67.7	56.6	59.5	55.2	
			5.4	54	56.4	52.9	54.2	64.6	51.8	53.3	51.0	
			0	48	52.6	49.1	48.9	62.1	48.0	48.0	48.0	6
		117.0	30.0	76	75.4	74.4	75.8	71.2	70.1	73.7	64.8	
			20.0	68	67.3	66.3	67.6	65.9	61.9	65.6	59.0	
			10.0	60	59.8	58.7	58.6	60.6	54.3	56.6	52.8	
			0	47	52.6	51.6	49.0	55.4	47.0	47.0	47.0	
SAE 4340	0.20 diam. B	190.0	0	70	73.4	73.9	71.5	91.5	70.0	70.0	70.0	13
			60.0	122	119.8	120.4	124.3	122.6	116.7	123.0	107.6	
			90.0	150	147.2	147.7	145.4	138.2	144.5	144.6	127.1	
		260.0	0	92	86.7	90.1	83.8	98.2	92.0	92.0	92.0	13
			60.0	137	131.8	135.2	139.4	135.5	137.2	147.4	130.8	
			90.0	157	157.2	160.6	163.8	154.2	162.7	171.0	149.8	
		300.0	0	87	91.2	89.4	81.0	93.6	87.0	87.0	87.0	13
			60.0	134	135.8	134.0	137.7	134.9	132.0	143.5	129.6	
			90.0	161	160.5	158.7	163.7	155.5	157.2	169.2	150.9	
	0.30 diam. B	158.5	57.5	115	110.5	115.2	116.9	108.6	115.5	118.4	102.3	14
			0	70	65.2	69.8	68.4	80.1	70.0	70.0	70.0	
		195.0	48.0	96	110.8	99.1	103.4	96.9	102.5	110.0	97.5	6
			0	66	74.5	62.9	59.0	64.8	66.0	66.0	66.0	
	0.313 diam. B	220.0	76.4	139	139.8	-----	-----	-----	-----	-----	-----	6
	0.20 diam. B	220.8	75.0	150	138.7	-----	-----	-----	-----	-----	-----	6
	0.25 diam. B	226.5	75.0	150	139.6	-----	-----	-----	-----	-----	-----	6
SAE 8630	0.30 diam. B	208.0	52.0	106	116.8	107.7	112.2	105.2	108.5	117.8	104.5	14
			0	70	77.4	68.3	64.2	71.0	70.0	70.0	70.0	
		146.5	53.0	107	103.5	107.8	109.3	101.4	108.5	111.3	95.8	14
			0	67	61.8	66.2	64.8	75.8	67.0	67.0	67.0	
		107.0	47.5	95	87.8	93.3	92.0	86.0	91.9	90.4	77.2	14
			0	53	49.3	54.7	55.4	69.2	53.0	53.0	53.0	

[a]B means bar; S means sheet.

[b]Calculated S_p above σ_u; $S_p = \sigma_u$ used.

TABLE I.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[U.S. Customary Units]

