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DERIVATION OF JACK MOVEMENT INFLUENCE COEFFICIENTS AS A BASIS FOR SELECTING WALL CONTOURS GIVING REDUCED LEVELS OF INTERFERENCE IN FLEXIBLE WALLED TEST SECTIONS

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1. Introduction

Self-streamlining test sections having rigid sidewalls but flexible top and bottom walls have been under development for many years. (Reference 1 is an extensive bibliography covering all adaptive tunnels). A wall-setting algorithm for two-dimensional testing, developed by Judd[2], has been in regular use at southampton since 1976, most recently with a transonic test section. The algorithm predicts, from measurements made only at the walls and without reference to the model, the adjustments in the shapes of the walls required to eliminate their interference effects at the model. The algorithm has proved capable, in many cases, of driving the walls directly to the shapes of unloaded streamlines. As yet there is no equivalent algorithm ready for use in the three-dimensional testing which is commencing in the same test section.

At this stage in the evolution of the new testing techniques the notion has gradually emerged of choosing the walls' shapes which give minimum interference in the following way. A pre-requisite is a method for quantifying the interferences. For the transonic flexible walled tunnel currently in use such a method has long been in use in two-dimensional testing[3] and an equivalent has been developed recently (by I. Cook - work to be published) for use with three-dimensional models. The information provided by either method comprises the distributions, along the centerline of the test section, of the wall-induced u (streamwise) or v (vertical cross-stream) perturbations to the free stream velocity or Mach number vector. In two-dimensional testing these are the only wall-induced components, and they arise only from the loadings on the top and bottom walls when they are not properly streamlined. In three-dimensional testing there is a third component of wall-induced perturbation, a cross-stream component in a horizontal plane, and loadings from all four walls contribute in general to all three components of perturbation. Adjustments to the shapes of the flexible top and bottom walls can only be expected in principle to eliminate the first two mentioned components in three-dimensional testing, and these only on one line, say along the center of the test section,or along a pair of lines symmetrically placed either side of the vertical centerline. The consequence of this restriction is not addressed in this report.

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The u and v perturbation distributions can, in principle, be converted into the distributions of wall curvature required to eliminate the perturbations. The additional information required for this conversion is a set of measures of the perturbations induced along the line by local movements of each wall.

As the shapes of the flexible walls are controlled by jacks, 40 in all, and there are two perturbation components to control, it is possible in principle to eliminate these components at 20 points in the test section. It is assumed for the time being that these points would lie along the centerline in line with each jack pair, although this is not a necessary restriction.

This report covers work done towards providing data on the influence of the movement of wall-control jacks on the Mach number perturbations along the test section. The data was derived using an existing streamline-curvature program, and for use is reduced to matrices of influence coefficients.

2. Perturbations induced by the movement of one jack

The main interest is in the level of perturbation near to a model, that is near to the centerline of the test section, and therefore perturbations have been computed on the centerline, and also along parallel lines above and below the centerline covering the portion of the depth of the test section usually occupied by a model. A sketch of an empty test section is shown on Figure 1, with one jack moved from the straight. The influence of its movement has been computed along the centerline (B) and also along lines A and C which are above and below the centerline by one-twelfth of the depth h. The information for line B will be used in determining the influence coefficients, while that for lines A and C allows the perturbations to be quantified which will exist off-center when they have been eliminated on-center. The flow perturbations are resolved in the manner also shown on Figure 1 into vertical and horizontal perturbations in the free-stream Mach number M_∞. The magnitudes of perturbations, which depend on M_∞ and on jack movement and spacing, have been computed over a range of Mach number up to 0.85

for all jack spacings in use in the transonic test section. The information given in this report applies only to the closest jack spacing (one inch) which is used in the regions of the walls closest to the model.

The u and v perturbations in Mach number are shown on Figures 2 and 3 for two free-stream Mach numbers and one value of jack displacement into the test section, the jack being moved in the manner shown on Figure 1. There is a strong Mach number dependence particularly in M_u, and also a tendency with increased Mach number for the perturbations to be more strongly confined to the regions above the moved jacks.

The question of dependence of the perturbations on the amount by which a jack is moved is addressed on Figure 4, where two features from perturbation distributions such as Figures 2 and 3 are picked out for emphasis. Figure 4 shows on the left just the peak value of the u-perturbation on the centerline above the jack, as influenced by jack movement and free-stream Mach number. The lines are nearly straight, and could be so considered for small jack movements. On the right of the same figure is plotted just the gradient of M_v/M_∞ (as a positive number), again for the centerline above the moved jack. The strong M_∞ dependence is again seen, also the suggestion that, for small jack movements, the slope could be considered to vary linearly with the movement.

