ALLEVIATION OF ADVERSE AXIAL STATIC PRESSURE GRADIENTS IN THE TWO-DIMENSIONAL TEST SECTION OF THE IAR 1.5m WIND TUNNEL

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Abstract

Calibrations of the new, variable porosity, two-dimensional test section of the IAR 1.5m trisonic wind tunnel, made during commissioning in 1989, showed the existence of an adverse axial pressure gradient. A preliminary modification of the test section has been made to provide some control over the re-entry flow from the plenum chamber into the downstream diffuser section. Results from initial trials indicate that flat axial pressure distributions can be achieved at all subsonic/transonic Mach numbers, for the 2% porosity setting on the top and bottom walls which was selected as optimum during previous calibrations. The modification has also proved effective in eliminating a pronounced peak in the fluctuating wall static pressure power spectrum, (at ~400 Hz), which has been present in all previous configurations of the two-dimensional test section. A permanent modification of the facility, based on the results of this investigation, is in progress.

Introduction

A new two-dimensional test section for the IAR 1.5m Trisonic Wind Tunnel was commissioned in 1989. In it the porosity of the top and bottom walls is provided by 60° inclined holes having integral splitter plates, and is variable in the range of 0.5% to 6% total open area ratio. This hole configuration was chosen for the new test section as it is quite effective in suppressing edge-tone noise (~6 kHz), and also in cancelling shock and expansion waves generated by the model under test.[1,2]

Calibrations of this new test section in 1989[3] revealed that with the new wall configuration there was greater mass outflow from the test section than with the original configuration, (20.5% porosity, normal holes), and this resulted in an adverse axial pressure gradient in the test section that could not be removed. These calibrations also confirmed the continued existence of peaks, (at ~400 Hz.), in the power spectrum of fluctuating wall static pressure which had been noted in the original, (pre-1989, 20.5% wall porosity), configuration. These static pressure fluctuation peaks were believed to be associated with the free jet issuing from the end of the sidewalls of the two-dimensional channel, as these terminated some distance upstream from the end of the plenum chamber.

The desire to correct the adverse pressure gradient prompted modification of the two-dimensional test section. Initially an interim modification was made to lengthen the test section sidewalls; this was expected to provide some control over the re-entry flow and also to eliminate the free jet.

Measurements made in the thus modified test section indicate that the axial static pressure distribution can be fully corrected to a zero pressure gradient along the test section at all subsonic/transonic Mach numbers, with the 2% optimum top and bottom wall porosity. In addition, the fluctuating wall static pressure peak at approximately 400 Hz. present at transonic speeds has been eliminated.

Based on the results of this preliminary investigation, a permanent modification of the two-dimensional test section is in progress. Completion is expected in the Spring of 1994 at which time a more complete evaluation and calibration of the modification will be performed, including use of a static pressure probe mounted on the test section centreline.

Test Section Modification

The modifications to the two-dimensional test section configuration are shown diagrammatically in Figure 1. The solid sidewalls were lengthened to prevent the uncontrolled flow communication between the test section and plenum chamber, which previously had been possible through two large openings at their downstream end. The original reasons for these

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*At testing time, Research Officer. Presently, President, YuMex Consulting, Ottawa, Canada shortened sidewalls were both to minimise the possibility of choking the channel at the higher Mach numbers due to the blockage of the 3-D model support, and also to avoid excessive transient loading on the sidewall structure during tunnel start-up and shut-down. Preliminary measurements of transient pressure differences across the sidewall, as well as experience with a similar two-dimensional test section configuration (T-38 wind tunnel), indicate that transient loadings should not be excessive with the modified sidewalls, although this has still to be verified for high static pressure conditions. The extension of the sidewalls allowed the existing sidewall 'constraining wall' structure to be used, both as a diffuser and as conventional re-entry flaps for controlling the plenum ejection flow. The purpose of these 'constraining walls' in the original test section configuration had been to 'capture' the free jet emerging from the (short) test section, in order to reduce the very severe lateral vibrations experienced by the three-dimensional model supporting strut.

