Suppression of Background Noise in a Transonic Wind-Tunnel Test Section

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The perforated walls of transonic wind tunnels create such intense noise that the fluctuating pressure measurements and other dynamic data acquired on aerospace models can be adversely influenced. For an aerospace vehicle in-flight, the dynamic environments, e.g., fluctuating pressures, cause structural vibrations and the vibration of avionics packages. The suppression of transonic wind-tunnel background noise has been the goal of many investigators over the years; nevertheless, high-amplitude noise levels still exist in many transonic wind tunnels. Some exploratory tests were recently performed in the transonic test section of the NASA Marshall Space Flight Center 14-in. wind tunnel to suppress the background noise. In these tests, the perforated walls of the test section were covered with fine wire screens. The screens eliminated the edge tones generated by the holes in the perforated walls and significantly reduced the tunnel background noise. The tunnel noise levels were reduced to such a degree by this simple modification at Mach numbers 0.75, 0.9, 1.1, 1.2, and 1.46 that the fluctuating pressure levels of a turbulent boundary layer could be measured on a 5° half-angle cone.

Introduction

OVER the past 50 years, the determination of aerodynamic loads on airplanes and space vehicles has been achieved for the most part through the testing of scale models in wind tunnels. During the early years of wind-tunnel testing there was a need for only subsonic wind-tunnel testing. However, when it became apparent that high-subsonic and even supersonic flight could be accomplished, the demand for transonic wind-tunnel testing became a reality. It was then, during the late 1940's, that the first transonic wind tunnels were developed for load determination.

During the early years of transonic wind-tunnel testing, it was observed that tunnel blockage and reflected shock waves from models would seriously affect the determination of loads. In regard to the blockage phenomenon, a shock wave could stand in the tunnel test section or the tunnel would not start. In regard to shock wave reflections, the shock waves which originate at the model (in the same way as the prototype) would reflect from the wind-tunnel walls back onto the model, influencing any data being acquired. Thus, a need existed to develop a technique for minimizing these effects.

The utilization of porous walls with plenum suction was one technique developed to alleviate blockage and shock wave reflections. The porous wall technique was developed through the late 1940's and early 1950's. During the mid-1950's, this technique was further refined in an attempt to cancel any shock waves at the walls which emanated from a test model. Thus, shock wave reflections could be minimized. It was noticed that cancellation could be achieved better at some Mach numbers than others. Thus, the fixed porosity walls did not appear to be optimum for all Mach numbers. It was in the early to mid-1960's that the technique of a variable porosity wind-tunnel wall was developed at the NASA Marshall Space Flight Center (MSFC). Then, with the variable porosity wall, the wave cancellation could be optimized for any test Mach number.

With the development of high-performance (high-dynamic pressure) flight vehicles, such as the Saturn space vehicles in the 1960's, unsteady aerodynamic phenomena became a significant aspect of overall vehicle design considerations. At the present time, unsteady aerodynamic phenomena are a significant aspect of the space shuttle vehicle design considerations. As can be seen from Fig. 1, a spark shadowgraph of a space shuttle model at the freestream Mach number of 1.1, extremely complex flowfields (oscillating shock waves, choked turbulent mixing, separated flows, shock wave impingement, etc.) exist and these flowfields fluctuate unsteadily in time as the vehicle ascends through the maximum dynamic pressure flight regime. The fluctuating flowfields result in structural vibrations and the vibration of sensitive avionic components such as rate gyros. Consequently, the fluctuating pressures along with other unsteady aerodynamic phenomena are required to be defined through the transonic flight regime.

