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A WAKE TRAVERSE TECHNIQUE FOR USE IN A TWO DIMENSIONAL TRANSONIC FLEXIBLE WALLED TEST SECTION

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CONTENTS

1. INTRODUCTION

Reported two-dimensional validation data[1] from the Transonic Self-Streamlining Wind Tunnel (TSWT), at Southampton, U.K., concerns only model lift. Of course, the acquisition of drag data is equally important but this data was not available for the series of reported tests.

The reason for this situation is that the models tested provided only data on their pressure distributions. This information was numerically integrated over the model surface to determine lift, pressure drag and pitching moment. However, the pressure drag is only a small component of the total drag at nominal angles of attack and cannot be used to assess the quality of flow simulation.

This report describes an intrusive technique for obtaining information on the total drag of a model in TSWT. The technique adopted is the wake traverse method. The associated tunnel hardware and control and data reduction software are outlined and some experimental results are presented for discussion.

2. TRAVERSE HARDWARE

An existing rigid sidewall plate has been modified to carry a pitot-static probe and its jack mechanism (see Figure 1). The probe was a combination of a disc-static type with a conventional pitot type. Since the probe would be traversed in a region of the test section flow influenced by model induced downwash, the probe design was chosen for its insensitivity to flow angle in one plane. For this particular application, this plane was the vertical.

The probe was held in the test section by stainless steel tubes connected to a narrow plate, able to move vertically within a slot cut in the sidewall (see Figure 1). This plate was of sufficient length to ensure that the sidewall slot was not uncovered in the test section throughout the range of movement of the probe. The probe was able to move 7.62 cm (3 inches) above and 2.54 cm (1 inch) below the tunnel centreline, these limits being set by mechanical considerations. However, the entire traverse hardware can be inverted to allow the probe to traverse to 7.62 cm (3 inches) below the tunnel centreline should it become necessary.

The movement band was considered adequate for traversing envisaged high speed wakes and would also allow investigations of the flexible wall boundary layers. Thick model wakes were not expected, since the angle of attack was limited by model loading and the availability of wall movement for streamlining.

The probe was positioned by a jacking mechanism (see Figure 1) which was similar to that of a TSWT wall jack. This design feature ensured the traverse was compatible with the wall control system developed for TSWT[1]. The jack was powered by a 3-phase S_{LO} - S_{YN} type MO51-DW6O1 stepper motor connected through a worm reduction gear to a lead screw, to which the probe was attached. The probe translated vertically at a rate of 0.43 mm(.017 inch) per second. This was considered sufficiently slow to allow continual sampling of probe pressures during a steady sweep of the probe.

The vertical position of the probe relative to the tunnel centreline datum was determined by a linear potentiometer with a 10.16 cm (4 inch) stroke capable of a measuring accuracy of $\pm$.01016 cm($\pm$.004 inch). The spanwise position of the probe was set on the tunnel centreline, although there is an option to position the probe off centreline should this prove necessary.

The probe pressure signals were fed directly to a computer from a transducer, together with tunnel reference pressures.

3. TRAVERSE SOFTWARE

The software had three function:

1) Position the probe.
2) Acquire probe and reference pressures.
3) Analyse the pressures to determine the model drag coefficient C_D.

The movement function was achieved in the following manner:

a) The operator informs the computer where the probe is to move to relative to the tunnel centreline.
b) The direction of movement of the probe is determined from its current location, and the traverse jack control system is loaded with direction information.
c) The operator indicates that the traverse can commence by depressing the 'computer-return' key.
d) The probe moves and its position is continually scanned until the desired position is reached within a tolerance of ±.0.127 mm ($\pm$.005 inch).

Traverse data acquisition was performed by sampling the pressure transducer channels. Each recorded pressure was in fact the average of fifteen samples taken at 1 milli-second intervals, to reduce the effect of signal noise. All pressure signals were referenced to channel 'zeroes' taken before each traverse, to eliminate long term amplifier drift.

Each time the probe position was sampled, the position the three tunnel and probe pressures were recorded as a data set. The reference stagnation pressure was assumed atmospheric. Unfortunately, due to computer 'housekeeping' the data sets were not obtained at regular movement intervals in the traverse.

