Wind-Tunnel Wall Interference Studies at High Subsonic Speeds

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With the introduction of the ventilated test section in wind tunnels for high-speed subsonic and transonic testing, new procedures have been sought to extend the classical wall interference methods for correcting model test data. Because of the complex nature of the interferences, a satisfactory general analytical solution to the interference problem for ventilated walls is yet to be achieved. In this program, a solid-wall test section and several ventilated test section configurations were used to investigate experimentally and evaluate the wall interference on four force models. The model force data generated in the solid-wall test section were corrected by the application of classical theoretical wall corrections and used as a basepoint for evaluating the data obtained in the ventilated test sections. One of the force models used has been tested in the NASA/Langley Research Center 8-ft transonic pressure tunnel, and substantial data were available for comparison purposes with data generated in the North American Rockwell Corporation Trisonic wind tunnel. The result of this program was the development of a porous-slot test section having a wall porosity of 5.7%. This test section design produces a wall interference-free environment for moderately sized models up to 1% blockage with wing span to test section width ratios as large as 0.71.

Nomenclature

M = Mach number, dimensionless
S = model wing area, ft²
C = test section cross-section area, ft²
b = model wing span, ft
$\bar{c}$ = mean aerodynamic chord, ft
w = test section width, ft
RN = Reynolds number, dimensionless
q = dynamic pressure, psf
C_L = lift coefficient, lift/qS, dimensionless
C_D = drag coefficient, drag/qS, dimensionless
α = model angle of attack, deg
C_m = pitching moment coefficient, pitching moment/$q S c$, dimensionless
C_{D_B} = drag coefficient, C_D, corrected for base drag, dimensionless

Introduction

AN experimental research program was recently undertaken at the Los Angeles Division of North American Rockwell Corporation to develop a ventilated test section design which would produce wall interference-free wind-tunnel test data for models of moderate size throughout the subsonic speed range. In utilizing this approach, many of the complex problems that exist in the formulation of wall interference corrections for ventilated type test sections are circumvented. The program included an investigation of the effects of test section porosity configuration changes and model size changes on three-component model force data and drag rise characteristics. The models used in this program ranged from 0.5 to 1.5% blockage with wing span to test section width ratios from 0.33 to 0.81, in order to evaluate the relationship of wall interference effects to model size.

Table 1 Model designations

	Model no. 1	Model no. 2	Model no. 3	Model no. 4
Wing area, ft²	2.867	2.877	2.759	3.602
Wing span, in.	59.7	57.0	28.0	67.0
Type of model support	Sting	Sting	Sting	Sting
% blockage $\alpha = 0°$	1.0	0.8	0.5	1.5
Mach No. range tested	0.5–0.775	0.3–0.85	0.7–0.96	0.6–0.80

Description of Facilities

North American Rockwell Corporation Trisonic Wind Tunnel

The series of tests were conducted in the transonic test section of the North American Rockwell Corporation Trisonic 7 × 7-ft wind tunnel. This facility is an atmospheric exhaust, blowdown tunnel capable of operating at Mach numbers from 0.2 to 3.5. The transonic test section has four perforated walls

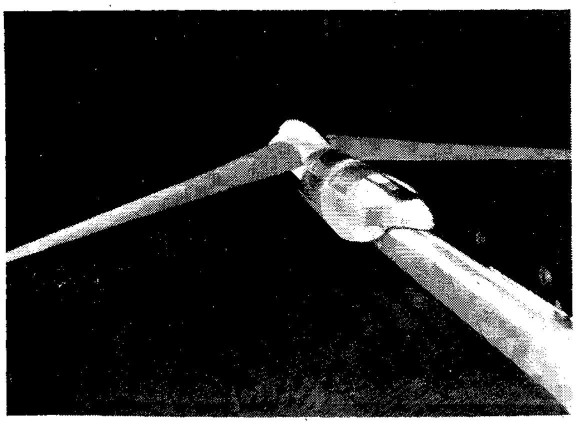

Fig. 1 Trisonic 19.7% porous test section, model 1.

