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## A PRELIMINARY STUDY OF THE EFFECT OF COMPRESSIVE LOAD ON THE FAIRNESS OF A LOW-DRAG WING SPECIMEN WITH Z-SECTION STIFFENERS

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# A PRELIMINARY STUDY OF THE EFFECT OF COMPRESSIVE LOAD ON THE FAIRNESS OF A LOW-DRAG WING SPECIMEN WITH Z-SECTION STIFFENERS

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## SUMMARY

A low-drag airfoil specimen was loaded in compression, and surveys of the fairness of the surface were made at different stresses as well as at zero load after successively higher stresses had been applied and removed. The tests reported and the discussion of the significance of the results obtained suggest a procedure for determining the probable outcome of a particular type of construction for a low-drag wing.

## INTRODUCTION

If full advantage is to be taken of the aerodynamic properties of a low-drag wing, the wing should retain its aerodynamically smooth and fair surface after the airplane has been subjected to its maximum applied flight load. In order to study the effect of compressive stresses on the fairness of the wing surface, a series of compression tests was made on a low-drag-airfoil specimen of NACA section 67,1-113. The wing structure consisted of a skin with spanwise Z-section stiffeners supported by two end ribs and two intermediate ribs. The stiffeners were attached to the skin with rivets driven by riveting method E of reference 1. Nominal dimensions of the skin and stiffeners are given in figure 1. As shown in figure 2, the tests were made in the 1,200,000-pound-capacity testing machine in the NACA structures research laboratory. Compressive loads corresponding to average stresses of 0, 5000, 0, 15,000, 0, 21,500, 0, 25,000, and 0 pounds per square inch were successively applied, and surveys of the fairness of the surfaces were made at all except the two highest loads.

## MEASUREMENT OF AERODYNAMIC FAIRNESS

The aerodynamic fairness of the wing was judged by the method outlined under "Practical surface conditions and construction accuracy," a section of the Discussion in reference 2. The method employed is summarized in the following statement from reference 2: "In general, it has been found that the fairness of the important forward part of the wing is satisfactory if a straight edge may be rolled smoothly over the surface, thus indicating freedom from flats or concavities in the normally convex surfaces."

A 6-inch-square grid was marked on the upper and lower surfaces of the airfoil. The surveys of fairness were made at the spanwise center of each block in the grid and extended from 20 to about 70 percent of the chord from the leading edge. The deviations from fairness, as detected by the straight-edge rolling test and recorded in figure 3, were classified as follows:

(a) The light lines indicate flat areas just perceptible to the observer by means of the straight-edge test.

(b) The heavy lines indicate flat spots that are clearly evident but are not, in general, bad enough to show any light under the straight edge.

(c) The medium lines indicate flat spots that are intermediate between the two foregoing classifications.

## RESULTS OF FAIRNESS SURVEYS

The first survey was made at zero load and, from the results obtained (fig. 3), the wing could not be clearly shown to be aerodynamically fair before loading. The surveys made at average compressive stresses of 5000 and 15,000 pounds per square inch showed a tendency toward an increasing number of flat areas with load. When the stress was reduced to zero from 15,000 pounds per square inch, however, no clearly evident change in the extent of flat areas from the original zero-load condition was observed.

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At a stress of 21,500 pounds per square inch, a visible wave pattern had developed. (See fig. 2.) When this stress was removed, the surface survey showed that some additional depressions or flat areas had resulted. (See fig. 3.) On the basis of experience gained in wind-tunnel testing of low-drag airfoils over a period of several years, it is believed that these additional flat areas would not definitely be expected to increase the drag of an airfoil. The survey made after application and removal of an average compressive stress of 25,000 pounds per square inch revealed such an increase in the number and severity of the permanent depressions and flat areas that the wing specimen could definitely be regarded as not aerodynamically fair.