The reduction of the pressure data was performed off-line using a reported numerical technique[2], to determine the drag coefficient C_D. From this reference

$$C_D = \int_{-\infty}^{+\infty} C_D' \, d(Y/_c)$$

where the local drag component in the wake.

$$C_D' = 2 \left(\frac{H_1}{H_o}\right)^{\frac{\gamma-1}{2\gamma}} \left(\frac{P_1}{P_o}\right)^{\frac{\gamma+1}{2\gamma}} \left(\frac{\lambda_1}{\lambda_o}\right)^{\frac{1}{2}} \left\{1 - \left(1 - \frac{\lambda_2}{\lambda_o}\right)^{\frac{1}{2}}\right\} ,$$

$$H = P + \tfrac{1}{2}\rho V^2 = P\,(1 + \tfrac{1}{2}\gamma M^2)$$

and $\lambda_o \triangleq \dfrac{H_o - P_o}{P_o}$; $\lambda_1 \triangleq \dfrac{H_1 - P_1}{P_1}$; $\lambda_2 \triangleq \dfrac{H_o - H_1}{H_1}$

Note suffix 'o' corresponds to local freestream values and suffix '1' to probe values.

The pressures indicated by the probe were corrected for probe interferences, using the calibration curve shown on Figure 2 and discussed in the following section. A correction for the finite size of the probe was also included in the calculation of C_D. No account was taken of the possible components to C_D at the wake edges due to differences between the local freestream and the reference freestream.

4. OPERATION

There are two optional methods for performing a wake traverse in a shallow flexible walled test section. The first option is to streamline the walls around the probe and model during the wake traverse. With this method different streamline contours would be required for each vertical position of the probe. In the second option the walls could be set to streamlined contours found with only the model present in the test section. The walls would then remain fixed throughout each wake traverse. In view of the low blockage of the probe and its mounting tubes, and the fact that they did not form a two dimensional shape, it was considered more practical to use the second method. Therefore the walls were fixed during a traverse, for all wake data discussed here.

The probe was calibrated in TSWT with the flexible walls set 'aerodynamically straight'[3] over a range of test Mach numbers up to 0.8. The probe was positioned on the tunnel centreline and a C_p correction was determined, based on the tunnel reference static pressure and reference Mach number. The onset of compressibility is clearly visible in the probe calibration shown on Figure 2, at Mach numbers greater than about 0.6.

During each wake traverse the freestream Mach number was held nearly constant by manual adjustments of the induced air pressure. For wakes thicknesses of the order 2.54 cm (1 inch), the probe traversing speed required the tunnel to be run for about six minutes.

5. EXPERIMENTAL RESULTS

A NACA 0012-64 Schlieren model of 10.16 cm (4 inch) chord was used for the preliminary wake traverse work reported here. The ratio of test section height to model chord was 1.5. The wake traverses were performed 2¼ chords downstream of the model trailing edge, and over sufficient vertical distance to locate both edges of the wake i.e. to locate where the local Mach number became near constant with probe movement.

Traverses were performed at reference Mach numbers of 0.3, 0.5, 0.6 and 0.7 for angles of attack of 0°, 2° and 4° (see Table 1) with the walls streamlined. The drag data is summarised on Figure 3, a plot of C_D-v-M_∞ for different angles of attack. The onset of wave drag is particularly evident above Mach 0.6. Also included on Figure 3 are reported C_D values[4] at $M_\infty = .17$ which agree reasonably well with the lower Mach number (i.e. $M_\infty < .6$) TSWT results over the α range. The low Reynolds number of the TSWT tests ($R_C = 0.67\text{-}1.3 \times 10^6$) has limited the amount of available reference drag data.

To supplement the above data with walls streamlined, a series of traverses were performed with the walls 'aerodynamically straight' at M_∞ equal to 0.5 and 0.7

(see Table 1) to observe the effect of strong boundary interference. For all cases, the effect of straight walls was to displace the wake vertically.