Test Description

This investigation in the modified two-dimensional test section covered Mach numbers in the range 0.2 to 0.9, but all runs were performed at low Reynolds numbers because of load limitations imposed by the interim nature of the extended sidewall structure. The majority of the test runs were performed using the previously determined optimum top and bottom wall porosity of τ=2%, but several runs also were made with a porosity of τ=3%.

The wall static pressure distributions were measured using tubes installed on the top and bottom perforated walls. In 2-D testing at IAR, such measurements are routinely used in determining corrections for wall interference. The objective of the experiment was to confirm the ability of the proposed modification to control the axial pressure distribution, rather than to achieve the flattest possible gradient for any test condition. Accordingly, the data presented here do not necessarily represent the best result possible.

Measurements of the static pressure fluctuations, both at an orifice in the test section sidewall, (0.75m upstream of the model centreline), and in the plenum chamber were made using fast response (0-10 kHz) Kulite differential pressure transducers, using as reference a highly damped pressure whose value was close to the test section static pressure. The signals were recorded, both on a Racal analog tape recorder (0-20 kHz) for post-test analysis using an HP 35665A Dynamic Signal Analyzer (0-100 kHz), and also as RMS values.

Results and Discussion

a) Axial Static Pressure Distributions (Empty Test Section)

Two different configurations of the modified test section were investigated (see Figure 1). In the first, steel plates were used to blank off the plenum chamber from the downstream channels formed between the 'constraining wall' diffuser and the main 1.5m wind tunnel diffuser. Effectively this blanking plate configuration prevented flow from the plenum chamber directly to the main diffuser, and hence represented a classical ventilated wall test section with the re-entry flaps being used to control the plenum chamber ejection, and hence the static pressure distributions along the test section.[4] In the second configuration the blanking plates were omitted, thus allowing free flow communication between the plenum chamber and the end of the diffuser formed by the 'constraining walls'.

It was shown that the pressure distribution along the test section could be controlled successfully using either configuration. While the majority of the test was performed with the blanking plates installed, the configuration having no blanking plates, although unusual, has been selected for the final test section modification for two reasons. Firstly, it provided a somewhat greater range of adjustment of the axial pressure gradient (especially at lower Mach numbers), and secondly, it avoided the need to design the blanking plates to withstand the transient loadings during the wind tunnel start-up process, (see Figure 2), caused by different fill-up times for the plenum chamber and 'constraining wall' channels.

With the classical configuration the flow in the test section is controlled using the sidewall re-entry flaps, while with the second configuration, flow control is achieved by a combination of the re-entry flaps and the variable diffusion provided by the 'constraining walls'. It was shown that a slight change in the diffusion angle affected the pressure level in the plenum chamber, thus adding another dimension to the process of controlling the main flow in the test section of this facility.

The associated geometrical configurations of the constraining walls, for the several subsonic and transonic Mach numbers covered, are shown in Table 1. It should be noted that this table represents the configurations with the blanking plates installed, since most runs were performed using that configuration.

A comparison of the results obtained in the empty test section of the original and modified configurations is shown in Figure 3 for a typical subsonic case, (M = 0.4). These are presented as Mach number variations relative to the nominal (reference) Mach number, $\Delta M = M_{loc.} - M_{ref.}$. As can be seen, the pressure distribution along the modified test section is flat, and shows only minor irregularities. It is worth noting that the static pressure orifices in the pressure tubes are located only 25 mm from the porous wall and thus may be subject to some influence of the inflow/outflow through the porous wall.

It should be noted that the various comparisons between the original and modified test section results shown herein are being made at different stagnation pressure levels. To investigate any Reynolds number effect on the pressure distributions, two runs were made with different stagnation pressures at Mach number 0.6 in the modified test section. The results did show some dependence on the stagnation pressure, but it is not anticipated that this would invalidate the qualitative conclusions of the investigation. However, the Reynolds number effect needs to be explored more fully when the final modification is commissioned.

