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BUCKLING TESTS OF FLAT RECTANGULAR PLATES UNDER COMBINED SHEAR AND LONGITUDINAL COMPRESSION

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SUMMARY

An experimental investigation was made to validate a theoretical parabolic interaction curve for the elastic buckling of flat rectangular plates under combined shear and longitudinal compression loads. The four flat rectangular plates tested formed the sides of a square box having corner angles. Although some of the experimentally determined points lie above and others below the theoretical interaction curve, the average of the individual experimental points plotted very closely to this theoretical curve recommended for design use. The experimental results were also compared with a theoretical interaction curve for the walls of a square tube without corner angles.

INTRODUCTION

Because the plate elements in an aircraft structure are often subject to both compression and shear simultaneously, design calculations must take into account the combinations of direct compression and shear that will cause these plate elements to buckle.

A theoretical interaction curve for the elastic buckling of a long flat plate under combined compression and shear is available for design purposes. An investigation was made to provide an experimental check on the validity of this theoretical interaction curve. Because the experimental work was done on a square tube constructed of four flat plates, the experimental results were also compared with a theoretical interaction curve for the elastic buckling of the walls of a long square tube under combined compression and shear.

DISCUSSION OF THEORIES

The theoretical interaction curve for the elastic buckling of a long flat plate with elastically restrained edges under combined compression and shear as derived in reference 1 is given by the equation

$$R_c + R_s^2 = 1 \quad (1)$$

where

R_c ratio of compressive load for buckling under combined load to compressive load for buckling under compression alone

R_s ratio of shear load (or torque) for buckling under combined load to shear load for buckling under shear alone

The curve of equation (1) is shown in figure 1 as the curve labeled "plate.

Because of the difficulty of testing a single plate in combined compression and shear, however, four similar plates were assembled in the form of a square box as shown in figures 2 and 3. Except for the presence of the corner angles, this box is a square tube.

The interaction curve for one wall of a square tube differs from that for a single plate because the continuity of the walls restricts the possible buckling patterns to those that give continuity of the nodes around the tube. The theoretical interaction curve for a long square tube with perfect continuity between the four walls was determined in reference 2 and is shown in figure 1 as the curve labeled "tube" for comparison with the theoretical interaction curve for a long flat plate described by equation (1).

The presence of the corner angles in the built-up tube (or box) of figures 2 and 3 reduces the effects of this wall-to-wall continuity, however, and tends to isolate each wall of the box; thus each wall behaves as a plate with elastic restraint at its edges. The experimental results for the box tested in this investigation should therefore be expected to lie between the two theoretical curves of figure 1.

DETERMINATION OF BUCKLING

Compression and torsion loads were applied to the box simultaneously in various combinations in which the ratio of compression load to torsion load was maintained constant throughout each test. Buckling was detected by the use of electrical strain-gage rosettes. In order to insure that some of the gages would be at or near a buckle crest, the gages were mounted on the outside of the box along the entire length of the longitudinal center line of each plate as shown in figure 3. Principal strains computed from the strain-gage-rosette data were plotted both as compressive load-strain curves and torsion load-strain curves. Buckling was determined by the first appearance of strain reversal on any of the gages distributed along the face as described in reference 3; either the compression or torsion load-strain curves were used.

RESULTS AND CONCLUSIONS

Presentation of Results

Figure 4 shows a set of load-strain curves obtained for one plate (plate A) of the box for the different ratios of compression to shear. Both the compression and torsion load-strain curves are presented to show the combinations of loading. The strain readings are those for the gage which first showed reversal; the circled number by the curve indicates the gage so designated in figure 3. Short horizontal lines have been drawn on each curve to indicate the point of strain reversal. The relative loads are indicated by the fraction; thus, if P_0 is the buckling compressive load without torque and if T_0 is the buckling torque without compression, then the fraction signifies the approximate value of

$$\frac{P/P_0}{T/T_0}$$

where P and T are the applied compressive load and torque, respectively, for the particular curve. Thus, for the curve marked 7/3,

$$\frac{P}{P_0} = 0.7$$

and

$$\frac{T}{T_0} = 0.3$$

Values of the ratios R_c and R_s were computed for each loading condition from the formulas

$$R_c = \frac{P_1}{P_0}$$

and

$$R_s = \frac{T_1}{T_0}$$

where P_1 and T_1 are the particular combination of applied compressive load and torque (both well within the elastic range) that caused buckling.

