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THE DESIGN OF TEST-SECTION INSERTS FOR HIGHER SPEED AEROACOUSTIC TESTING IN THE AMES 80- BY 120-FOOT WIND TUNNEL

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Nomenclature

D = diameter of circular open-jet test section, ft
f = frequency, Hz
l = length of test section length, ft
m_{bl} = mass per unit area of porous layer, kg/m^2
Δp = total pressure loss in a section of the wind tunnel, lb/ft^2
q_o = dynamic pressure in the test section, lb/ft^2
R_f = specific flow resistance, mks rayls
R_{TL} = transmission loss of limp layer, dB
U = average airspeed at start of test section, knots
U_c = convection speed of shear layer vortices, ft/s
η = pressure loss coefficient, $\Delta p/q_o$
θ = angle relative to surface normal, deg
ρc = characteristic impedance of air, 407 mks rayls
ω = frequency, rad/s

Abstract

An engineering feasibility study was made of aeroacoustic inserts designed for large-scale acoustic research on aircraft models in the 80- by 120- Foot Wind Tunnel at NASA Ames Research Center. The goal was to find test-section modifications that would allow improved aeroacoustic testing at airspeeds equal to and above the current 100 knots limit. Results indicate that the required maximum airspeed drives the design of a particular insert. Using goals of 200, 150, and 100 knots airspeed, the analysis led to a 30 × 60 ft open-jet test section, a 40 × 80 ft open-jet test section, and a 70 × 110 ft closed test section with enhanced wall lining, respectively. The open-jet inserts would be composed of a nozzle, collector, diffuser, and acoustic wedges incorporated in the existing 80 × 120 ft test section. The closed test section would be composed of approximately 5-ft acoustic wedges covered by a porous plate attached to the test-section walls of the existing 80 × 120. All designs would require a double row of acoustic vanes between the test section and fan drive to attenuate fan noise and, in the case of the open-jet designs, to control flow separation at the diffuser downstream end. The inserts would allow virtually anechoic acoustic studies of large helicopter models, jets, and V/STOL aircraft models in simulated flight. Model scale studies would be necessary to optimize the aerodynamic and acoustic performance of any of the designs. Successful development of acoustically transparent walls, though not strictly necessary to the project, would lead to a porous-wall test section that could be substituted for any of the open-jet designs, and thereby eliminate many aerodynamic and acoustic problems characteristic of open-jet shear layers.

Introduction

Much of the current research on aircraft noise is on simulation of flight effects in large wind tunnels that have been modified or constructed to have proper acoustic quality.[1] Large size avoids the difficulty of certain small scale simulations—for example, hot gas effects, boundary-layer effects, engine inlet mass flows, and helicopter rotor Reynolds number, advance ratio, and Mach number. For acoustics, accuracy requires that the acoustic field be probed sufficiently far from the model that the data can be extrapolated to large distances.

The purpose of this paper is to examine the feasibility of developing a large, aeroacoustic test section that could be inserted into the NASA Ames 80- by 120-Foot Wind Tunnel closed test section.* The concept is based on the premise that the 80 × 120-ft test section is sufficiently large that an open-jet nozzle and collector could be inserted into the existing test section to create a large free jet, large enough for large-scale powered-lift or rotary-wing testing, yet small enough for far-field acoustic measurements in a surrounding anechoic test hall. There are no other wind tunnels near the size of the 80 × 120. Helicopter detection studies could be made using full-size or small-scale models that would allow large distances between the model and upstream microphones. Powered V/STOL models could be tested with actual power plants and without acoustic interference from floors or nearby walls. Aircraft flyover could be simulated that may provide data equivalent to FAA certification test data. Acoustic investigations could be made of advanced jet engines such as will be required for the new supersonic transport concepts. The cost of developing a complete wind tunnel including drive system would be avoided.

Early in the study, it became clear that airspeeds greater than the present maximum of 100 knots in the 80 × 120 would be desirable for aeroacoustic research of many classes of aircraft. Since different speed goals lead to different insert designs, this report consists of three parts that address the conceptual design of aeroacoustic inserts for maximum airspeeds of 100, 150, and 200 knots, and a part on the required duct silencer.

The Existing 80- by 120-Foot Wind Tunnel

The Ames 80- by 120-Foot Wind Tunnel[3,4] is a non-return, closed-test-section wind tunnel that shares the same fan-drive system as the 40- by 80-Foot Wind Tunnel as shown in Figs. 1a and 1b. When operating in the 80 × 120 mode, large vanes close off the 40 × 80 circuit so that the airflow enters the 80 × 120 inlet, passes through the test section via a 5-to-1 rectangular (conical) contraction, through two vane sets, one of which turns the airflow 45°, through the fan drive, and out the exhaust in the south end of the facility. The inlet contains acoustically treated flow-straightening vanes and a turbulence dampening screen. The rectangular test section is 80 feet high, 120 feet wide (not counting the 10-in. sound-absorbent wall lining and 6-in. floor/ceiling lining), and roughly 300 ft long.

The test section wall linings,[2] composed of fiberglass batts wrapped in cloth and covered with a 40%-open-area perforated steel plate, are designed to absorb and thereby attenuate model noise propagating through the walls or out the inlet and exhaust, and to reduce reflections so that acoustic studies can be made of powered models. The side-wall lining is 10 in. thick, and the floor and ceiling linings are 6 in. thick. The sound absorption has not been measured *in situ*, but laboratory and wind-tunnel tests[5,6] indicate that the linings will absorb 70% or more of the incident acoustic energy for frequencies above 80 Hz, in the case of the 10-in. lining, and 125 Hz, in the case of the 6 in. lining.

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*This paper is a summary of the study[2] reported in NASA Technical Paper 3020.

Six 40-ft diameter fans are located in the wind-tunnel drive section in two horizontal rows of three fans each.[2] The fans were designed with low tip speed (377 ft/s at 180 rpm) for minimum noise. In addition, the inflow has been improved, and the number of rotor and stator blades was chosen to minimize modal radiation. Nonetheless, the fans are partially visible from the test section and therefore generate considerable background noise.