Attempts to define unsteady aerodynamic environments from wind-tunnel tests through the transonic flight regime have been only moderately successful. Evidence exists which indicates that the porous wind-tunnel walls that alleviate blockage and provide wave cancellation also produce high background noise levels in the wind-tunnel test section,[1-9]

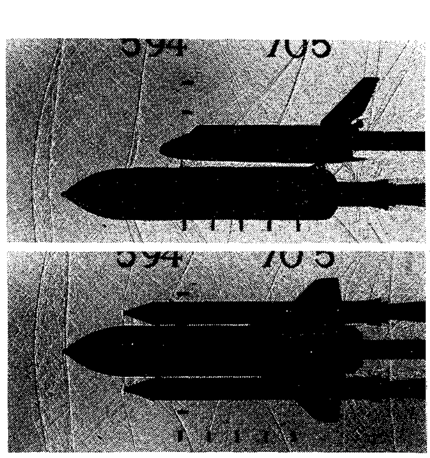

Fig. 1 Space shuttle flowfield showing flow unsteadiness ($M_\infty = 1.1$ and $R_{n/ft} = 8.7 \times 10^6$).

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Index categories: Subsonic and Transonic Flow; Nonsteady Aerodynamics.

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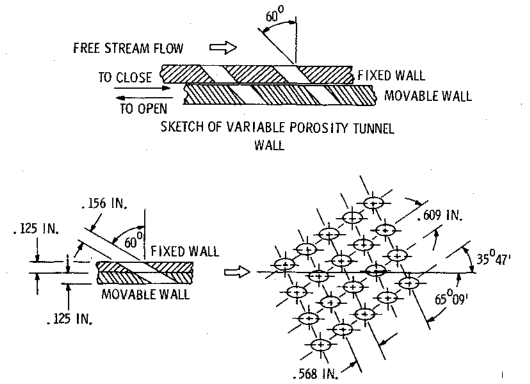
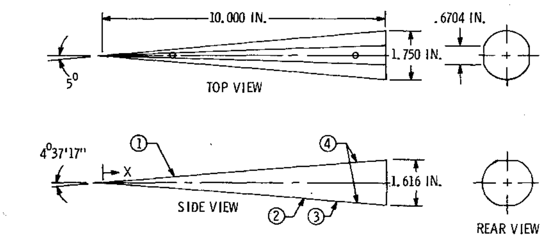


Fig. 2 Wall geometry of NASA MSFC 14-in. transonic test section.



INSTRUMENTATION:

LOCATION	X(IN.)	TYPE
1	2.500	KULITE TRANSDUCER
2	7.500	KRISTAL TRANSDUCER
3	8.250	ORIFICE (STATIC)
4	9.000	ORIFICES (STATIC)

Fig. 3 Calibration cone and instrumentation.

literally drowning out the unsteady aerodynamic effects in some cases. As a result, the accuracy and quality of unsteady aerodynamic data are thought to be compromised by the noise generated at the porous walls in the transonic regime.

In recent transonic wind tunnel tests at MSFC, the application of woven wire screen to the porous (elliptical holes) wind-tunnel walls in the 14-in. Trisonic Wind Tunnel (TWT) facility has resulted in a significant reduction of the background noise levels. It is thought that the application of screen could reduce the background noise levels in other transonic facilities. Thus, the primary purpose of this paper is to present the experimental technique and some results associated with the noise suppression testing accomplished in the MSFC 14-in. TWT facility.

Discussion

Apparatus and Test Parameters

The transonic wind tunnel that was used for the noise suppression studies reported here was the MSFC 14-in. Trisonic Wind Tunnel facility.[10] A comprehensive description of this facility is given in Ref. 10. In brief, the facility is a 14-in. square cross-section blowdown wind tunnel with a removable test section. During transonic testing, walls with variable porosity are used to minimize blockage and shock wave reflections. The porosity can be varied in the manner shown in Fig. 2. It can be seen that the walls consist of two plates (one sliding) with elliptically shaped slanted holes. It is the relative displacement of the plates that provides the capability of varying the porosity. During the testing that is reported here, the porosity was varied from 0 to the maximum of 5.4% of the wall area.

The test model from which the wind-tunnel background noise was measured is shown in Fig. 3. This model was sting mounted . It was a 5° half-angle cone with a flat surface milled on the two diametrically opposed sides, so that the pressure transducers could be flush mounted. The length of the cone was 10 in.

