# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE 2085

## STRESS-STRAIN AND ELONGATION GRAPHS FOR ALUMINUM-ALLOY 75S-T6 SHEET

By James A. Miller

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## SUMMARY

Results of tests on duplicate longitudinal and transverse specimens of aluminum-alloy 75S-T6 sheets with nominal thicknesses of 0.032, 0.064, and 0.125 inch are presented in the following form:

Tensile and compressive stress-strain graphs and stress-deviation graphs to a strain of about 1 percent

Graphs of tangent modulus against stress, in compression

Auxiliary graphs for estimating plastic buckling stress

Stress-strain graphs for tensile specimens tested to failure

Graphs of local elongation and of elongation against gage length for tensile specimens tested to fracture

The stress-strain, stress-deviation, tangent-modulus, and auxiliary graphs are plotted on a dimensionless basis to make them applicable to material with yield strengths which differ from those of the test specimens.

## INTRODUCTION

The present report is the fifth of a series presenting data on high-strength aluminum-alloy sheet (references 1 to 4). The data are presented in tables and graphs. Graphs of reduced modulus against stress in compression for a rectangular section have been omitted in this report since the tangent modulus is now considered best for use in determining the buckling strength of members in the inelastic range (reference 5). In their place auxiliary curves for estimating plastic buckling stress based upon the values of tangent modulus are given. An example illustrating the use of these curves was given in reference 6. The graphs are presented in dimensionless form to make them applicable to sheets of these materials with yield strengths which differ from those of the test specimens. All data are given for duplicate specimens.

The report gives the results of tests on aluminum-alloy 75S-T6 sheet, in thicknesses of 0.032, 0.064, and 0.125 inch, obtained from the Aluminum Company of America.

The author expresses his appreciation to Mr. P. L. Peach and Mrs. P. V. Jacobs who assisted in the testing and in the preparation of the graphs.

This investigation, conducted at the National Bureau of Standards, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

## MATERIAL

The sheets were of aluminum alloy 75S in the heat-treated (T6) condition as furnished by the manufacturer.

## DIMENSIONLESS DATA

### Test Procedure

Tensile tests were made on two longitudinal (in direction of rolling) specimens and on two transverse (at right angles to the direction of rolling) specimens from a sheet of each thickness. The specimens corresponded to specimens of type 5 described in reference 7.

The specimens were tested in a beam-and-poise, screw-type, testing machine of 50-kip capacity with the use of the poise for the 5-kip range. They were held in Templin grips. The strain was measured with a pair of 1-inch Tuckerman optical strain gages attached to opposite sheet faces of the reduced section. The rate of loading was about 2 ksi per minute.

Compressive tests were made on two longitudinal and two transverse specimens from each sheet. The specimens were rectangular strips 0.50 inch wide by 2.25 inches long with the exception of the 0.125-inch-thick transverse specimens which were made 0.475 inch wide.

The compressive specimens were tested between hardened-steel bearing blocks in the subpress described in reference 8. The loads were applied by the testing machine that was used for the tensile tests. Lateral support against premature buckling was furnished by lubricated solid guides as described in reference 9. The strain was measured with a pair of 1-inch Tuckerman optical strain gages attached to opposite edge faces of the specimen. The rate of loading was about 2 ksi per minute.

## Test Results

The results of the tensile and compressive tests are given in table I. Each value of Young's modulus in the table was taken as the slope of a least-squares straight line fitted to the lower part of the stress-strain curve. The yield strengths determined by the offset method were obtained from the stress-strain curves and the experimental values of Young's modulus. The yield strengths determined by the secant method were obtained from the stress-strain curves and values of secant modulus 0.7 and 0.85 times the experimental values of Young's modulus.

## Stress-Strain Graphs

The stress-strain graphs are plotted in dimensionless form in figures 1 to 6. The coordinates $\sigma$ and $\epsilon$ in these graphs are defined by

$$\sigma = \frac{s}{s_1}$$

$$\epsilon = \frac{eE}{s_1}$$

where

$s$ stress corresponding to strain $e$

$s_1$ secant yield strength (0.7E)

$E$ Young's modulus

Composite dimensionless stress-strain graphs which show the bands within which the data fall for tests of a given kind and a given direction in the sheet are shown in figures 7 and 8. The maximum width of band in terms of $\sigma$ is less than 0.015. Each band represents data for six specimens; the widths might have been greater if tests had been made on a larger number of specimens.

## Stress-Deviation Graphs

Dimensionless stress-deviation graphs are shown in figures 9 to 14. The ordinates are the same as those used for the stress-strain graphs. The abscissas are the corresponding values of $\delta = \epsilon - \sigma$. All the curves intersect at the point $\sigma = 1$, $\delta = 3/7$, which corresponds to the secant yield strength (0.7E). This point is indicated on the graphs by a short vertical line.

The graphs were plotted on log-log paper to indicate which portion of the stress-strain curves can be represented by the analytical expression given in reference 10:

$$e = \frac{s}{E} + K\left(\frac{s}{E}\right)^n$$

This expression holds when the plot of deviation against stress on logarithmic paper follows a straight line. (See reference 10.) The graphs indicate that the relationship holds for the compressive specimens and for the longitudinal tensile specimens for values of $s/s_1 > s_2/s_1$, where $s_2$ is the secant yield strength (0.85E). For these, the ratios $s_1/s_2$, given in table I, can be used to obtain values of the shape parameter $n$ as shown in reference 10. Other straight lines can be drawn on these graphs from which values of the constants $K$ and $n$ can be obtained for analytical expressions which fit more closely other parts of the stress-strain graphs.

## Tangent-Modulus Graphs

Dimensionless graphs of tangent modulus against stress for the compressive specimens are shown in figures 15 to 20. The ordinates are the ratios of tangent modulus $E_t$ to Young's modulus. Each value of tangent modulus was taken as the ratio of a stress increment to its strain increment for the successive pairs of points shown in the stress-strain graphs. The abscissas are the mean values of $\sigma$ for the stress increments. The values of $E_t/E$ increased with $\sigma$ up to $\sigma$ equal to 0.5 or 0.6. The initial modulus values are lower than the average value for this region and approach the modulus of elasticity in tension.

The limits within which the tangent-modulus curves fell are shown in figure 21. The maximum spread in values of $E_t/E$ is 0.075. An example of the use of the graphs of tangent modulus against stress is given in reference 6.

Auxiliary Graphs for Estimating Plastic Buckling Stress

Dimensionless graphs for estimating plastic buckling stresses are shown in figures 22 to 24. The ordinates are ratios of $E_t/E$ to $\sigma$ and the abscissas are the corresponding values of $\sigma$.

The limits of the dimensionless graphs for estimating plastic buckling stresses are shown in figure 25. An example of the use of these graphs is given in reference 6.

## TENSILE STRESS-STRAIN TESTS TO FAILURE

### Procedure

Tensile tests to failure were made on two longitudinal and two transverse specimens from a sheet of each thickness. The specimens corresponded to specimens of type 5 described in reference 7.

The tests were made in fluid-support, Bourdon tube, hydraulic testing machines having Tate-Emery load indicators. The specimens were held in Templin grips. They were tested at a cross-head speed of about 0.1 inch per minute. Autographic load-extension curves were obtained with a Templin type stress-strain recorder by using a Peters averaging total-elongation extensometer with a 2-inch gage length and a magnification factor of 25.

Stresses based on the original cross section and the corresponding strains based on the original gage length were determined from these curves. The data for the portion at and beyond the knee of each curve were combined with stress-strain data on duplicate specimens on which strain up to the knee of the curve had been measured with Tuckerman optical strain gages.

### Stress-Strain Graphs

The resulting stress-strain curves are shown in figures 26 to 28. Values of tensile strength and of elongation in 2 inches are given in the tables accompanying each figure. The values of elongation usually corresponded to a strain of about 0.009 less than the maximum recorded strain under load.

## LOCAL-ELONGATION TESTS

### Procedure

Photogrid measurements (reference 11) were made on two longitudinal and two transverse tensile specimens from a sheet of each thickness. The specimens corresponded to specimens of type 5 described in reference 7. The photogrid negative was made from the master grid described in reference 1. The specimens were coated with cold top enamel. This has been found to be less critical with respect to exposure time than the photoengraving glue mentioned in reference 11. The prints were also usually easier to measure near the fracture. The specimens were held in Templin grips and were fractured in a testing machine at a cross-head speed of about 0.1 inch per minute.

Measurements of grid spacing were made by the technique described in reference 1 except that a measuring engine having a microscope with magnification of about 100 diameters was used. The instrument was read to 0.001 millimeter (1 division on the barrel).

### Graphs of Local Elongation

The local elongations, in percent of the original spacing, plotted against the distance before testing from one end of the gage length, are shown in figures 29 to 34. The fracture in each case occurred in the grid spacing in which the greatest elongation took place.

### Graphs of Elongation Against Gage Length

The elongations in percent of the original gage length were computed for various gage lengths from the local-elongation data. These values are plotted against gage length in figures 35 to 40. The gage lengths were plotted to a logarithmic scale to present a large range of values on a single graph.

National Bureau of Standards
Washington, D. C., February 3, 1948

REFERENCES

1. Miller, James A.: Stress-Strain and Elongation Graphs for Aluminum Alloy R301 Sheet. NACA TN 1010, 1946.

2. Miller, James A.: Stress-Strain and Elongation Graphs for Alclad Aluminum-Alloy 75S-T Sheet. NACA TN 1385, 1947.

3. Miller, James A.: Stress-Strain and Elongation Graphs for Alclad Aluminum-Alloy 24S-T Sheet. NACA TN 1512, 1948.

4. Miller, James A.: Stress-Strain and Elongation Graphs for Alclad Aluminum-Alloy 24S-T81 Sheet. NACA TN 1513, 1948.

5. Shanley, F. R.: Inelastic Column Theory. Jour. Aero. Sci., vol. 14, no. 5, May 1947, pp. 261-267.

6. Ramberg, Walter, and Miller, James A.: Determination and Presentation of Compressive Stress-Strain Data for Thin Sheet Metal. Jour. Aero. Sci., vol. 13, no. 11, Nov. 1946, pp. 569-580.

7. Anon.: General Specification for Inspection of Metals. Federal Specification QQ-M-151a, Federal Standard Stock Catalog, sec. IV, pt. 5, Nov. 27, 1936.

8. Aitchison, C. S., and Miller, James A.: A Subpress for Compressive Tests. NACA TN 912, 1943.

9. Miller, James A.: A Fixture for Compressive Tests of Thin Sheet Metal between Lubricated Steel Guides. NACA TN 1022, 1946.

10. Ramberg, Walter, and Osgood, William R.: Description of Stress-Strain Curves by Three Parameters. NACA TN 902, 1943.

11. Brewer, Given A., and Glassco, Robert B.: Determination of Strain Distribution by the Photo-Grid Process. Jour. Aero. Sci., vol. 9, no. 1, Nov. 1941, pp. 1-7.

TABLE I.— RESULTS OF TENSILE AND COMPRESSIVE TESTS ON ALUMINUM-ALLOY 75S-T6 SHEET

| Specimen | Test | Direction | Thickness (in.) | Young's modulus, E (ksi) | Yield strength: Offset method (Offset = 0.2 percent) (ksi) | Yield strength: Secant method $s_1$ (0.7E) (ksi) | Yield strength: Secant method $s_2$ (0.85E) (ksi) | $s_1/s_2$ | Tensile Strength (ksi) | Elongation in 2 in. (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| 032-T1L | Tensile | Longitudinal | 0.0312 | 10,490 | 77.3 | 77.8 | 76.7 | 1.014 | 85.3 | 13.0 |
| 032-T2L | ----do----- | -----do----- | .0311 | 10,370 | 77.4 | 77.9 | 77.0 | 1.011 | 85.3 | 12.0 |
| 032-T1T | ----do----- | Transverse | .0312 | 10,370 | 71.0 | 72.9 | 68.3 | 1.067 | 83.3 | 11.5 |
| 032-T2T | ----do----- | -----do----- | .0311 | 10,390 | 71.1 | 72.9 | 68.2 | 1.069 | 83.2 | 12.0 |
| 032-C1L | Compressive | Longitudinal | .0311 | 10,650 | 72.4 | 74.9 | 69.0 | 1.085 | ---- | ---- |
| 032-C2L | ----do----- | -----do----- | .0312 | 10,650 | 72.6 | 75.1 | 69.2 | 1.086 | ---- | ---- |
| 032-C1T | ----do----- | Transv-rse | .0312 | 10,640 | 77.3 | 79.3 | 75.2 | 1.054 | ---- | ---- |
| 032-C2T | ----do----- | -----do----- | .0311 | 10,610 | 77.4 | 79.3 | 75.3 | 1.053 | ---- | ---- |
| 064-T1L | Tensile | Longitudinal | .0640 | 10,360 | 75.8 | 76.3 | 75.1 | 1.015 | 83.7 | 9.5 |
| 064-T2L | ----do----- | -----do----- | .0640 | 10,320 | 74.9 | 75.2 | 74.2 | 1.014 | 82.5 | 9.5 |
| 064-T1T | ----do----- | Transverse | .0640 | 10,390 | 71.3 | 72.9 | 68.7 | 1.062 | 82.5 | 10.0 |
| 064-T2T | ----do----- | -----do----- | .0639 | 10,410 | 72.7 | 74.3 | 70.1 | 1.061 | 83.7 | 11.0 |
| 064-C1L | Compressive | Longitudinal | .0640 | 10,630 | 70.0 | 71.9 | 67.1 | 1.070 | ---- | ---- |
| 064-C2L | ----do----- | -----do----- | .0640 | 10,640 | 70.9 | 72.8 | 68.1 | 1.069 | ---- | ---- |
| 064-C1T | ----do----- | Transverse | .0640 | 10,620 | 76.1 | 77.8 | 74.2 | 1.049 | ---- | ---- |
| 064-C2T | ----do----- | -----do----- | .0639 | 10,660 | 78.2 | 80.1 | 76.4 | 1.049 | ---- | ---- |
| 125-T1L | Tensile | Longitudinal | .1335 | 10,330 | 78.2 | 78.7 | 77.6 | 1.015 | 85.0 | 11.0 |
| 125-T2L | ----do----- | -----do----- | .1335 | 10,320 | 77.8 | 78.3 | 77.2 | 1.015 | 85.1 | 11.0 |
| 125-T1T | ----do ---- | Transverse | .1334 | 10,310 | 73.4 | 75.3 | 70.9 | 1.062 | 84.4 | 10.5 |
| 125-T2T | ----do----- | -----do----- | .1334 | 10,270 | 74.0 | 75.9 | 71.4 | 1.063 | 84.8 | 11.5 |
| 125-C1L | Compressive | Longitudinal | .1335 | 10,570 | 74.7 | 77.2 | 71.9 | 1.073 | ---- | ---- |
| 125-C2L | ----do----- | -----do----- | .1334 | 10,580 | 75.0 | 77.5 | 72.2 | 1.073 | ---- | ---- |
| 125-C1T | ----do----- | Transverse | .1336 | 10,550 | 80.3 | 82.3 | 78.6 | 1.047 | ---- | ---- |
| 125-C2T | ----do----- | -----do----- | .1334 | 10,560 | 80.0 | 81.9 | 78.3 | 1.046 | ---- | ---- |