The $M_\infty \triangleq .7$; $\alpha = 4^o$ case shows the largest difference between streamlined and straight wall wake profiles as shown on Figure 4. These profiles relate favourably to the wakes shown in the spark schlieren on Figure 5 also taken at $M_\infty \triangleq .7$ with the walls straight and streamlined. This case serves to illustrate the severe interference which can be generated by a straight walled test section at high subsonic Mach numbers. The act of wall streamlining correctly positioned the model shock[1] and is shown here to produce a reasonable value for drag.

6. CONCLUSIONS

1. The wake traverse technique can provide reasonable estimates of model drag over a Mach number range to 0.7.

2. Wall streamlining has an effect on model drag which becomes more significant with increasing Mach number.

3. The wake traverse hardware and software is adequate for future testing.

7. SYMBOLS

C	-	Model chord
C_D	-	Drag coefficient
C_p	-	Pressure coefficient = $\frac{P_1 - P}{\frac{1}{2}\rho V^2}$
H	-	Total head
M	-	Local Mach number
M_∞	-	Freestream Mach number
P	-	Reference, or freestream static pressure
P_1	-	Static pressure indicated by wake traverse probe.
V	-	Freestream air velocity.

Y_T - Wake thickness

Y - Vertical position relative to the tunnel centreline.

Y_C - Vertical position of the mid-wake point relative to centre-line.

γ - Ratio of specific heats for air.

ρ - Freestream air density.

8. REFERENCES

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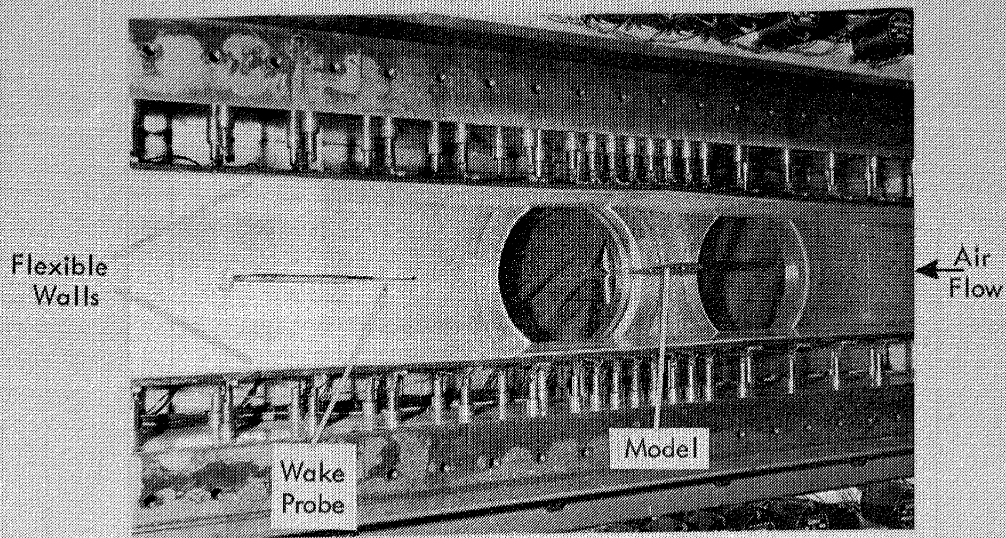
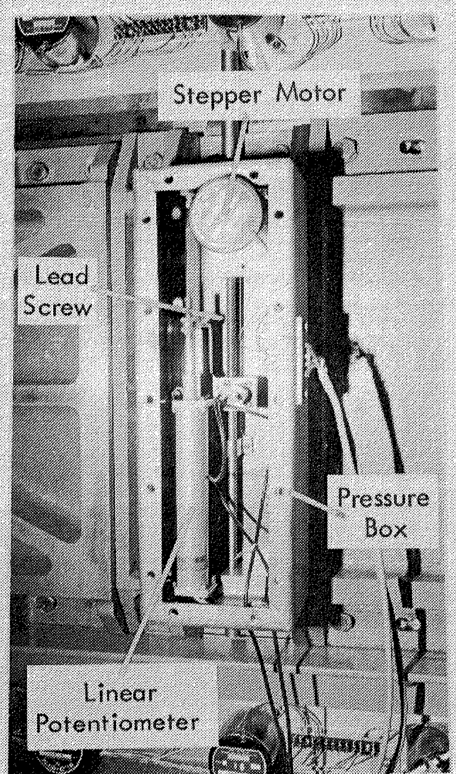
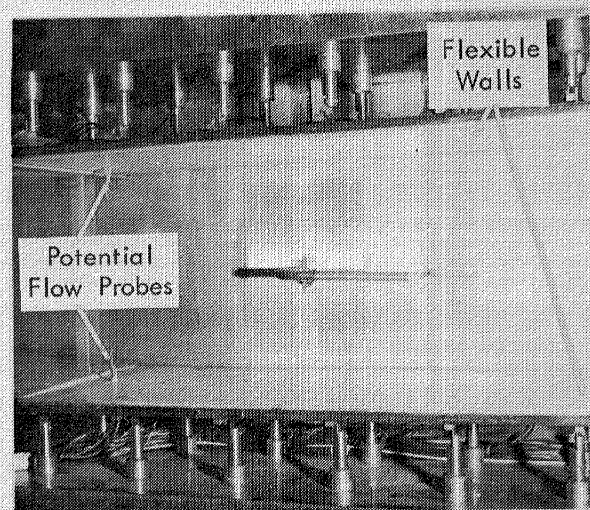
Table 1. Summary of TSWT Wake Traverse Data