3. Perturbations induced by movement of two opposite jacks

If the perturbation at a point in the flowfield arising from the movement of a jack is proportional to its movement, then it is possible that the effects of the movement of two jacks could be additive. Of particular interest would be movements of a pair of opposite jacks

(i) differentially. The movement of the jacks would be toward or away from each other. The expectation would be that on the centerline the v-component would be non-existent (and hopefully acceptably small off-center in the region of the model), leaving merely a streamwise centerline perturbation,

(ii) collectively. The movement of the jacks would be either both upward or both downward. Such movements are intended to induce v-perturbations with low levels of u component on the centerline.

The results of computations for Mach 0.7 for differential movement are shown on Figure 5. The jacks have both been moved into the test section by the same distance as for Figure 2. At this Mach number it is seen that on the centerline (line B) the maximum perturbation $^{M_u}/_{M_\infty}$ is about .0026. On Figure 5, where two opposite jacks have been moved by the same amount, the maximum perturbation in $^{M_u}/_{M_\infty}$ is seen to be doubled at about 0.0052. evidently at this position in the test section the individual contributions to the u-perturbation are additive. Further, since the v-perturbations from the two jacks are in opposition, the resultant levels of $^{M_v}/_{M_\infty}$ are low, and zero on the centerline.

There is similar evidence on Figure 6, but slight asymmetry. The jacks have been moved the same distance as for the data of Figure 3 where a peak value of $^{M_v}/_{M_\infty}$ of about ±0.0007 at $\frac{x}{h}$ = ±0.2 is seen for Mach 0.7 on the centerline. With two opposite jacks moved collectively by the same distance Figure 6 shows that the peak value of v-perturbation is doubled, with no change in the position of the peak. On the centerline M_u is low, but evidently there is a strong gradient in M_v across the depth of the test section.

Further evidence of the additive nature of the effects of jack movements is provided on Figure 7 where the walls are assumed curved in arcs to induce along the centerline relatively strong v-perturbations and weak u-perturbations. The continuous lines are values computed from the streamline curvature program. The discrete points have been calculated just from a matrix of $^{M_v}/_{M_\infty}$ influence coefficients which has been assembled from the data of Figure 3. In calculating these points, 15 jacks were assumed moved collectively by amounts equal to the displacement of the centerline from straight. The agreement between the two sources of data on $^{M_v}/_{M_\infty}$ is seen to be good, supporting the opinion that the perturbations induced by jacks are additive. The variation of $^{M_u}/_{M_\infty}$ across the center of the test section is small.

4. Concluding comments

Following the experiences outlined in this work it is planned that information of the kind contained in Figures 5 and 6, converted into the form of influence coefficients, will form the basis of the proposed new method of selecting wall contours giving low u- and v-components of wall-induced Mach number perturbation. While the motivation has been the problem of streamlining around three-dimensional models, it appears that it may also be applicable in two-dimensional testing.

5. References

1. Tuttle, M.H. and Plentovich, E.B. Adaptive wall wind tunnels - a selected, annotated bibliography. NASA Tech. Memo. 84526, November 1982.

2. Judd, M., Wolf, S.W.D. and Goodyer, M.J. Analytical work in support of the design and operation of two-dimensional self streamlining test sections. NASA CR-145019, July 1976.

3. Goodyer, M.J. and Wolf, S.W.D. Development of a self-streamlining flexible walled transonic test section. AIAA Journal, Vol.20, No.2, Feb. 1982.