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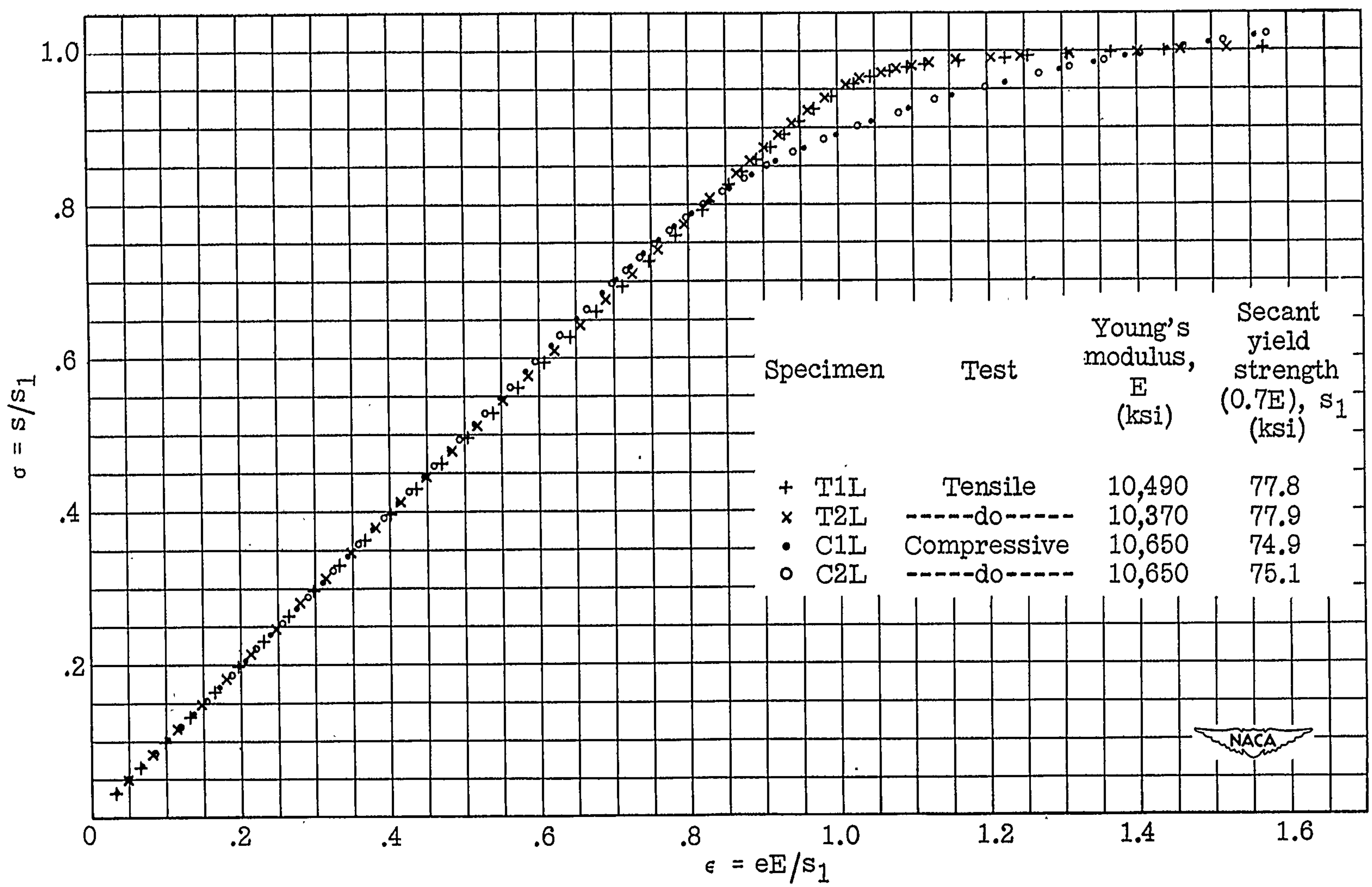


Figure 1.- Dimensionless stress-strain graphs. 75S-T6 sheet, longitudinal specimens 0.032 inch thick.

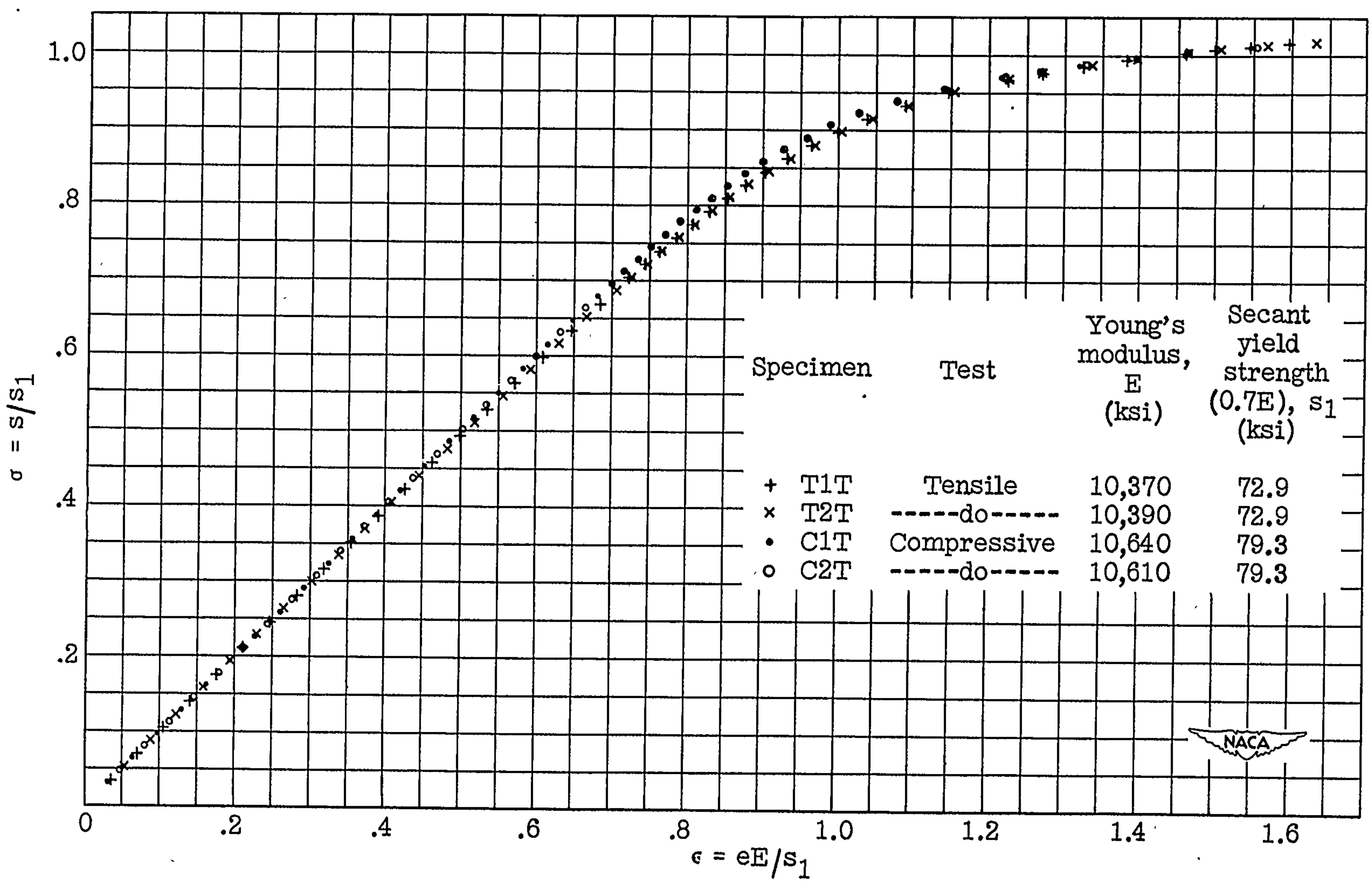


Figure 2.- Dimensionless stress-strain graphs. 75S-T6 sheet, transverse specimens 0.032 inch thick.

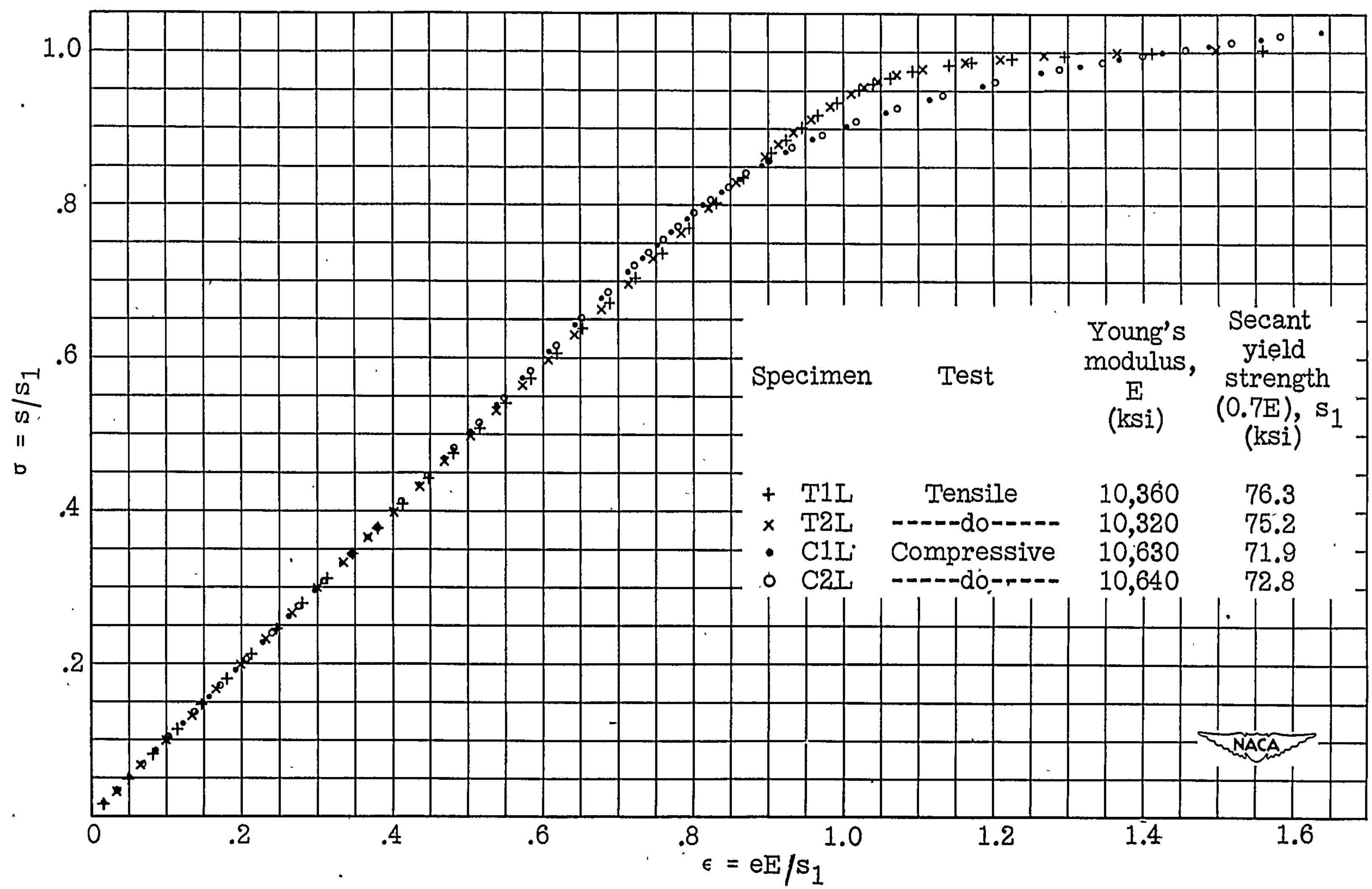


Figure 3.- Dimensionless stress-strain graphs. 75S-T6 sheet, longitudinal specimens 0.064 inch thick.

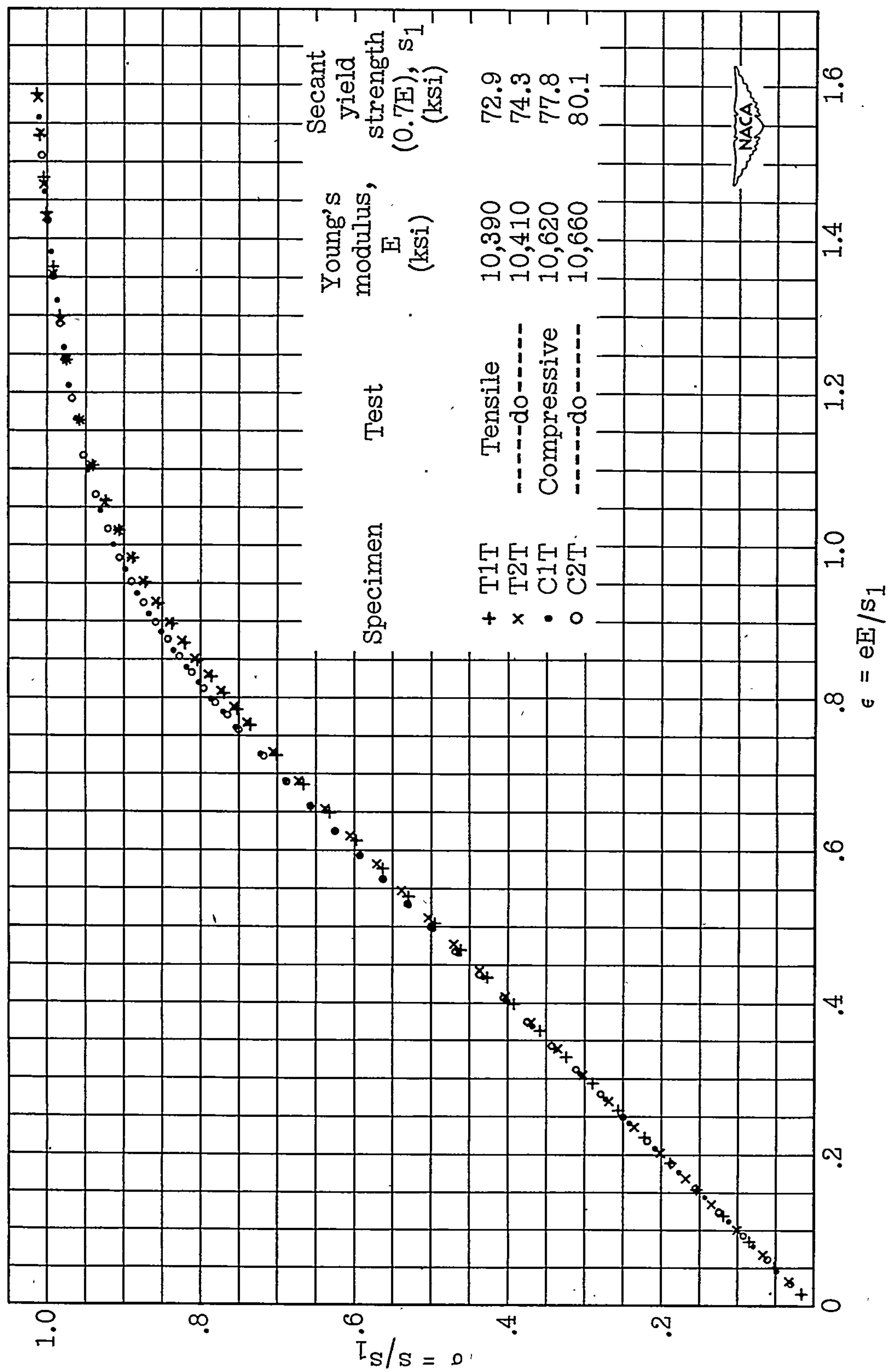


Figure 4.- Dimensionless stress-strain graphs. 75S-T6 sheet, transverse specimens 0.064 inch thick.

