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THE RELATION BETWEEN SPANWISE VARIATIONS IN THE CRITICAL MACH NUMBER AND SPANWISE LOAD DISTRIBUTIONS

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SUMMARY

Data are presented to show the changes that occur in the spanwise load distributions on wings when the critical Mach number is exceeded. These data indicate that the magnitude of the changes in spanwise load distribution varies with the magnitude of the spanwise variation in the critical Mach numbers of the sections. Means of reducing the magnitudes of such changes are considered.

INTRODUCTION

The results of tests of numerous airfoils at high speeds indicate that there may be considerable changes in the spanwise load distributions on a wing when the critical Mach number of the wing is exceeded. After the local Mach number on an airfoil section exceeds a value of unity, a compression shock is formed that results in a decrease in the lift coefficient on the section for the same angle of attack (references 1 to 3). These decreases of lift coefficient generally occur at different flight speeds on the various sections of a wing. A change in the spanwise load distribution would therefore usually be expected to occur on a wing operating at a Mach number above that at which a loss of section lift coefficient first occurs since, at this Mach number, some sections will have experienced a greater loss in lift than other sections. Such changes affect the wing bending moments, the airplane trim, and the stability characteristics.

The possibility that such changes may occur has been recognized for several years (reference 4). A means is available for estimating the magnitude of the changes through the use of the low-speed lifting-line theory and two-dimensional high-speed wind-tunnel data (reference 5).

An analysis of the results of wind-tunnel tests in two-dimensional flow (references 1 to 3) indicates that the magnitude of the loss in lift coefficient which occurs at supercritical Mach numbers is a function of the amount by which the operating Mach number exceeds the critical Mach number. The magnitudes of the changes in the spanwise distribution of load on most airplane wings should therefore be expected to vary with the magnitude of the spanwise variations of the section critical Mach number.

The purpose of the present paper is to illustrate the relationship between the spanwise variations of load distribution and the section critical Mach number. In order to show this relationship, subcritical and supercritical load distributions and variations of critical Mach number, calculated from pressure measurements made during high-speed wind-tunnel tests, are shown for three tapered wings. Means of reducing the indicated changes are considered.

EXPERIMENTAL RESULTS

Figure 1 shows the spanwise load distributions for a wing (NACA 23015 root section and NACA 4412 tip section) on which there is a large spanwise variation in the section critical Mach number. Figure 2 shows the spanwise load distributions for a wing (Boeing 117 section, 22 percent thick at root and 12 percent thick at tip) on which the spanwise variation in the section critical Mach number is moderate. These two wings were tested in the Langley 8-foot high-speed tunnel. Figure 3 shows the spanwise load distributions for a wing (NACA 63(420)-422 root section and NACA 63(420)-517 tip section) on which there is only a slight spanwise variation in the section critical Mach number. This wing was tested in the Ames 16-foot high-speed tunnel. The distributions have been determined for a wing lift coefficient of 0.2. The supercritical span loadings are for the Mach numbers at which the variations from the subcritical loadings are most pronounced. The loadings are presented in the conventional manner - that is, as c_nc plotted against the distance from the center of the wing along the semispan, where c_n is the section normal-force coefficient and c is the section chord. The spanwise variations in the section critical Mach number M_{cr} are also shown in the figures. These variations in critical Mach number are determined for the angles of attack corresponding to a wing lift coefficient C_L of 0.2 at low speeds.

The results shown were obtained from data recorded during tests of wing models that spanned the throats of the tunnels. The air flow over the wing sections near the tips was therefore approximately two dimensional as compared with the flow that would have been present had the wing been tested with free tips. Unpublished data obtained during wind-tunnel tests at high speeds of a wing with a free tip indicate that the critical Mach number of a wing section is greater when the section is operating in the air flow near a free tip than when the section is operating in a two-dimensional flow. If the wings had been tested with free tips at the same angles of attack, the critical Mach numbers of the tip sections would therefore probably have been greater than the critical Mach numbers measured during the present tests.

DISCUSSION

The results presented in figure 1 show the radical changes that can occur in spanwise load distribution on a wing with a large spanwise variation in the section critical Mach number. A considerable change in load distribution on a wing with a moderate spanwise variation in the critical Mach number is shown in figure 2, and a negligible change on a wing with a small spanwise variation in the critical Mach number is shown in figure 3. These experimental results thus indicate that the magnitude of the change in the spanwise load distribution on a wing at supercritical Mach numbers varies with the magnitude of the spanwise variation in the critical Mach number of the wing sections.