A comparison of the pressure distributions for a typical transonic case (M = 0.8) is presented in Figure 4, and again it is seen that the pressure distribution in the modified test section is quite uniform. In Figures 3 and 4, the curves shown for the original test section configuration represent the flattest pressure distributions that it was possible to achieve prior to the present modification.

The effectiveness of slanted holes equipped with splitter-plates is demonstrated in Figure 5. It can be seen that a change in porosity level from 2% to 3% has a pronounced effect on the static pressure distributions along the test section, indicating that this specific perforated wall configuration is very effective in bleeding-off mass flow from the test section into the plenum chamber.

b) Fluctuating Wall Static Pressure

Frequency spectra obtained in the original and modified test sections are compared in Figures 6 and 7 for transonic Mach numbers of 0.7 and 0.8. It is seen that the pronounced peak in the fluctuating wall static pressure power spectrum which is present in the original test section, (at 392Hz. and 426 Hz. for Mach numbers of 0.7 and 0.8 respectively), is eliminated by the test section modification. This result supports the hypothesis that the peak at approximately 400 Hz was generated by mixing between the secondary plenum flow and the main flow emerging from the original two-dimensional channel as a free jet. Measurements of the fluctuating pressure in the plenum chamber show a similar peak in that power spectrum, suggesting that the disturbances originating with the free jet are being propagated upstream through the test section and plenum chamber.

Figure 8 presents some RMS measurements of the sidewall pressure fluctuations in normalized form (Cp_{rms}). Results obtained during the present investigation, mostly in the modified test section but also with the original configuration, are compared with those from the original test section calibration made in 1989[5]. The difference between the sidewall and centreline static pressure fluctuation levels, (between approximately 0.5% and 0.8% in Cp_{rms}), measured during the original test section calibration is attributed to the contribution from the wall boundary layer[6], and is expected to be essentially the same with the modified test section. For the original test section configuration, the present measurement at Mach number 0.4 was made at the same Reynolds number as in the 1989 calibration, and the two results are in good agreement. For the other Mach numbers at which comparisons are possible, (0.7 and 0.8), the Reynolds numbers are not identical, but the two results nevertheless agree to within about 0.15% in Cp_{rms}. To investigate the effect of blowing pressure, (Reynolds number), three runs were made with the modified sidewall configuration, at M = 0.6 and stagnation pressures corresponding to Reynolds numbers of 6, 15, and 22×10^6/ft. The results indicated a trend towards lower Cp_{rms} levels with increased stagnation pressure, the values measured being 1.56%, 1.40% and 1.37% respectively. As the data for the modified test section were obtained at low stagnation pressures, the Cp_{rms} levels that were measured may be somewhat greater than might have been obtained at higher stagnation pressure.

Comparison of the results obtained with the original and modified test section configurations indicates that there is no change in the level of Cp_{rms} at a Mach number of

0.7, but that there is some reduction in level above this Mach number. As noted above, this reduction may be slightly conservative because of the effect of blowing pressure. Below a Mach number of 0.7 the results from the modified test section show progressively higher Cp_{rms} levels as Mach number decreases. This result is thought to be due to a problem in the measured data, whereby the signal-to-noise ratio deteriorated (as a result of inadequate gain) as Mach number (and hence dynamic pressure) was reduced - the result of most runs being made at a constant stagnation pressure. This conclusion is supported by the fact that results obtained with the original sidewall configuration at M = 0.4 for the higher Reynolds number of 15×10^6/ft. show good agreement with previous data, while greatly increased Cp_{rms} levels were measured for the reduced Reynolds number, (and dynamic pressure), appropriate to the data for the modified configuration. At M = 0.3 where the result for each configuration was obtained at the same (low) stagnation pressure, quite similar Cp_{rms} levels were recorded in both cases. Here there is an indication of some reduction in level with the modified configuration, but this is likely within the measurement uncertainty because of the poor signal-to-noise ratio.

