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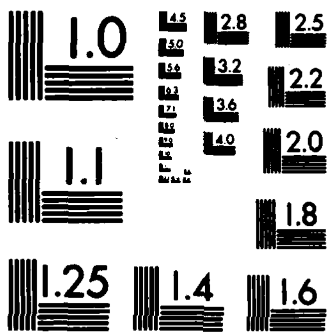
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GTWT Flow-Through Anechoic Chamber Design

J. H. Prout

Technical Memorandum
File No. 86-113
18 July 1986
Contract N00024-85-C-6041

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The Pennsylvania State University
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flow control
construction details

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Preliminary cost figures are presented to provide estimates of the funding required to complete the flow-through anechoic chamber at the Garfield Thomas Water Tunnel. Information necessary to obtain these estimates required major decisions on the philosophy of design and operation of the chamber. ARL/PSU personnel involved in these decisions were C. B. Burroughs, G. C. Lauchle, J. H. Prout, F. E. Smith and D. E. Thompson. Necessary modifications to

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Appendix A describes the design of a simple adjustable wedge mechanism. Appendix B contains a survey of existing air flow anechoic chambers. Appendix C includes copies of reports on flammability of anechoic wedge materials.

From: J. H. Prout

Subject: <u>GTWT Flow-Through Anechoic Chamber Design</u>

Abstract: Preliminary cost figures are presented to provide estimates of the funding required to complete the flow-through anechoic chamber at the Garfield Thomas Water Tunnel. Information necessary to obtain these estimates required major decisions on the philosophy of design and operation of the chamber. ARL/PSU personnel involved in these decisions were C. B. Burroughs, G. C. Lauchle, J. H. Prout, F. E. Smith and D. E. Thompson. Necessary modifications to the existing chamber building were discussed with the following University architects: T. A. Heltman, R. E. Tennent and J. L. Zeiders.

Abstract [continuation]:

Plenum wall details were discussed with L. R. Quartararo who performed tests of a 1/6 scale model of the chamber as part of the requirements for his Master's degree in architectural engineering at ARL/PSU. This report describes the construction details and turbulence control measures that resulted from these discussions. The total cost to complete the anechoic chamber test facility is estimated to be approximately $330K. This figure does not include cost of instrumentation or signal processing equipment.

Appendix A describes the design of a simple adjustable wedge mechanism.

A need for quieter, more efficient air-moving and hydraulic machinery has been recognized by the U.S. Navy and certain industries. The predominate sources of unwanted noise are propulsors and fans. Since considerable expertise in propulsor design exists at the Garfield Thomas Water Tunnel of the Applied Research Laboratory, an anechoic chamber has been proposed as an addition to the GTWT facility to enhance ARL's acoustic measurement technology and to be used in conjunction with acoustic investigations in the 48-inch diameter water tunnel. A fundamental component of this test facility, the Axial Flow Research Fan [AFRF], was designed in 1974 as a joint effort of E. P. Bruce, R. E. Henderson and D. E. Thompson. The AFRF was assembled and tested by E. P. Bruce and first reported in Ref. [1]. This device allows air-moving propulsors to be designed and tested in a manner similar to that used for water-moving propulsors in the water tunnel. In 1980, as part of the building expansion program, an acoustically designed outer structural shell was added to the GTWT building to house this flow-through chamber.

Completion of this acoustic test facility will require an especially designed acoustic wedge structure, a sound isolating wall for the control room and a partial re-configuration of the AFRF. In the past year, numerous meetings were held with University architects, ARL research investigators and others to establish the major design goals and operating philosophy so that a realistic estimate could be obtained for the completion of the facility.

A schematic drawing of the anechoic chamber is shown in Fig. 1. The anechoic wedge structure [inner room] and sound attenuating wall were not designed nor funded at the time the outer shell was built. These are the major items needed to make the facility operational.

Important performance goals are that air must flow into the chamber at low velocity, turbulence at the AFRF inlet must be kept at a very low level and, at the same time, the anechoic properties of the wedge structure must be preserved. Major points to be considered were:

(1) Anechoic chamber cut-off frequency of 140 Hz or lower.
(2) Use of fiberglass wedges for fire safety.
(3) Minimum of 90 square feet open area at inlet wall for noiseless flow.
(4) Control of turbulence at the AFRF by means of adjustable inlet wall openings in the inlet wall opposite the AFRF bellmouth.
(5) Provision for microphone traverse of the AFRF inlet at far field.
(6) Attenuation of noise from driving fan to better than 10 dB signal-to-noise ratio at AFRF inlet.

Wedge Structure

The anechoic chamber, as it was originally conceived, was to be equipped with 3-foot fiberglass wedges which would have resulted in a cut-off frequency at about 100 Hz. Due to the building dimensions, however, the working width [between the wedge tips] would not have allowed a full - 90 to + 90 degrees traverse of the microphone about the AFRF inlet [assuming that the far field is at least five times the duct diameter]. At a conference of ARL personnel, it was decided that the use of 2-foot wedges [which would result in a cut-off frequency of 140 Hz] would not seriously degrade the intended measurements. These shorter wedges would allow room for a full - 90 to + 90 degree microphone traverse.