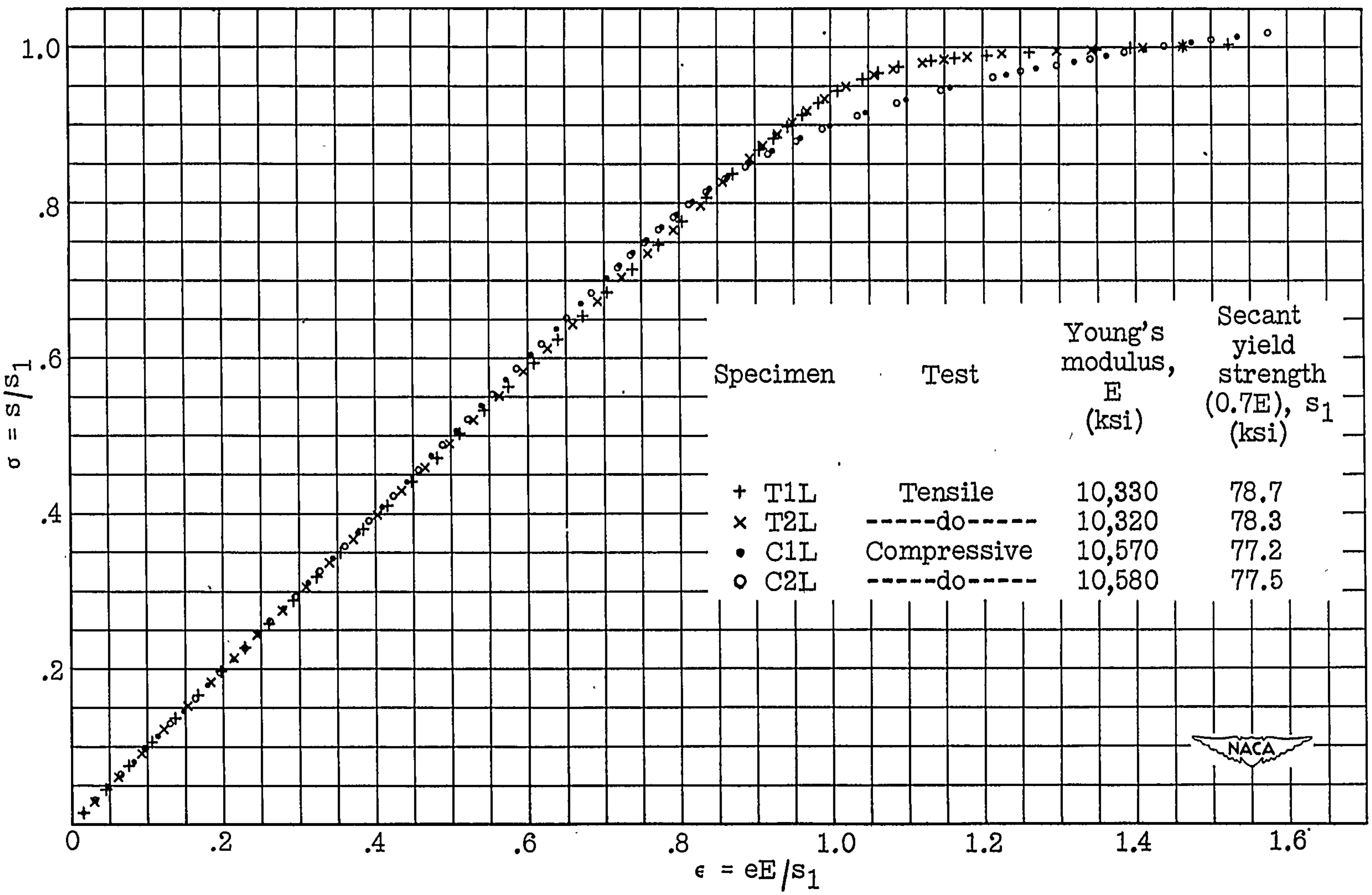


Figure 5.- Dimensionless stress-strain graphs. 75S-T6 sheet, longitudinal specimens 0.125 inch thick.

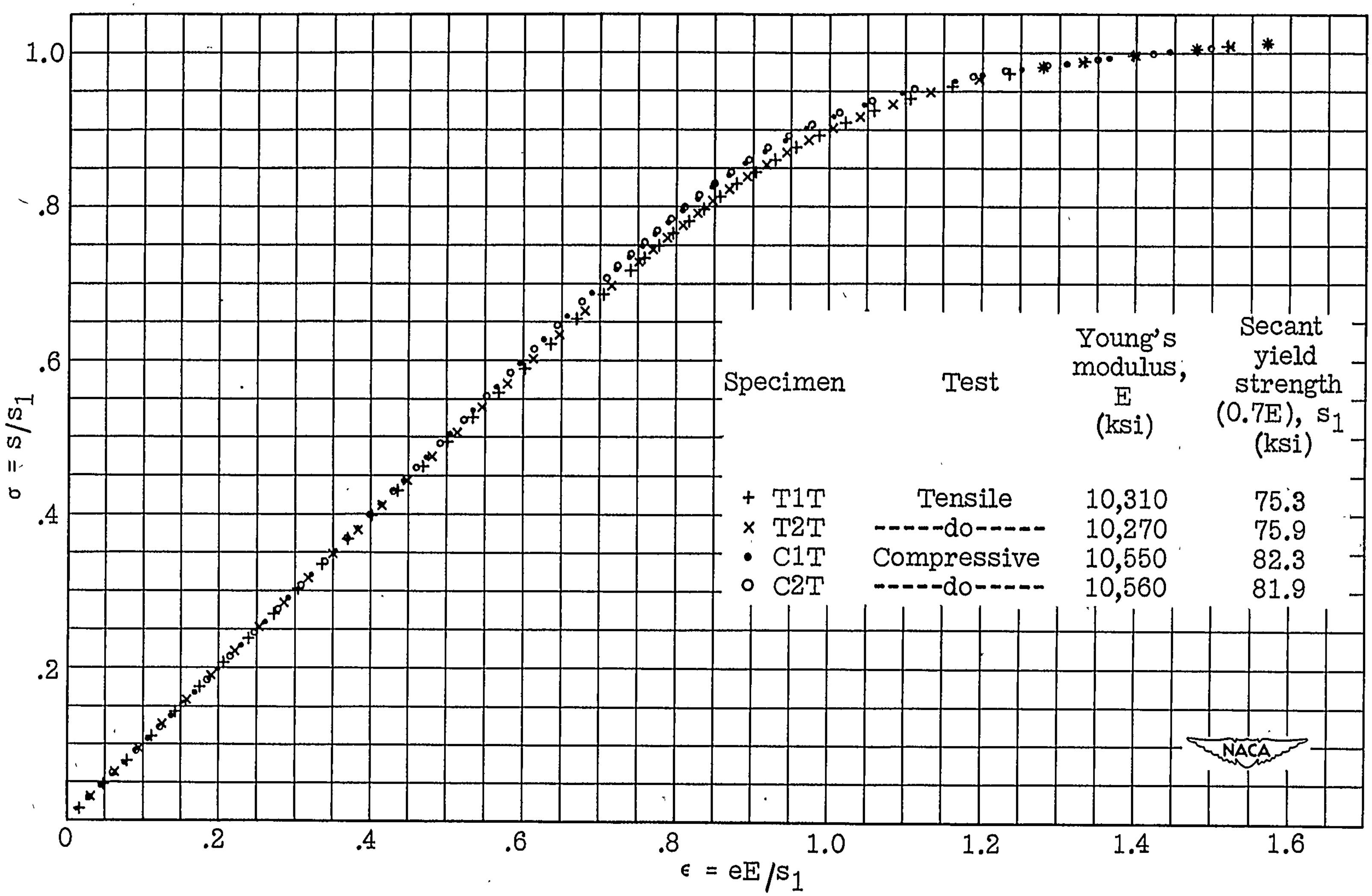


Figure 6.- Dimensionless stress-strain graphs. 75S-T6 sheet, transverse specimens 0.125 inch thick.

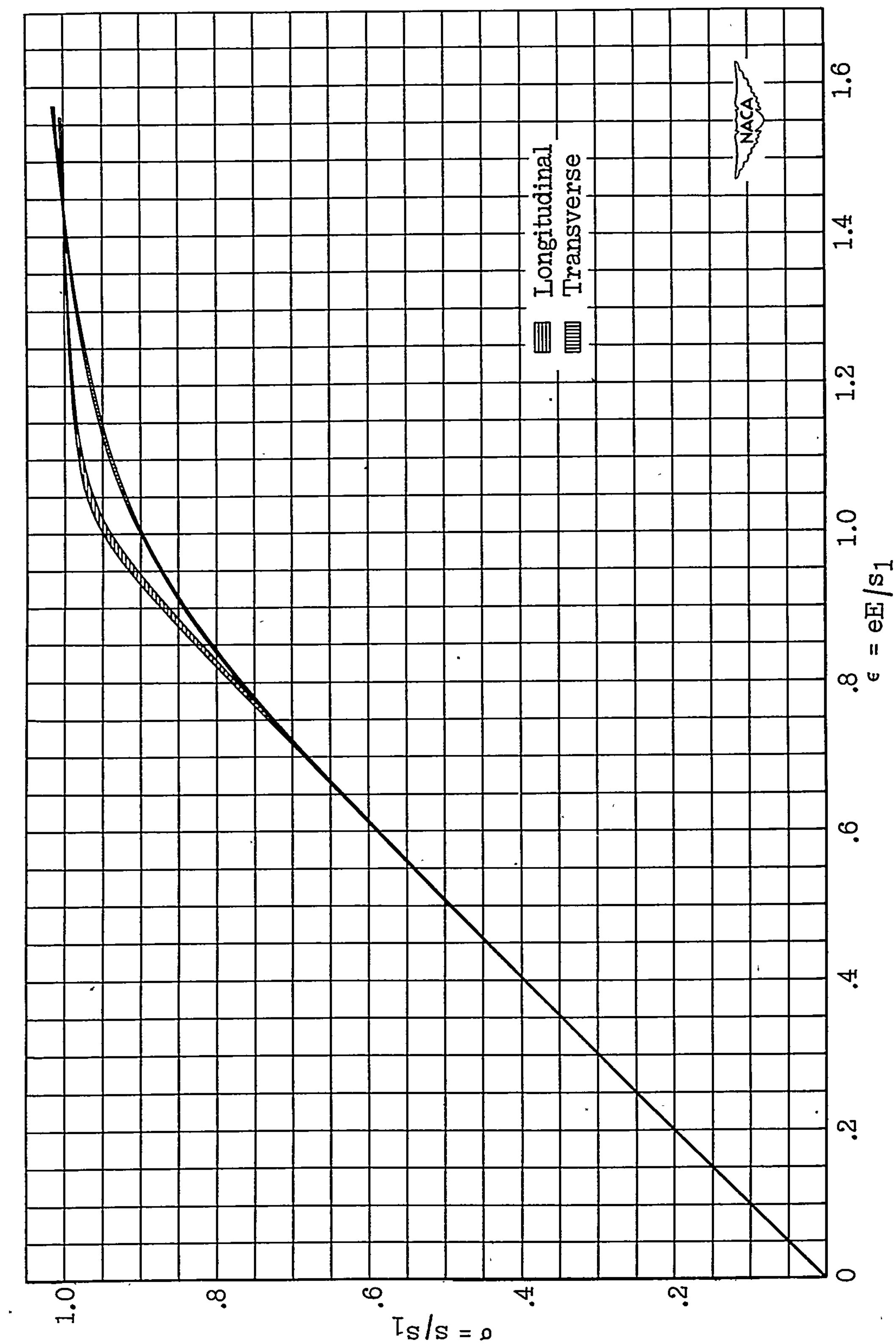


Figure 7.- Limits of dimensionless tensile stress-strain graphs. 75S-T6 sheet 0.032, 0.064, and 0.125 inch thick.

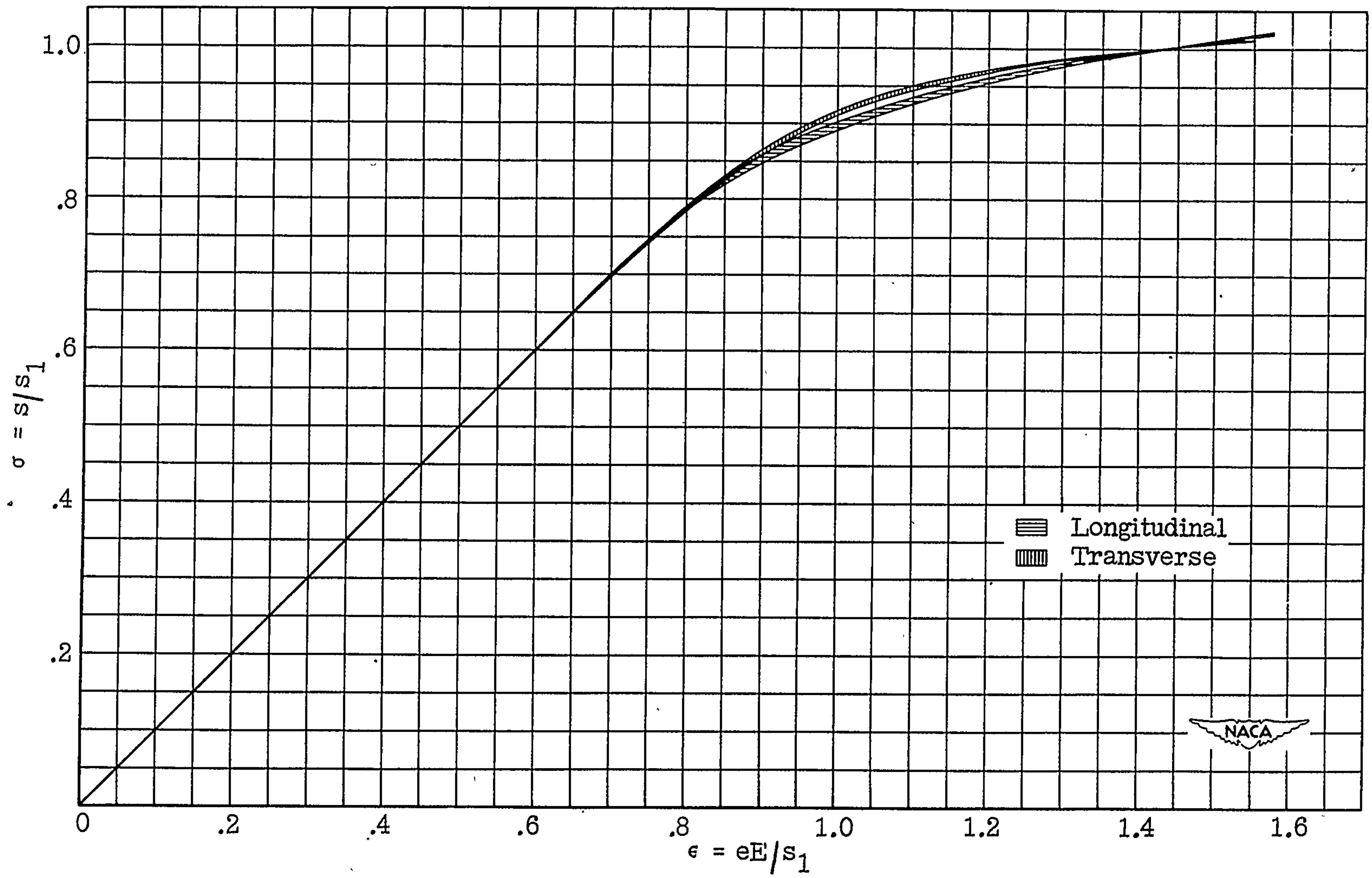


Figure 8.- Limits of dimensionless compressive stress-strain graphs. 75S-T6 sheet 0.032, 0.064, and 0.125 inch thick.