30- by 60- Foot Open-Jet Wind Tunnel for 200 knots Airspeed

The open-jet test section is the obvious choice for achieving 200 knots, since a new contraction and throat would leave considerable space between the test section and surrounding 80 × 120 walls for placement of microphones outside the flow, relatively far from the model.

Furthermore, acoustic reflections would be much easier to minimize in an open jet than in a closed jet since the reflecting walls in the anechoic room could be well treated.

Open-Jet Shear Layer

Acoustic Interference. The shear layer between an open-jet flow and quiescent air outside the test section allows the aircraft-model noise to propagate out of the flow with little reflection, at least for the low speeds and propagation directions used in typical facilities. Thus, an acoustic-free field can be established and sampled in or out of the flow. However, turbulence and vortices in the shear layer perturb the core flow in the jet and can, under the right conditions, interact with the collector and nozzle in such a way as to cause the entire jet to oscillate, sometimes violently. Jet oscillations can also couple with room-acoustic modes. Furthermore, the entrainment of air causes significant recirculation flows in the acoustic hall. And, the shear layer distorts, scatters, and refracts the transmitted sound depending on propagation angle, flow Mach number, and acoustic frequency.

Methods have been developed to successfully correct for refraction; for example, the method developed by Amiet.[7] Amiet models the shear layer as a thin interface and predicts the acoustic-ray refraction as illustrated in Fig. 2. The solid line represents the refracted acoustic ray; the dashed line represents the propagation path of the same ray propagating in a uniform velocity field without a shear layer. The true directivity of a point source can be deduced from measurements of apparent directivity since the refracted angle of a sound ray can be predicted.

However, the situation is much more complex with a large noise source and a nearby observer because the observer cannot be sure where the sound originated; the ray/shear layer intercept angle is ambiguous. Sound from a distributed source will be spread by the introduction of a shear layer as illustrated in Fig. 2. To eliminate this problem it would be necessary to enlarge the open jet. Or, if one had great confidence in the shear-layer refraction model, the microphones could be placed at points where the acoustic rays coalesce outside the jet as illustrated in Fig. 2. In theory, every acoustic ray that arrived at the receiver location without a shear layer will focus at a single displaced point if a shear layer were introduced. It does not matter where the ray originated on the source. Data acquired at that focus point could be used to reconstruct the original acoustic radiation without shear layer.

Methods[8,9] have also been proposed to deal with spectral broadening, amplitude fluctuations, and phase fluctuation. However, impulse signatures can be badly distorted in time and phase by the shear layer. Consequently, many researchers studying rotor noise, for example, prefer to place their microphones inside the open jet despite the limitations imposed by the near acoustic field.

Shear-Layer Spread. The data of Van Ditshuizen et al.[10] indicate that each of the rectangular-jet shear layers in the DNW 8- × 6-m open jet spreads over a total angle of 8.2°. This is 3° to 4° less than that of a round jet. The potential core is taken to be that region between the shear layers where the mean velocities are at least 99% of the centerline velocity.

In fact, the shear layer influences the flow outside the 8.2° wedge-shaped region because of the unsteady velocities induced by vortices moving in the shear layer.[11] The DNW calibration data[10,12] in Fig. 3 show longitudinal and lateral turbulence distributions in a cross section 7 m downstream of the 8- × 6-m nozzle exit. The region of low turbulence is only 40-50% of the potential core width, as defined above, and outside that region the turbulence increases rapidly. The influence of the shear layer is, therefore, important over a total angle of approximately 32°. This is a fundamental problem with open jets and may or may not be important for potential users of such a facility, depending on the specific model size and test requirements. For this design study, an 8° shear layer total angle corresponding to the limits of good mean flow will be used.

Test Section and Nozzle Size for 200 knots Airspeed

The purpose of this section is to define the largest open-jet test-section insert practicable in the existing 80 × 120 closed test section that meets the 200 knots airspeed requirement and acoustic requirements. A limit on model size and the related test-section size depends on the acoustic requirement to measure noise in the acoustic far field of the source. In general, the microphone-to-model distance should be greater than each of the following dimensions: (a) one acoustic wavelength, and (b) two source lengths, the source length being the largest distance between any two noise sources on the model.[10]

Another limitation on test-section area is the need to have an adequate open space between the jet and the walls of the test chamber for microphone placement outside the flow, even though microphones could and would be used in the flow. A reasonable open space for the microphones would be around 20 ft between the shear layer and the wedge tips. At DNW, the free space to the side and below the test section is approximately 40 ft and 20 ft, respectively.

Based on these acoustic requirements of model size, acoustic wavelength, and microphone location, the appropriate maximum open-jet nozzle size for a 200 knots airspeed would be around 30-ft high by 60-ft wide. Rotorcraft-model scale would be on the order of one half. This would give a shear-layer to wedge-tip clearance of 17 to 25 ft to the side and 12 to 20 ft above and below the test section. At the turntable center, the core flow is 22 ft deep and 53 ft wide.

Because most models would be mounted at the turntable center, the nozzle should be around one nozzle-width upstream of the turntable center. With a shear layer spread of 8° total angle, the free-jet width at the model would be 0.86 of the nozzle width. Of course, the model span would have to be significantly less than the free-jet width to minimize "wall" effects.

The collector lip should be located so as to maintain an acoustic free field from 30° to 145° measured from the turntable center, 0° being the upstream direction. This would barely allow capture of peak sound levels from jets, which are maximum near 140°. Many categories of propeller or rotor noise would radiate outside the flow. Some types of noise such as high-speed helicopter noise, however, radiate forward and would have to be captured inside the test section. Usually, the microphones would be downstream of the nozzle, but in some cases microphones would be placed upstream of the nozzle near the 80 × 120 inlet guide vanes.