The computed values of R_c and R_s are plotted in figures 5(a) to 5(d) as points representing buckling detected by gages on the plates A to D, respectively. Figure 5 also includes the theoretical interaction curves for the plate and for the tube.

Concluding Discussion

The fact that some of the experimental points lie below the plate theoretical interaction curve and others lie above the tube theoretical interaction curve (and some are even greater than unity) – although the points for each individual plate follow a consistent path – suggests that initial out-of-flatness of the plate may either advance or delay buckling. This conclusion is further confirmed by the fact that a reversal of the shear by reversing the torque raised the experimental points for plate A from below the plate theoretical curve to above the tube theoretical curve as shown in figure 6.

In order to minimize the individual deviations from the theoretical interaction curves, the experimental points in figure 5 were averaged and the results are shown in figure 7(a). The average experimental points are seen to agree better with the plate theoretical curve of equation (1) than with the tube theoretical curve; this better agreement suggests that, because of the great stiffness provided by the double angles at the corners of the box, the walls of the box act almost as individual plates. Further confirmation of this fact is shown in figure 7(b) in which are plotted the average of the experimental points in figure 6 for the oppositely directed torques on plate A.

Because the average experimental points are only slightly different from the plate theoretical curve described by equation (1) and because the connecting angles in an aircraft structure are usually of greater stiffness than those in the square box tested, the interaction formula of equation (1) is concluded to be suitable for design purposes.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., September 10, 1948

REFERENCES

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2. Budiansky, Bernard, Stein, Manuel, and Gilbert, Arthur C.: Buckling of a Long Square Tube in Torsion and Compression. NACA TN No. 1751, 1948.

3. Hu, Pai C., Lundquist, Eugene E., and Batdorf, S. B.: Effect of Small Deviations from Flatness on Effective Width and Buckling of Plates in Compression. NACA TN No. 1124, 1946.