The outboard movement of the center of load on the semispan of a wing at supercritical Mach numbers, as shown in figures 1 and 2, decreases the downwash in the region of the tail for a given wing lift coefficient and decreases the change in downwash for a given change in wing lift coefficient. These variations change the elevator deflection required for trim and increase the stability of the airplane. Such an outboard movement of the center of load also increases the bending moments on a wing structure. If the outboard movement occurs when the wing is supporting its maximum design load, the factor of safety for the wing structure is decreased. The decrease in the lift coefficient on a wing for a given angle of attack at supercritical Mach numbers requires that the angle of attack of the airplane be increased in order to maintain a given lift coefficient. This increase in angle of attack leads to changes in the elevator deflection required for trim and to increases in the stability at supercritical Mach numbers, in addition to the changes produced by a spanwise movement of the center of load.

Because the outboard movement of the center of load produces detrimental changes, this movement should be held to a minimum. A comparison of results in figures 1 to 3 indicates that, for a definite moderate lift coefficient, the outboard movement can be reduced by designing the wing-fuselage combination to give the same critical Mach number for each of the wing sections. The obvious method of obtaining this result is to design the wing with the same section and the same section lift coefficient at each station and to reduce to a minimum the interference effects on the wing. The results presented in figure 3 indicate that the same result may be accomplished by using the proper combination of various wing sections. The outboard movement of the center of load may also be reduced by so deflecting "dive-recovery" flaps placed inboard on the lower surfaces of the wing that the lift increases on the inboard sections where the greater losses in lift occur. Dive-recovery flaps placed outboard would increase rather than decrease the wing bending moments for a given lift and would be less effective than inboard flaps in reducing the total changes in the elevator deflection required for trim and in reducing the stability of an airplane.

CONCLUDING REMARKS

A comparison of the results of tests of three different tapered wings indicates that the magnitude of the spanwise movement of wing center of load at supercritical Mach numbers varies with the magnitude of spanwise variation in critical Mach number; consequently, it may prove desirable in the design of wings for high-speed airplanes to choose sections, thickness-to-chord ratios of sections, and section load distributions to provide a constant value of the spanwise critical Mach number.

Some of the effects of the spanwise shift of the center of load may be overcome by the use of dive-recovery flaps placed inboard.

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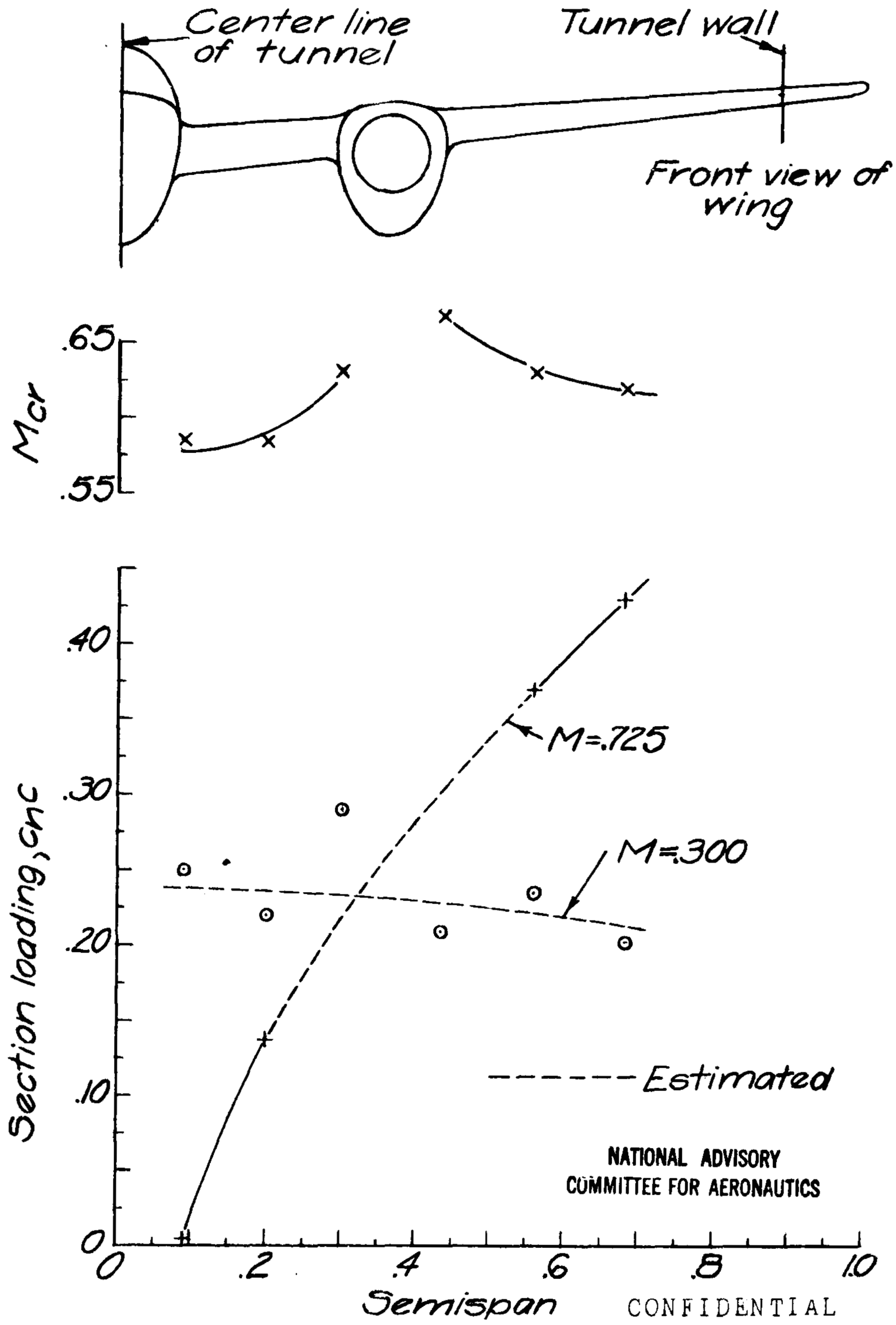