Collector and Diffuser

Most open-jet wind tunnels have collectors designed to capture the free jet and feed the airflow into a diffuser downstream. The diffuser then allows the air to decelerate and recover its static pressure as it moves toward a drive fan. Aerodynamically, a free-jet collector must capture the jet and shear layers as smoothly as possible to avoid pressure fluctuations in the test section. Abramovich[14] showed analytically that the collector should just capture the jet core mass equal to that emitted from the nozzle in order to avoid a longitudinal *static* pressure gradient in the test section (not to be confused with unsteady pressure). Entrained flow in the shear layer would be cut off. In practice, however, this would require a collector immersed in the shear layer. Such a collector would experience strong *unsteady* pressure fluctuations which can radiate upstream acoustically, and trigger vortex shedding from the nozzle lip that can create flow oscillations at resonance conditions.[15] Thus, the collector leading edge should not intrude too far into the shear layer. (Likewise, a collector that is too large will result in unnecessarily high flow losses as discussed in the following section, Open-Jet Flow Losses.)

Based on published reports and discussions with wind tunnel designers and operators, it is likely that all open-jet wind tunnels built to date will develop flow oscillations at some flow speed, and, if flow speed is further increased, those oscillations can grow to violent levels. This may be a fundamental limitation of the open-jet wind tunnel. The oscillations are created by a feedback loop involving unsteady pressures on the collector or diffuser, which radiate acoustic waves upstream, which in turn trigger vortex shedding from the nozzle, which creates unsteady pressures on the collector or diffuser, and so on. The mechanism has been reported by Rebuffet and Guedel[13] to be an edge-tone type resonance with the following frequency dependence on vortex convection speed in the shear layer, U_c, and length of the open jet, l:

$$f = (n + 1/4)U_c / l \qquad \text{where } n = 1,2,3\ldots \quad (1)$$

If the flow oscillations couple with an acoustic or mechanical room mode, structural failure of the facility can follow! Typical speeds at which strong flow oscillations begin are in the neighborhood of 150 knots, although each facility is different.

To delay the onset of flow oscillations, two methods are available. The first method is to install vortex generators on the nozzle lip. Martin et al.[15] developed triangular vanes which dramatically reduced dynamic pressure and turbulence fluctuations in the Langley 14- by 22-Foot Wind Tunnel. To control vane noise, they used foam material, flow trips, cavity plugs, and special streamlining. However, the vanes caused the required fan power to increase 30% and reduced the area of the uniform flow in the test section.

The second method to control open-jet oscillations is to optimize the collector shape. NASA Langley has developed a three-sided collector for the 14- by 22-Foot Wind Tunnel illustrated in Fig. 4. That collector has flat surfaces separated from the diffuser by a 6-ft gap (adjustable to 1.5 ft). The gap was optimized for minimum turbulence in the test section.[16] The side walls are set at 14.5° to the free stream, and the top is set 6° to the freestream. In retrospect, the top angle could have been greater in order to avoid unnecessary air spillage (private communication with Zachary Applin, NASA Langley Research Center). Therefore, 14.5° will be used for collector sides, top and bottom in the design proposed here. The Langley collector stabilizes the flow in the jet sufficiently that the nozzle vanes are not needed.

Figure 5 shows the DNW collector geometry which is similar, but not identical, to the collector in the Langley 14- by 22-Foot Wind Tunnel. It is proposed that the DNW or Langley design would be a good starting point for the experimental development of a collector for an open jet in the 80 × 120, although it is possible that the optimum collector for each facility is unique.

Open-Jet Flow Losses. It would be advantageous for the acoustics if the open-jet test section were long. However, this affects the flow losses. The flow losses of an open-jet wind tunnel are caused by the loss of kinetic energy in the core flow as it mixes in the turbulent shear layer between the core flow and quiescent air outside the jet. In this process, there is also energy lost as the jet entrains air or gives up air to the volume outside the jet, a mechanism which can drive large circulating flows in the room outside the jet. If the test chamber surrounding the jet is ventilated, the entrained flow adds mass flow to the jet and reduces the local test-section loss, but the drive fan must produce more energy to propel the entrained flow along the duct. Consequently, the aerodynamic losses of an open-jet test section are much higher than a closed-jet test section as shown by Idelchik[17] in Fig. 6. Although Idelchik's curve shows how the open-jet losses go up as the length of the open section increases, it is not clear how the losses depend on where the collector throat (i.e., diffuser inlet) is located relative to the shear-layer width. For flow stability, it can be argued that the collector throat should be as far outboard as possible to avoid impingement of a the shear layer on the collector. However, the increased volume of circulating flow will drive the flow losses up. Since the DNW and Langley 14- by 22-Foot Wind Tunnels have collector throats with a cross section similar to the nozzle cross section, that arrangement will be recommended here.

According to J. D. Vagt of Porsche (unpublished presentation at Subsonic Aero. Testing Assoc. 23d Annual Meeting, Palo Alto, Calif., June 10, 1987), an open-jet test section which is too short can result in incorrect drag measurements from vehicles. This is caused by deformation of streamlines and a longitudinal pressure gradient as the flow passes the body and curves into the collector. Vagt recommends that the ratio of open-jet length to hydraulic diameter be greater than 2.96. For a 30 × 60 open jet, the hydraulic diameter is 40 ft, and the recommended minimum open-jet length by Vagt's criterion is 118 ft.

With the open-jet loss factors of Idelchik[17] summarized in Ref. 2, the estimated test-section loss increased from 7% of the total circuit loss for the closed 80 × 120 test section to 71% for the 30 × 60 insert.

The flow losses can be illustrated in terms of test-section speed as shown in Fig. 7. Despite the higher losses of the open jet, the reduced test-section area creates a maximum jet speed in the 30 × 60 more than twice that of the existing 80 × 120. The limit of 219 knots in the 30 × 60 was reached when the fan-pressure rise limit of 55 lb/ft^2 was reached. The 80 × 120 top speed of 108 knots is limited by the available fan power of 135,000 hp. A 150-ft long open jet would decrease the maximum flow speed in the test section to 195 knots. Thus, there would be an 11% speed penalty for the longer test section.

The addition of the acoustic vane set between the open jet and fan drive, to be described in the next section, increases the losses and reduces the test-section speed of the 30 × 60 nozzle for the 120-ft to 197 knots. Thus, the 30 × 60 is the largest open-jet test section that will (approximately) achieve the goal of 200 knots top speed. Model scale testing would be required to verify that an adequate fan stall margin exists.