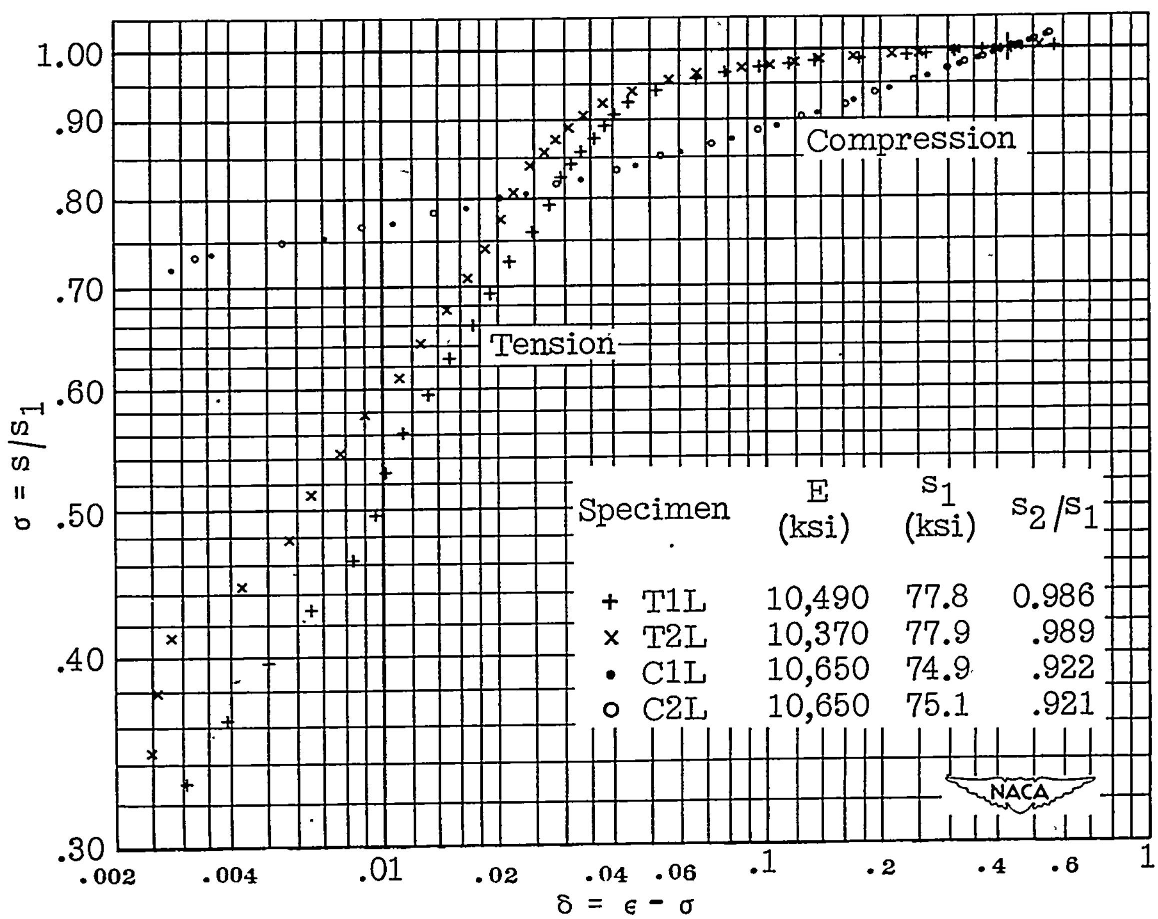


Figure 9.- Dimensionless stress-deviation graphs. 75S-T6 sheet, longitudinal specimens 0.032 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7E); $s_2$, secant yield strength (0.85E).

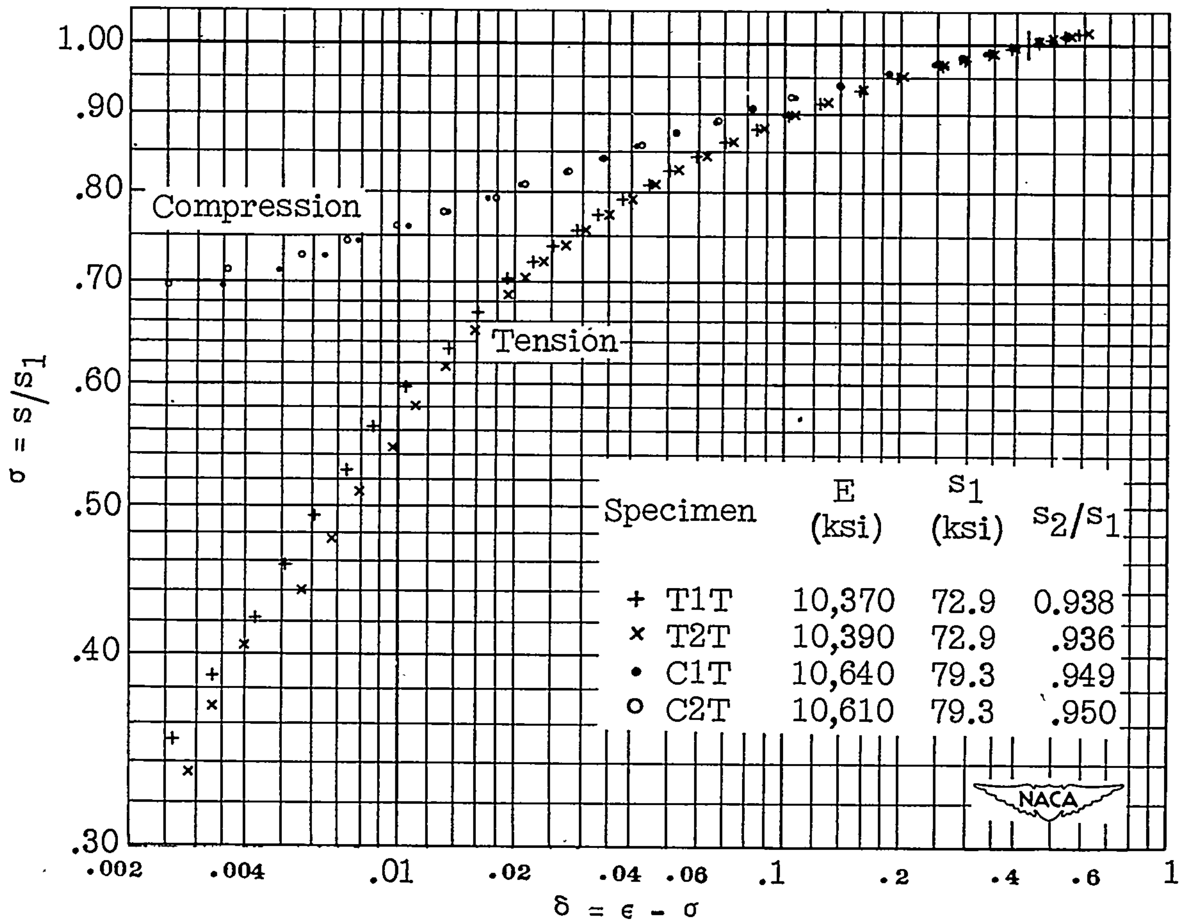


Figure 10.- Dimensionless stress-deviation graphs. 75S-T6 sheet, transverse specimens 0.032 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7E); $s_2$, secant yield strength (0.85E).

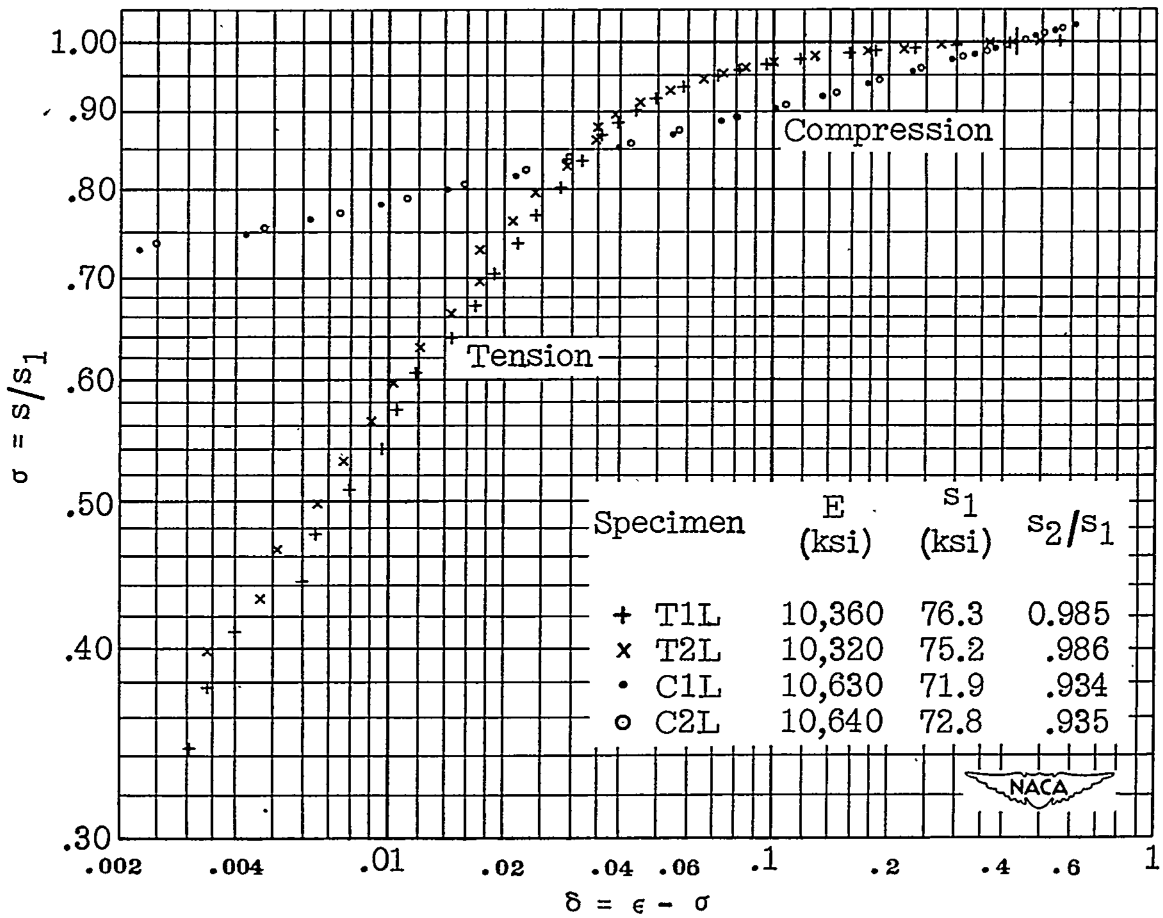


Figure 11.- Dimensionless stress-deviation graphs. 75S-T6 sheet, longitudinal specimens 0.064 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7E); $s_2$, secant yield strength (0.85E).

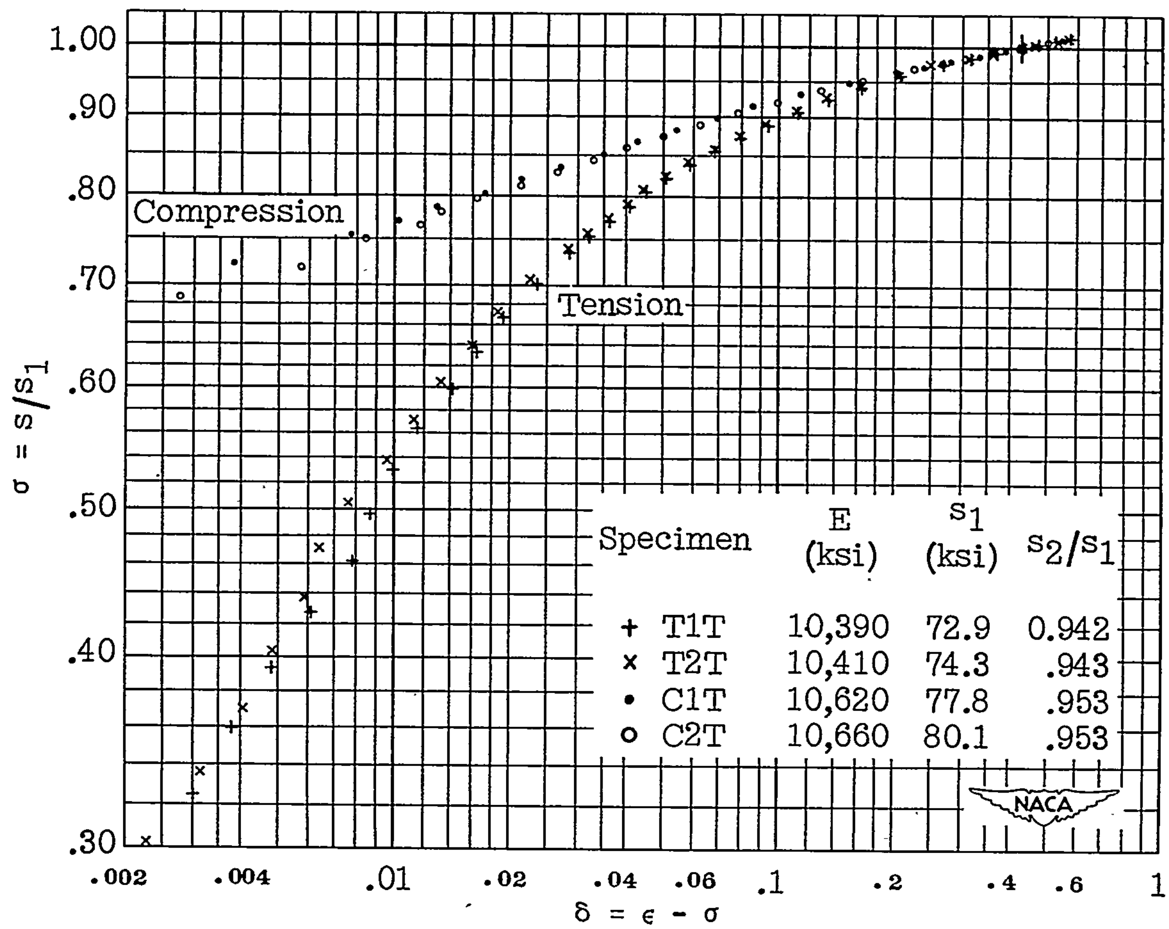


Figure 12.- Dimensionless stress-deviation graphs. 75S-T6 sheet, transverse specimens 0.064 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7E); $s_2$, secant yield strength (0.85E).

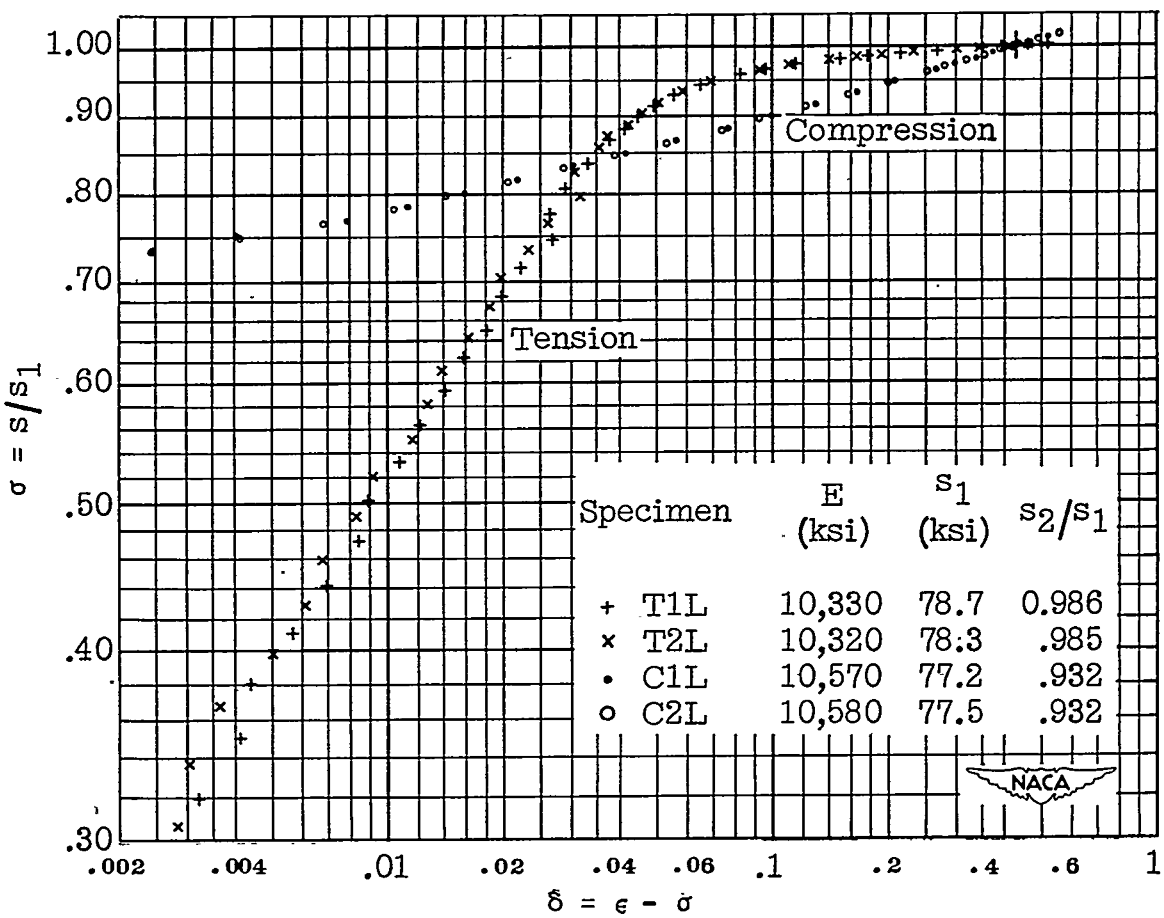


Figure 13.- Dimensionless stress-deviation graphs. 75S-T6 sheet, longitudinal specimens 0.125 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7E); $s_2$, secant yield strength (0.85E).