Table 1 Screen specifications

	Mesh/in.	Wire diam (in.)	Open area (%)
Small hole	100	0.0045	30.3
Medium hole	40	0.010	36.0
Large hole	20	0.016	46.2

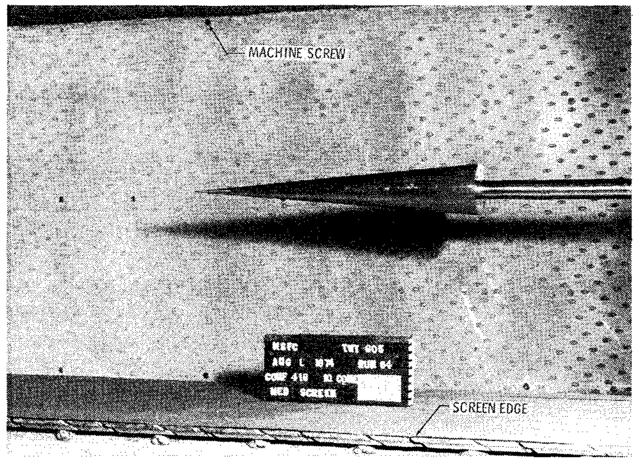


Fig. 4 Test installation with medium screen.

Both static and dynamic pressure data were acquired during the test. Since the emphasis in this paper is on the tunnel background noise, only the dynamic data will be reported. The data acquisition system used to acquire the dynamic data had a flat frequency response from about 20 Hz to 20 kHz. These data were recorded at 60 in./sec using a magnetic tape recorder and IRIG extended band FM. As shown in Fig. 3, two types of pressure transducers were used to acquire the noise data. It is believed that the forward transducer was in transitional flow during parts of the testing; however, the aft transducer was always in an attached turbulent boundary layer. Consequently, only the data from the aft pressure transducer will be reported. This will provide consistency in the data reported. The dynamic data acquired from the aft pressure transducer was analyzed during and subsequent to the test with a true root-mean-square (rms) voltmeter. The time constant for the meter was 1-2 sec and the rms values reported are in each case, the average value of the meter readings over the steady-state wind-tunnel operating time.

All of the testing was conducted at the discrete Mach numbers of 0.75, 0.9, 1.1, 1.2, and 1.46. The total pressure was varied in steps of 18, 22, 28, and 44 psia at select porosity settings and select Mach numbers, with the total temperature being in the range $544.5 \leq T \leq 573.1°R$. The resulting range of Reynolds number per ft was $3.7 \times 10^6 \leq R_N \leq 13.7 \times 10^6$.

The screens that were attached to the porous wind-tunnel walls to achieve the noise suppression were stainless steel with the specifications given in Table 1. In addition to the screens, a fibermetal material "Feltmetal" was also used. The type of Feltmetal used is given in Ref. 11 as 347-10-20-AC3A-A. The attachment of the screens for a typical test condition is shown in Fig. 4.

Phenomenon of Wind-Tunnel Background Noise and Suppression

There are many sources of wind tunnel background noise.[3] A review of Refs. 1-9, along with an evaluation of the MSFC 14-in. TWT facility, indicated that the most significant noise source to suppress for background noise reduction was that due to the elliptical holes of the porous walls. Thus, only the source mechanism of cavity generated noise will be considered here and only one hole will be considered. In the actual case, the tunnel porous walls are composed of many holes.

The suppression of the tunnel background noise was achieved through an understanding of the basic unsteady fluid

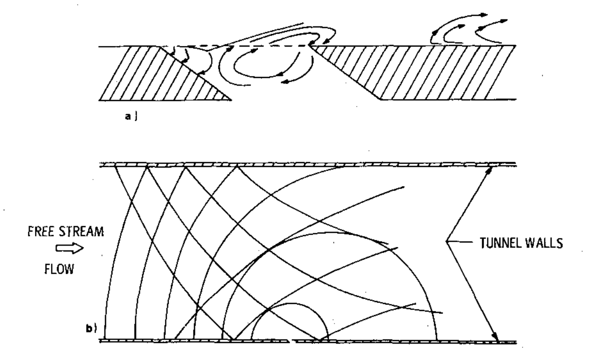


Fig. 5 Noise mechanism. a) Edge tone noise source. b) Radiated noise due to edge tone.