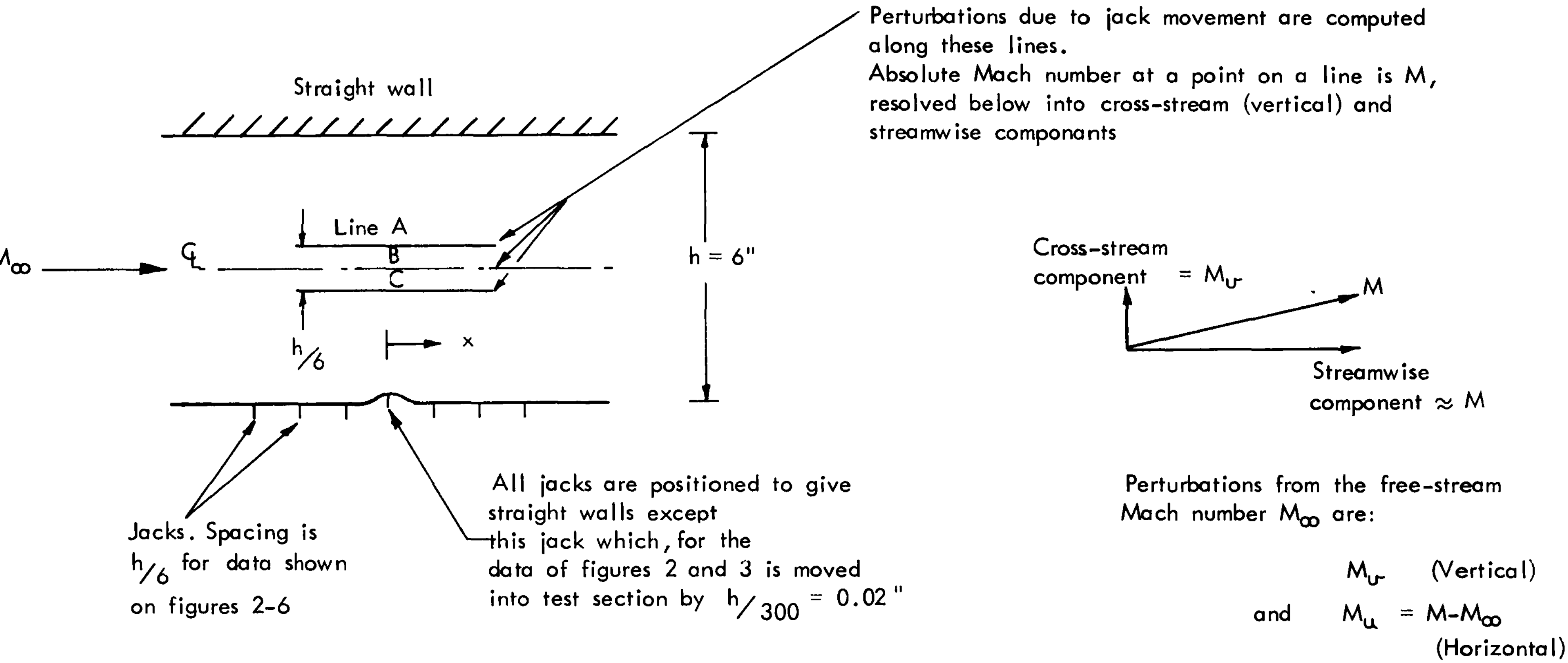

FIG. 1 GEOMETRY OF AN EMPTY FLEXIBLE WALLED TEST SECTION, SHOWING ONE JACK DISPLACED FROM STRAIGHT AND THE LINES ALONG WHICH THE RESULTANT Mach PERTURBATIONS HAVE BEEN COMPUTED.