(d) Stainless steels and superalloys

Material	Specimen dimensions and type, in. (a)	σ_u, ksi	S_m, ksi	S_f, ksi	Calculated fatigue limit, S_p, ksi							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
321 stainless	0.090 × 0.20 S	86.1	0	31	32.0	-----	-----	-----	-----	-----	-----	8
347 stainless	0.064 × 1.0 S	90.0	27.5	55	54.9	-----	-----	-----	-----	-----	-----	9
AM 355 SCT	0.036 S	211.0	86.0	138	143.0	-----	-----	-----	-----	-----	-----	20
AM 350 CRT	0.050 × 1.0 S	233.0	0	75	78.7	78.1	73.1	86.6	75.0	75.0	75.0	19
↓	↓	↓	20.0	90	93.0	92.4	92.5	99.2	89.6	94.4	88.3	↓
			40.0	107	108.1	107.6	110.9	111.7	104.6	112.8	102.3	
			100.0	165	159.4	158.9	159.6	149.4	156.6	160.8	142.8	
403 stainless	0.050 × 1.0 S	195.0	50.0	100	108.2	-----	-----	-----	-----	-----	-----	9
PH 15-7	0.025 × 0.75 S	201.0	0	79	71.8	75.1	70.7	80.9	79.0	79.0	79.0	16
↓	↓	↓	33.5	100	96.4	99.7	102.3	100.9	104.5	110.1	99.1	↓
			67.0	123	124.0	127.3	129.9	121.0	131.1	137.3	119.9	
PH 17-7	0.037 × 0.92 S	205.1	0	74	72.8	-----	-----	-----	-----	-----	-----	15
Stellite 31	0.25 diam. B	123.0	0	42	47.1	-----	-----	-----	-----	-----	-----	17
S-816	0.25 diam. B	147.0	0	55	55.8	-----	-----	-----	-----	-----	-----	17
6.3% Mo-Waspalloy	0.25 diam. B	156.0	0	59	58.8	-----	-----	-----	-----	-----	-----	17
Inconel X-550	0.25 diam. B	173.5	0	52	64.3	-----	-----	-----	-----	-----	-----	17
16-25-6 Timken	0.25 diam. B	120.0	0	52	45.5	-----	-----	-----	-----	-----	-----	17
Hy-Tuf	0.313 diam. B	220.0	82.5	150	141.4	-----	-----	-----	-----	-----	-----	6
18% Ni-Marage	0.75 diam. B	269.0	67.5	135	135.0	-----	-----	-----	-----	-----	-----	18
18% Ni-Marage	0.75 diam. B	293.0	69.0	138	137.8	-----	-----	-----	-----	-----	-----	18
403 stainless	0.25 diam. B	141.0	0	61	53.7	-----	-----	-----	-----	-----	-----	17

[a]B means bar; S means sheet.

TABLE I.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Concluded

[U.S. Customary Units]