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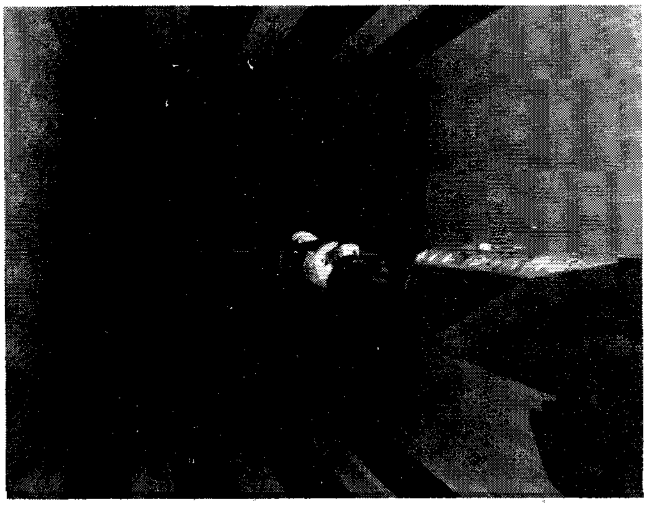

Fig. 2 Trisonic 5.7% porous floor and ceiling slotted test section, model 1.

14.5 ft long, enclosed by a plenum chamber. Adjustable ejector openings located at the downstream end of the side walls of the test section provide plenum chamber pumping. An adjustable diffuser section downstream of the model support system is used for subsonic Mach number control.

The test section walls have a porosity of 19.7% with a tapered transition area approximately $3\frac{1}{2}$ ft long at the upstream end of the perforated section. For these tests, the porosity of the walls was varied from 0 to 19.7% by covering selected portions of the walls with 2-in.-wide masking tape placed in strips parallel to the flow direction along the entire length of the test section. These configurations are illustrated in Figs. 1–3. (Because the tape configuration tends to create an optical illusion, it should be explained that in Fig. 2 the model support hardware shown in the foreground does not extend into the test section, and the taped walls of Fig. 3 are flush with the solid walls in the background.) The facility is described in greater detail in Ref. 1.

Langley Research Center 8-ft Transonic Pressure Tunnel

The Langley transonic tunnel is a single-return, closed-circuit pressure type, capable of operating at atmospheric stagnation pressure and below. The test section of the tunnel is rectangular in cross section and has a cross-sectional area of approximately 50 ft². The upper and lower walls of the test section are slotted, and the open area of the slots comprises approximately 5% of the total periphery of the test section. The test section side walls are solid. The facility is described in greater detail in Ref. 2.

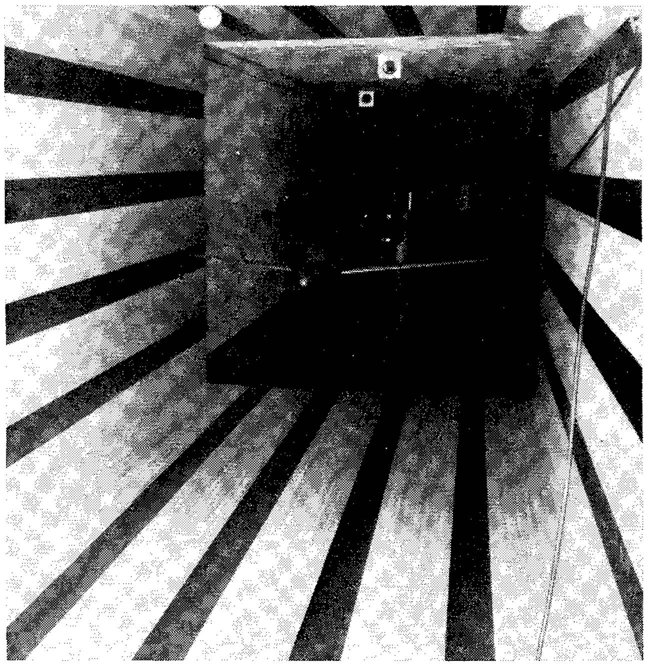

Fig. 3 Trisonic 5.7% porous symmetrically slotted test section, model 2.