A comparison of wake profiles for a typical transonic two-dimensional model, measured close to the test section centreline in the original and modified test sections, is presented in Figure 9. With the original test section configuration the measurement station for the wake pitot probes was only 0.575m upstream of the end of the sidewalls, but this distance is approximately doubled by the extended sidewall modification. Figure 9 shows that a significantly smoother wake profile is obtained with the modified sidewall configuration, again suggesting that elimination of the free jet is responsible for the improvement. The wake profiles shown were obtained by traversing a pitot probe through the airfoil wake in approximately 1.5 seconds, so that the unevenness in the profile measured in the original test section is seen to indicate a flow unsteadiness at quite low frequency. The improved result obtained with the sidewall extension is therefore quite surprising, as the power spectra of the measured sidewall fluctuating pressure, (Figure 7), did not show any improvement at such low frequencies, (<250 Hz.).

Conclusion

An interim modification has been made to the IAR two-dimensional test section, which has been demonstrated to be effective in correcting an adverse axial static pressure gradient. It was shown that the axial pressure distributions were fully correctable at all subsonic/transonic Mach numbers for the previously determined optimum top and bottom wall porosity of τ=2%. In addition, the modification has eliminated a static pressure fluctuation peak at approximately 400 Hz. which has previously been present at transonic speeds. A permanent modification of the two-dimensional test section, based on the results of this investigation, is in progress.

Acknowledgment

The author wishes to acknowledge the support received from the Director and staff of the High Speed Aerodynamics Laboratory of IAR, both during the investigation and in preparation of this paper.

References

[1]Dougherty, N. S., Anderson, C. F, and Parker, R. L., "An Experimental Study on Suppression of Edgetones from Perforated Wind Tunnel Walls," AIAA Paper 76-50, 1976.

[2]Elfstrom G. M., Medved B. L., and Rainbird W. J., "Wave Cancellation Properties of a Splitter-Plate Porous Wall Configuration", Journal of Aircraft, Vol. 26, No. 10, October 1989, Pages 920-924

[3]Ohman L. and Brown D., "Performance of the New Roll-In Roll-Out Transonic Test Sections of the NAE 1.5m X 1.5m Blowdown Wind Tunnel," ICAS-90-6.2.2, Stockholm, September 1990

[4]Goethert H. B., "Transonic Wind Tunnel Testing," Pergamon Press, Bristol, 1961

[5]Ohman L. H. et al., "New Transonic Test Sections for the NAE 5ft x 5ft Trisonic Wind Tunnel", Aeronautical Note, NAE-AN-62, NRC No. 31216, Ottawa, Canada

[6]Willmarth, W. W., "Pressure Fluctuations Beneath Turbulent Boundary Layers", Annual Review of Fluid Mechanics, Vol. 7, 1975