Figure 1.- Measured spanwise load distributions and spanwise variation of section critical Mach number on tapered wing with NACA 23015 root section and NACA 4412 tip section at $C_L = 0.2$.

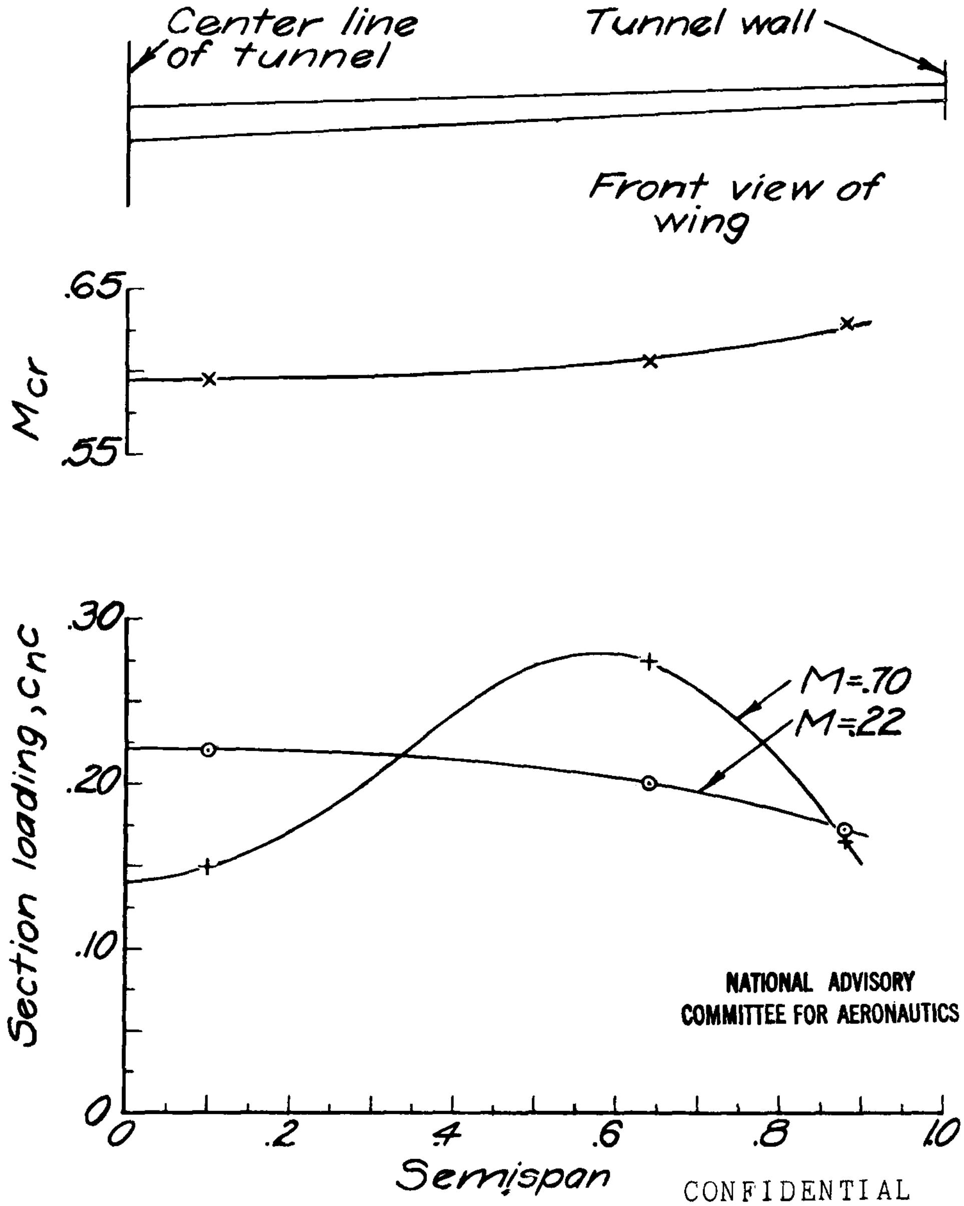

Figure 2.- Measured spanwise load distributions and spanwise variation of section critical Mach number on tapered wing