Model and Instrumentation

Four wind-tunnel force models were used in these studies. For the purpose of simplification, the models will be designated by number as shown in Table 1.

Each model consisted of a wing and a fuselage with no horizontal or vertical tail surfaces. The relative sizes of the models tested in comparison to the test section area yielded blockage ratios of 1.5% or less. Each model contained Task Corporation six-component internal force balance instrumentation. Each model contained pressure instrumentation for correcting the drag data for base and balance chamber pressures. Boundary-layer transition strips of 0.0053-in.-diam grit were placed on the upper and lower wing surfaces in a 0.10-in.-wide band. The leading edge of the grit band was located 0.40 in. aft of and parallel to the wing leading edge.

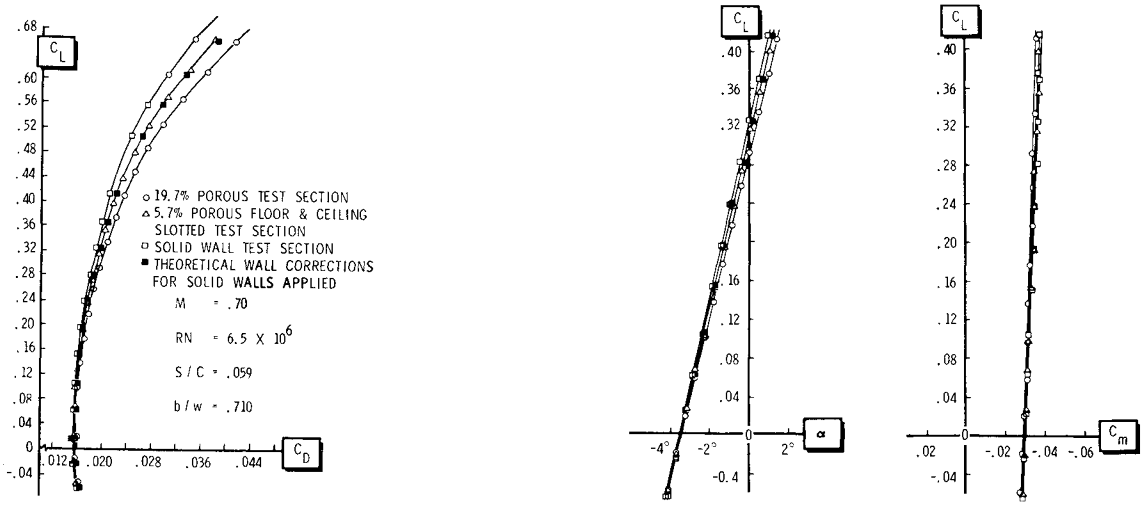

Fig. 4 Effect of test section wall configuration, model 1.