(e) Titanium

Material	Specimen dimensions and type, in. (a)	σ_u, ksi	S_m, ksi	S_f, ksi	Calculated fatigue limit, S_p, ksi							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
Pure	0.060 × 1.50 S	110.0	25.5	51	54.8	-----	-----	-----	-----	-----	-----	6
Pure	0.060 × 1.50 S	133.0	28.5	57	63.5	-----	-----	-----	-----	-----	-----	6
Pure	S	120.0	31.0	62	62.1	-----	-----	-----	-----	-----	-----	6
75A	0.040 × 0.50 S	95.8	42.0	70	65.2	-----	-----	-----	-----	-----	-----	6
75A	0.040 × 0.50 S	99.8	44.4	74	68.5	-----	-----	-----	-----	-----	-----	6
Pure	0.050 × 0.5 S	98.4	27.0	45	52.6	-----	-----	-----	-----	-----	-----	6
Pure	0.050 × 0.5 S	102.5	36.0	60	61.6	-----	-----	-----	-----	-----	-----	6
C-110 M	0.045 × 0.5 S	141.2	54.0	90	87.2	-----	-----	-----	-----	-----	-----	6
B120 VCA	0.040 × 0.5 S	136.3	28.0	55	64.0	-----	-----	-----	-----	-----	-----	21
2.5Al-16V	0.020 × 1.0 S	170.0	0	47	51.0	41.8	37.4	42.0	47.0	47.0	47.0	22
↓	↓	↓	35.0	70	77.1	67.9	70.8	68.4	72.5	80.1	72.1	↓
↓	↓	↓	69.3	90	106.5	97.3	100.5	94.2	102.1	108.3	97.0	↓
2.5Al-16V	0.063 × 1.0 S	161.0	0	50	49.1	46.5	43.6	50.6	50.0	50.0	50.0	22
↓	↓	↓	42.5	85	81.4	78.8	83.1	79.7	81.7	89.0	79.5	↓
↓	↓	↓	77.0	100	112.3	109.7	110.6	103.4	113.1	115.5	103.0	↓
2.5Al-16V	0.125 × 1.0 S	168.0	0	45	50.6	42.8	41.9	50.0	45.0	45.0	45.0	22
↓	↓	↓	87.8	114	123.9	116.2	118.2	111.6	118.1	120.7	109.4	↓
5Al-2.5Sn	0.10 × 0.20 S	115.6	35.3	70	64.6	-----	-----	-----	-----	-----	-----	8
4Al-3Mo-1V	0.065 S	196.0	82.0	132	121.6	-----	-----	-----	-----	-----	-----	20
4Al-3Mo-1V	0.065 S	194.0	77.0	123	116.8	-----	-----	-----	-----	-----	-----	20
4Al-3Mo-1V	0.020 × 1.0 S	167.0	0	70	50.4	64.3	61.6	68.2	70.0	70.0	70.0	22
↓	↓	↓	47.5	95	86.7	100.7	104.1	96.3	107.1	111.9	97.9	↓
4Al-3Mo-1V	0.063 × 1.0 S	175.0	40.0	80	82.0	73.8	74.6	75.8	-----	-----	-----	22
↓	↓	↓	77.0	100	114.4	106.2	106.4	103.0	-----	-----	-----	↓
4Al-3Mo-1V	0.125 × 1.0 S	173.0	0	50	51.6	50.0	43.3	51.0	50.0	50.0	50.0	22
↓	↓	↓	40.0	80	81.6	80.0	83.9	79.2	80.1	87.5	78.5	↓
6Al-4V	0.063 × 1.0 S	166.0	0	50	50.2	46.5	43.7	51.5	50.0	50.0	50.0	22
↓	↓	↓	40.0	80	80.3	76.6	81.2	79.1	80.7	87.0	78.0	↓
↓	↓	↓	84.7	110	120.6	116.9	117.0	109.9	119.7	121.7	109.2	↓
6Al-4V	0.125 × 1.0 S	166.0	0	50	50.2	46.9	44.1	52.0	50.0	50.0	50.0	22
↓	↓	↓	41.0	82	81.1	77.9	82.4	80.2	80.7	88.0	78.5	↓
↓	↓	↓	84.7	110	120.6	117.3	117.3	110.2	119.7	121.7	109.2	↓
6Al-4V	0.045 × 0.5 S	165.9	63.7	102	100.7	104.6	104.1	102.7	-----	-----	-----	23
↓	↓	↓	49.9	95	88.6	92.4	93.0	94.2	-----	-----	-----	↓
6Al-4V-2Sn	0.375 diam. B	151.1	49.5	90	85.3	-----	-----	-----	-----	-----	-----	24
6Al-4V-2Sn	0.375 diam. B	176.1	57.7	105	97.1	-----	-----	-----	-----	-----	-----	24
6Al-4V-2Sn	0.375 diam. B	163.8	55.0	100	92.6	-----	-----	-----	-----	-----	-----	24
6Al-4V	0.036 S	165.0	78.0	125	113.9	-----	-----	-----	-----	-----	-----	20
6Al-4V	0.036 S	166.0	76.0	122	112.1	-----	-----	-----	-----	-----	-----	20
6Al-4V	0.10 × 0.20 S	165.3	35.3	70	76.4	-----	-----	-----	-----	-----	-----	8
8Al-1Mo-1V	0.050 × 1.0 S	152.0	0	60	47.0	52.9	50.4	56.5	60.0	60.0	60.0	19
↓	↓	↓	25.0	75	65.4	71.3	74.0	72.2	77.8	83.2	75.4	↓
↓	↓	↓	60.0	90	94.8	100.8	102.5	94.2	107.1	111.0	96.6	↓
13V-11Cr-3Al	0.10 × 0.20 S	199.5	39.9	79	85.9	-----	-----	-----	-----	-----	-----	8

[a]B means bar; S means sheet.

TABLE II.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS

[SI Units]