with root-section thickness ratio of 22 percent and tip-section thickness ratio of 12 percent at $C_L = 0.2$.

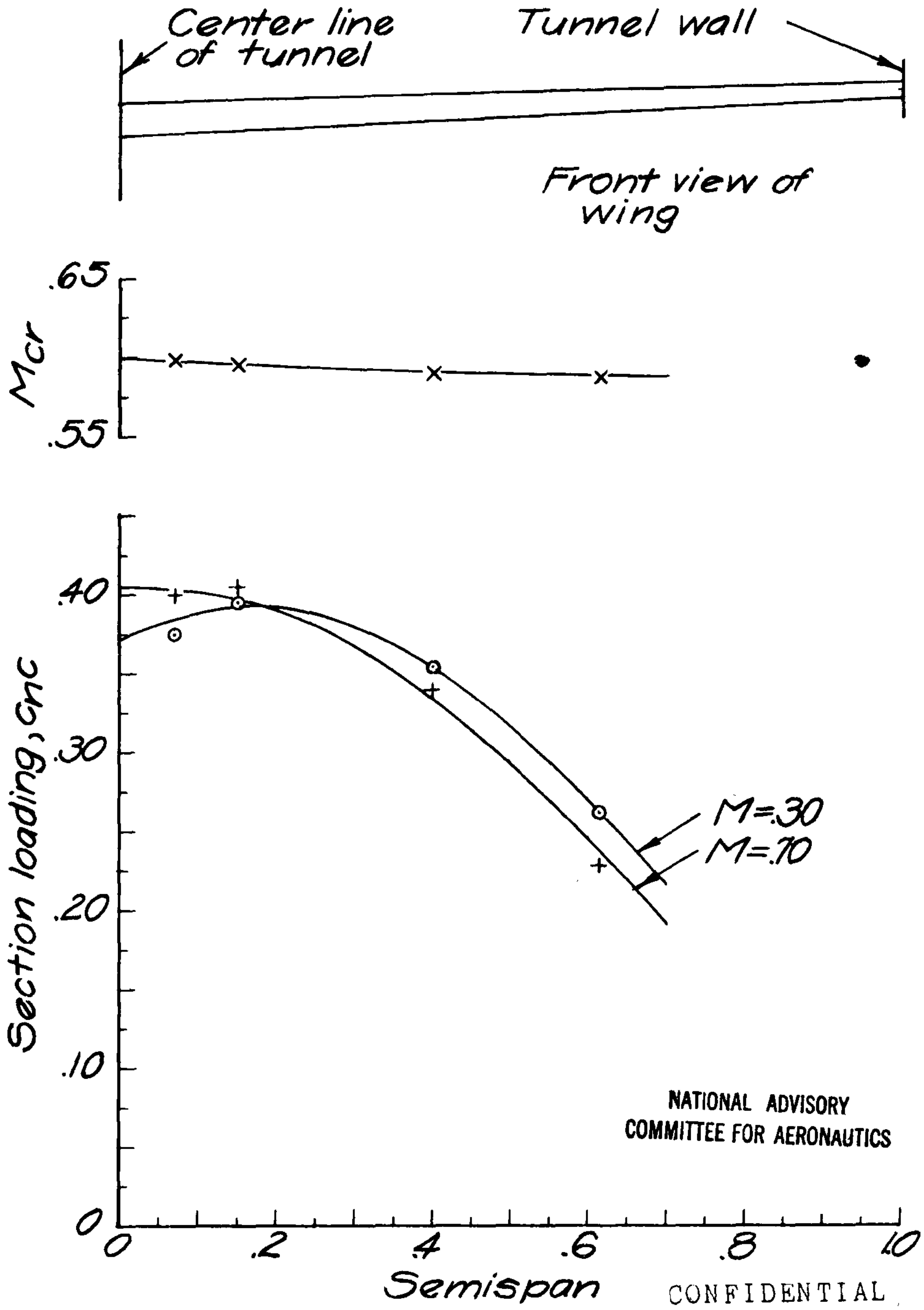

Figure 3.- Measured spanwise load distributions and spanwise variation of section critical Mach number on tapered wing with NACA 63(420)-422 root section and NACA 63(420)-517 tip section at $c_L = 0.2$.