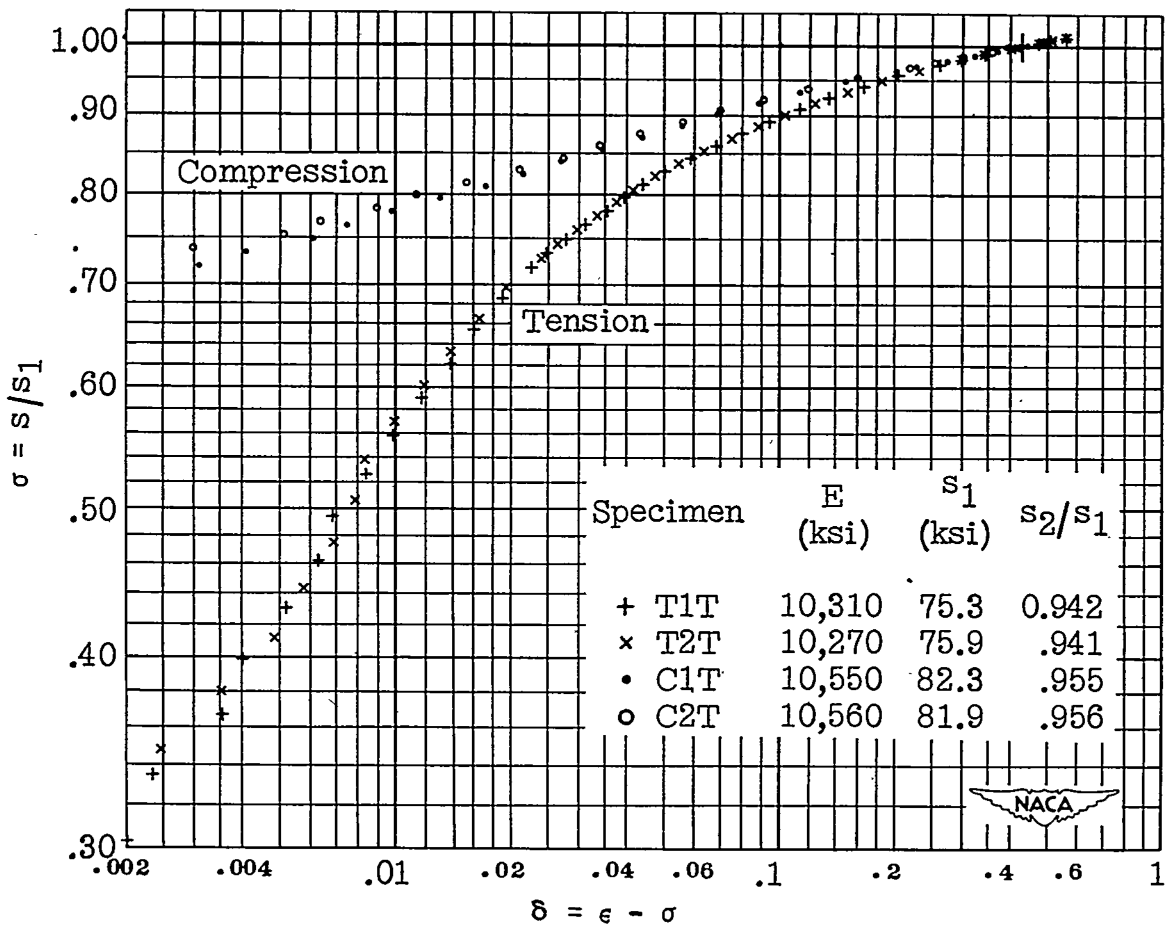


Figure 14.- Dimensionless stress-deviation graphs. 75S-T6 sheet, transverse specimens 0.125 inch thick. E, Young's modulus; $s_1$, secant yield strength (0.7E); $s_2$, secant yield strength (0.85E).

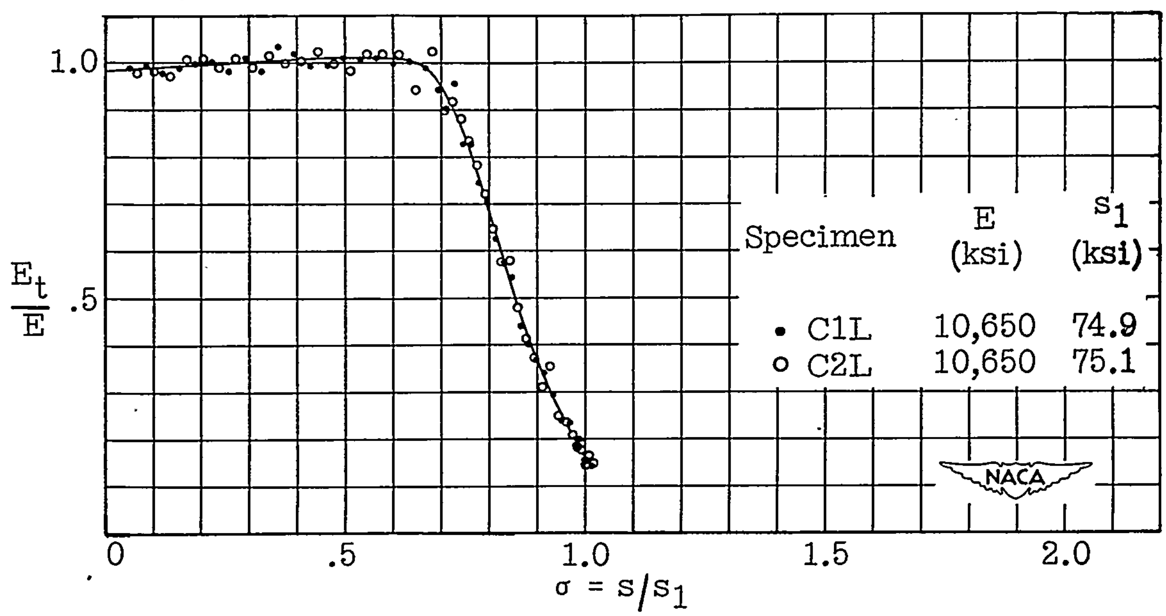


Figure 15.- Dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet, longitudinal specimens 0.032 inch thick.

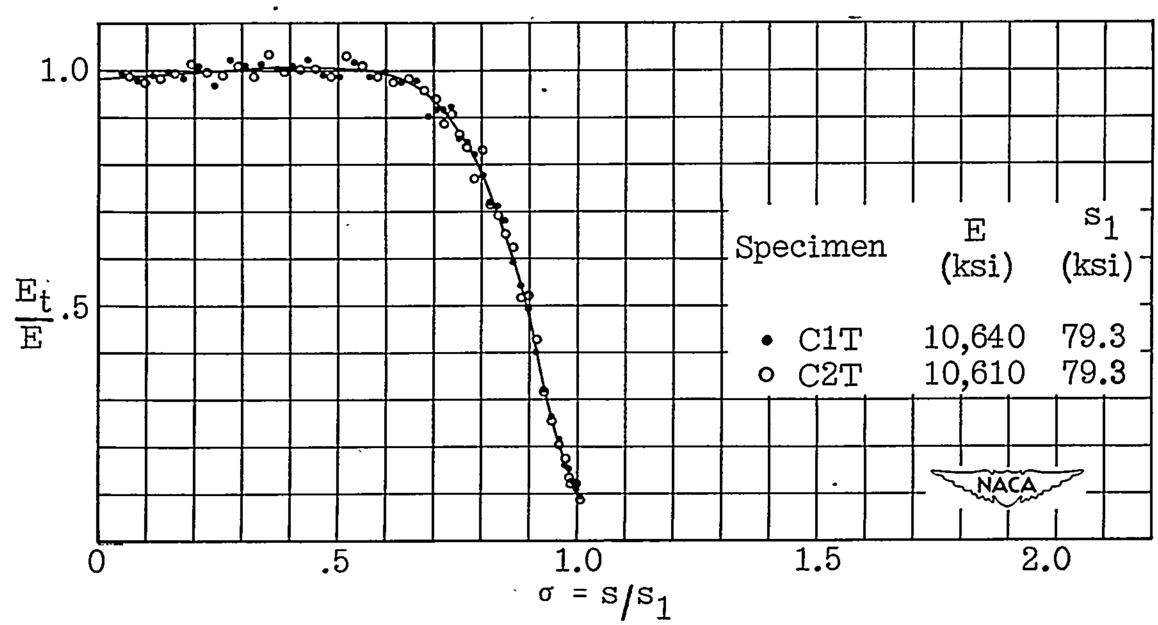


Figure 16.- Dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet, transverse specimens 0.032 inch thick.

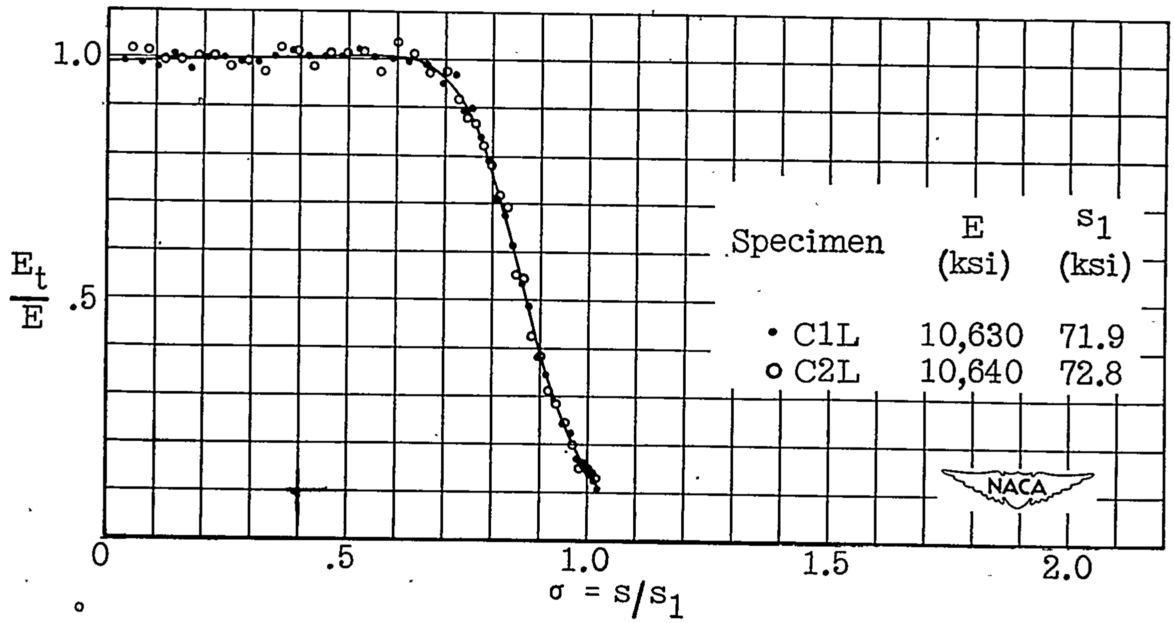


Figure 17.- Dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet, longitudinal specimens 0.064 inch thick.

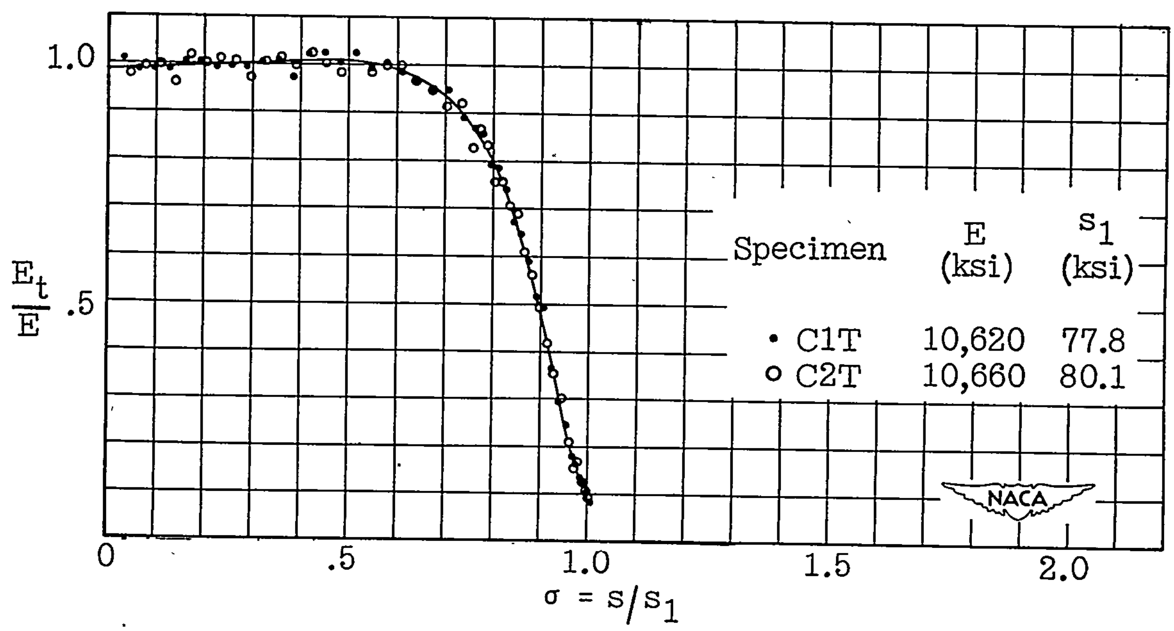


Figure 18.- Dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet, transverse specimens 0.064 inch thick.

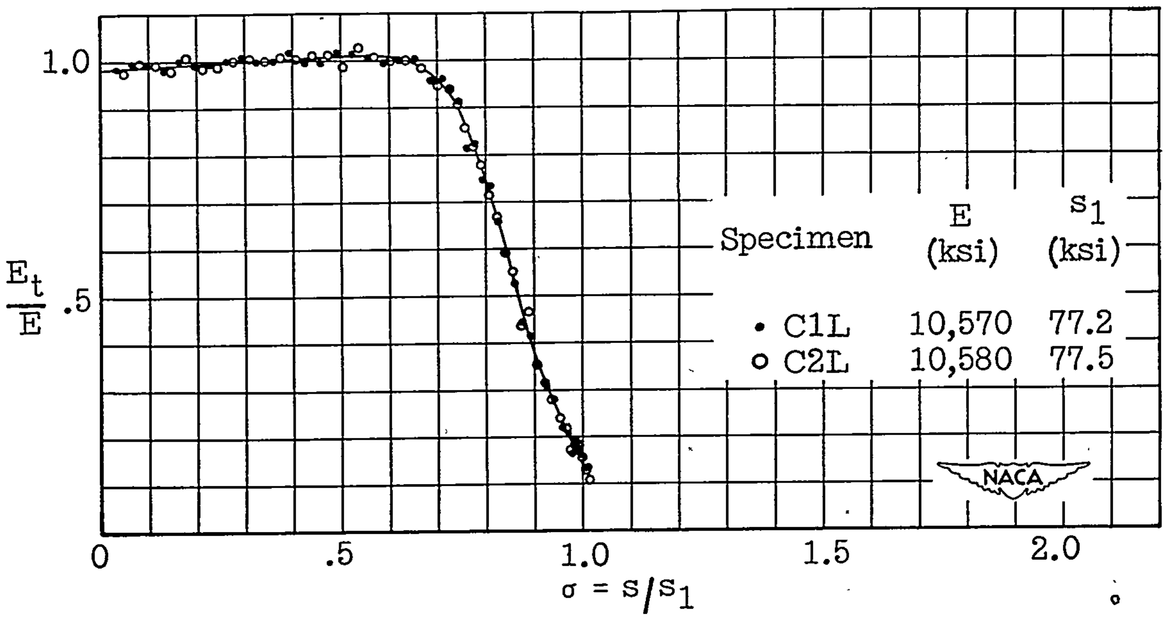


Figure 19.- Dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet, longitudinal specimens 0.125 inch thick.