## SIGNIFICANCE OF AERODYNAMIC FAIRNESS AT DIFFERENT STRESSES

From data taken in an investigation of the compressive strength of flat panels with Z-section stiffeners, it was found that the average ultimate stress for a skin-stiffener combination of the same proportions as that used in the airfoil specimen was 33,000 pounds per square inch. (See reference 3, fig. 5.) As previously stated, no definitely serious depressions and flat areas remained in the wing surface after removal of a stress of 21,500 pounds per square inch. This stress is 65 percent, or approximately two-thirds, of the average ultimate stress developed by the stiffened panels. As the maximum load that is normally expected to be carried by an airplane is two-thirds of the design failing load, it is concluded that a skin-stiffener structure of the relative proportions shown in figure 1 may be regarded as satisfactory for retaining an aerodynamically fair surface after a compression load corresponding to the maximum flight load has been applied and removed.

At zero stress or load, the skin of an airplane may have depressions or waves that are due to imperfect construction or are the result of a previously applied flight load that produced permanent set in the skin. These waves in the skin, regardless of their origin, are magnified at stresses below the buckling stress according to the following approximate equation

$$\delta_f = \frac{1}{1 - \frac{f}{f_{cr}}} \delta_o \qquad (1)$$

where $\delta_o$ and $\delta_f$ are the depths of the wave at zero stress and stress f, respectively, and $f_{cr}$ is the buckling stress. The quantity

$$\frac{1}{1 - \frac{f}{f_{cr}}}$$

is a magnification factor because it shows how the initial deflection $\delta_o$ is magnified by the stress f.

In high-speed level flight, the magnification factor should be small in order that slight waves and depressions which may have been present at zero stress are not magnified to such a degree that they cause a significant increase in drag. If f is the stress in level flight, then $f_{cr}$ must be large by comparison with f in order to keep the magnification factor small. The absolute magnitude of $f_{cr}$ should also be large enough that the stress corresponding to the maximum applied flight load does not exceed the buckling stress to such an extent that severe permanent buckles are formed in the skin.

If an airplane wing were constructed with the same skin-stiffener proportions as the airfoil tested in this investigation and if the design load factor were taken as 6.6 or higher, the wing structure would have a value of $f_{cr}$ in accordance with the foregoing requirements. With the design load factor taken as 6.6, the compressive stress in level flight would be $\frac{33000}{6.6}$ or 5000 pounds per square inch. If the buckling stress is taken as 20,000 pounds per square inch, an approximately correct value, the magnification factor for level flight is then only four-thirds. The results of the survey in figure 3 at a stress of 5000 pounds per square inch indicate that in the level-flight condition such a wing would show only a slight extension of the initial flat areas and depressions. As has been mentioned previously, furthermore, the surveys showed that no definitely serious permanent buckles developed in the test specimen until a stress of more than two-thirds of that corresponding to maximum strength was applied.

It is possible that a higher level-flight stress and a correspondingly lower design load factor could be used

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with the skin-stiffener combination of figure 1 without serious loss of fairness of the wing skin in level flight. The results of the fairness surveys in figure 3 do not permit a prediction of how much the level-flight stress might exceed 5000 pounds per square inch. The fairness surveys do indicate, however, that the level-flight stress should probably be less than 15,000 pounds per square inch.

## CONCLUSION

The tests reported herein and the discussion of the significance of the results obtained suggest a procedure for determining in advance the probable outcome of a particular type of construction for a low-drag wing.

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## REFERENCES

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3. Rossman, Carl A., and Schuette, Evan H.: Data on Compressive Strength of Flat Panels with Z-Section Stiffeners. NACA R.B., Sept. 1942.

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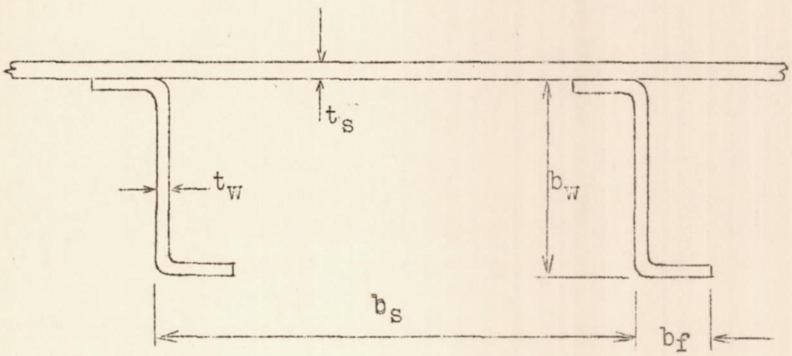


$t_s = 0.064$

$\frac{t_w}{t_s} = 0.63$

$\frac{b_s}{t_s} = 35$

$\frac{L}{b_w} = 12$

$\frac{b_w}{t_w} = 25$

$\frac{b_f}{b_w} = 0.4$

Figure 1.- Relative proportions of skin-stiffener combination used in test specimen L, rib spacing.