M_∞ (approx)	α (Deg.)	Streamlined Walls			Straight Walls	
		C_D	Y_T (Inches)	Y_C (Inches)	Y_T (Inches)	Y_C (Inches)
.7	0	.0064	.545	+. 06	.0375	+.108
.7	2	.0079	.552	+.0417	0.55	+.042
.7	4	.0124	.825	-. 133	1.446	+.244
.6	0	.0063	-342	+. 058	-	-
.6	4	.0088	.692	-. 196	-	-
.5	0	.0056	.408	+. 067	.437	+.035
.5	2	.0066	.392	-. 029	.579	-.035
.5	4	.0085	.596	-. 181	.537	-.102
.3	0	.0049	.317	+. 008	-	-
.3	4	.0083	.4625	-. 198	-	-



The wake probe mounted in TSWT downstream of a NACA 0012-64 schlieren model (above) with the walls streamlined for the test case of $M_\infty = .7 : \alpha = 4^o$.



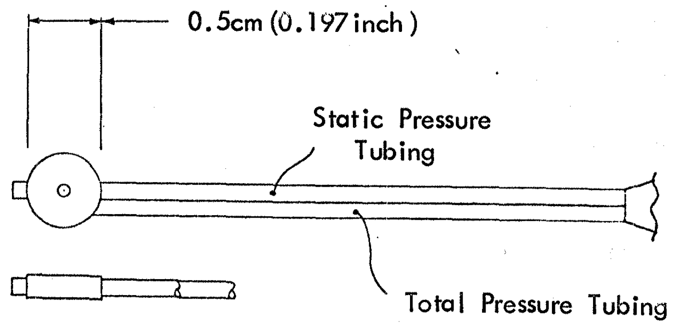


The wake traverse mechanism is mounted on a rigid sidewall plate (left with the pressure box open). The probe is connected by stainless steel tubes to a sliding plate flush with the sidewall of the test section (above).

FIG. 1 WAKE TRAVERSE HARDWARE IN SITU

WAKE PROBE

(Disc - Static Type)