Figures 8a-8c summarize the test-section and collector/diffuser geometry derived so far. The collector throat is located about 120 ft from the nozzle to give an adequate acoustic measurement arena outside the jet. That test section would allow far-field acoustic measurements from 32° to 146° to the side of the model (0° is the upstream direction) and from 19° to 154° below or above the model. It will be necessary to experimentally assess the effect of high-lift models on flow into the collector.

Diffuser. Because of the relatively short length of the existing 80 × 120 duct, the open-jet diffuser shown in Figs. 8a-8c has a truncated downstream end. Idelchik[17] developed diffuser loss estimates for truncated diffusers.[2]

Despite the aerodynamic losses of the truncated diffuser, the losses can be kept moderately low by using 4° diffuser wall angles so that the flow does not separate until it reaches the truncated end. This results in the shortest diffuser possible without compromising diffuser efficiency or creating unacceptable flow separation. The DNW diffuser wall angle[10] is 4.1°.

Another factor in the diffuser design is the aerodynamic influence of the acoustic vanes required to block fan noise. Two vane rows will be needed in the downstream end of the diffuser, as will be described in the section entitled Fan Drive Silencer. Although the primary function of these vanes is acoustic, they could also be used as flow control devices so that a greater diffuser wall angle could be tolerated.[18] Furthermore, it may be possible to splay the vanes and spread the flow outboard to minimize the separated flow regions behind the truncated diffuser and prevent spoiled flow from entering the fan drive.

Acoustic Test Hall

Wedges. Acoustic wedges will be required on certain areas of the test hall surrounding the open jet in order to achieve anechoic conditions. Other less critical areas can be covered with flat, absorbent liners. The DNW facility employs mineral wool wedges and liners.[19] The wall wedges are only 2.62 ft deep mounted over a 0.33-ft air gap, yet were reported to have 99% sound absorption down to 80 Hz; the floor wedges are 3.28 ft deep without air gap. All DNW wedges are protected by cloth and wire mesh. Blunt wedge tips must be avoided to prevent high-frequency reflections back into the room.[20]

Analysis of the absorption required to eliminate reflections down to 60 Hz (an arbitrary goal) led to 5-ft deep wedges. A careful development program could lead to shorter wedges, such as the DNW 3.28-ft mineral wool wedges, which are reported to have excellent impedance and, therefore, excellent absorption.

Both the collector and nozzle should be lined with absorbent material to minimize acoustic reflections. Uniform blankets can be employed, but for optimum performance, DNW uses multiple layers of mineral wool, each layer having a desired density and impedance.[19] The total DNW flat liner depth is 0.66 ft.

Acoustic Arena Geometry. For acoustic detection studies of aircraft, microphones could be placed upstream of the model and open-jet nozzle. The maximum distance from the model would be 306 ft, which is the distance to the 80 × 120 inlet guide vanes. Reflections from the nozzle or vanes would be a problem unless the surfaces were acoustically treated. One way to avoid reflections would be to use directional microphone arrays that would focus on the model and reject reflections from the nozzle or inlet vanes.[21]

40- by 80-Foot Open Jet for 150 Knots Airspeed

The primary advantage of a 40 × 80 open jet is that models sized for that test section could be operated in the closed 40-by 80-Foot Wind Tunnel or vice versa. However, that test-section size leaves approximately 10 ft between the shear layer and the wall wedges at the model center, which is inadequate for proper separation between the microphones, shear layer, and wedges. There is more room for inflow microphones than there would be in the 30 × 60 design. Unfortunately, models sized maximally for the 40 × 80 ft test section would likely be too close to the 90° microphones for acquiring far-field acoustic data from large source regions. Microphones could be placed upstream or downstream of large models and be in the acoustic far field. Based on the methodology described in the preceding section, the geometry of the 40 × 80-ft insert is shown in Figs. 9a and 9b. The estimated maximum airspeed would be 155 knots.

Two Closed Jets for 100 Knots Airspeed

Enhanced Wall Lining

The simplest modification to the 80 × 120-Foot Wind Tunnel would be to create an anechoic space in the existing test section. The maximum airspeed would then be close to the present 100 knots. Unlike the open-jet designs, all microphone locations would be inflow.

An acoustic wedge lining with a porous cover plate mounted at the wedge tips in order to protect the wedges from the flow would provide the necessary low-frequency sound absorption. See Figs. 10a and 10b. It may be that the wedge orientation could be alternated and sound absorption improved as is commonly done in anechoic rooms. Five-foot-deep wedges would result in a test section 70 × 110 ft in cross section.

The estimated maximum airspeed of a 70 × 110-ft test section with porous walls and a double acoustic-vane row is approximately 100 knots. Relative to the existing 80 × 120-ft tunnel, the loss in airspeed due to the acoustic vanes is approximately offset by the increased airspeed due to a smaller test section.

Acoustically Transparent Wall

There may be an alternative to the simple enhanced wall lining. Bauer[22] described an acoustically transparent wall that was designed to contain airflow like a test section wall, yet allow the measurement of model noise in the anechoic area outside the test section. That may be impossible to achieve perfectly, but a compromise between a little air leakage and a little sound attenuation might be acceptable. The interface between the jet and the quiescent air would refract and scatter sound. However, that transition would be thin and would match closely the thin shear- layer refraction model.[7]

The wall evaluated by Bauer was a composite of 34% open-area perforated metal plate covered by a sintered-metal mesh that gave a specific flow resistance, R_f, of 100 mks rayls. The transmission loss, R_{TL}, of a porous wall can be calculated as follows[23]:

$$R_{TL}\,10\log\left\{\left[1+1/2\left(R_f/\rho c\right)\cos\theta\right]^2\right\} \qquad \text{for } \omega \gg R_f/m_{b\ell} \quad (2)$$

Using Bauer's porous-wall specific flow resistance, 100 mks rayls, Eq. (2) gives a transmission loss of 1 dB, which is what Bauer measured. A porous layer would have even less transmission loss for sound incident at acute angles to the wall ($\theta > 0°$).