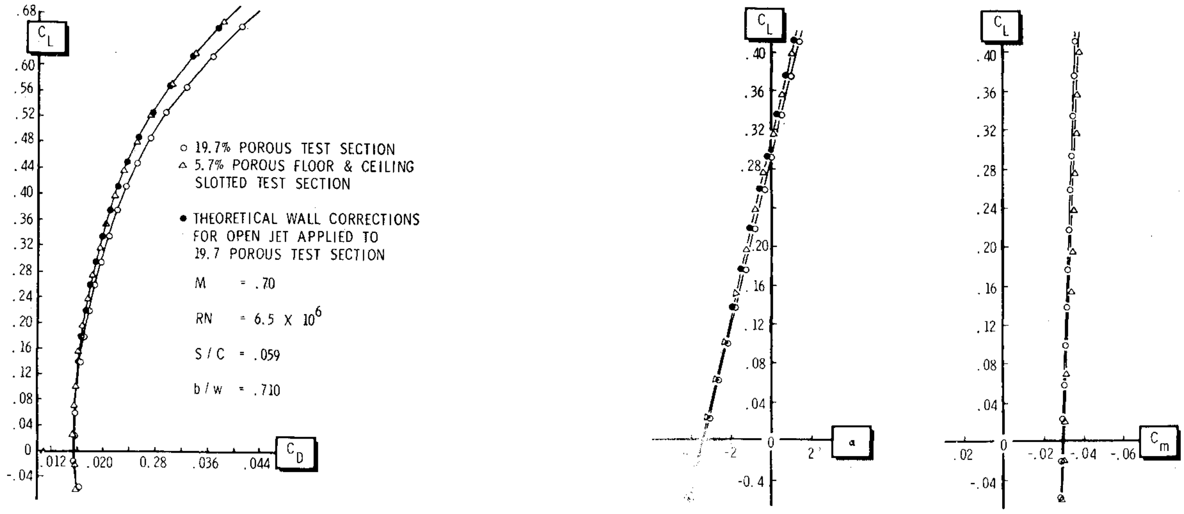

Fig. 5 Application of open-jet wall corrections to 19.7% porous test section, model 1.

Test Results

All data presented have been corrected for flow angularity as a function of angle of attack with the exception of pitching moment. Corrections to pitching moment data (all obtained with tail off) were negligible. The data presented herein are but a portion of the data obtained from these tests and are only intended to be representative of the trends and results established from these tests. A complete data presentation is contained in Ref. 3.

Figures 1–3 show three of the four test section configurations used in these tests. The solid wall test section configuration (not shown) consisted of all four walls sealed with tape. Figure 4 presents the lift, drag, and pitching moment variation with wall porosity at a constant Mach number for model no. 1. The darkened squares indicate a wall interference-free data level established by applying theoretical wall corrections to the solid wall data.[4] No wall corrections were applied to the pitching moment data. Figure 5 presents the same 5.7% porous test section data appearing in Fig. 4, but with a data level being established by correcting the 19.7% porous test section data with wall corrections for an open-jet condition. Since the solid wall and open-jet wall corrections correct the data to the same level, it can be considered that the 19.7% porous test section is sufficiently porous to generate the same data level as that obtained in an open jet test section. It is also seen that the 5.7% porous test section data level is in good agreement with the wall interference-free level. Models nos. 2 and 3 were tested in the same manner, and representative data showing effect of test section porosity obtained on these models are contained in Figs. 6–8. Figure 9 presents a comparison of model no. 1 data generated in the Trisonic 5.7% porous test section with data obtained with the same model in the Langley transonic tunnel. The remarkably close agreement is typical of the data over the range of Mach numbers tested.

Two configurations of the 5.7% porous test section were tested: one having solid side walls with the 5.7% open area composed of four porous floor slots and four porous ceiling slots (Fig. 2) and the other distributing the 5.7% open area into twice as many porous slots equally spaced on the four walls (Fig. 3). Test results contained in Fig. 10 show that the two test section configurations produce virtually identical data levels. Figure 11 presents the drag rise comparison of the 5.7% and 19.7% porous test sections at various lift coefficients for the no. 2 force model. No observable alteration of the model drag rise characteristics due to the change in porosity is indicated. Figure 12 presents the drag rise comparison of the 5.7% and 19.7% porous test sections utilizing the largest of the models tested (model no. 4). The purpose of this model was to determine if models having blockage ratios greater than 1% would produce data free from interferences in the 5.7% porous-slot test section. It is seen that the rate of drag rise obtained at lift coefficients of 0 and 0.20