dynamic mechanisms. The mechanism of cavity generated acoustic fields at subsonic and transonic Mach numbers has been determined experimentally.[12,13] The direct application of these results to the transonic wind tunnel noise phenomenon appears to be established empirically in Ref. 8. An independent evaluation of the wind-tunnel porous wall noise source mechanism has also been developed empirically.[5]

The results of all these references indicate that the background noise phenomenon can be considered in two parts, as shown in Fig. 5. The *first part* is the edge tone noise "source," which is shown in Fig. 5a.[12] From this figure, it can be seen that vortices are shed from the leading and trailing edges of the elliptical hole (cavity). An acoustic field is developed from the vortices shed at the trailing edge. This acoustic field sets up a steady-state acoustic feedback mechanism which systematically triggers the shedding of vortices from the leading edge of the cavity. This entire fluid dynamic steady-state feedback mechanism is the hole noise "source," and it has a monopole radiation pattern. The *second part* of the wind-tunnel background noise phenomenon pertains to the "propagation and reinforcement" of the acoustic waves in the wind tunnel. The propagation characteristics of a monopole acoustic source are shown in Fig. 5b.[13] In this figure the waves from the source and the waves reflected from the tunnel wall are in phase, so that they reinforce, resulting in an increased noise level. The reinforcement phenomenon occurs at the tunnel acoustic transverse mode natural frequencies. At other frequencies, this reinforcement phenomenon does not appear to exist and the radiation pattern is more complex than that shown in Fig. 5b. However, the reinforcement phenomenon is the most important in regard to the back-ground noise because of the increased amplitude of the waves.

It has been shown[5,8,12,13] that the edge tone noise source frequencies generated by a hole are predominantly a function of the hole width, freestream velocity, mode numbers (integers), and Mach number. Similarly, the tunnel acoustic transverse mode natural frequencies are predominantly a function of the width of the wind-tunnel test section, the freestream speed of sound, mode numbers (integers), and Mach number.[8,13] If one (or more) of the noise source frequencies is the same as one (or more) of the transverse mode natural frequencies of the wind tunnel, acoustic reinforcement is established, resulting in the high tunnel background noise level. Since the source frequencies and the tunnel natural frequencies are continuous functions of Mach number, a porous wall wind tunnel will have a resonant Mach number condition with the associated high background noise level, as has been measured in many transonic wind tunnels.

To achieve a reduction of the background noise, the straightforward approach was to eliminate the effects of the edge tone noise sources. That can be accomplished by suppressing the noise source feedback mechanism. It has already been shown[14] that an airfoil section with a slot experiences a significant increase in drag in comparison to a smooth airfoil. Through the application of screen over the hole in the airfoil,

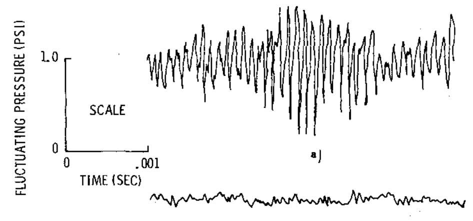


Fig. 6 Oscillogram of wind tunnel background noise a) without screens. b) with screens.

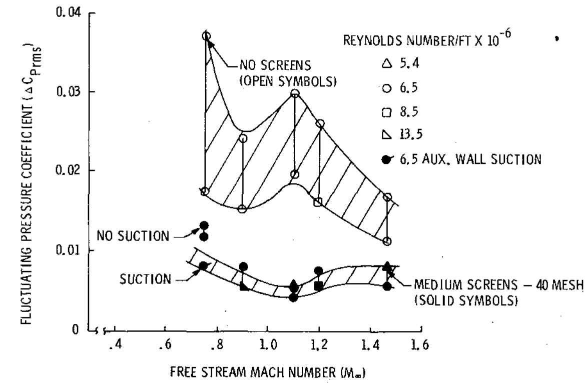


Fig. 7 Fluctuating pressure comparison of all test conditions vs freestream Mach number.

the drag was reduced to a level comparable to the smooth airfoil section. Thus, the application of screen to the airfoil suppressed the disturbance resulting from the slot. It was reasonable to expect that screen would also affect the holes in the tunnel walls in a similar fashion as it affected the airfoil. Thus, the concept of noise suppression in the MSFC 14-in. TWT converged toward the application of screen to the tunnel walls. A review of the literature,[8,12,15] indicated that a number of methods have been suggested to achieve suppression of the tunnel background noise.