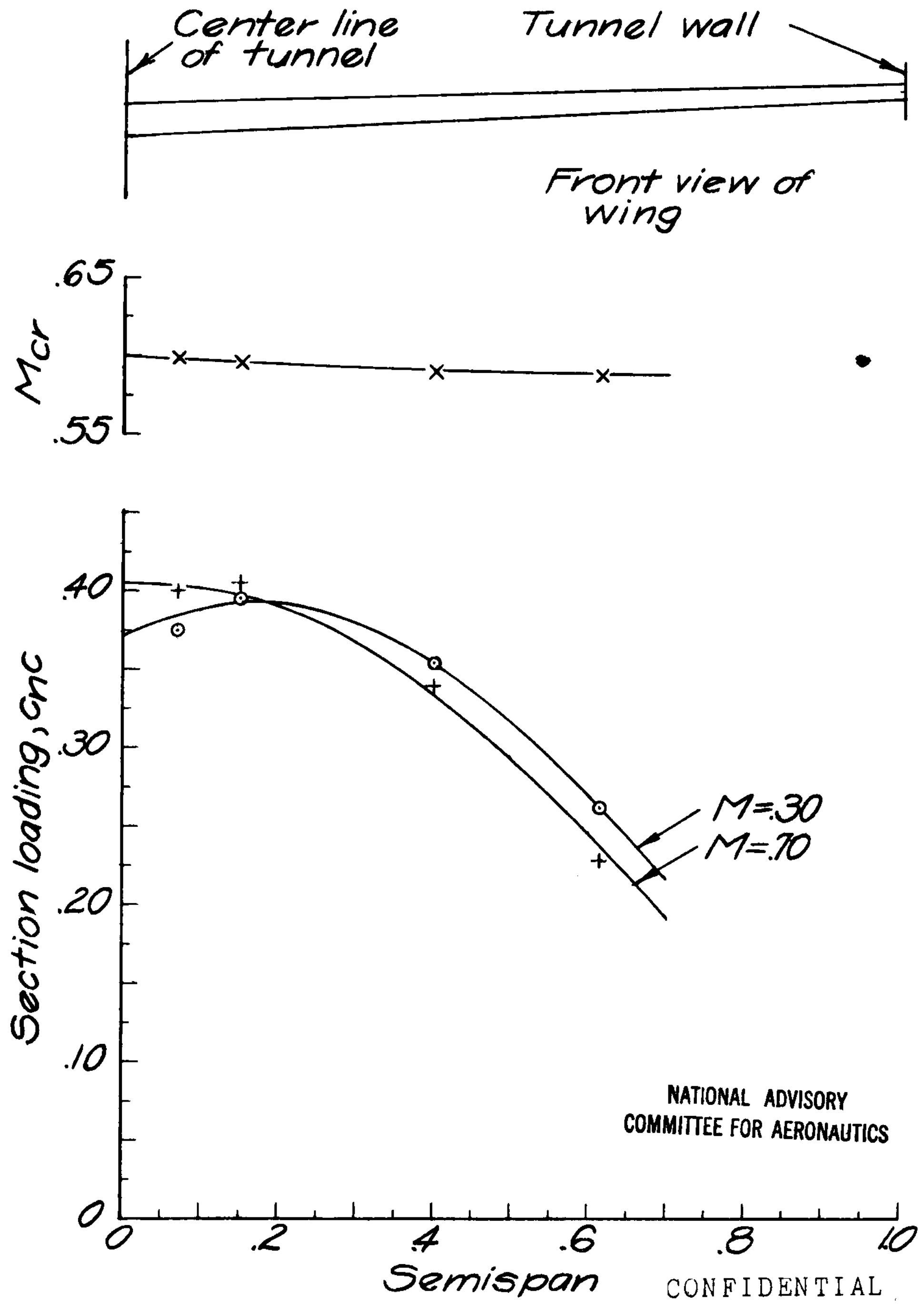

Figure 3.- Measured spanwise load distributions and spanwise variation of section critical Mach number on tapered wing with NACA 63(420)-422 root section and NACA 63(420)-517 tip section at $C_L = 0.2$.