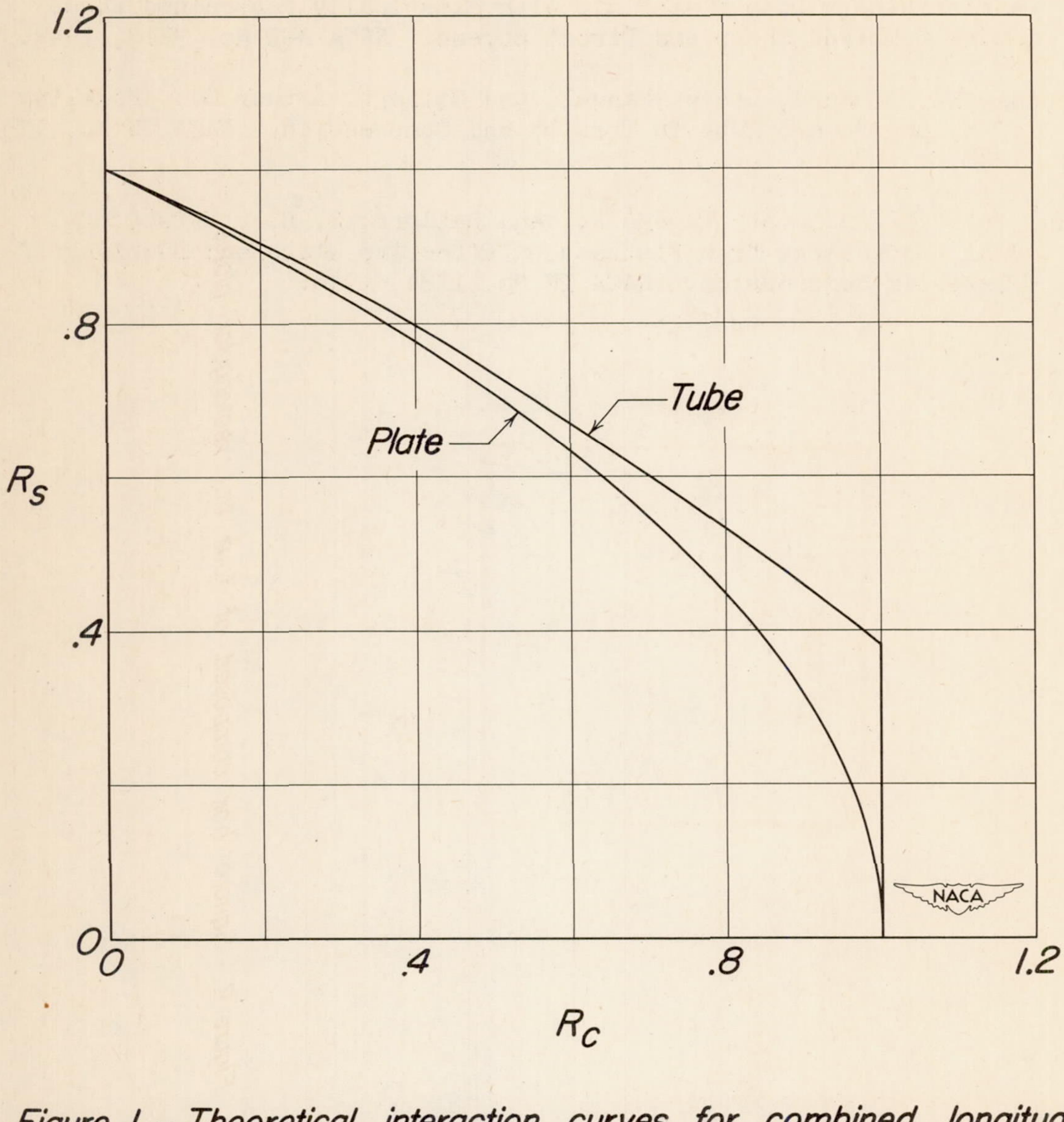


Figure 1. - Theoretical interaction curves for combined longitudinal compression and shear.

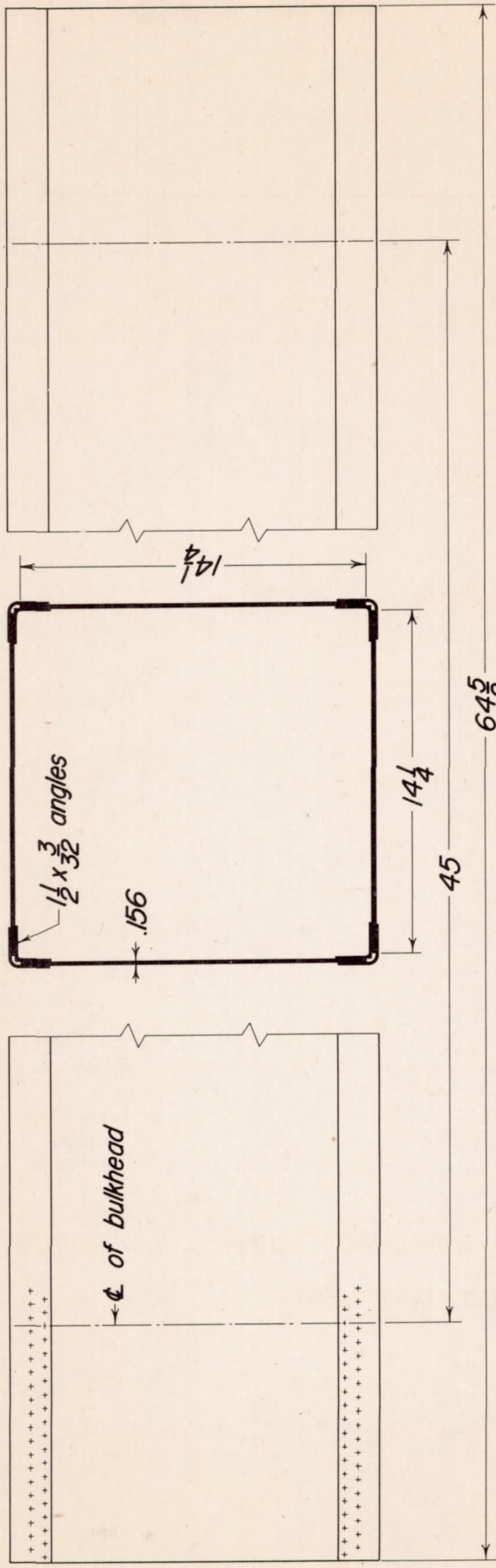


Figure 2.- Square box composed of four flat rectangular plates.