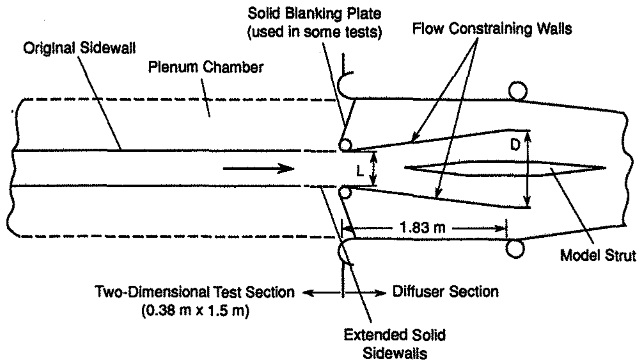

Fig. 1 Sketch of Two-Dimensional Test Section Configuration with Modifications

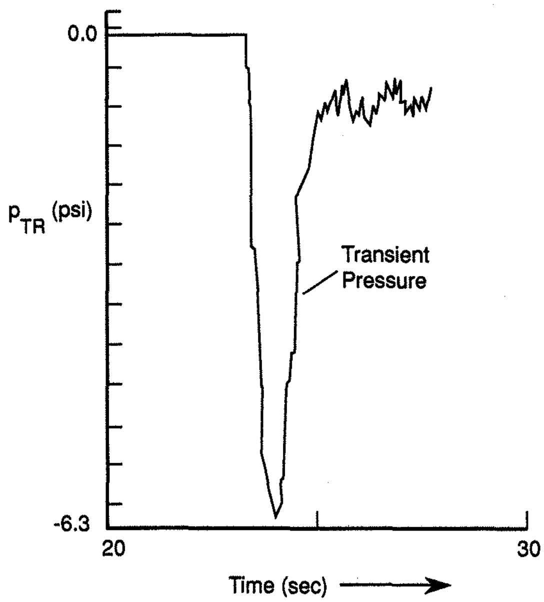

Fig. 2 Transient Pressure Difference Across Blanking Plate, M_{REF}=0.6, R_e=14.61x10^{6}ft^{-1}

M	L[in]	D[in]
0.2	36	39
0.3	36	39
0.6	32	35
0.8	28	31
0.9	19	24

Table 1 Constraining Wall Settings for Blanking Plate Configuration

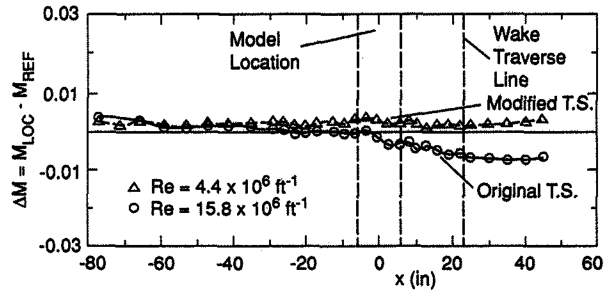

Fig. 3 ΔM Distributions Comparison for Original and Modified Test Section, Upper Tube, M_{REF}=0.4, τ=2%

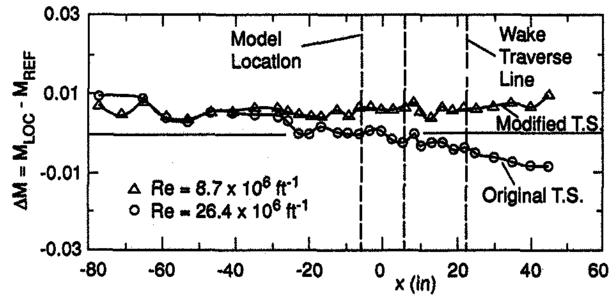

Fig. 4 ΔM Distributions Comparison for Original and Modified Test Section, Upper Tube, M_{REF}=0.8, τ=2%

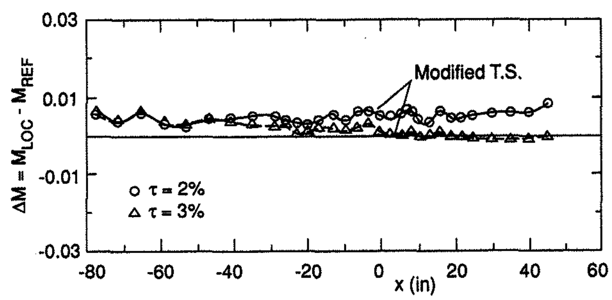

Fig. 5 ΔM Distributions Along Modified Test Section at Two Porosity Levels, (τ=2% and 3%), Upper Tube, M_{REF}=0.75, R_e=8.4x10^{6}ft^{-1}