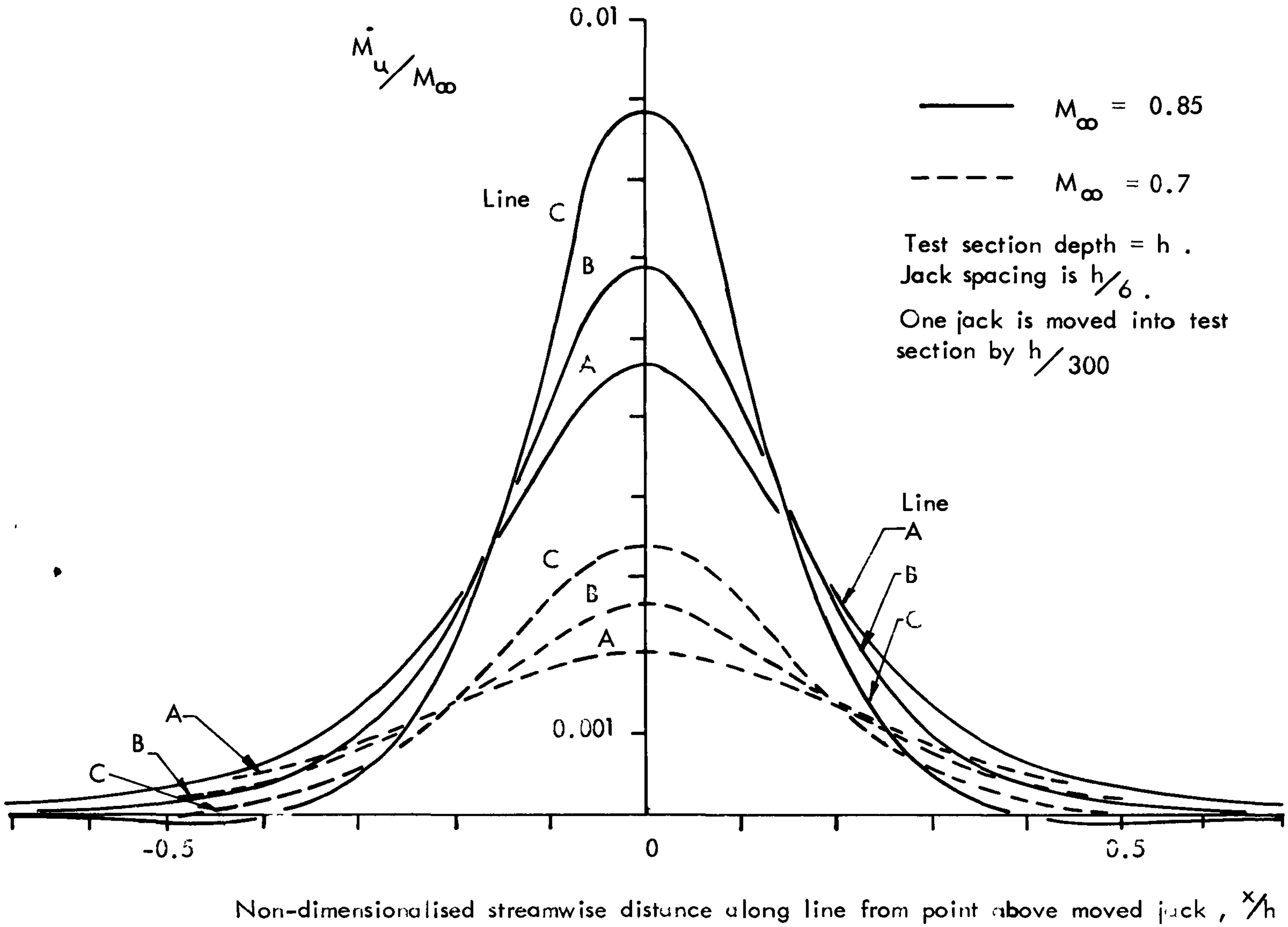

FIG . 2 VARIATION OF STREAMWISE PERTURBATION IN MACH NUMBER INDUCED BY A MOVEMENT OF ONE JACK INTO EMPTY, AND OTHERWISE STRAIGHT WALLED, TEST SECTION.