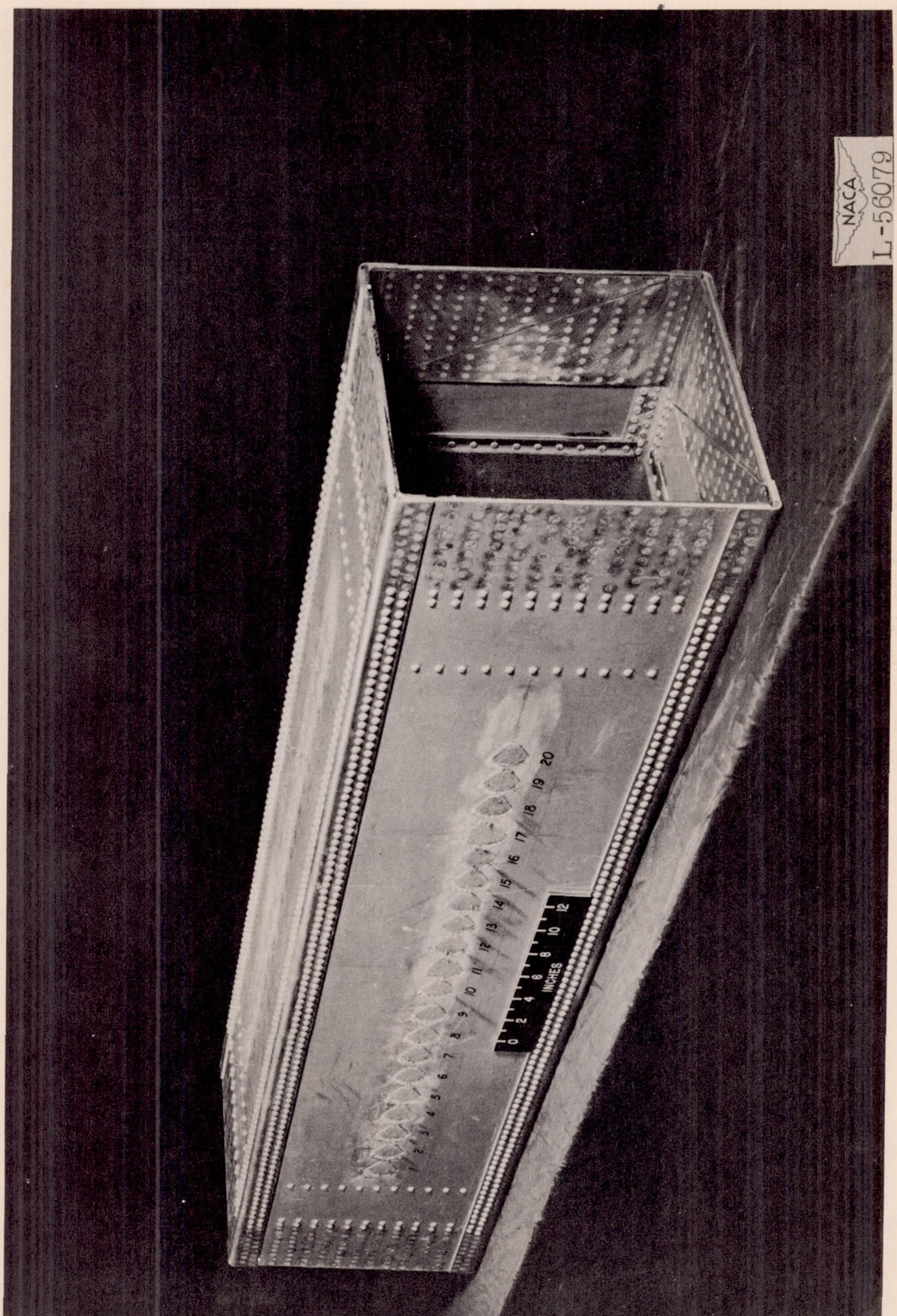


Figure 3.- Strain-gage location on flat-plate box.