(a) Bare aluminum

Material	Specimen dimensions and type, cm (a)	σ_u, MN/m^2	S_m, MN/m^2	S_f, MN/m^2	Calculated fatigue limit, S_p, MN/m^2: Case 3, Eq. (5)	Case 1, Best fit; adjusting S_o: Eq. (2)	Case 1: Gerber eq.	Case 1: Goodman eq.	Case 2, Using experimental S_o: Eq. (2)	Case 2: Gerber eq.	Case 2: Goodman eq.	Reference
2014-T6 (Formerly 14S-T6)	1.02 diam. B	544	424	518	534	560	497	484	602	508	471	10
↓	↓	↓	157	290	264	291	328	353	335	354	310	↓
↓	↓	↓	0	214	144	170	186	275	214	214	214	↓
2014-T6	0.25 × 0.95 S	490	0	104	139	---	----	---	----	----	----	8
2014-T6	1.02 diam. B	510	252	345	349	362	377	330	372	377	336	6
↓	↓	↓	59	186	184	197	204	196	266	223	204	↓
↓	↓	↓	0	166	141	155	148	155	166	166	166	↓
2020-T6	0.23 × 0.95 S	570	0	124	146	---	----	---	----	----	----	6
2024-T3 (Formerly 24S-T3)	0.23 × 2.54 S	504	337	421	437	441	411	400	446	420	387	5
↓	↓	↓	295	393	393	400	384	373	408	395	358	↓
↓	↓	↓	232	331	330	333	339	334	342	352	314	↓
↓	↓	↓	194	311	295	299	309	310	308	324	288	↓
↓	↓	↓	119	235	230	235	247	264	239	262	235	↓
↓	↓	↓	72	207	193	197	205	234	205	221	203	↓
↓	↓	↓	35	173	165	169	169	210	[b]177	[b]186	[b]173	↓
2024-T3 (Formerly 24S-T3)	0.08 × 1.27 S	497	0	152	140	---	----	---	----	----	----	7
2024-T3	0.08 × 1.27 S	495	0	145	139	---	----	---	----	----	----	6
2024-T3	0.08 × 1.27 S	501	0	145	140	---	----	---	----	----	----	6
2024-T3	0.08 × 1.27 S	493	0	138	139	---	----	---	----	----	----	6
2024-T3	0.08 × 1.27 S	493	0	138	139	---	----	---	----	----	----	6
2024-T3	0.10 × 2.54 S	509	295	393	393	406	391	380	----	----	----	6
↓	↓	↓	266	380	363	377	371	362	----	----	----	↓
↓	↓	↓	211	338	311	325	331	330	----	----	----	↓
↓	↓	↓	134	262	243	257	268	283	----	----	----	↓
↓	↓	↓	45	179	173	187	188	222	----	----	----	↓
2024-T3	0.16 × 1.27 S	494	0	138	139	---	----	---	----	----	----	6
2024-T3	0.23 × 2.54 S	497	104	207	217	208	219	207	206	229	207	6
↓	↓	↓	0	131	140	130	120	131	131	131	131	↓
2024-T4	0.75 diam. B	402	-265	-7	-19	1	-157	30	10	-174	-1	6
↓	↓	↓	-108	90	61	81	69	117	90	40	94	↓
↓	↓	↓	-49	117	97	116	138	150	126	108	129	↓
↓	↓	↓	0	159	129	149	190	177	159	159	159	↓
↓	↓	↓	108	228	211	230	284	237	243	255	224	↓
↓	↓	↓	265	359	362	382	373	326	394	354	319	↓
2024-T4	0.41 diam. B	589	284	380	381	405	401	388	----	----	----	6
2024-T4	0.41 diam. B	589	159	317	268	292	299	305	----	----	----	6
2024-T4	0.41 diam. B	538	259	345	356	355	352	342	----	----	----	6
↓	↓	↓	121	242	234	232	236	246	----	----	----	↓
2024-T4	0.51 diam. B	492	93	186	208	---	----	---	----	----	----	6
2024-T4	0.51 diam. B	486	93	186	208	181	197	184	185	206	188	6
↓	↓	↓	35	138	164	137	142	139	142	151	144	↓
↓	↓	↓	0	117	139	112	108	112	117	117	117	↓

[a]B means bar; S means sheet.
[b]Estimated S_o = 152 MN/m^2.

TABLE II.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[SI Units]