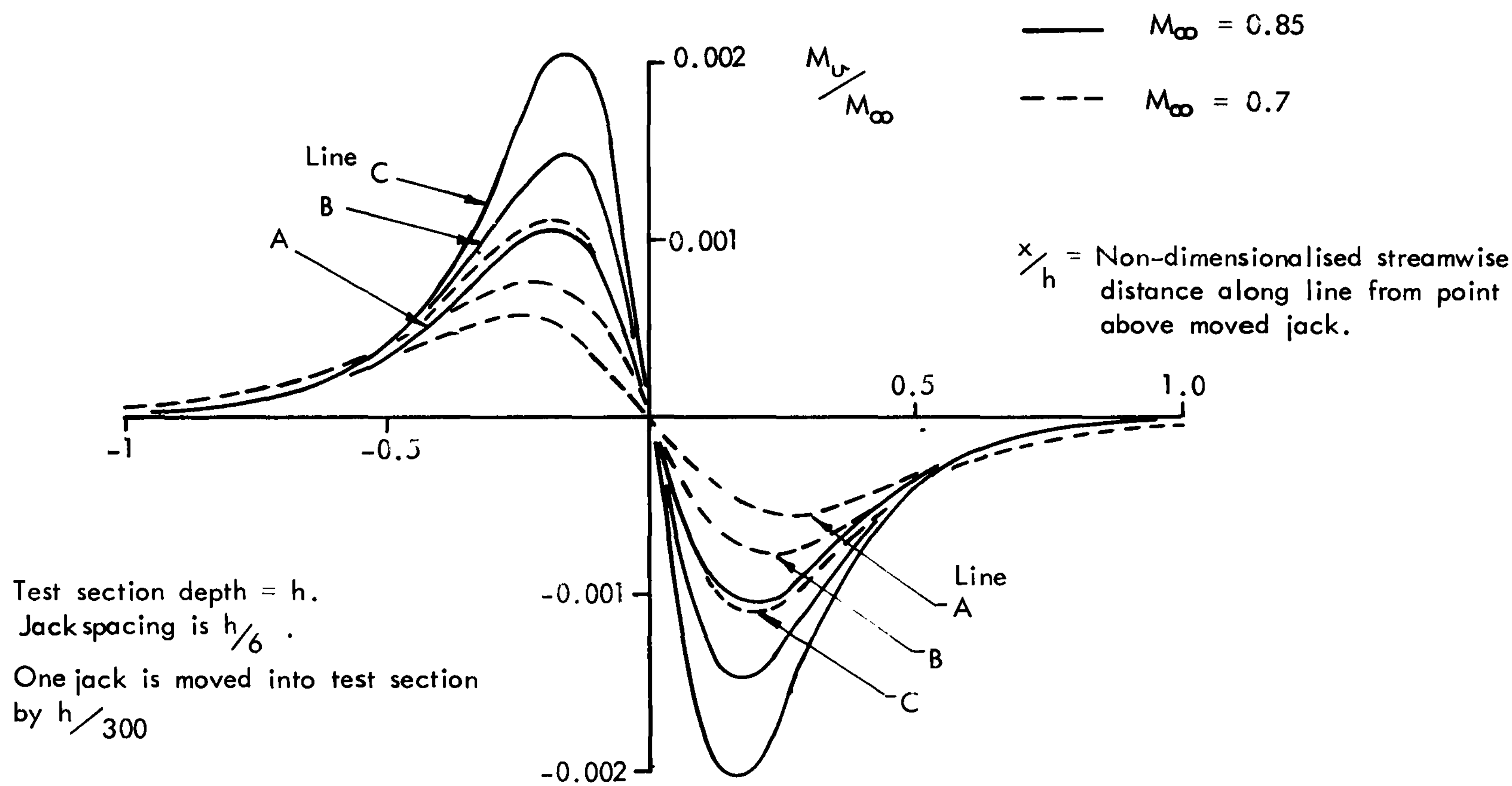

FIG. 3 VARIATION OF CROSS-STREAM PERTURBATION IN MACH NUMBER INDUCED BY A MOVEMENT OF ONE JACK INTO AN EMPTY, AND OTHERWISE STRAIGHT WALLED, TEST SECTION.