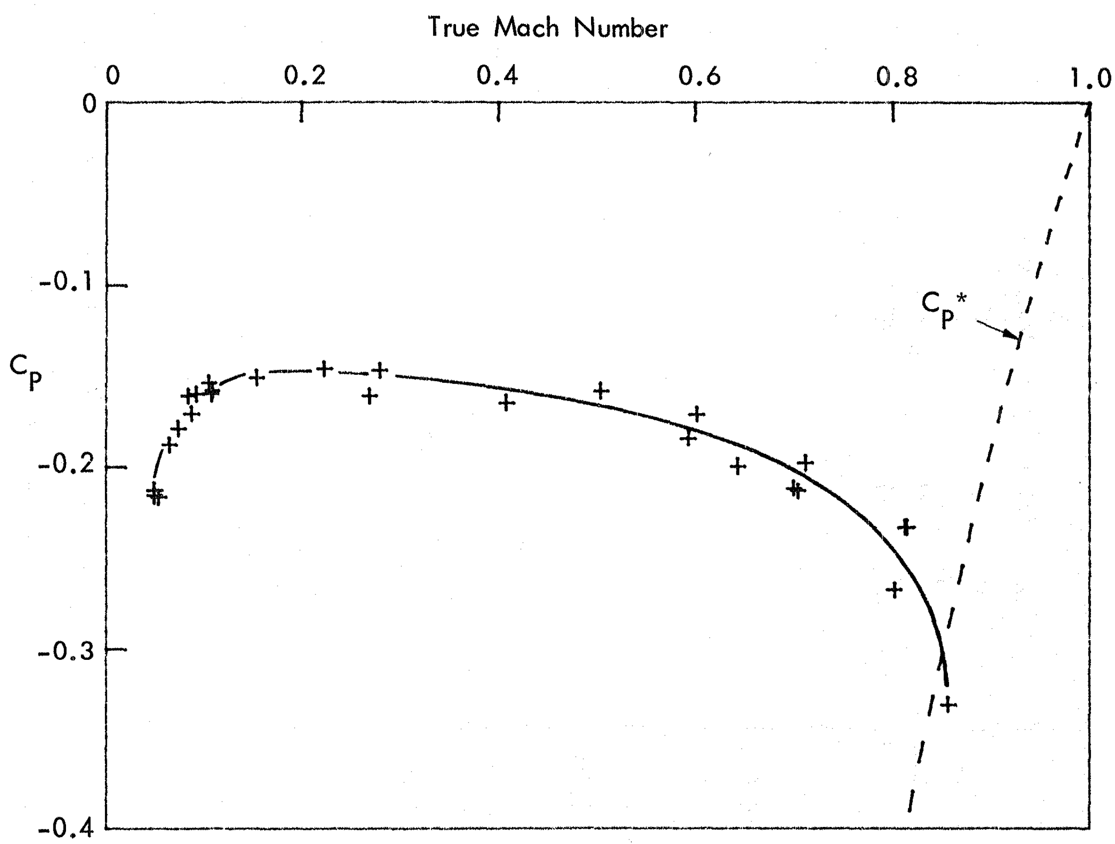


FIG. 2 WAKE PROBE CALIBRATION