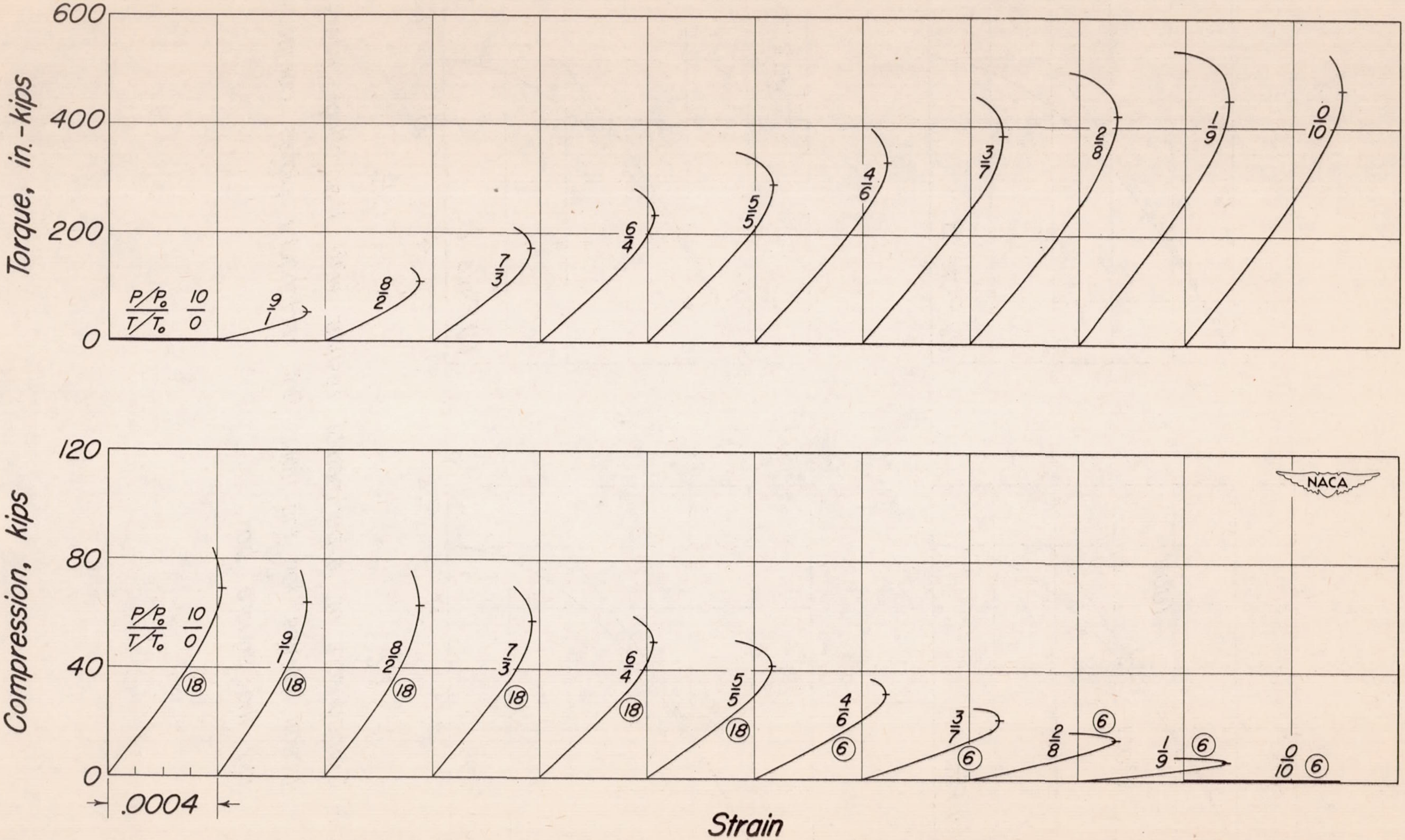


Figure 4.- Load-strain curves for one wall of the flat-plate box. Short horizontal lines indicate point of strain reversal; circled numbers refer to strain gage (fig. 3) which first showed reversal.