It can be shown that a porous wall with the above characteristics would have weak reflections inside the jet.[2] Microphones could be placed inside or outside the flow to capture the radiated model noise with little concern about sound attenuation (outside) or reflections (inside).

By eliminating the shear layer, the flow losses of the test section are reduced considerably. Liu and Mount[24] measured drag from a porous material like Bauer's that had approximately 20% more drag than a smooth flat plate. Figures 11a and 11b show a 40 × 80 test section with porous walls connecting an inlet nozzle and diffuser in the 80- by 120-Foot Wind Tunnel. The maximum test-section speed for that configuration is estimated to be 209 knots.

In addition to the acoustic and aerodynamic advantages, a wind tunnel with acoustically transparent walls would not require a collector—an expensive item. However, the savings might be offset by the necessity to support the fragile porous wall over a long length.

An Acoustic Vane Row to Control Background Noise

Each of the designs discussed above will require a duct silencer to attenuate the fan-drive noise entering the test section. Following are requirements and a conceptual design for that acoustic vane set.

Fan-Drive Silencers

To achieve the goal of 85 dB background noise at top speed of the facility,[2] it was determined that the fan noise would have to be attenuated by 15 to 20 dB. That high level of attenuation at low frequency will require large sound-absorbent vanes in the duct between the test section and turning vanes (vane set 4) upstream of the fans. Soderman[25,26] performed parametric studies of several silencer designs including fiberglass-filled and resonant-cavity vanes that might be appropriate for this application. The blockage must be 50% or less. If the open passages are large, the medium- and high-frequency sound would be able to pass through the silencer with little attenuation. Thus, a second row of vanes is required that are aligned to block the line of sight of the preceding vane row. This is the method used in the NAL Transonic Wind Tunnel located near Tokyo.[27,28]

Another method for improving the low-frequency attenuation of fan-drive noise would be to acoustically treat vane set 3, which closes off the 40 × 80 leg during operation of the 80 × 120, as shown in Fig. 13a, and creates a wall which faces the fan drive. The low-frequency fan noise propagating upstream will diffract around vane set 5 and strike vane set 3, an effect documented by Soderman and Hoglund[29] using another wind tunnel.

Using the methods of Ref. 2, the pressure loss of acoustic vanes was computed. Consider the following vane-row geometry: 1 m vane thickness; 1 m gap between vanes; 4 m channel length from aft end of nose to start of boattail. The computed pressure loss normalized by the local dynamic pressure (or loss coefficient) is 0.12. Assuming that the second vane row adds a loss coefficient of 0.12 without any interaction effects, the local loss coefficient for two vane rows is 0.24. If the vane set must be removed, the assembly could be mounted on tracks and rolled out of the wind tunnel when necessary.

Concluding Remarks

An engineering feasibility study was made of aeroacoustic inserts for the 80-by 120- Foot Wind Tunnel at NASA Ames Research Center. To achieve airspeeds of 200 and 150 knots with the necessary acoustic quality, the design process led to a 30- × 60- ft and 40- × 80- ft test section, respectively. A 100-knot test section would best be achieved with an enhanced lining in the existing closed test section. All designs would require installation of a double acoustic vane row between the test section and fan-drive section. The conceptual designs are described as follows as a function of maximum airspeed:

1. *200 knots: 30 × 60-ft open jet.* This is the largest possible test section which would achieve 200 knots maximum airspeed (approximately) and allow placement of microphones in the acoustic far-field of models sized for the test section. A nozzle, collector, and diffuser would be required. Acceptable flow quality and acoustic characteristics could be achievable. Acoustic detection studies could be made far upstream.

2. *150 knots: 40 × 80-ft open jet.* This concept is similar to item 1 with the advantage that models sized for the 40- by 80-Foot Wind Tunnel (closed section) could be tested in the aeroacoustic insert. Microphones would be placed inside the jet for acoustic measurements.

3. *100 knots: 80 × 120 with improved acoustic lining.* This is the simplest modification considered—only an improved wall lining would be installed in the existing wind tunnel. However, because of the need for good low-frequency absorption, acoustic wedges would probably be required with a porous wall placed over the wedges. The microphones would have to be installed in the flow. The top speed would be close to the present top speed of the 80-by 120-Foot Wind Tunnel, (approximately 100 knots), since the speed loss due to increased flow losses from the lining and acoustic vane set would be offset by the increased speed in a 20% smaller cross section, assuming a 5-ft deep lining on all four walls.

4. *100-200 knots: Acoustically transparent walls.* Acoustically transparent walls, which contain the airflow, could be incorporated with a nozzle and diffuser to achieve a desired airspeed. The transparent walls would separate the flow field from an anechoic room surrounding the test section. Model noise could be measured inside or outside the jet. This design would eliminate the unsteady flow from the open-jet shear layer, although some acoustic refraction and scattering by the boundary layer would occur. The open-jet collector would be eliminated, although a complex structure would be required to hold the transparent wall without interfering with the acoustic field. Because of the uncertainty of successfully developing this unproven concept, both from a structural and aeroacoustic standpoint, this concept must be considered a long shot.

It can be concluded from this study that an aeroacoustic insert in the Ames 80-by 120-Foot Wind Tunnel is technically feasible. The open-jet designs would be difficult to implement due to the size of the necessary components. However, they could allow for virtually anechoic acoustic studies of large helicopter models, jets, and V/STOL aircraft models in simulated flight at speeds up to 200 knots. Model scale studies would be required to resolve several problems such as (a) flow separation at the diffuser downstream end that could feed highly turbulent flow into the fan section, (b) attenuation of fan noise with acceptable flow loss and adequate fan stall margin, and (c) open-jet resonances which could perturb the flow and impose large unsteady loads on the wind tunnel structure. Those are the highest risk items in the development. Any of them might limit the top speed of the facility to something less that 200 knots or restrict the size of the test section.

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Fig. 1 NASA Ames 40- by 80-Foot/80- by 120-Foot Wind Tunnel. a) Photo of facility, b) plan view of circuit.