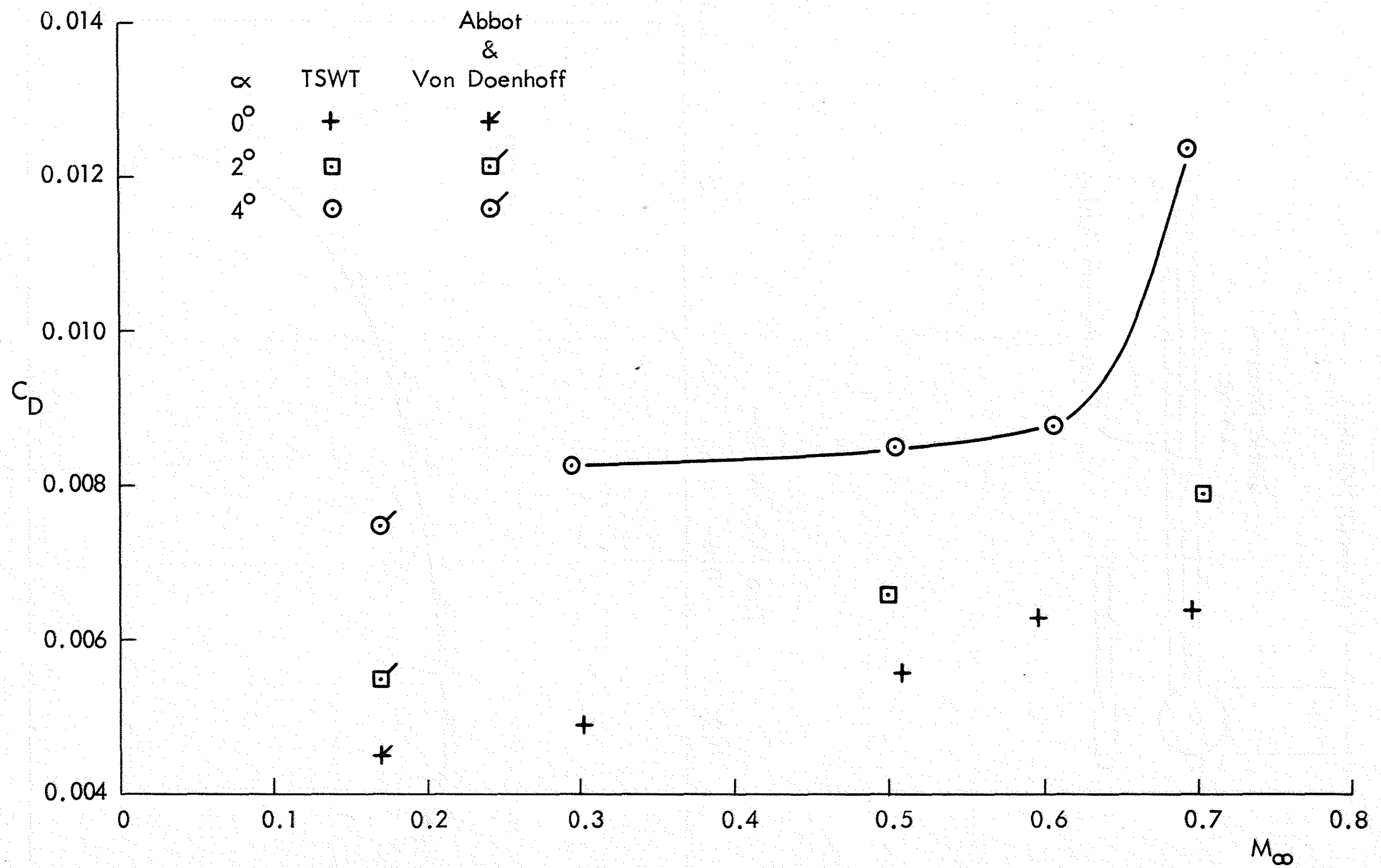


FIG. 3 NACA 0012-64 WAKE TRAVERSE DATA. WALLS STREAMLINED