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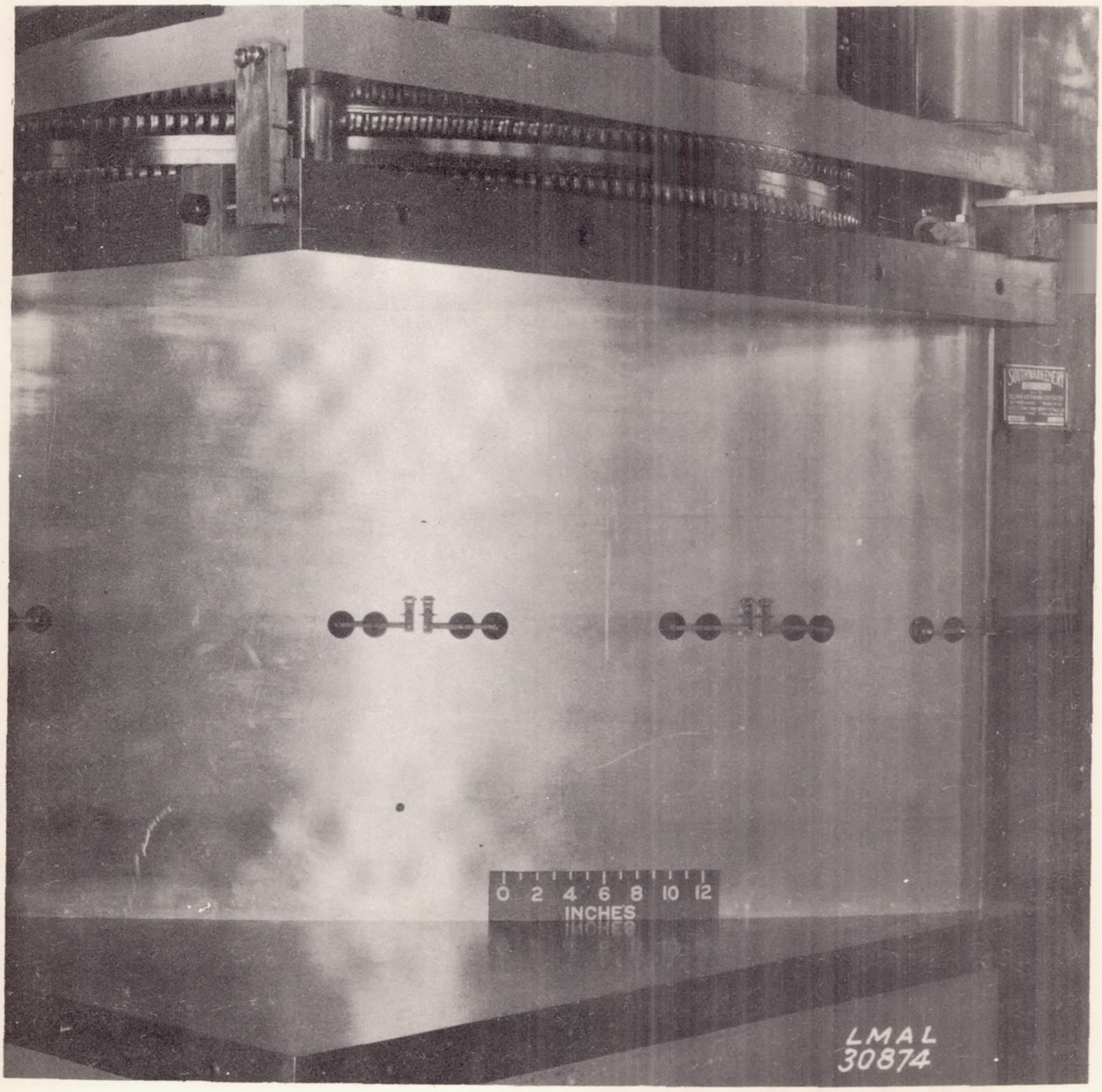


Figure 2.- Low-drag-airfoil specimen buckled in testing machine. Average compressive stress, 21,500 pounds per square inch.