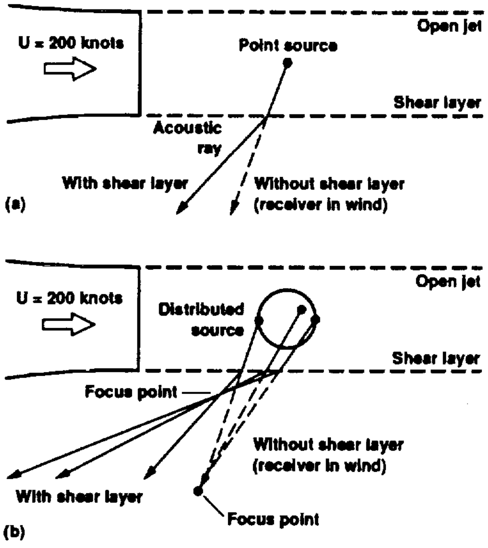

Fig. 2 Open-jet shear layer refraction which changes observed source directivity outside the jet; point-source and distributed-source propagation illustrated. a) Point noise source, b) distributed noise source.

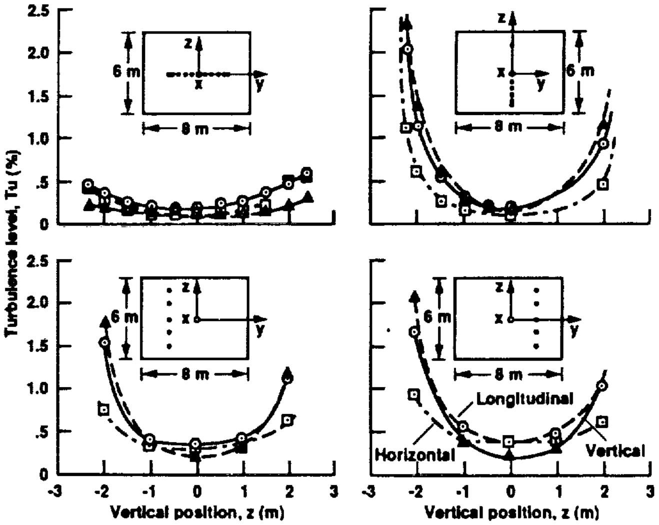

Fig. 3 Cross-stream distribution of turbulence in the DNW Wind Tunnel open jet (from Ref. 10).

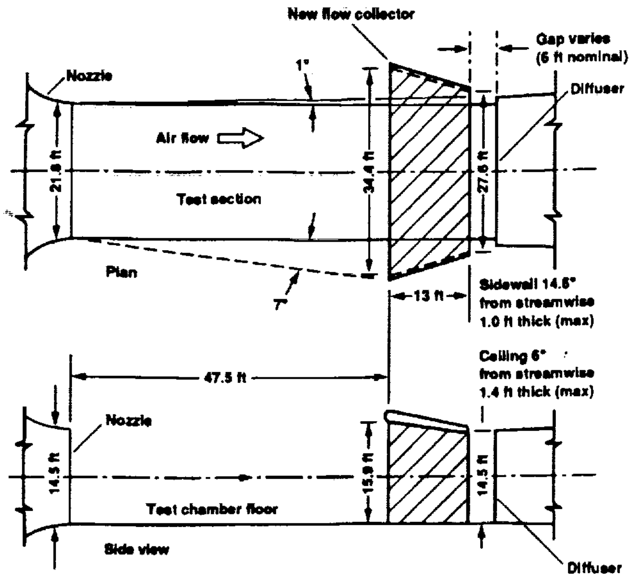

Fig. 4 Flow collector in NASA Langley 14- by 22-Foot Wind Tunnel.

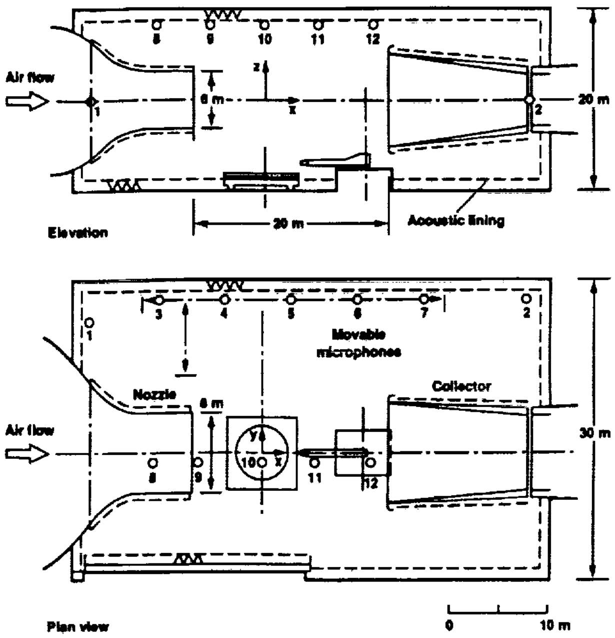

Fig. 5 DNW open-jet test section including nozzle and collector (from Ref. 10).

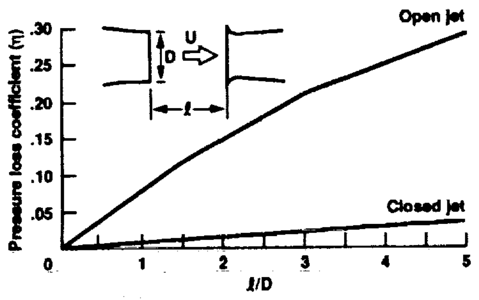

Fig. 6 Variation of loss coefficient with length of simple open or closed test section (from Ref. 17).