(a) Bare aluminum – Concluded

Material	Specimen dimensions and type, cm (a)	σ_u, MN/m^2	S_m, MN/m^2	S_f, MN/m^2	Calculated fatigue limit, S_p, MN/m^2							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
2024-T4 (Formerly 24S-T4)	1.02 diam. B	599	-38	76	113	87	70	83	93	79	89	10
↓	↓	↓	450	518	556	560	520	502	589	529	495	↓
			146	276	258	262	296	303	290	315	283	
			0	179	147	151	159	208	179	179	179	
2024-T4	0.72 diam. B	594	110	221	228	---	---	---	---	---	---	12
2219-T87	0.25 × 0.95 S	460	0	138	136	---	---	---	---	---	---	8
2219-T6	0.25 × 0.95 S	406	0	124	130	---	---	---	---	---	---	8
5456-H343	0.25 × 0.95 S	391	0	104	128	---	---	---	---	---	---	8
6061-T6 (Formerly 61S-T6)	0.32 × 2.54 S	317	86	173	182	---	---	---	---	---	---	9
7039-T6	0.25 × 0.95 S	442	0	124	134	---	---	---	---	---	---	8
7075-T6	0.25 × 0.95 S	544	0	90	144	---	---	---	---	---	---	8
7075-T6 (Formerly 75S-T6)	0.23 × 2.54 S	569	381	476	482	501	469	451	498	472	435	5
↓	↓	↓	321	428	417	437	429	413	437	435	394	↓
			251	359	349	368	379	368	373	385	344	
			215	345	317	336	351	346	335	357	318	
			130	255	244	263	281	293	265	288	258	
			48	242	180	199	206	241	201	213	201	
			0	166	146	165	159	210	166	166	166	
7075-T6 (Formerly 75S-T6)	1.02 diam. B	657	480	552	582	586	553	534	609	561	526	10
↓	↓	↓	145	276	258	262	293	303	279	309	279	↓
			0	173	150	153	156	203	173	173	173	
7075-T6	0.08 × 2.54 S	587	0	124	146	---	---	---	---	---	---	6
7075-T6	0.23 × 2.54 S	573	0	124	146	---	---	---	---	---	---	6
7075-T6	0.41 diam. B	655	145	290	258	274	275	283	---	---	---	6
↓	↓	↓	284	380	380	395	396	384	---	---	---	↓
7075-T6	0.41 diam. B	600	279	373	376	381	380	369	---	---	---	6
↓	↓	↓	128	255	243	247	250	260	---	---	---	↓
7075-T6	0.51 diam. B	561	100	200	219	196	213	199	---	---	---	6
7075-T6	0.51 diam. B	561	36	145	170	148	152	149	---	---	---	6
↓	↓	↓	-45	90	115	92	70	86	---	---	---	↓
7075-T6	0.51 diam. B	578	114	228	230	233	253	234	---	---	---	6
↓	↓	↓	46	186	179	182	190	184	---	---	---	↓
7075-T6	0.51 diam. B	597	135	269	248	261	274	261	256	279	251	6
↓	↓	↓	0	152	147	160	147	163	152	152	152	↓
7075-T6	0.51 diam. B	578	0	152	146	149	145	149	152	152	152	6
↓	↓	↓	-55	110	109	112	88	108	111	95	112	↓
7075-T6	0.51 diam. B	561	0	131	145	---	---	---	---	---	---	6
7075-T6	1.02 diam. B	568	136	186	248	201	215	205	229	253	230	6
↓	↓	↓	73	138	199	152	156	152	177	195	181	↓
			42	131	175	128	126	126	153	166	157	
			0	124	146	99	84	90	124	124	124	

[a]B means bar; S means sheet.

TABLE II.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[SI Units]