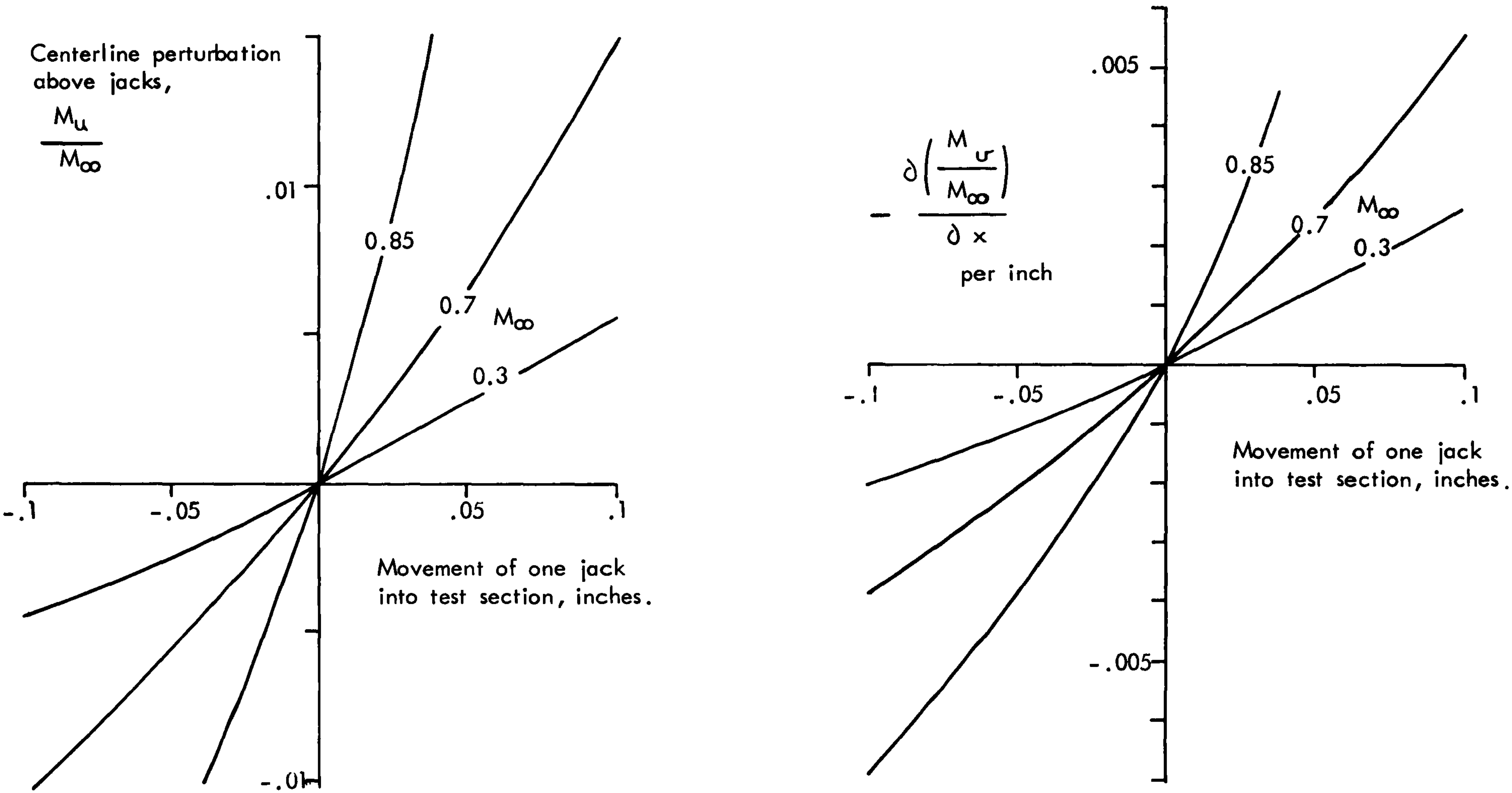

FIG. 4. PERTURBATIONS ON CENTERLINE ABOVE SINGLE MOVED JACK — EFFECT OF MACH NUMBER AND WAVE AMPLITUDE. OTHER WALL IS STRAIGHT.