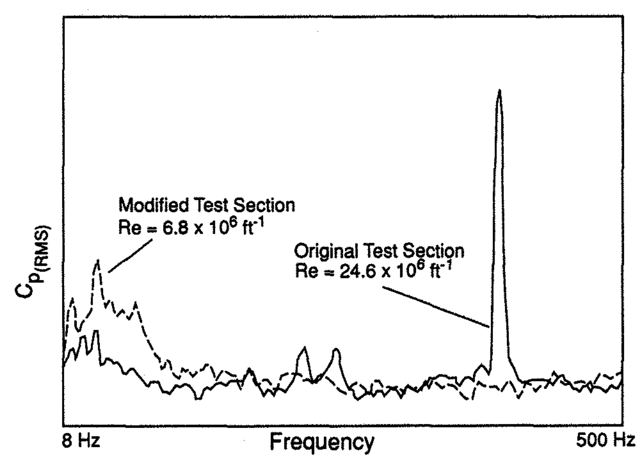

Fig. 6 Power Spectra Comparison at M_{REF}=0.7

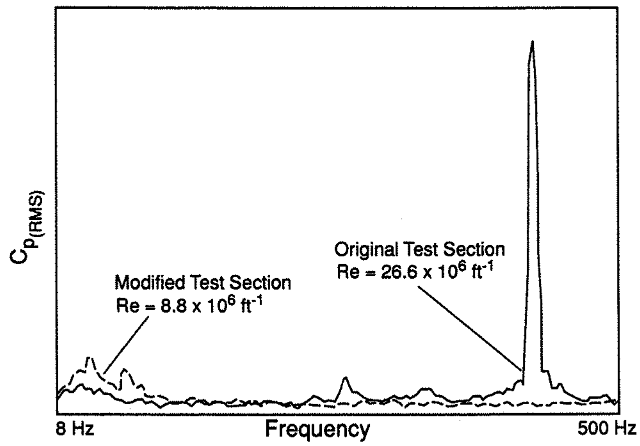

Fig. 7 Power Spectra Comparison at M_{REF}=0.8

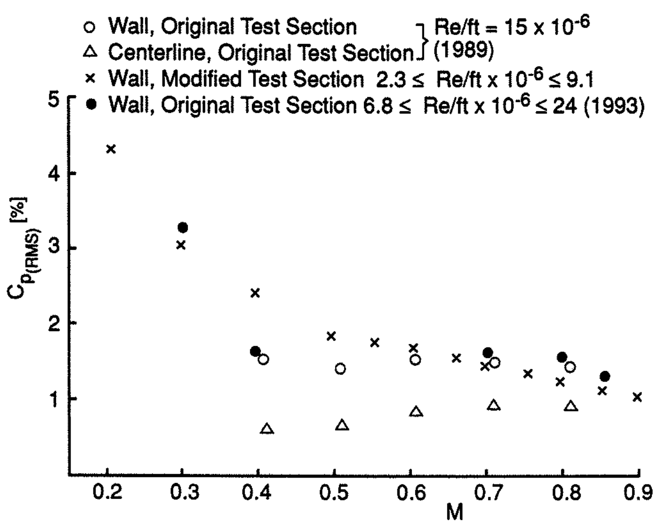

Fig. 8 Static Pressure Fluctuations Versus Mach Number, τ=2%

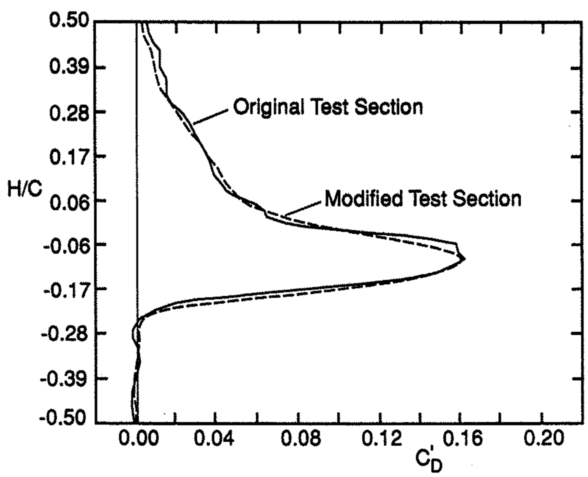

Fig. 9 Wake Profiles at M_{REF}=0.8 and α=2.3°