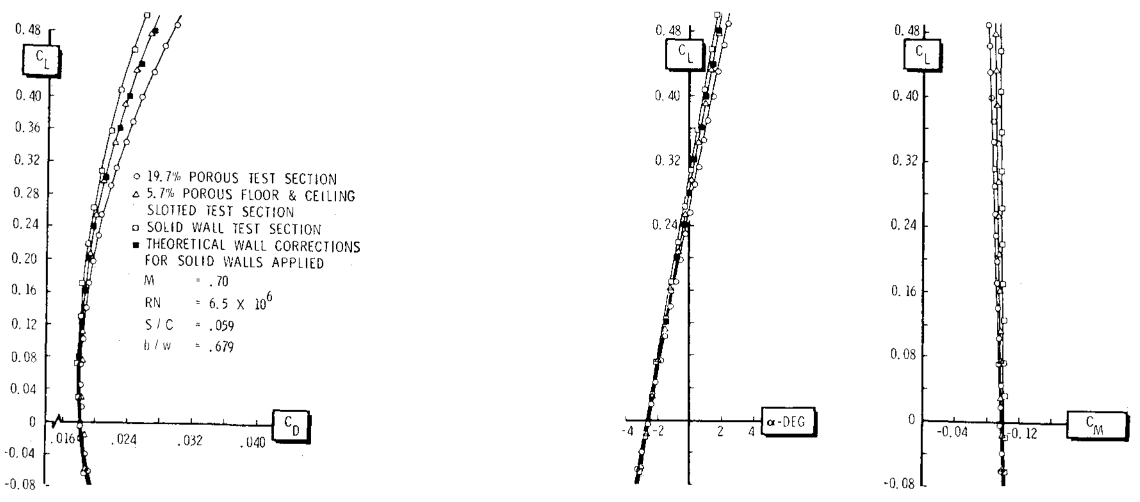

Fig. 6 Effect of test section wall configuration, model 2.

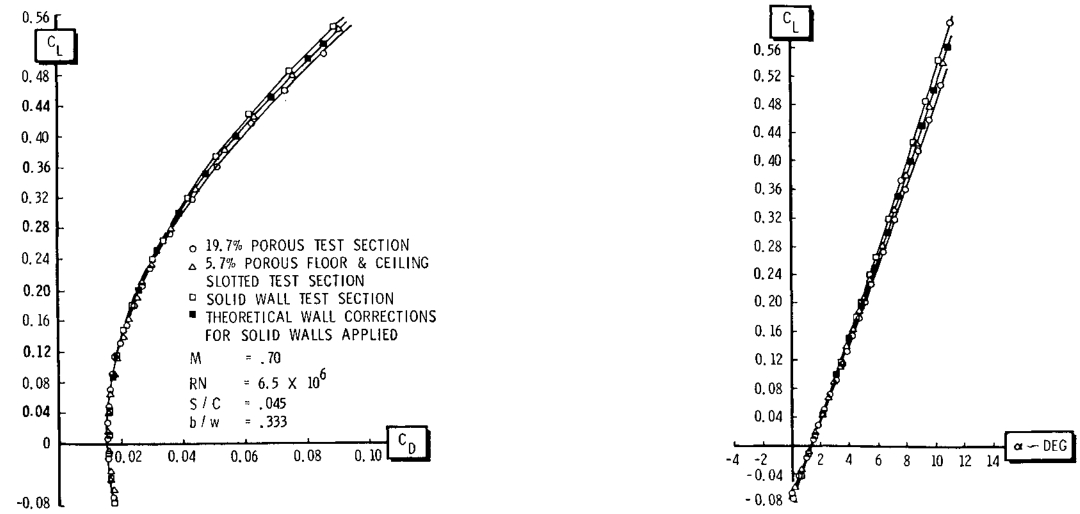

Fig. 7 Effect of test section wall configuration, M = 0.70, model 3.