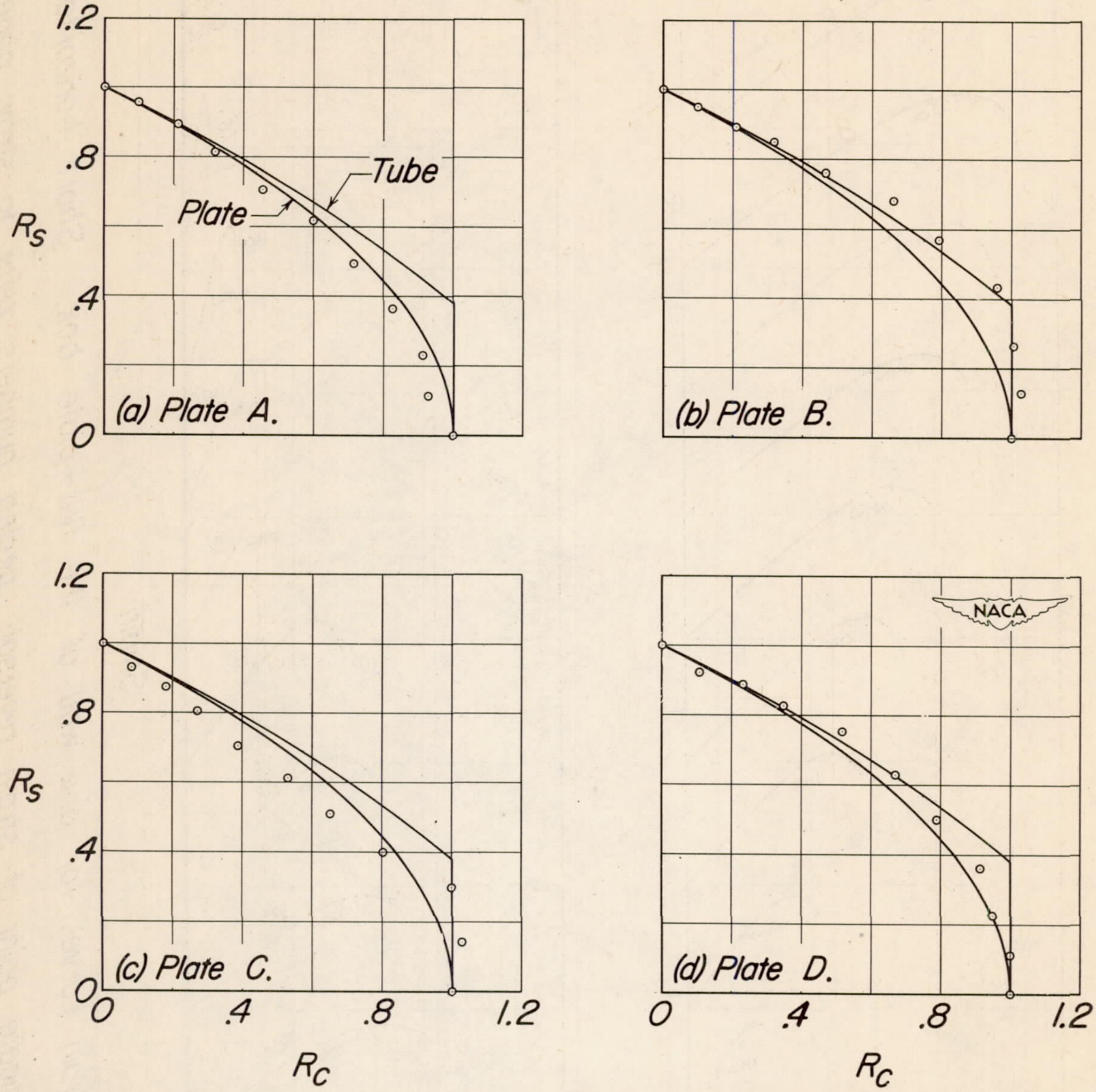


Figure 5.- Comparison of experimental results with theoretical interaction curves for the four flat rectangular plates composing the square box.