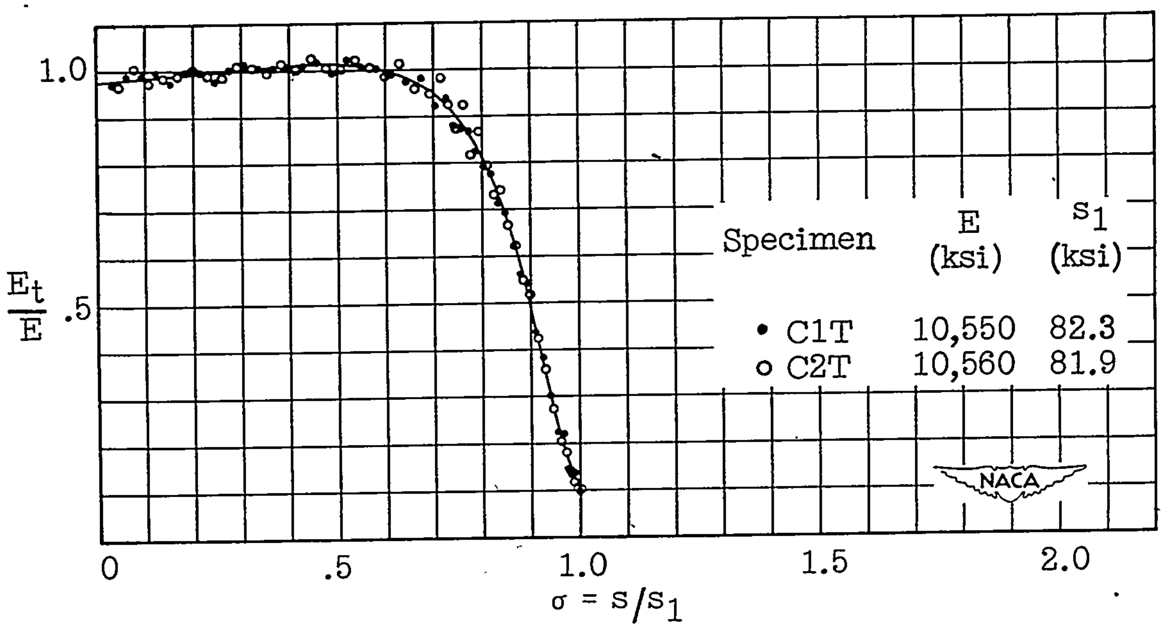


Figure 20.- Dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet, transverse specimens 0.125 inch thick.

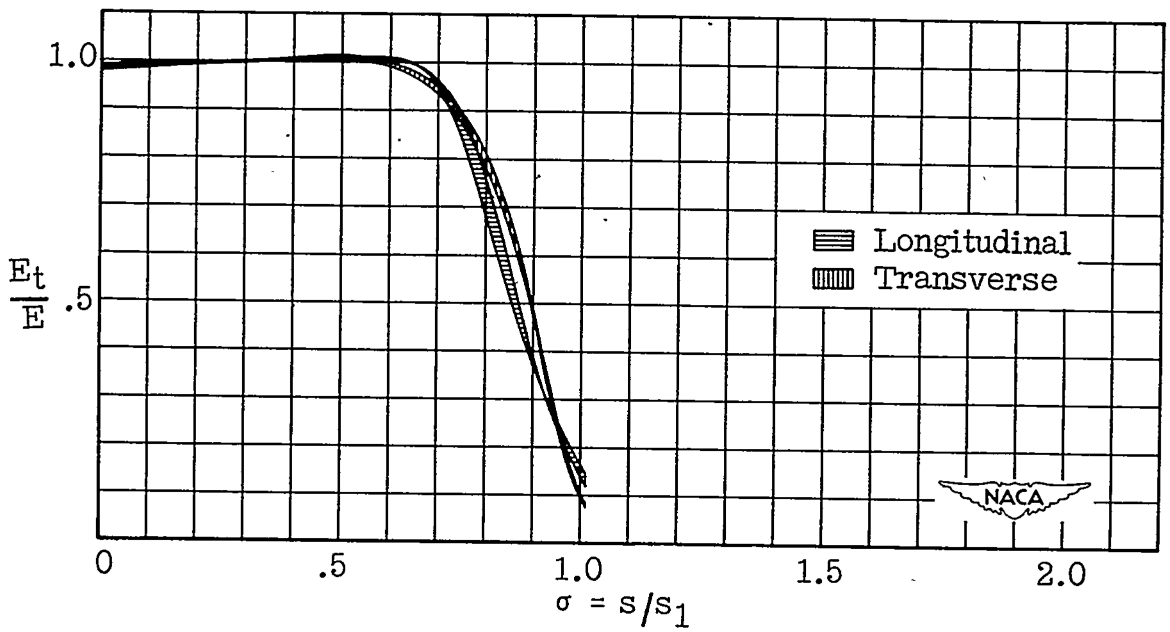


Figure 21.- Limits of dimensionless compressive graphs of tangent modulus against stress. 75S-T6 sheet 0.032, 0.064, and 0.125 inch thick.

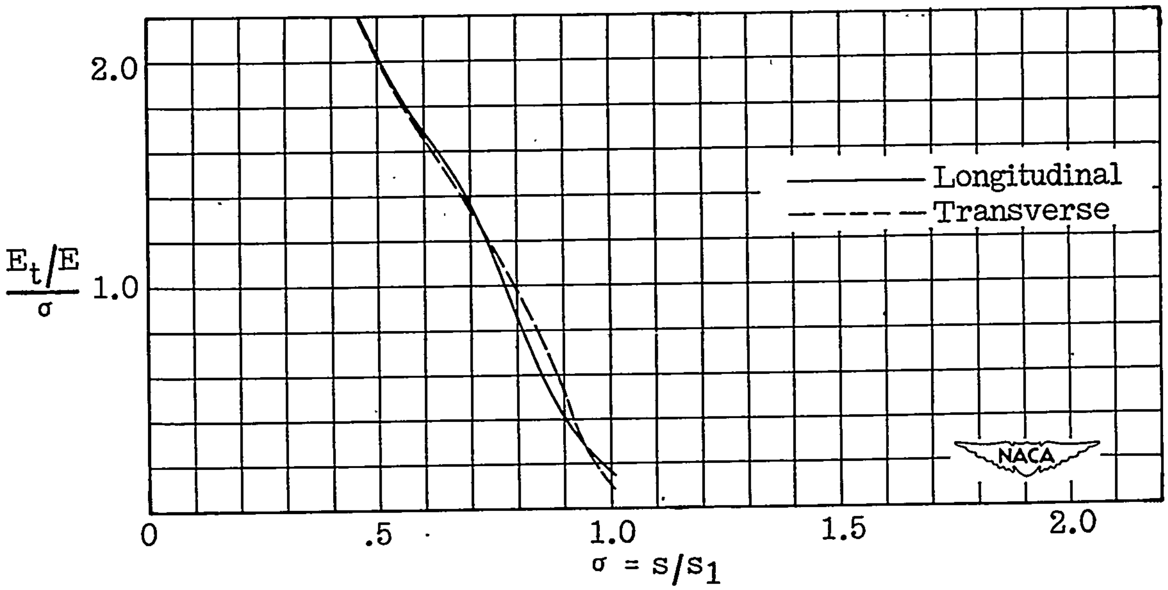


Figure 22.- Auxiliary dimensionless curves for estimating plastic buckling stress. 75S-T6 sheet 0.032 inch thick.

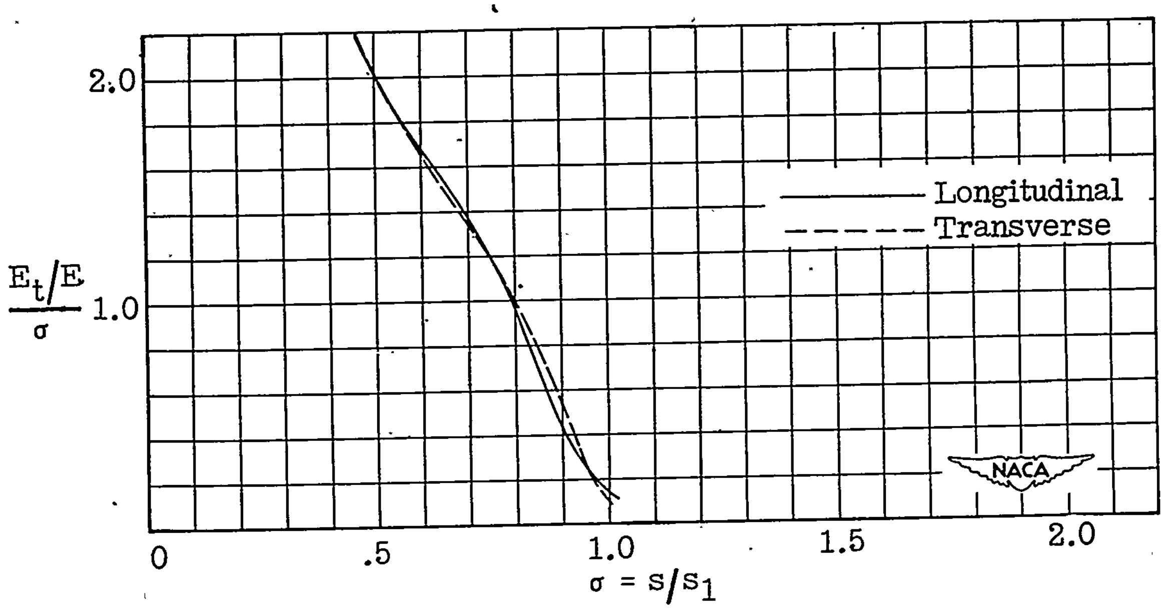


Figure 23.- Auxiliary dimensionless curves for estimating plastic buckling stress. 75S-T6 sheet 0.064 inch thick.

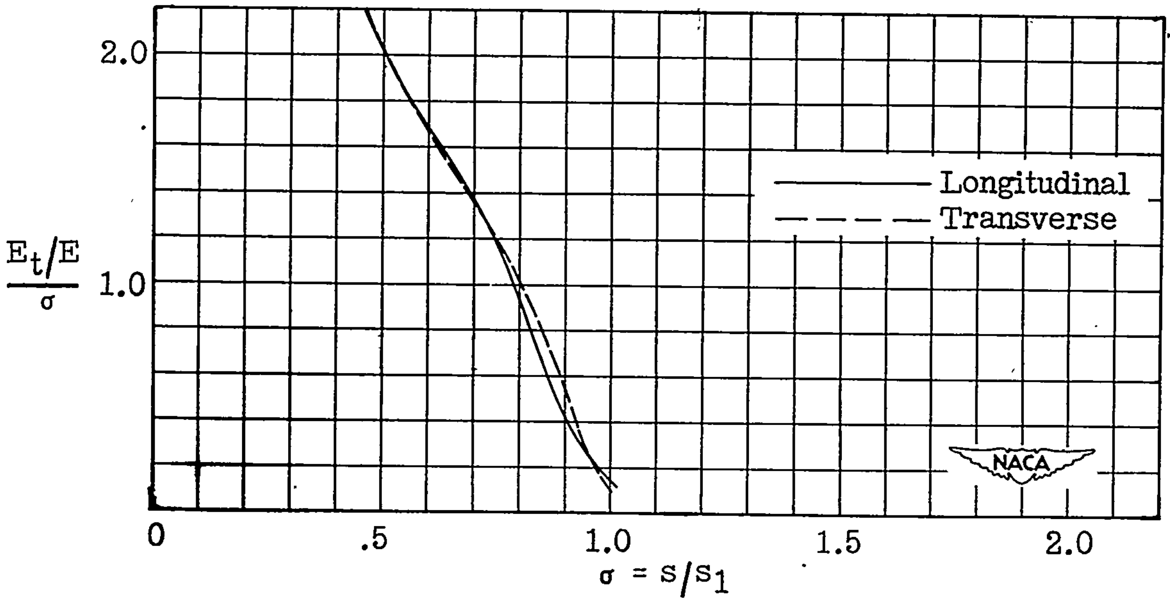


Figure 24.- Auxiliary dimensionless curves for estimating plastic buckling stress. 75S-T6 sheet 0.125 inch thick.

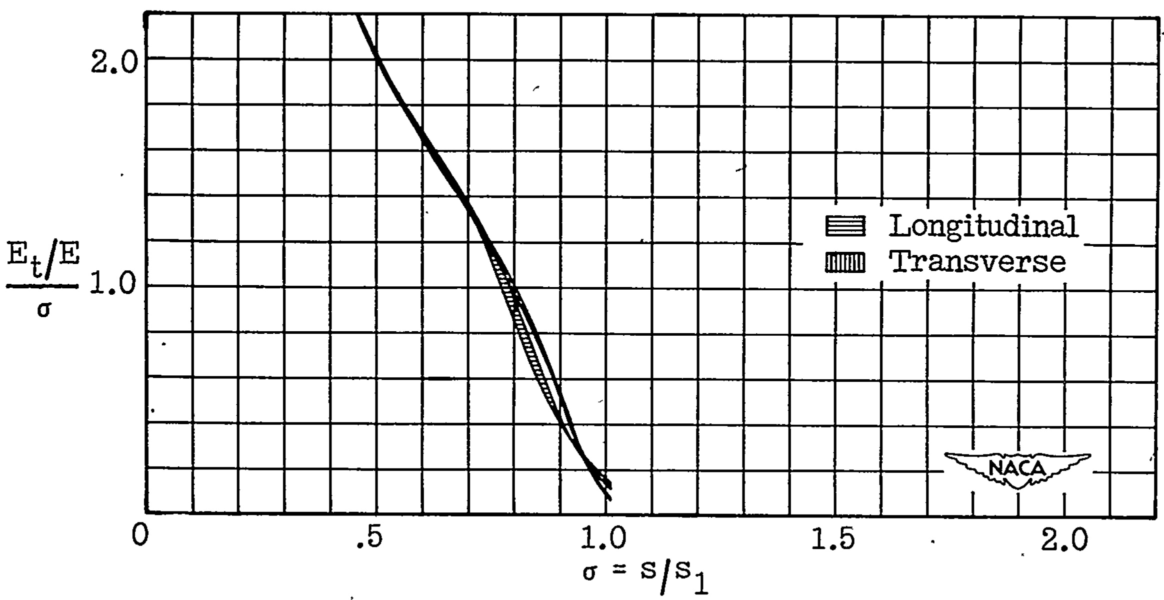


Figure 25.- Limits of auxiliary dimensionless curves for estimating plastic buckling stress. 75S-T6 sheet 0.032, 0.064, and 0.125 inch thick.

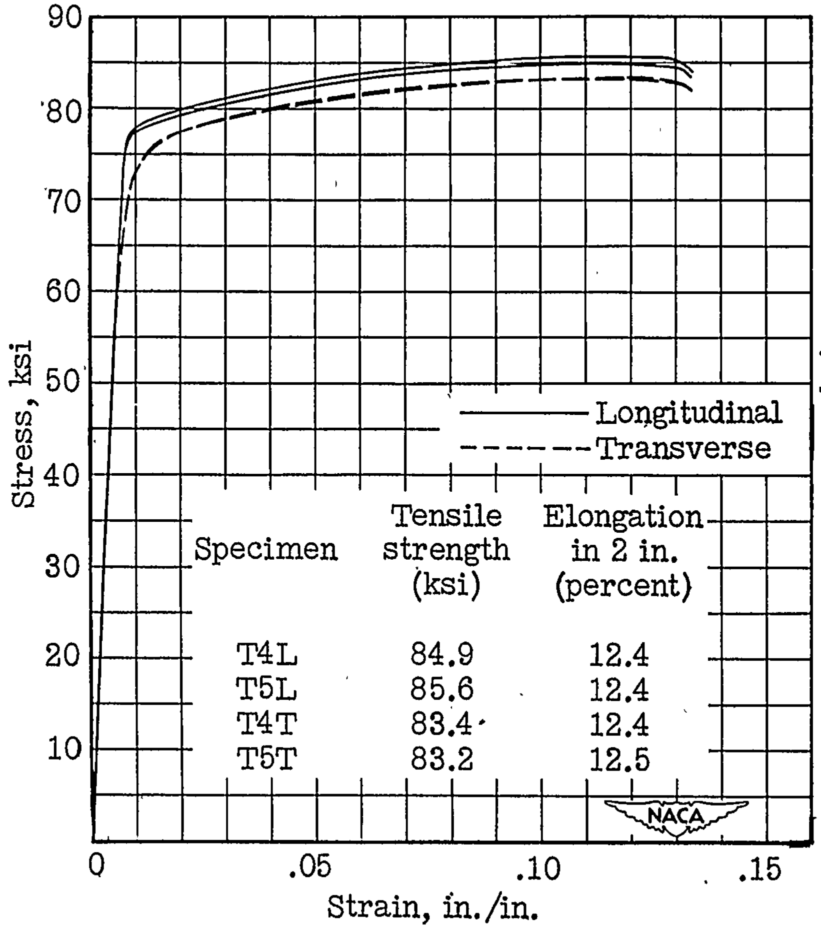


Figure 26.- Tensile stress-strain curves to failure. 75S-T6 sheet 0.032 inch thick.