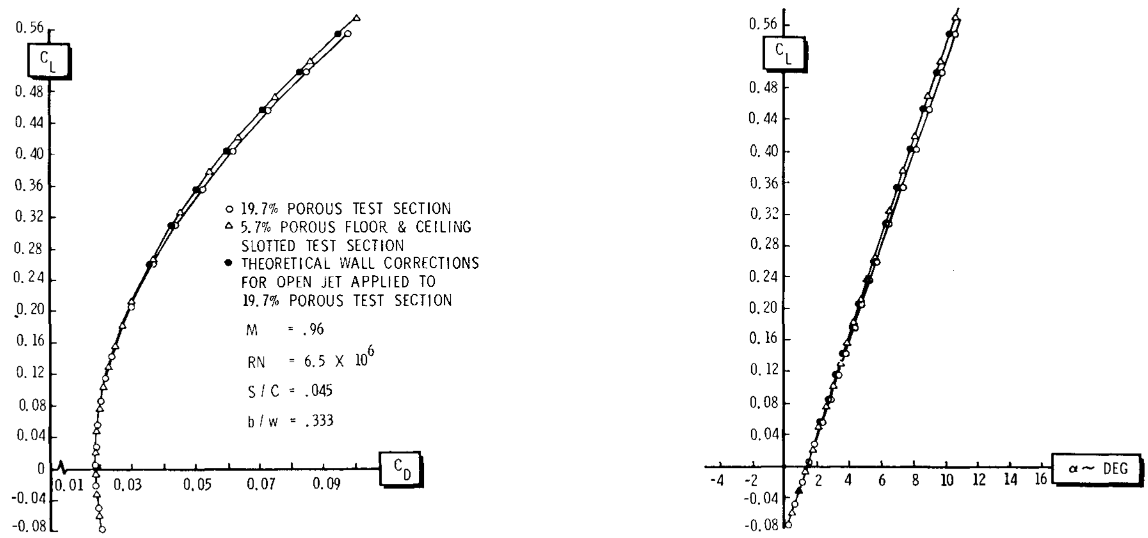

Fig. 8 Effect of test section wall configuration, M = 0.96, model 3.

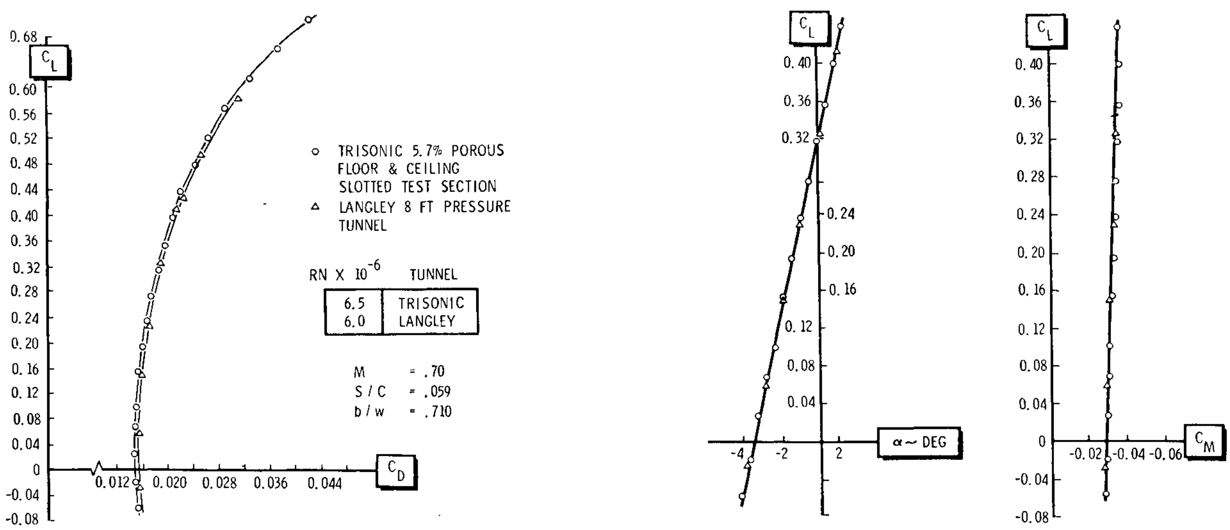

Fig. 9 Comparison of wind tunnels, model 1.