Although polyurethane foam wedges of the same length would result in a lower cut-off frequency, the potential fire hazard and the possibility of rapid deterioration [and consequent frequent replacement] due to chemical contamination contributed to the decision to use fiberglass wedges. Fiberglass wedges are treated with a protective binder and covering so that fiberglass dusting does not present a danger to personnel after installation. Indeed, during fabrication of the wedge block structures, only ordinary dust collection practices are necessary to protect assembly personnel.

Scale model experiments, conducted by L. R. Quartararo, showed that air inlet openings should be provided only in the chamber wall opposite to the AFRF inlet and that adjustment of these openings could be used to control turbulence at the AFRF. L. R. Quartararo recommended that the total open area at the inlet wall be 90 square feet or greater to eliminate noise due to local air turbulence. A proposed adjustment mechanism is described in the Appendix.

The unusual height of the GTWT anechoic chamber and the fact that the AFRF and control room are located on the second floor raised questions of where to place the wire grid floor inside the chamber. It is customary to suspend a wire grid floor above the floor wedges to provide access to monitoring microphones and equipment under test. It is also customary to provide an access door from the control room which opens onto this wire grid floor. After some discussion, the ARL group decided that the wire grid floor and the control room access door could be eliminated since a door was already provided at the first floor level. By using removable floor wedges, portable scaffolding can be erected inside the chamber to gain access to microphones and the AFRF inlet. It was agreed that this should be satisfactory for the practical operation of this chamber since equipment support points will be incorporated in the wedge structure at installation. The scaffolding can also be used within the plenum space to make adjustments to the air flow. Access to the plenum space will be provided through the plenum wall at the first-floor level.

Fan Noise

The Axial Flow Research Fan [AFRF] in its present tubular configuration is shown in Fig. 2. The bellmouth [Fig. 2, Item 1] will extend into the anechoic chamber. In the test section [Fig. 2, Item 3], a model motor supplies power to drive the test rotor [Fig. 2, Item 4]. The main air mover [Fig. 2, Item 6] drives air through the AFRF and returns it to the chamber through the plenum wall. The main body of the AFRF assembly is located in the second floor control room.

Noise measurements made in the control room at 1 meter in front of the bellmouth showed that the noise produced by the auxiliary fan [Fig. 2, Item 6] is unacceptable when sound surveys are to be made. Duct silencers on the inlet and outlet of the auxiliary fan [Fig. 2, Item 6] will be required to reduce this noise level which, in turn, will require re-configuration of the AFRF because of space limitations in the control room. The duct dimensions of the silencers, when selected for lowest pressure drop, indicate that a larger, quieter fan could be employed. A survey has shown that several choices are available.

Plenum Wall

Conventional anechoic chambers are built with fiberglass wedge blocks arranged in alternating orientation as shown in Fig. 3. A typical 3-peak wedge block is shown in Fig. 4. The wedge base frame is made of 1.5" × 1.5" lightweight galvanized steel angle stock. Air breathing chambers used for internal combustion engine testing have been successfully built by omitting the center wedge peak in each 3-peak block. This leaves the 1.5" wedge base frame extending into the open space. The appearance of a wall with these center peaks removed is indicated in Fig. 3. Shaded areas indicate the omitted wedge peaks. The GTWT chamber requires much better control of turbulence than can be realized with this simple construction, however.

The study by L. R. Quartararo [2] showed that turbulence at the AFRF inlet could be controlled by adjusting the individual openings in the inlet wall. With the assumption that adjustable openings in each block of wedges would be expensive to produce and mechanically difficult, he designed an air inlet wall with two or three wedge peaks arranged in line so that an entire vertical row could be mounted on a single strip extending the height of the chamber. Adjustment could then be made by moving the entire strip into or out of the air inlet slot. A plenum wall based on this design is shown in Fig. 5. This configuration has been designated LRQ-5-8 since it is based on Quartararo's best wall No. 5 and contains eight vertical slits across the useful width. This wall uses standard wedge components with some wedge peaks cut short. Air inlets are not incorporated in the wedge blocks adjacent to the side walls to keep turbulence at a minimum. When the slots are adjusted for 90 square feet open however, the range of adjustment is insufficient.

A modification of this wall designated LRQ-5-9 is shown in Fig. 6. This wall has the same vertical slit design but contains nine slit rows. The range of adjustment is satisfactory but the construction requires some non-standard wedge units.

Another variation of LRQ-5 is shown in Fig. 7. This design uses all standard wedge units and gives a satisfactory range of adjustment although the number of vertical sections has been reduced to four. The number of adjustable openings has been increased to give a satisfactory adjustment range. Construction is simplified since all slits are identical although more adjustment mechanisms are required than for LRQ-5-8 and LRQ-5-9.