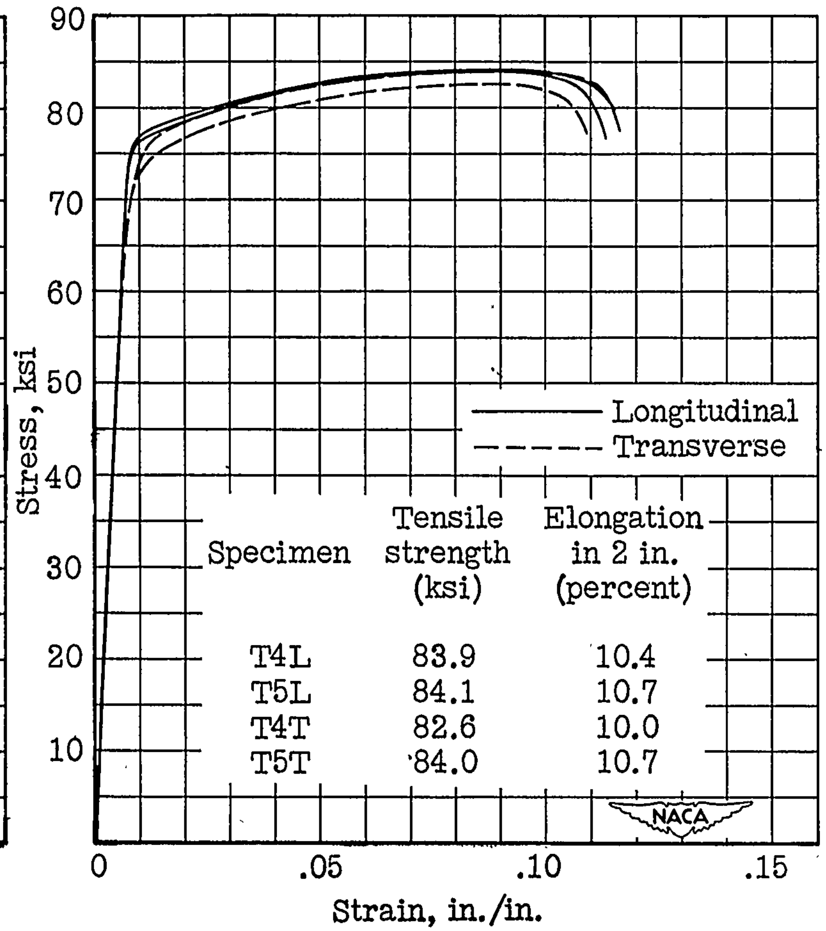


Figure 27.- Tensile stress-strain curves to failure. 75S-T6 sheet 0.064 inch thick.

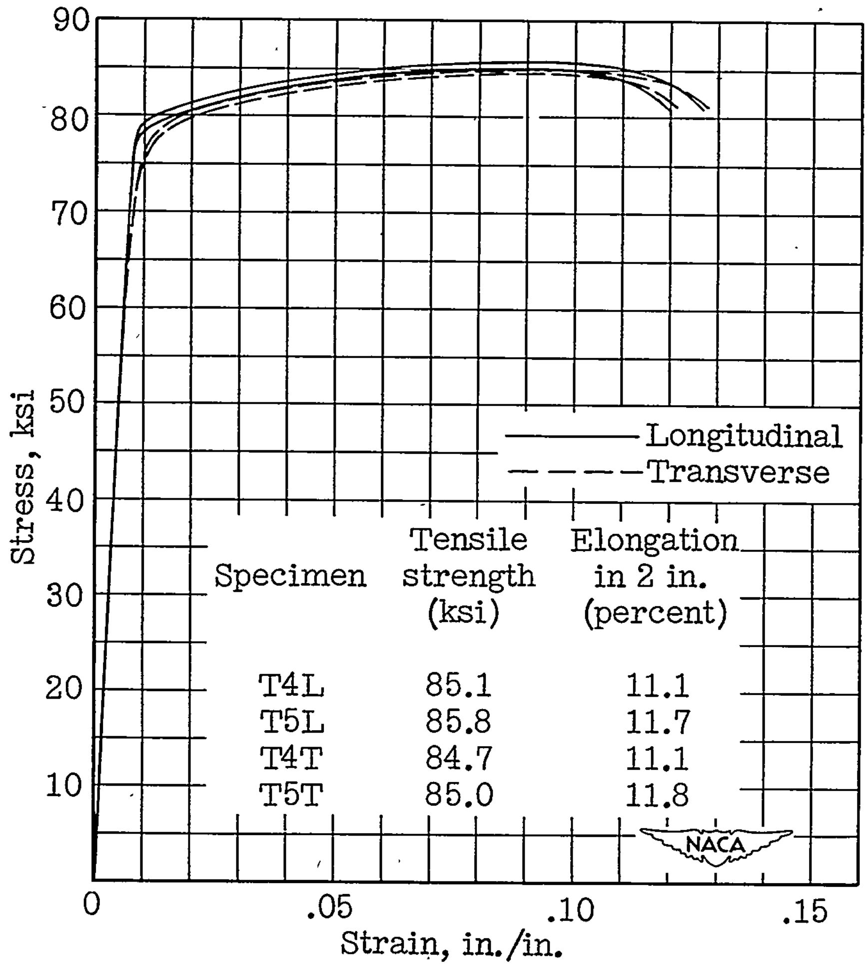


Figure 28.- Tensile stress-strain curves to failure. 75S-T6 sheet 0.125 inch thick.

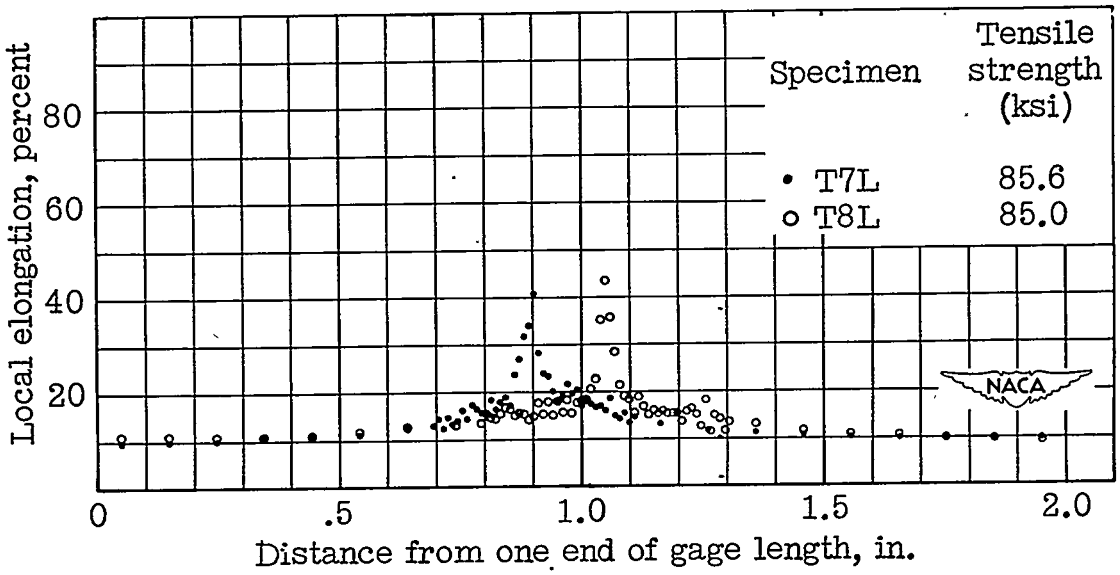


Figure 29.- Local elongation. 75S-T6 sheet, longitudinal specimens 0.032 inch thick.

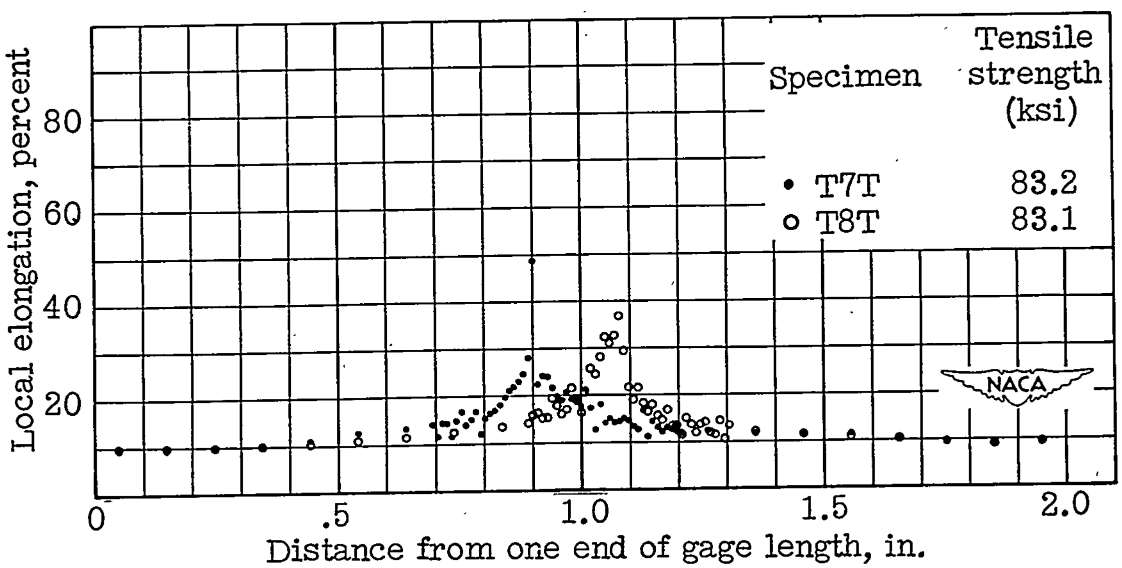


Figure 30.- Local elongation. 75S-T6 sheet, transverse specimens 0.032 inch thick.

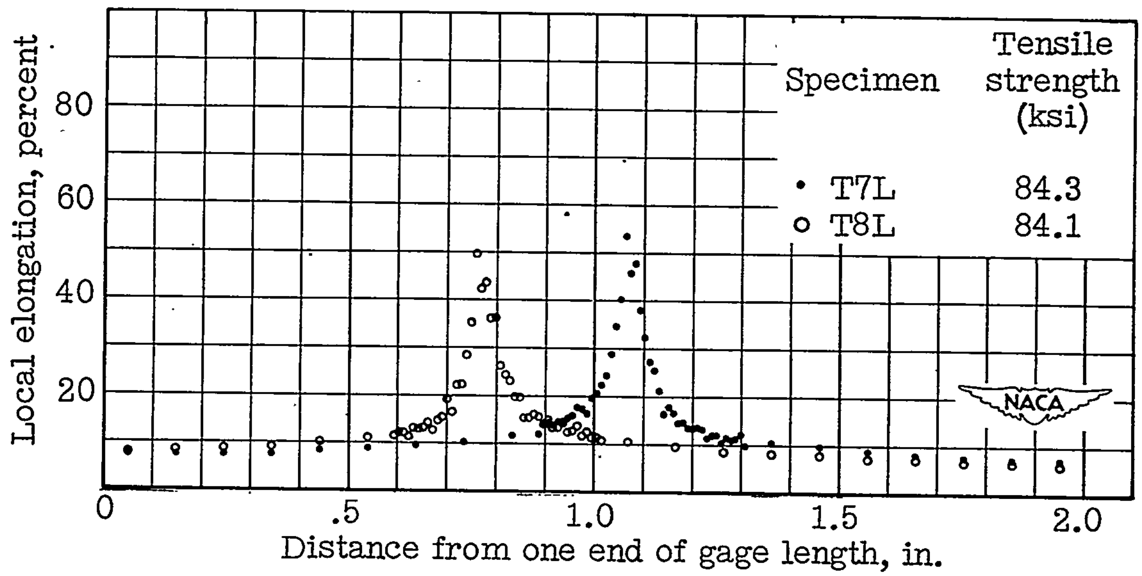


Figure 31.- Local elongation. 75S-T6 sheet, longitudinal specimens 0.064 inch thick.

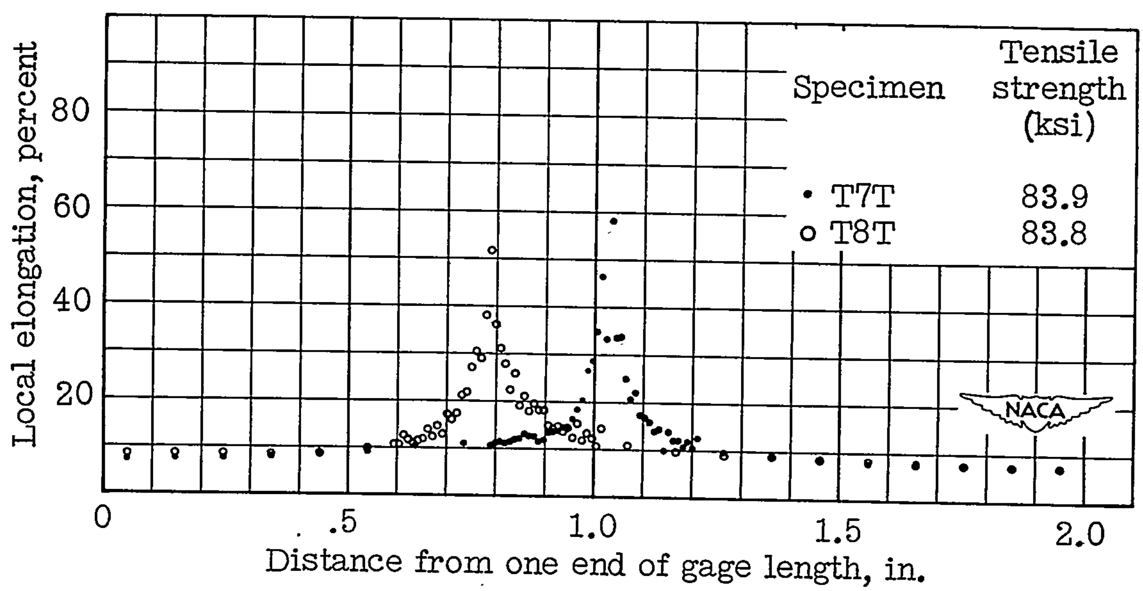


Figure 32.- Local elongation. 75S-T6 sheet, transverse specimens 0.064 inch thick.

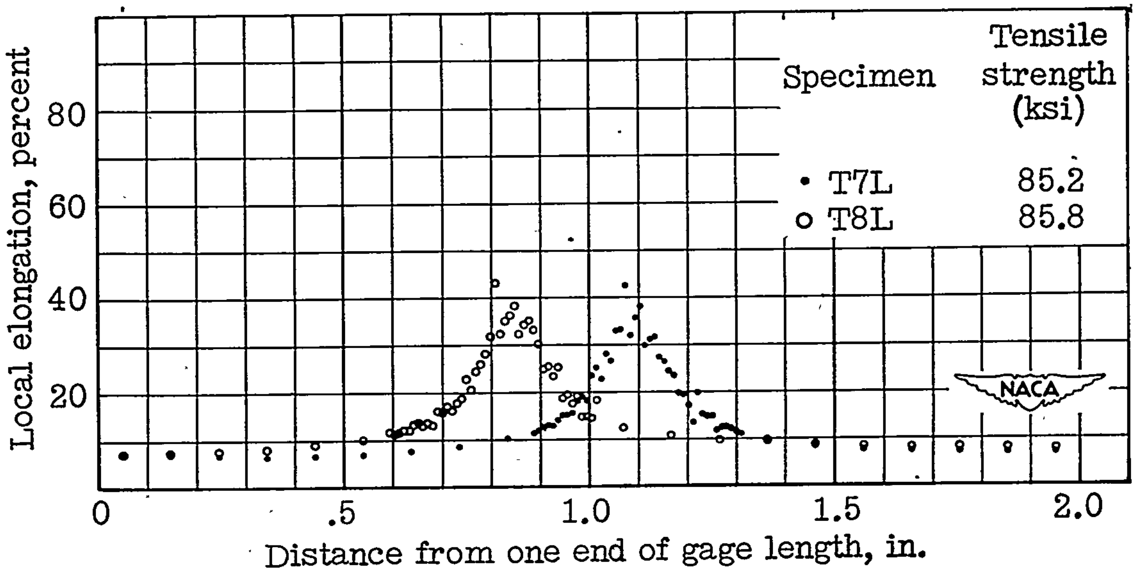


Figure 33.- Local elongation. 75S-T6 sheet, longitudinal specimens 0.125 inch thick.