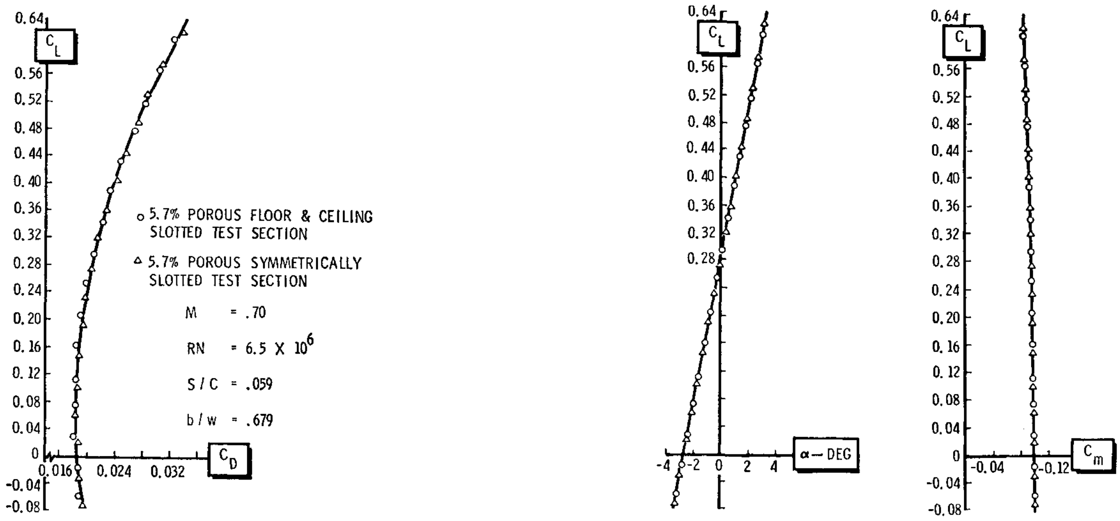

Fig. 10 Effect of test section wall arrangement, model 2.