Experimental Results

Although there were a number of parameters varied during the testing in addition to four types of screens, only the main results are presented. These include the tunnel background noise without screens and the cone fluctuating pressures with medium screen. These results are typical for all four types of screens tested. Furthermore, the data that will be reported pertain only to the aft pressure transducer, which was always in an attached turbulent boundary layer.

Shown in Fig. 6 are typical oscillograms of the measured unsteady pressures with and without screens. These oscillograms are to the same scale, with the Mach number, total pressure, and total temperature being identical for each case. From these records, it can be seen that the net effect due to the addition of the screen is a significant reduction of the background noise level.

To compare various Mach numbers, total pressures, etc., the remainder of the data will be presented in terms of the fluctuating pressure coefficient. The nondimensional fluctuating pressure coefficient is defined as $\Delta C_{P_{rms}} = P_{rms}/q_\infty$, where P_{rms} is the rms value of the fluctuating pressure and q_∞ is the freestream dynamic pressure.

The general results of the present experiments are shown in Fig. 7. The band of all data acquired without screen is given, along with the corresponding band with medium screen. In the no-screen case, the large range in $\Delta C_{P_{rms}}$ at a particular Mach number results primarily from the various porosity settings and to a lesser extent upon the Reynolds number. The narrow band for the medium screen case is consistent with the fact that the noise source has been suppressed. At the test

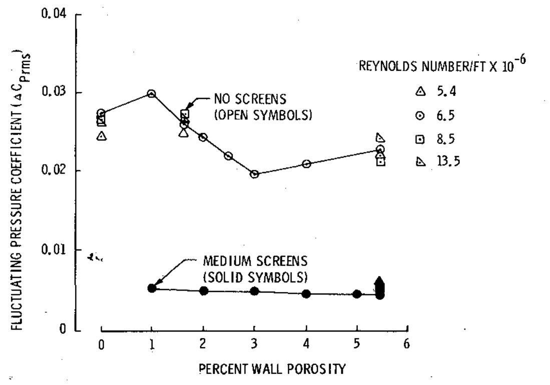


Fig. 8 Effect of porosity on tunnel fluctuating pressures for $M_\infty = 1.1$.

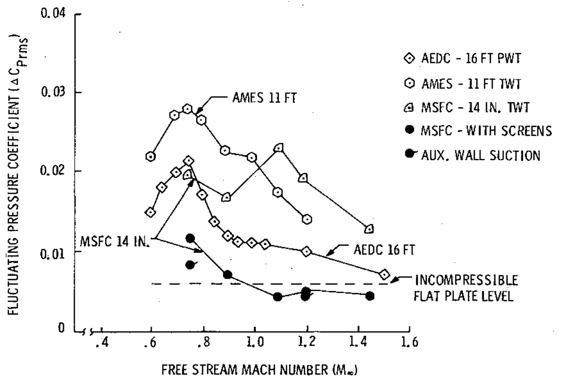


Fig. 9 Fluctuating pressure comparison of various wind tunnels vs freestream Mach number.

Mach numbers of 0.9, 1.1, 1.2, and 1.46 this particular facility utilizes wall suction as a means of achieving optimum flow quality. However, at the Mach number of 0.75, the normal operating conditions are such that wall suction is not required, and these conditions with medium screen are represented by the solid symbols at Mach number 0.75. When wall suction is implemented at $M_\infty = 0.75$, an additional noise reduction is achieved, as can be seen by the solid flagged symbol. With the wall suction, the tunnel wall turbulent boundary layer is reduced, which additionally minimizes the radiated noise effect due to wall pressure fluctuations. Although the data presented in Fig. 7 are over $0.75 \leq M_\infty \leq 1.46$, tests conducted subsequent to those reported here indicate $\Delta C_{Prms} \approx 0.008$ at $M_\infty = 0.4$ and 0.6 with screens and suction.