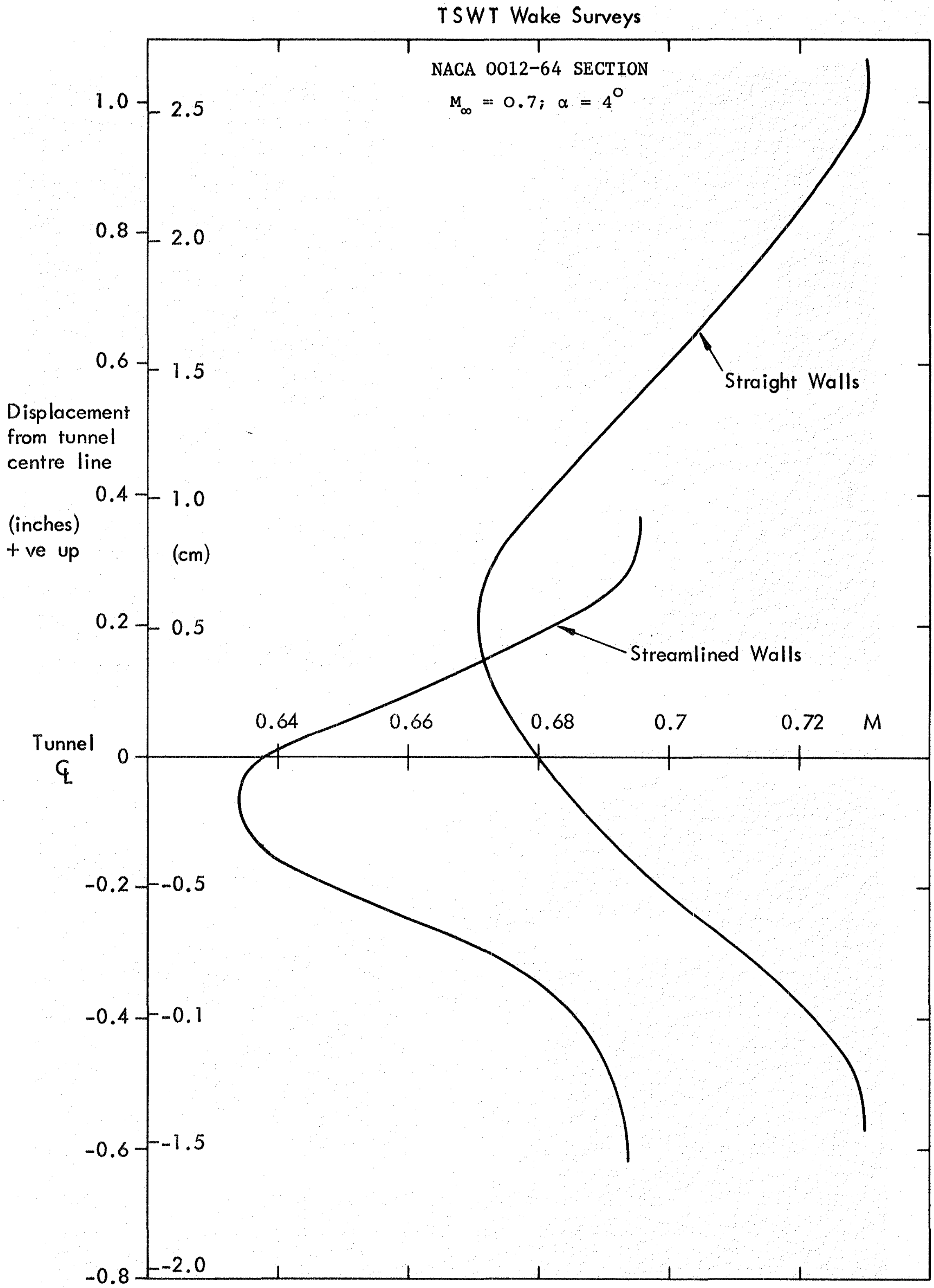
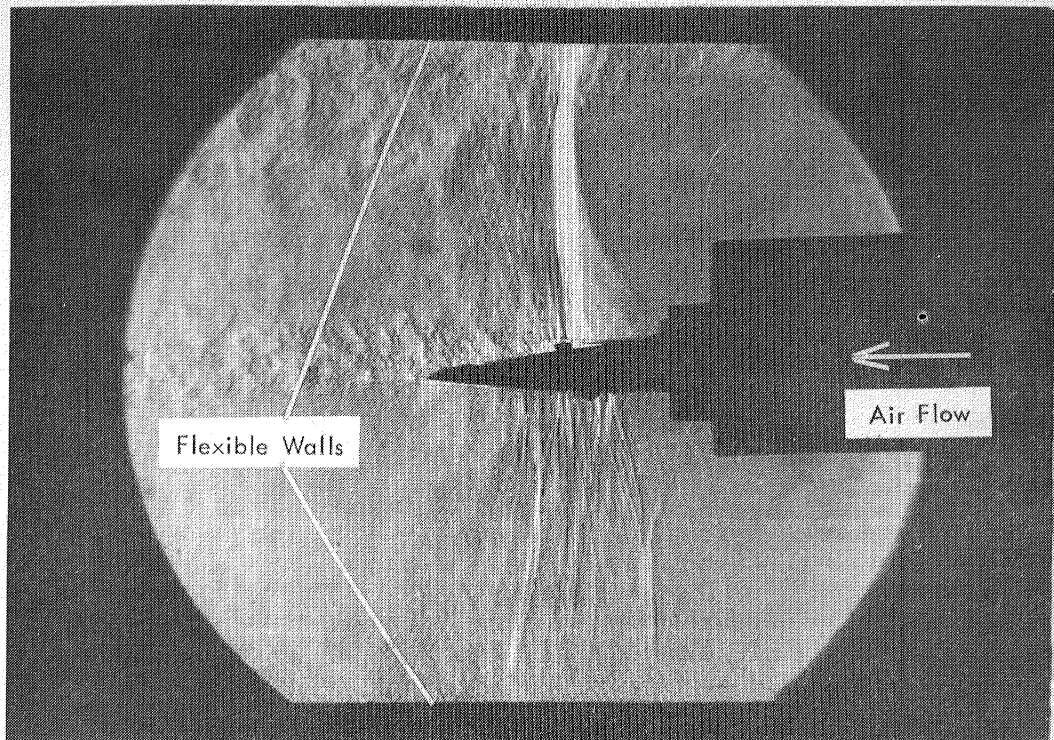