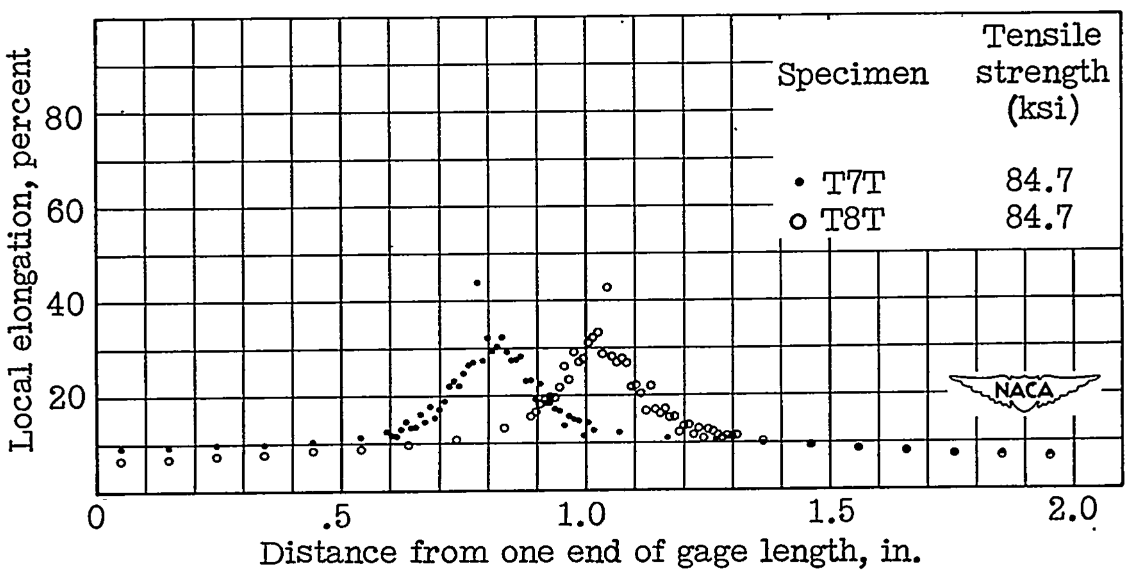


Figure 34.- Local elongation. 75S-T6 sheet, transverse specimens 0.125 inch thick.

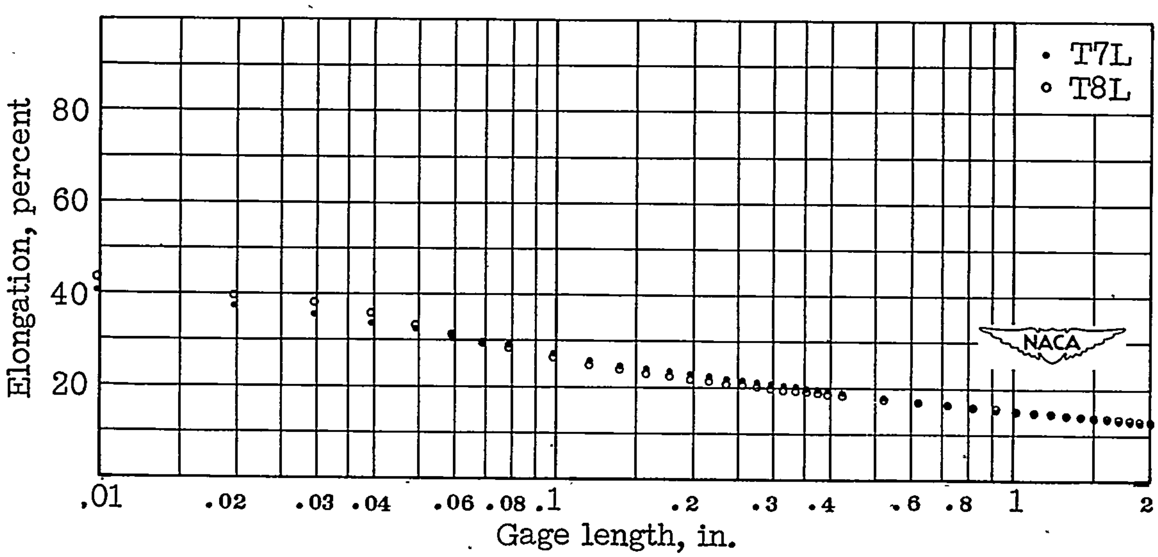


Figure 35.- Elongation against gage length. 75S-T6 sheet, longitudinal specimens 0.032 inch thick.

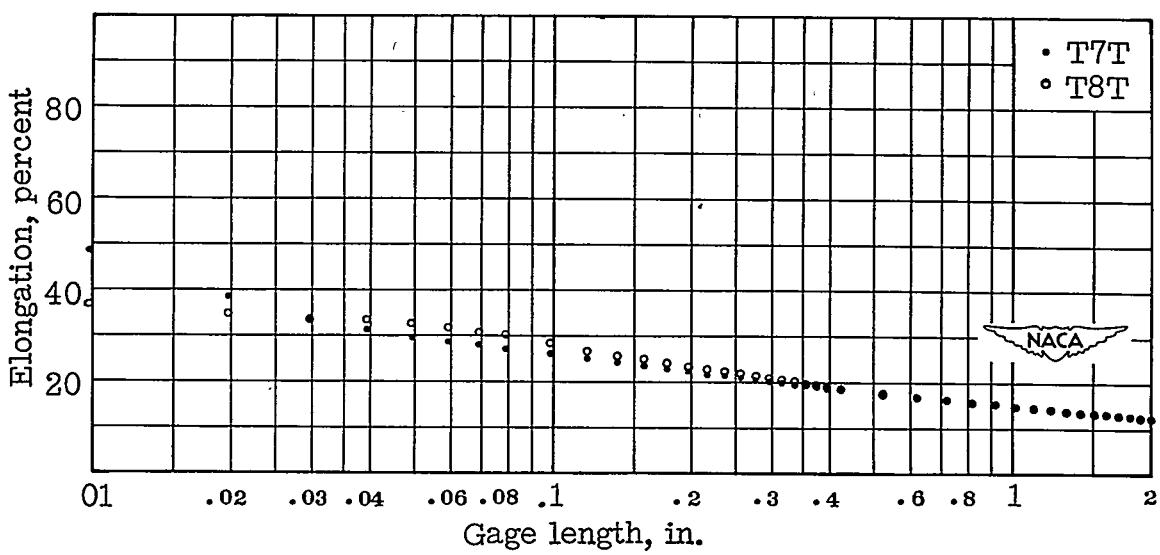


Figure 36.- Elongation against gage length. 75S-T6 sheet, transverse specimens 0.032 inch thick.

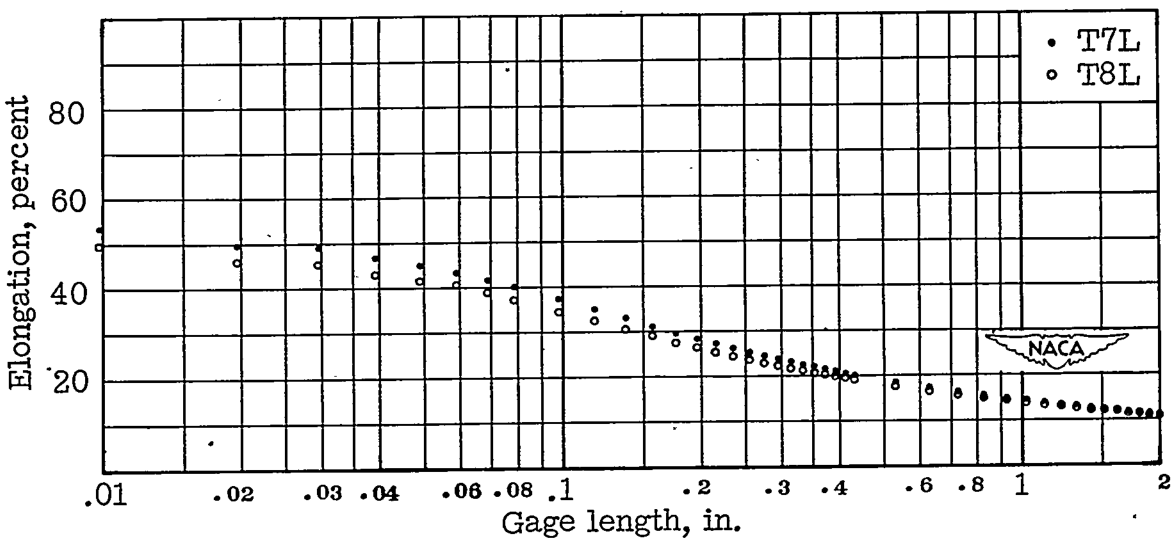


Figure 37.- Elongation against gage length. 75S-T6 sheet, longitudinal specimens 0.064 inch thick.

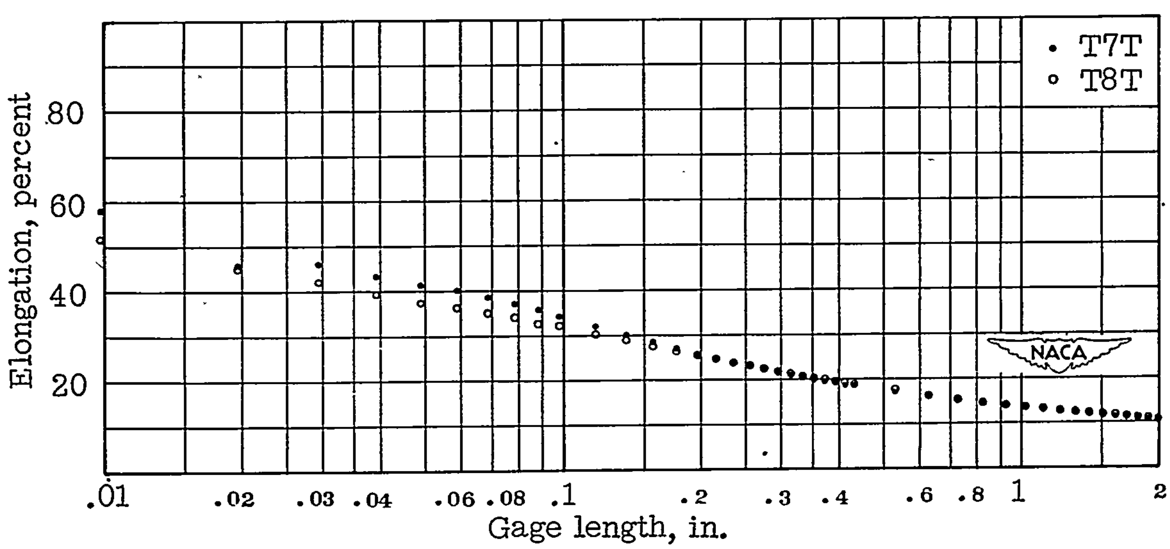


Figure 38.- Elongation against gage length. 75S-T6 sheet, transverse specimens 0.064 inch thick.

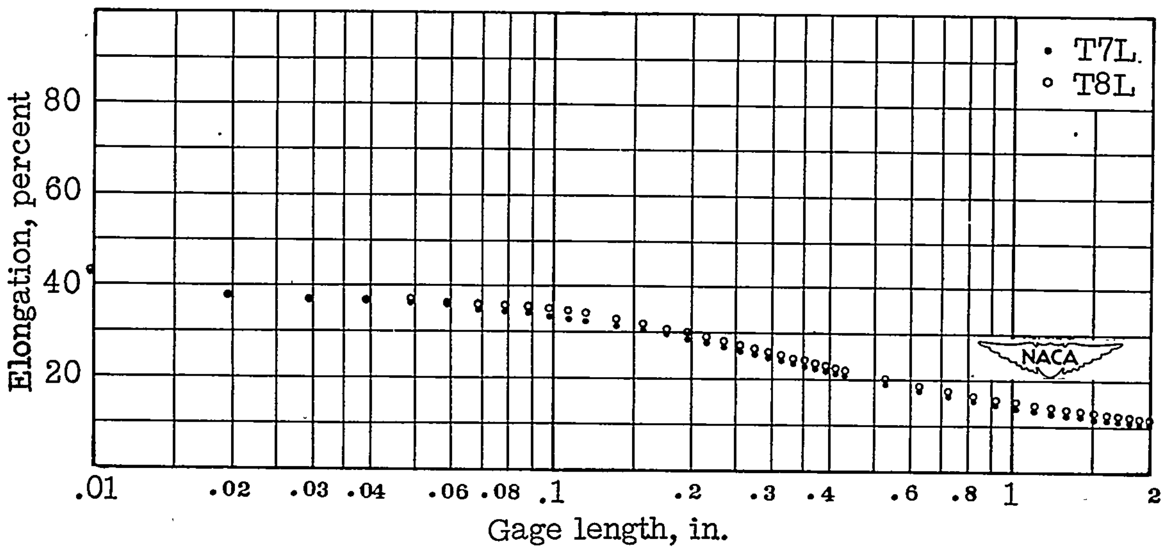


Figure 39.- Elongation against gage length. 75S-T6 sheet, longitudinal specimens 0.125 inch thick.

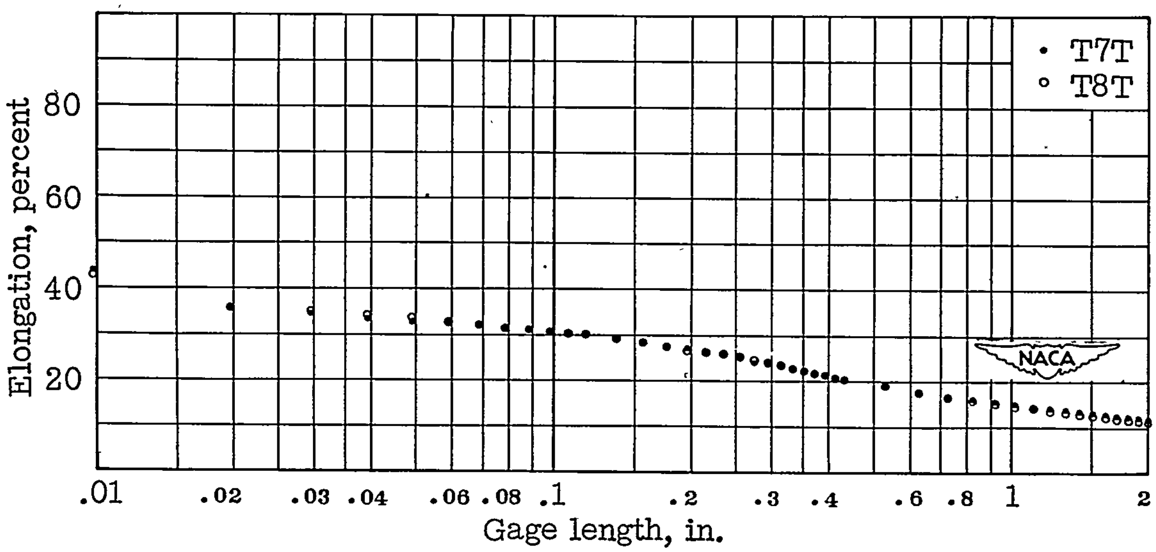


Figure 40.- Elongation against gage length. 75S-T6 sheet, transverse specimens 0.125 inch thick.

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