The effects of wall porosity and Reynolds number are shown in Fig. 8 with and without screens. For the conditions tested, it appears that the effect of Reynolds number is not significant for all cases. Also the effect of porosity is not significant when the noise source is suppressed. On the other hand, for the case without screens, the tunnel background noise is a strong function of porosity.

Shown in Fig. 9 is a comparison of the background noise from two other wind tunnels. The data presented for the Ames 11-ft Unitary tunnel and Arnold Engineering Development Center (AEDC) 16-ft Propulsion Wind Tunnel (PWT) are averages of the values presented in Ref.8. The effect of Reynolds number has been averaged out for comparison purposes. Similarly, the MSFC results represent the average values at the normal operating condition of the facility. This figure shows that each facility has its own resonant Mach number, with the level of the maximum values being about the same. Also shown in this figure is the effect of the screen as compared to the no-screen case and the effect of wall suction as already delineated. It can be seen that the effect of the screen is significant and the resulting levels are comparable to the incompressible flat plate level given in Ref. 16. Although the comparisons in Fig. 9 are valid for all three tunnels, these

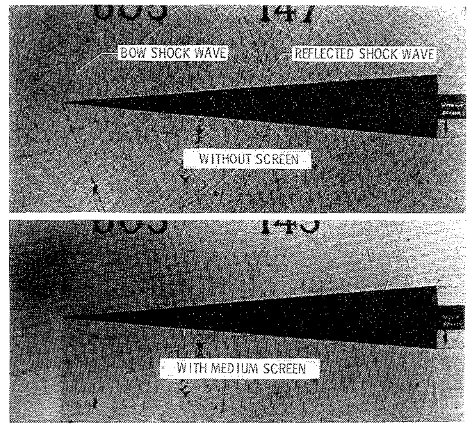


Fig. 10 Wind-tunnel flowfield showing noise reduction ($M_\infty = 1.1$ and $R_{n/\mathrm{ft}} = 6.6 \times 10^6$).

levels are not the minimum background noise levels for these tunnels. In fact, it can be seen in Ref.7 that flat plate measurements in the Ames 11-ft tunnel are lower than the 10° cone data presented herein. This may also hold true for the AEDC 16-ft tunnel and the MSFC 14-in. Tunnel.

The shadowgraph pictures shown in Fig. 10 provide the optical-flow visualization which serves to substantiate the previous results. It can be seen in this figure that the background noise field is significantly reduced with the application of the screen. The dotted lines in Fig. 10 serve to indicate the locations of the bow shock wave and the reflected shock wave from the tunnel walls. Further examination of these pictures indicates that the reflected shock wave does not appear to be significant when screens are applied; however, in the case with no screens, it cannot be determined if a reflected shock exists because of the strong background noise. In that part of the picture showing the medium screens, it is thought that the remaining waves emanate from the machine screws holding the screens to the wall and from an aluminum tape strip that secures the leading edge of the screen. To evaluate the effect of the screens on reflected shock waves and model generated expansion waves, additional studies are required.

Conclusions

From the results of the wind-tunnel data presented here, the following can be concluded: 1) the MSFC 14-in. TWT background noise has been defined for various Mach numbers, porosities, and Reynolds numbers; 2) the MSFC 14-in. TWT background noise is comparable to other transonic wind tunnels without screens; 3) significant noise suppression was achieved with screen and Feltmetal through the elimination of the edge tone noise source due to the porous walls; 4) the noise suppression technique delineated herein can be applied inexpensively to other facilities; 5) with the application of the noise suppression technique, certain dynamic data, e.g., fluctuating pressures, acquired in transonic facilities will be of a significantly increased accuracy and quality; 6) the lack of an effect due to shock wave reflections, although encouraging, is not conclusive; thus, additional studies are required to evaluate shock wave reflections and other flow properties with the addition of screens.

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