(b) Clad aluminum

Material	Specimen dimensions and type, cm (a)	σ_u, MN/m^2	S_m, MN/m^2	S_f, MN/m^2	Calculated fatigue limit, S_p, MN/m^2							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
2024-T3 (Formerly 24S-T3)	0.81 × 1.27 S	465	0	90	94	---	---	---	----	----	----	11
2024-T3	0.04 × 2.54 S	457	293	366	348	369	353	351	----	----	----	6
↓	↓	↓	142	228	202	224	236	255	----	----	----	↓
2024-T3	0.51 × 1.27 S	428	99	166	160	---	---	---	----	----	----	6
2024-T3	0.51 × 1.27 S	456	91	152	160	---	---	---	----	----	----	6
2024-T3	0.51 × 1.27 S	457	87	145	157	---	---	---	----	----	----	6
2024-T3	0.51 × 1.27 S	433	95	159	158	---	---	---	----	----	----	6
2024-T3	0.10 × 2.54 S	465	221	276	275	277	276	271	----	----	----	6
↓	↓	↓	159	228	219	220	222	223	----	----	----	↓
↓	↓	↓	104	166	172	173	171	179	----	----	----	↓
2024-T3	0.10 × 2.54 S	479	368	421	434	431	400	395	439	411	393	6
↓	↓	↓	237	297	293	290	296	295	297	315	289	↓
↓	↓	↓	170	228	231	228	239	244	239	261	237	↓
↓	↓	↓	112	179	181	179	186	199	187	210	192	↓
↓	↓	↓	91	166	165	161	166	183	170	190	175	↓
↓	↓	↓	74	145	151	148	150	170	159	175	162	↓
↓	↓	↓	29	117	118	115	106	135	[b]123	[b]132	[b]126	↓
2024-T3	0.10 × 2.54 S	476	237	297	293	295	293	289	----	----	----	6
↓	↓	↓	181	242	240	242	245	245	----	----	----	↓
↓	↓	↓	117	186	184	187	186	194	----	----	----	↓
2024-T3	0.10 × 2.54 S	458	176	235	233	233	235	231	----	----	----	6
↓	↓	↓	108	173	174	175	173	177	----	----	----	↓
2024-T3	0.10 × 2.54 S	460	121	193	185	---	---	---	----	----	----	6
2024-T3	0.10 × 2.54 S	457	108	173	173	---	---	---	----	----	----	6
2024-T3	0.10 × 1.27 S	443	95	159	160	---	---	---	----	----	----	6
2024-T3	0.10 × 1.27 S	424	91	152	152	---	---	---	----	----	----	6
2024-T3	0.10 × 1.27 S	475	108	173	177	---	---	---	----	----	----	6
2024-T3	0.16 × 2.54 S	505	117	186	190	---	---	---	----	----	----	6
2024-T3	0.23 × 2.54 S	478	92	152	165	---	---	---	----	----	----	6
2024-T2	0.26 × 2.54 S	481	112	179	182	---	---	---	----	----	----	6
7075-T6	0.10 × 2.54 S	560	293	366	355	365	360	355	----	----	----	6
↓	↓	↓	248	331	312	322	323	322	----	----	----	↓
↓	↓	↓	184	262	253	264	266	272	----	----	----	↓
↓	↓	↓	134	214	211	221	221	233	----	----	----	↓
7075-T6	0.16 × 1.27 S	537	0	110	108	---	---	---	----	----	----	6
7075-T6	0.16 × 2.54 S	524	207	276	270	266	269	266	----	----	----	6
↓	↓	↓	108	173	186	182	179	186	----	----	----	↓
7075-T6	0.23 × 2.54 S	521	92	145	173	---	---	---	----	----	----	6
7075-T6	0.10 × 2.54 S	553	259	324	322	321	320	317	----	----	----	6
↓	↓	↓	159	228	232	231	231	237	----	----	----	↓
7178-T6	0.32 × 1.27 S	545	117	186	195	---	---	---	----	----	----	6

[a]B means bar; S means sheet.
[b]Estimated S_o = 103 MN/m^2.

TABLE II.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[SI Units]

(c) Low alloy steel

Material	Specimen dimensions and type, cm (a)	σ_u, MN/m^2	S_m, MN/m^2	S_f, MN/m^2	Calculated fatigue limit, S_p, MN/m^2							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
SAE 2330	0.76 diam. B	849	304	607	615	644	656	593	690	694	591	14
↓	↓	↓	0	449	377	377	382	477	449	449	449	↓
SAE 4130	0.19 × 2.54 S	807	531	759	[b]807	805	722	678	803	717	644	5
			295	580	596	572	588	567	560	580	504	
			171	490	491	467	493	508	462	489	433	
			83	414	422	398	417	467	391	411	381	
			37	373	389	365	374	446	357	368	352	↓
		↓	0	331	363	339	337	428	331	331	331	6
		807	207	524	520	513	523	491	484	509	447	
			138	469	464	457	466	455	427	453	407	
			69	414	413	405	404	418	375	391	364	
↓	↓	↓	0	324	363	356	338	382	324	324	324	↓
SAE 4340	0.51 diam. B	1311	0	483	506	510	493	631	483	483	483	13
			414	842	827	831	858	846	805	849	742	
		↓	621	1035	1016	1019	1003	954	997	998	877	↓
		1794	0	635	598	622	578	678	635	635	635	13
			414	945	909	933	962	935	947	1017	903	
		↓	621	1083	1085	1108	1130	1064	1123	1180	1034	↓
		2070	0	600	629	617	559	646	600	600	600	13
			414	925	937	925	950	931	911	990	894	
	↓	↓	621	1111	1107	1095	1130	1073	1085	1167	1041	↓
	0.76 diam. B	1094	397	794	762	795	807	749	797	817	706	14
		↓	0	483	450	482	472	553	483	483	483	↓
		1346	331	662	765	684	713	669	707	759	673	6
	↓	↓	0	455	514	434	407	447	455	455	455	↓
	0.80 diam. B	1518	527	959	965	----	----	----	----	----	----	6
	0.51 diam. B	1524	518	1035	957	----	----	----	----	----	----	6
↓	0.64 diam. B	1563	518	1035	963	----	----	----	----	----	----	6
SAE 8630	0.76 diam. B	1435	359	731	806	743	774	726	749	813	721	14
		↓	0	483	534	471	443	490	483	483	483	↓
		1011	366	738	714	744	755	700	749	768	661	14
		↓	0	462	426	457	447	523	462	462	462	↓
		738	328	656	606	644	635	593	634	624	533	14
↓	↓	↓	0	366	340	377	382	477	366	366	366	↓

[a]B means bar; S means sheet.