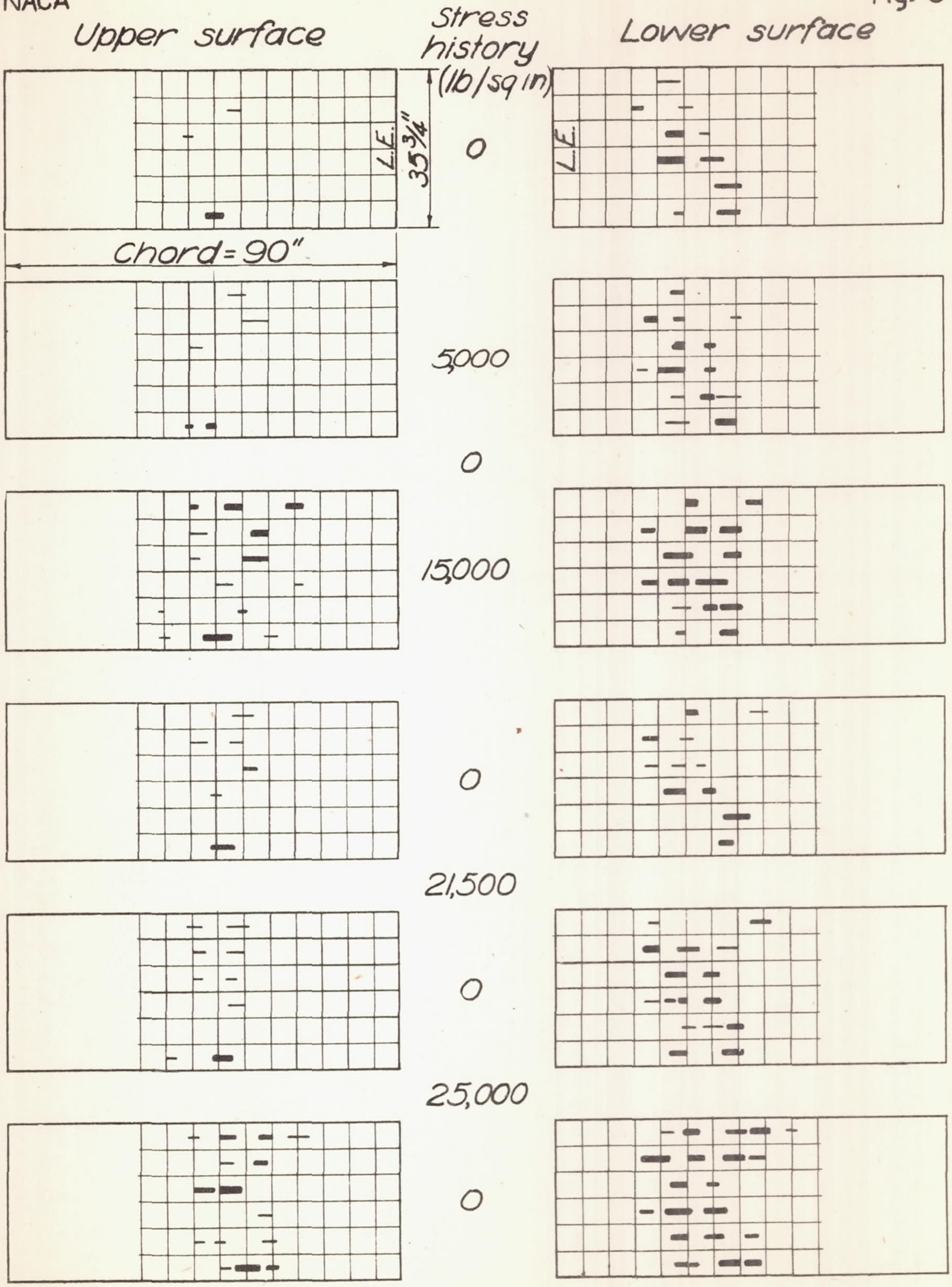


Figure 3.- Location of flat spots on low-drag airfoil specimen under end compression. Weight and length of lines indicate severity and extent of depressions.

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