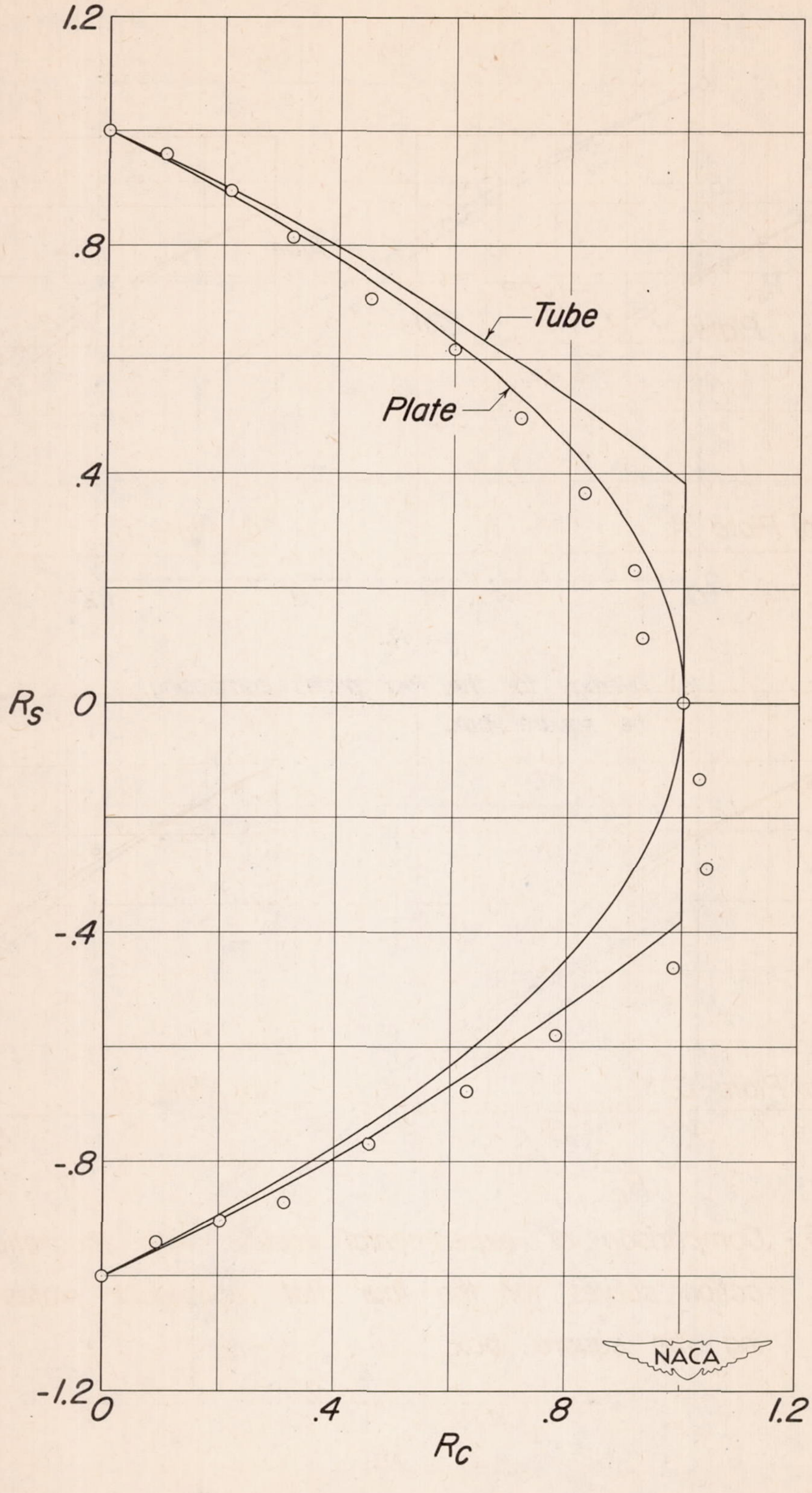
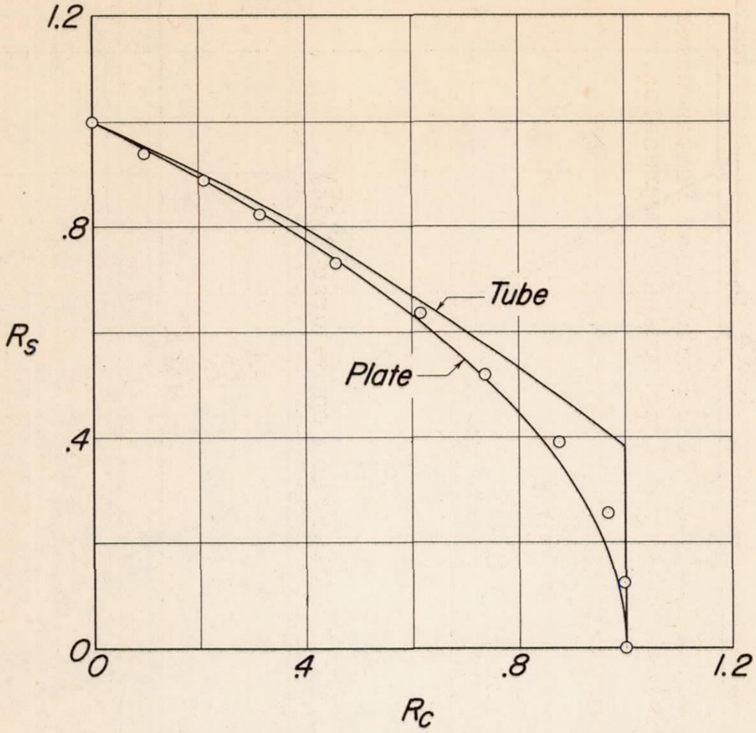
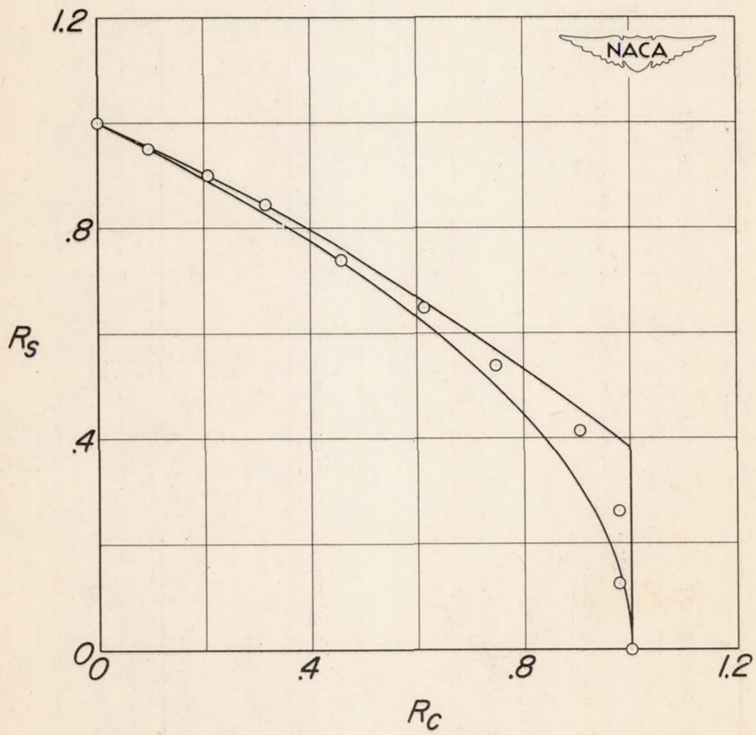


Figure 6.- Comparison of experimental results with theoretical interaction curves for the two directions of torque. Plate A.



(a) Average for the four plates composing the square box.



(b) Average for the two directions of torque.

Figure 7. - Comparison of average experimental results with theoretical interaction curves.