[b]Calculated S_p above σ_u; $S_p = \sigma_u$ used.

TABLE II.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Continued

[SI Units]

(d) Stainless steels and superalloys

Material	Specimen dimensions and type, cm (a)	σ_u, MN/m^2	S_m, MN/m^2	S_f, MN/m^2	Calculated fatigue limit, S_p, MN/m^2							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
321 stainless	0.23 × 0.51 S	594	0	214	221	----	----	----	----	----	----	8
347 stainless	0.16 × 2.54 S	621	190	380	379	----	----	----	----	----	----	9
AM 355 SCT	0.09 S	1456	593	952	987	----	----	----	----	----	----	20
AM 350 CRT	0.13 × 2.54 S	1608	0	518	543	539	504	598	518	518	518	19
			138	621	642	638	638	684	618	651	609	
			276	738	746	742	765	771	722	778	706	
			690	1139	1100	1096	1101	1031	1081	1110	985	
403 stainless	0.13 × 2.54 S	1346	345	690	747	----	----	----	----	----	----	9
PH 15-7	0.06 × 1.91 S	1387	0	545	495	518	488	558	545	545	545	16
			231	690	665	688	706	696	721	760	684	
			462	849	856	878	896	835	905	947	827	
PH 17-7	0.09 × 2.34 S	1415	0	511	502	----	----	----	----	----	----	15
Stellite 31	0.64 diam. B	849	0	290	325	----	----	----	----	----	----	17
S-816	0.64 diam. B	1014	0	380	385	----	----	----	----	----	----	17
6.3% Mo-Waspalloy	0.64 diam. B	1076	0	407	406	----	----	----	----	----	----	17
Inconel X-550	0.64 diam. B	1197	0	359	444	----	----	----	----	----	----	17
16-25-6 Timken	0.64 diam. B	828	0	359	314	----	----	----	----	----	----	17
HY-TUF	0.80 diam. B	1518	569	1035	976	----	----	----	----	----	----	6
18% Ni-Marage	1.91 diam. B	1856	466	932	932	----	----	----	----	----	----	18
18% Ni-Marage	1.91 diam. B	2022	476	952	951	----	----	----	----	----	----	18
403 stainless	0.64 diam. B	973	0	421	371	----	----	----	----	----	----	17

[a]B means bar; S means sheet.

TABLE II.- EXPERIMENTAL AND PREDICTED FATIGUE LIMITS – Concluded

[SI Units]