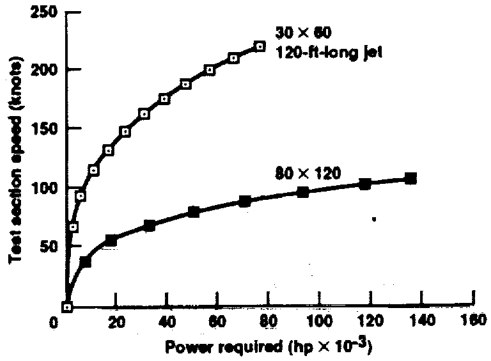

Fig. 7 Estimated test-section speed of the closed (existing) 80- × 120-ft and open 30- × 60-ft test sections. Acoustic vane loss not included. 80 × 120 max speed limited by power available. 30 × 60 max speed limited by max allowable fan pressure rise.

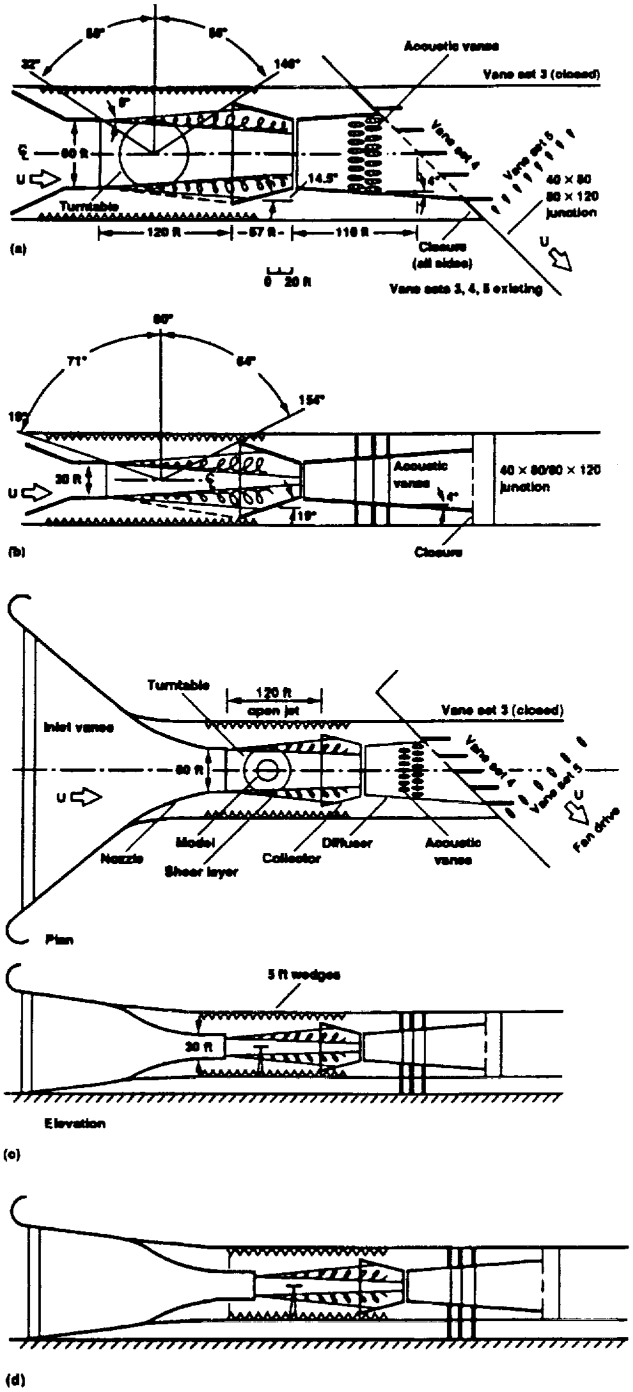

Fig. 8 30- × 60-ft open jet with nozzle, collector, diffuser, and acoustic vanes. a) Plan view, b) elevation, c) overall perspective.

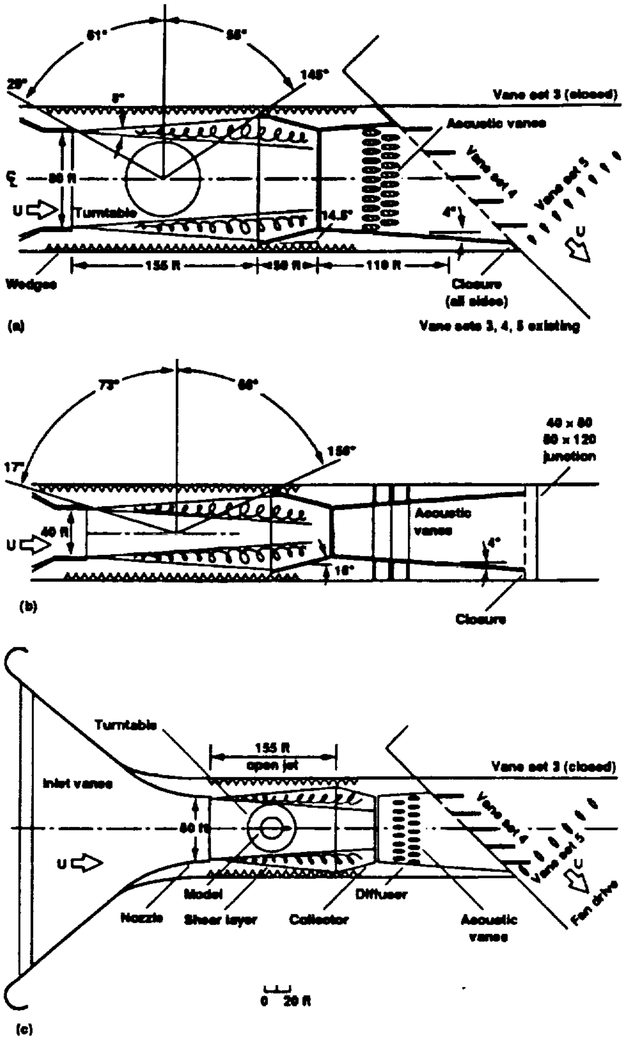

Fig. 9 40- × 80-ft open jet with nozzle, collector, diffuser, and acoustic vanes. a) Plan view, b) elevation.