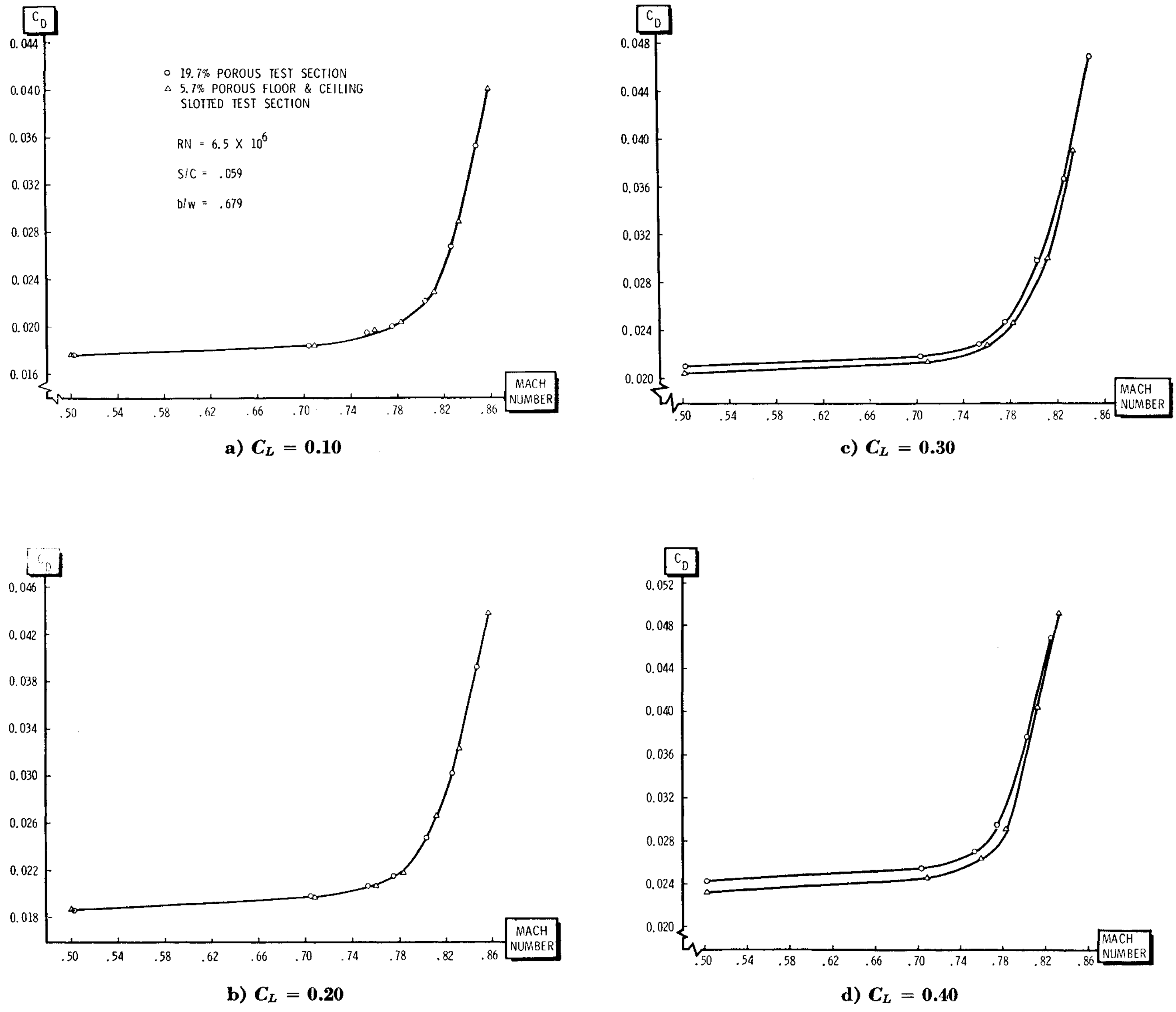

Fig. 11 Drag rise comparison, model 2.

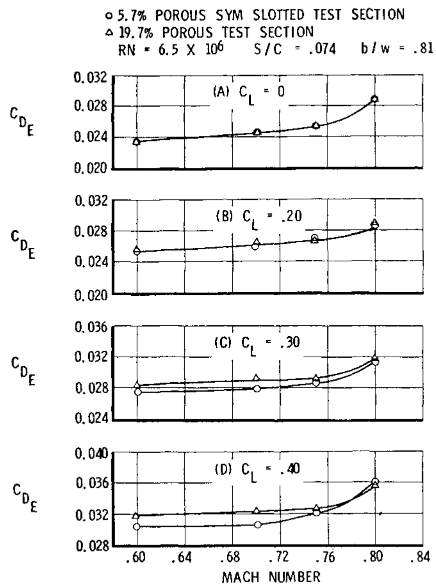

Fig. 12 Drag rise comparison, model 4.

are identical between the two test sections but at lift coefficients of 0.39 and 0.40 the drag rise becomes substantially different.

Conclusions

An analysis of the data leads to the following conclusions, the first five of which relate to models of 1% blockage area or less: 1) a ventilated test section configuration with 5.7% open area distributed over porous slots produces data in very close agreement with a wall interference-free data level established by corrected solid wall data; 2) a ventilated test section having solid side walls and 5.7% open area distributed over porous slots in floor and ceiling produces practically identical data to that from a test section where the 5.7% open area is distributed over porous slots on all four walls; 3) the 19.7% porous test section is of sufficient porosity to produce data that are characteristic of an open-jet test section; 4) data variations with lift produced in the Trisonic 5.7% open-area porous-slot test section are in good agreement with those obtained in the Langley 5% open-area slotted tunnel; 5) a change in test section porosity from 19.7 to 5.7% does not alter the subsonic drag rise characteristics of a 1% or less blockage model even though the level of wall interference produced by each test section is substantially different; 6) data taken through a normal angle of attack range in the 5.7% porous test section no longer appear to be interference-free when the model size is as large as 1.5% blockage area.

References

[1] "User's Manual for the NAR Trisonic Wind Tunnel," NA-60-764, Oct. 1960, North American Rockwell Corporation, Los Angeles, Calif.

[2] "Characteristics of Nine Research Wind Tunnels of the Langley Aeronautical Laboratory," 1957, NACA.

[3] Ongarato, J. R., "Trisonic Wind Tunnel Studies to Investigate Tunnel Wall Interference and Sector Support Effects at Subsonic and High Subsonic Mach Numbers," NA-66-322, Aug. 1966, North American Rockwell Corporation, Los Angeles, Calif.

[4] Pankhurst, R. C. and Holder, D. W., *Wind-Tunnel Technique*, Pitman, London, 1952, pp. 363–375.