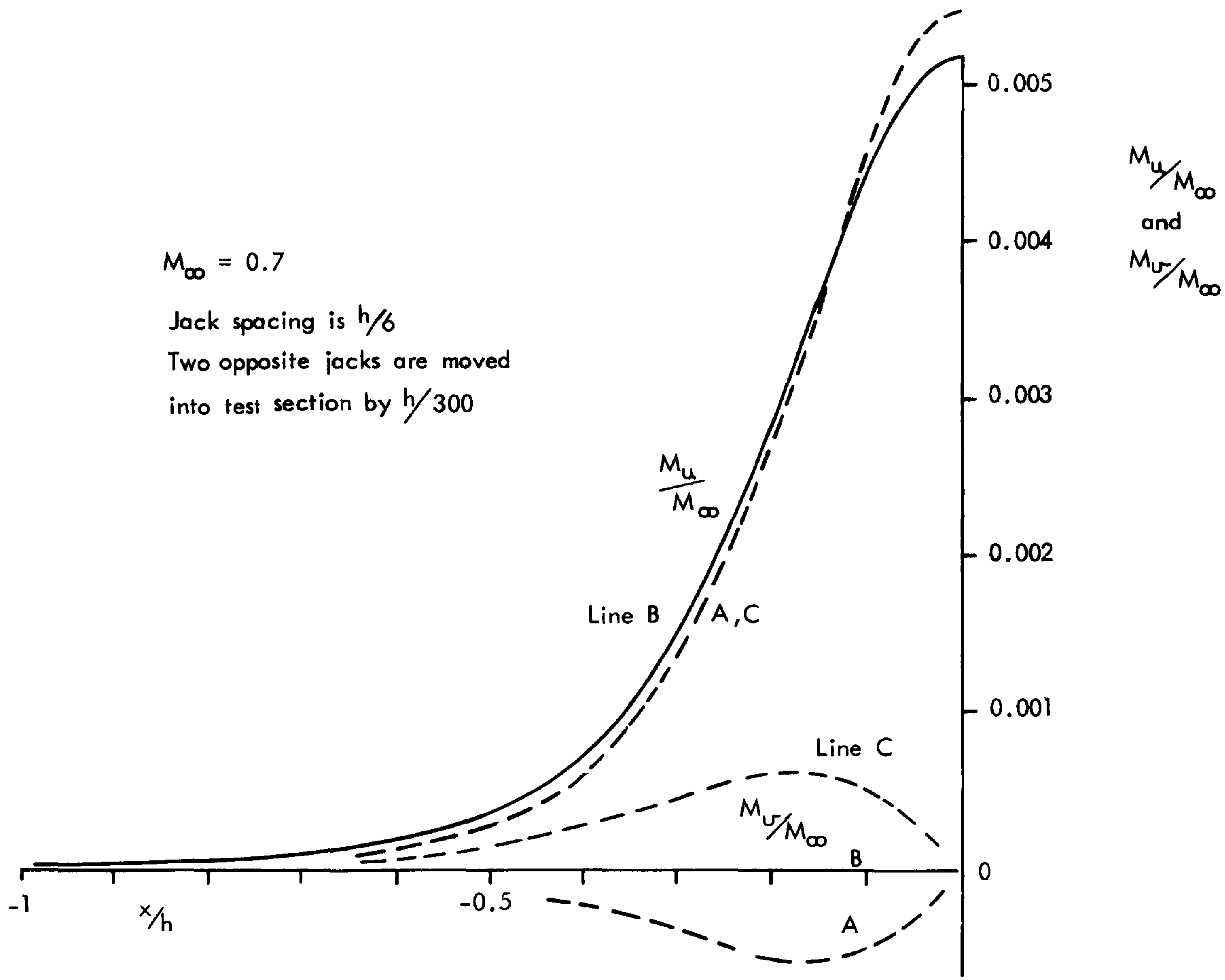

FIG. 5 DISTRIBUTION OF MACH NUMBER PERTURBATIONS RESULTING FROM DIFFERENTIAL MOVEMENT OF TWO OPPOSITE JACKS (THE TEST SECTION IS OTHERWISE STRAIGHT AND EMPTY) TO INDUCE u - PERTURBATIONS, WITH ZERO M_v ON CENTERLINE.

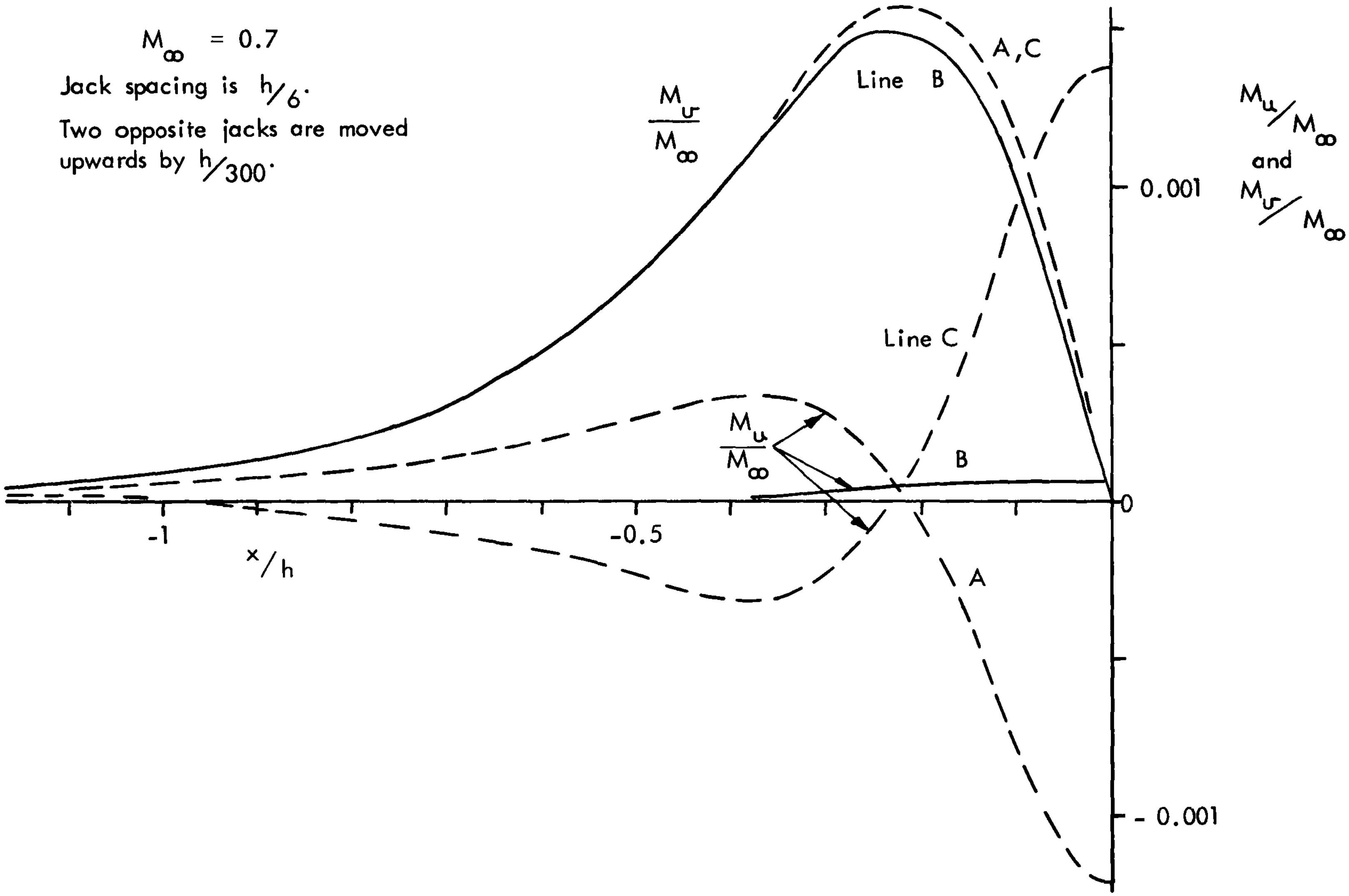

FIG. 6 DISTRIBUTION OF MACH NUMBER PERTURBATIONS RESULTING FROM COLLECTIVE MOVEMENT OF TWO OPPOSITE JACKS (THE TEST SECTION IS OTHERWISE STRAIGHT AND EMPTY) TO INDUCE v - PERTURBATIONS AND LOW M_u ON CENTERLINE