(e) Titanium

Material	Specimen dimensions and type, cm (a)	σ_u, MN/m^2	S_m, MN/m^2	S_f, MN/m^2	Calculated fatigue limit, S_p, MN/m^2							Reference
					Case 3	Case 1			Case 2			
						Best fit; adjusting S_o			Using experimental S_o			
					Eq. (5)	Eq. (2)	Gerber eq.	Goodman eq.	Eq. (2)	Gerber eq.	Goodman eq.	
Pure	0.15 × 3.81 S	759	176	352	378	---	---	---	---	---	---	6
Pure	0.15 × 3.81 S	918	197	393	438	---	---	---	---	---	---	6
Pure	S	828	214	428	428	---	---	---	---	---	---	6
75A	0.10 × 1.27 S	661	290	483	450	---	---	---	---	---	---	6
75A	0.10 × 1.27 S	689	306	511	473	---	---	---	---	---	---	6
Pure	0.13 × 1.27 S	679	186	311	363	---	---	---	---	---	---	6
Pure	0.13 × 1.27 S	707	248	414	425	---	---	---	---	---	---	6
C-110M	0.11 × 1.27 S	974	373	621	602	---	---	---	---	---	---	6
B120 VCA	0.10 × 1.27 S	940	193	380	442	---	---	---	---	---	---	21
2.5Al-16V	0.05 × 2.54 S	1173	0	324	352	288	258	290	324	324	324	22
↓	↓	↓	242	483	532	469	489	472	500	553	497	↓
			478	621	735	671	693	650	704	747	669	
2.5Al-16V	0.16 × 2.54 S	1111	0	345	339	321	301	349	345	345	345	22
↓	↓	↓	293	587	562	544	573	550	564	614	549	↓
			531	690	775	757	763	713	780	797	711	
2.5Al-16V	0.32 × 2.54 S	1159	0	311	349	295	289	345	311	311	311	22
↓	↓	↓	606	787	855	802	816	770	815	833	755	↓
5Al-2.5Sn	0.25 × 0.51 S	798	244	483	446	---	---	---	---	---	---	8
4Al-3Mo-1V	0.17 S	1352	566	911	839	---	---	---	---	---	---	20
4Al-3Mo-1V	0.17 S	1339	531	849	806	---	---	---	---	---	---	20
4Al-3Mo-1V	0.05 × 2.54 S	1152	0	483	348	444	425	471	483	483	483	22
↓	↓	↓	328	656	598	695	718	664	739	772	676	↓
4Al-3Mo-1V	0.16 × 2.54 S	1208	276	552	566	509	515	523	---	---	---	22
↓	↓	↓	531	690	789	733	734	711	---	---	---	↓
4Al-3Mo-1V	0.32 × 2.54 S	1194	0	345	356	345	299	352	345	345	345	22
↓	↓	↓	328	552	563	552	579	546	553	604	542	↓
6Al-4V	0.16 × 2.54 S	1145	0	345	346	321	302	355	345	345	345	22
↓	↓	↓	328	552	554	529	560	546	557	600	538	↓
			584	759	832	807	807	758	826	840	753	
6Al-4V	0.32 × 2.54 S	1145	0	345	346	324	304	359	345	345	345	22
↓	↓	↓	283	566	560	538	569	553	557	607	542	↓
			584	759	832	809	809	760	826	840	753	
6Al-4V	0.11 × 1.27 S	1145	440	704	695	722	718	709	---	---	---	23
↓	↓	↓	344	656	611	638	642	650	---	---	---	↓
6Al-4V-2Sn	0.95 diam. B	1043	342	621	589	---	---	---	---	---	---	24
6Al-4V-2Sn	0.95 diam. B	1215	398	725	670	---	---	---	---	---	---	24
6Al-4V-2Sn	0.95 diam. B	1130	380	690	639	---	---	---	---	---	---	24
6Al-4V	0.09 S	1139	538	863	786	---	---	---	---	---	---	20
6Al-4V	0.09 S	1145	524	842	773	---	---	---	---	---	---	20
6Al-4V	0.25 × 0.51 S	1141	244	483	527	---	---	---	---	---	---	8
8Al-1Mo-1V	0.13 × 2.54 S	1049	0	414	324	365	348	390	414	414	414	19
↓	↓	↓	173	518	451	492	511	498	537	574	520	↓
			414	621	654	696	707	650	739	766	667	
13V-11CR-3Al	0.25 × 0.51 S	1377	275	545	593	---	---	---	---	---	---	8

[a]B means bar; S means sheet.

TABLE III.- RESULTS OF SPECIAL FATIGUE TESTS

Material	σ_u, ksi (MN/m^2)	Predicted by eq. (3)		Experimental			S_o, ksi (MN/m^2) (used in eq. (3))
		S_m, ksi (MN/m^2)	S_a, ksi (MN/m^2)	S_m, ksi (MN/m^2)	S_a, ksi (MN/m^2)	Fatigue cycles applied	
2024-T81 (Clad)	64.6 (446)	55 (380)	9.6 (66)	55 (380)	8 (55)	4 058 170 run-out	13 (90) estimated
2618 (Clad)	59.0 (407)	50 (345)	9.0 (62)	50 (345)	8 (55)	2 505 000 run-out	12 (83) estimated
				45 (311)	13 (90)	169 000 failed	
AM 350 CRT	223.0 (1549)	169 (1168)	54.0 (373)	180 (1242)	42 (290)	4 001 000 run-out	70 (483) estimated
				175 (1208)	47 (324)	312 000 failed	
				170 (1171)	52 (359)	183 000 failed	

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