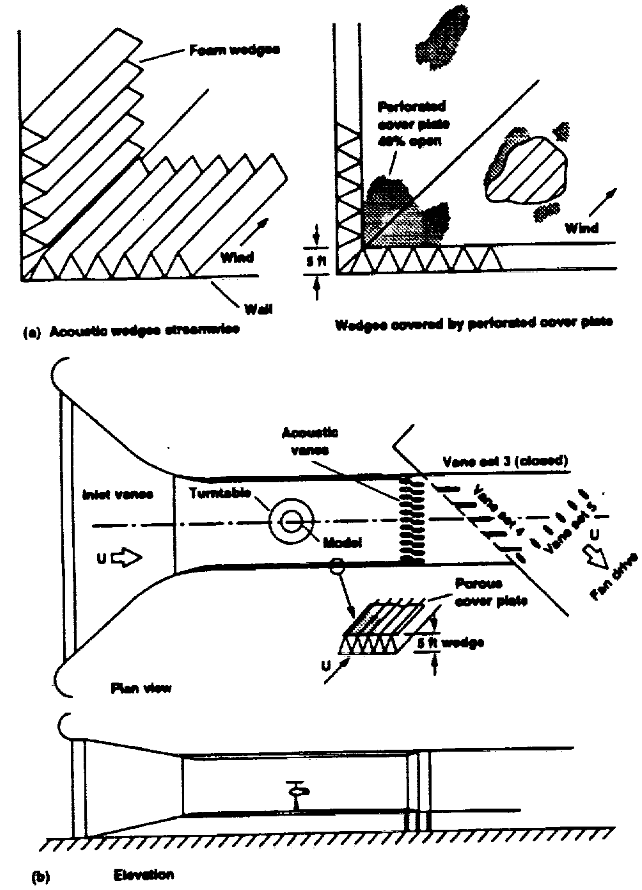

Fig. 10 Two possible configurations of enhanced acoustic linings attached to the 80 × 120 walls, floor, and ceiling. a) Close view, b) far view.

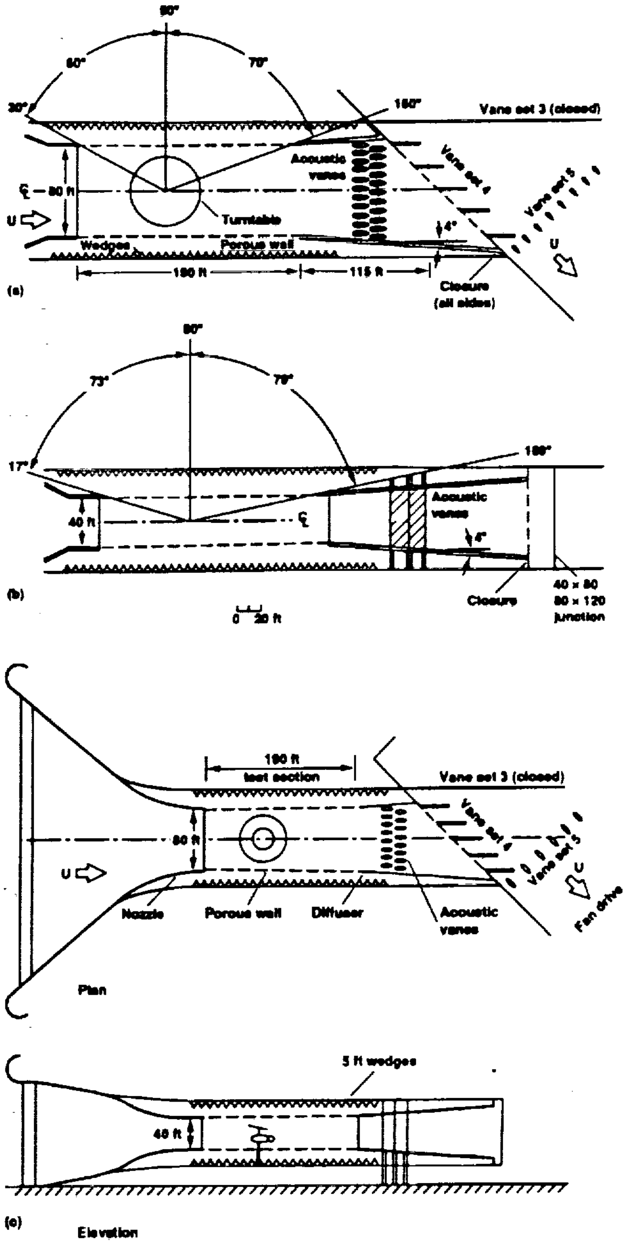

Fig. 11 40- × 80-ft test section with acoustically transparent walls. a) Plan view, b) elevation.

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13. ABSTRACT *(Maximum 200 words)*

An engineering feasibility study was made of aeroacoustic inserts designed for large-scale acoustic research on aircraft models in the 80- by 120-Foot Wind Tunnel at NASA Ames Research Center. The goal was to find test-section modifications that would allow improved aeroacoustic testing at airspeeds equal to and above the current 100 knots limit. Results indicate that the required maximum airspeed drives the design of a particular insert. Using goals of 200, 150, and 100 knots airspeed, the analysis led to a 30 × 60 ft open-jet test section, a 40 × 80 ft open-jet test section, and a 70 × 110 ft closed test section with enhanced wall lining, respectively. The open-jet inserts would be composed of a nozzle, collector, diffuser, and acoustic wedges incorporated in the existing 80 × 120 ft test section. The closed test section would be composed of approximately 5-ft acoustic wedges covered by a porous plate attached to the test-section walls of the existing 80 × 120. All designs would require a double row of acoustic vanes between the test section and fan drive to attenuate fan noise and, in the case of the open-jet designs, to control flow separation at the diffuser downstream end. The inserts would allow virtually anechoic acoustic studies of large helicopter models, jets, and V/STOL aircraft models in simulated flight. Model scale studies would be necessary to optimize the aerodynamic and acoustic performance of any of the designs. Successful development of acoustically transparent walls, though not strictly necessary to the project, would lead to a porous-wall test section that could be substituted for any of the open-jet designs, and thereby eliminate many aerodynamic and acoustic problems characteristic of open-jet shear layers.

14. SUBJECT TERMS

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