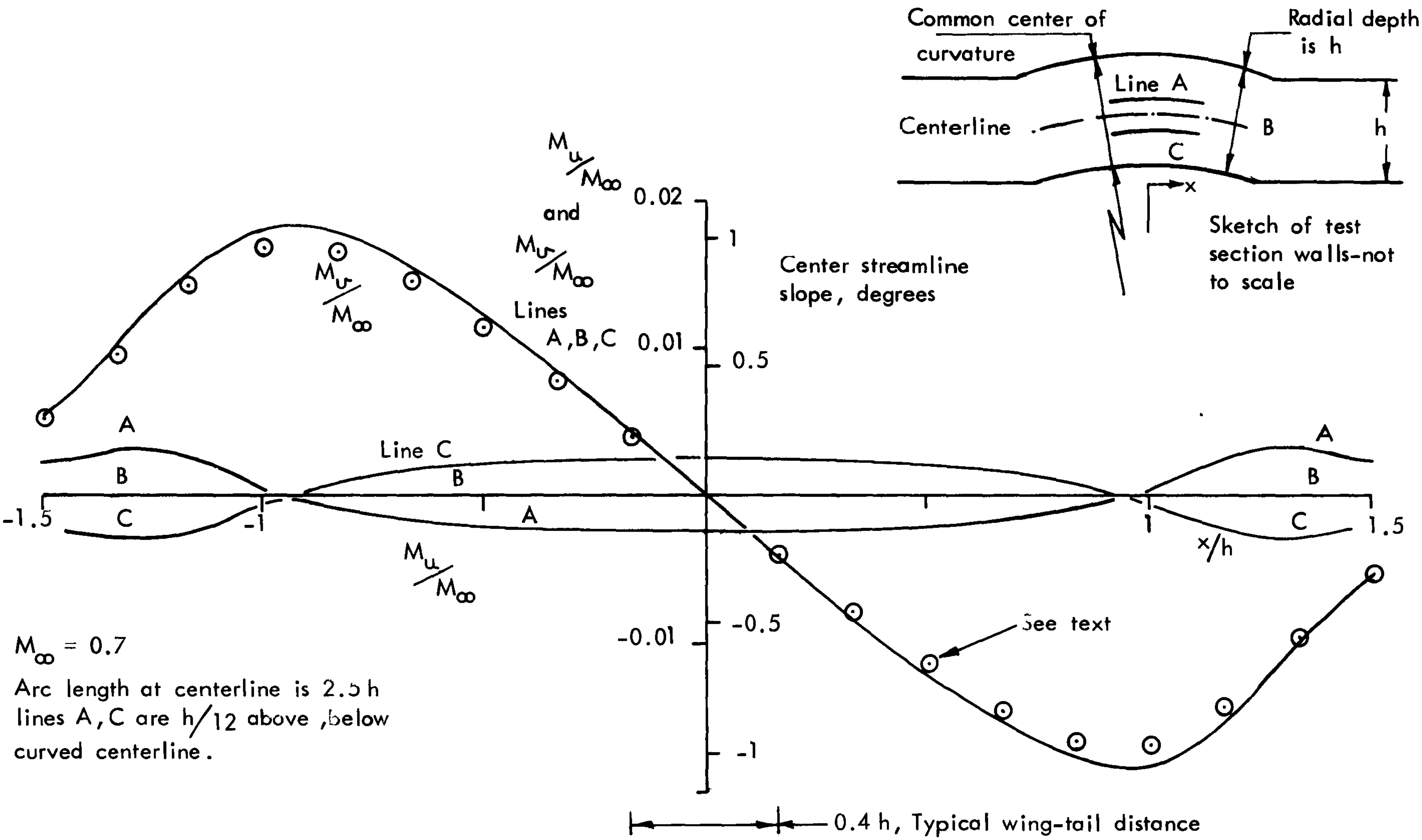

FIG. 7 COMPUTATIONS FOR WALLS CONTOURED TO INDUCE AT CENTERLINE A LINEAR VARIATION OF M_υ ALONG MODEL, WITH ZERO M_u. FLOW CURVATURE WILL INDUCE $\frac{1}{2}$° CHANGE OF FLOW DIRECTION OVER REPRESENTATIVE DISTANCE FROM WING TO TAIL.

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16 Abstract

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