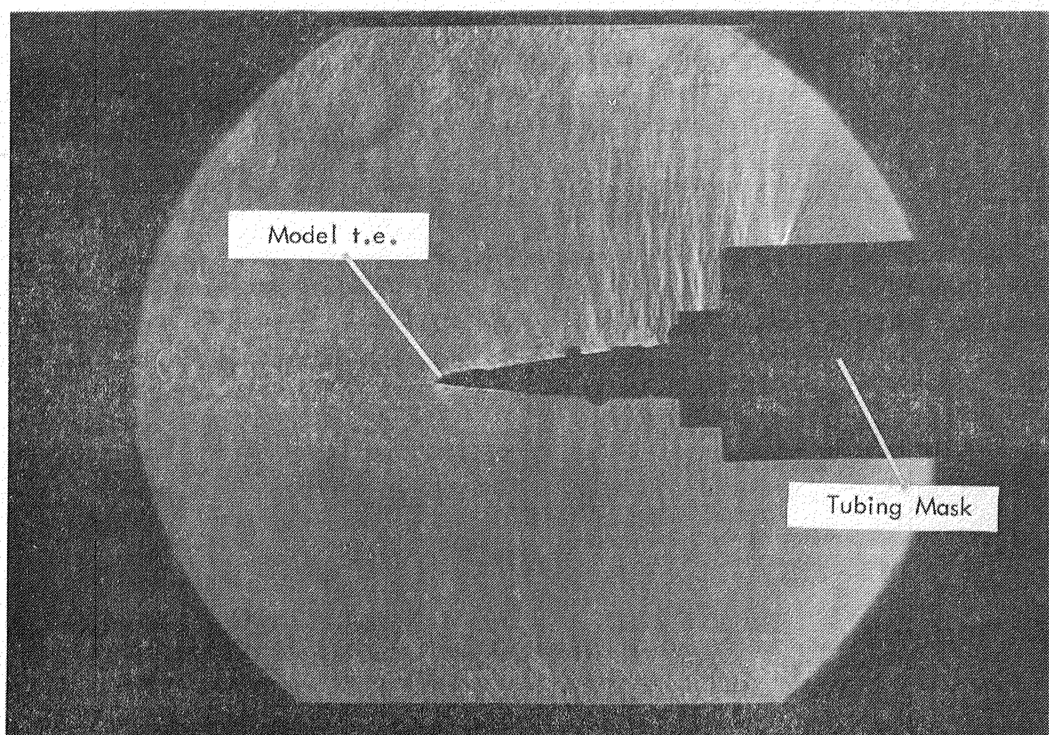
FIG. 4 COMPARISON OF NACA 0012-64 SECTION WAKES WITH THE TEST SECTION WALLS SET STRAIGHT AND STREAMLINED :

NACA 0012-64 Section

Mach No = .7 ; α = +4°



Flexible Walls Set Straight



Flexible Walls Streamlined

FIG. 5 SPARK SCHLIEREN PICTURES SHOW THE EFFECTS OF WALL STREAMLINING

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16. Abstract

This report describes an intrusive technique for obtaining information on the total drag of a model in TSWT. The technique adopted is the wake traverse method. The associated tunnel hardware and control and data reduction software are outlined and some experimental results are presented for discussion.

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