A possible advantageous design could use all 2-peak wedge blocks in order to simplify construction. Figure 8 shows the first attempt in this respect. This design has several objections:

(1) The dominant diagonal configuration may prevent adequate turbulence control.
(2) The adjustment mechanisms may interfere with each other.
(3) No satisfactory method could be devised to hang the 2-peak wedge units in the horizontal position.

A second attempt to design a wall with predominantly 2-peak wedge units resulted in the configuration shown in Fig. 9. The cross-shaped openings are alternated in an attempt to compensate for a possible tendency to generate a swirling motion in the air flow. Each set of adjustable wedges can be mounted on a single frame which reduces the amount of adjustment hardware. The mounting problem for the horizontal 2-peak wedge units remains.

Preforated Wall (Design of Choice)

All of the plenum wall configurations proposed so far have a major objection in common: the adjustment mechanism extending into the plenum space presents many obstructions that can be expected to generate turbulence. In addition, the wedge frame extends about 1.5 inches into each end of the opening as indicated in Fig. 10. To slide the wedge into the opening, it must be shortened by about two inches on each end. The Z-bar mounting also presents a mechanical obstruction to the movement of the wedge. In spite of reasonable precautions in designing the flow path through the opening, some turbulence can be expected to propagate through the chamber to the AFRF inlet.

A conference was held in order to find a solution to this problem. An additional concern was the cost involved in building the adjustment mechanisms in spite of the simple design.

At this meeting, a wall configuration was proposed that employed two layers of perforated material over the openings left by removing the center wedge of each 3-peak wedge block. This reopened the possibility of using the conventional alternating wedge block pattern shown in Fig. 3. Since no complex adjustment mechanisms extend into the plenum space, the chance for turbulence generation is greatly reduced. The appearance of this wall can be seen in Fig. 11. As in previous designs, no inlets are provided in the wedge blocks adjacent to the side walls [only the wedge blocks having air inlets are indicated in the figure]. Note that the general appearance of the wall is similar to the wall of a conventional anechoic chamber where the 3-peak wedge blocks are alternated in horizontal and vertical positions.

The open space left by omitting the center wedge will be covered with a window screen having approximately 72% open area. A second layer of perforated sheet having approximately 32% open area will be mounted on the back [inside the plenum space] of the wall supporting members. The space between this perforated sheet and the openings in the wedge blocks would be about six inches. Figure 12 shows details of this arrangement for two adjacent wedge blocks. Note that there are no turbulence-producing structures extending into the plenum space.

Air flow can be adjusted as required by simply covering the necessary areas of the rear perforated sheet. The entire rear perforated surface can be reached by means of the portable scaffold equipment proposed for use in the chamber.

Reconfiguration of the AFRF

Space restrictions in the control room will require a reconfiguration of the AFRF as shown in Fig. 13. This drawing is based on the existing Joy fan although the dimensions of the duct silencers indicate that a new fan with larger inlet and outlet ports could be considered. A larger fan could also result in a lower noise level.

Figure 14 shows a schematic of the air path through the anechoic chamber and AFRF facility with cross-sectional areas drawn to scale. Note that the ceiling plenum and rear plenum chambers act as a "settling section" to aid in smoothing the air flow as it enters the chamber. Although the area changes are small compared to those in the open jet facility, the effect has a tendency to reduce turbulence.

Turbulence Control

Control and minimization of turbulence at the AFRF inlet is a primary concern for the GTWT anechoic chamber. The study by L. R. Quartararo [2] showed that steady state laminar flow at the AFRF inlet could be controlled by adjusting the air inlet openings in the plenum wall. While this promises to give smooth mean flow through the chamber, small eddies can still be generated by the wedges themselves and the room geometry. Measurements in the small temporary chamber now in use at the GTWT have indicated that turbulence can be generated in the immediate vicinity of the bellmouth due to air movement into the adjacent corners of the wedge structure.

Figure 15 shows some of the methods of turbulence control that have been proposed for use inside the anechoic chamber. In the immediate vicinity of the bellmouth, fiberglass cloth could be arranged to cover the corners of the chamber so that the air flow is funneled smoothly into the AFRF inlet. Since this will change the operation of the bellmouth, it may also be advantageous to reshape the bellmouth contour. Fiberglass cloth is essentially transparent to acoustic waves so that the properties of the chamber will not be compromised. Indeed, fiberglass cloth could be used on the side walls of the chamber as well for additional turbulence control if needed. An open cell foam sheet has been used successfully to reduce turbulence in the open jet facility and may prove desirable for this purpose over the entire air inlet wall.

A simple honeycomb filter placed between the test section and auxiliary fan has been used successfully to reduce turbulence in the AFRF [see Fig. 2]. The symmetry of placement within the anechoic wedge structure and the fact that the chamber side walls are in the acoustic far field tend to favor low turbulence at the AFRF or other fan inlet.

Cost Estimates

Completion of the GTWT anechoic chamber test facility requires expenditures for at least two major items. First, the acoustic wedge system must be installed by a company whose specialty is acoustic test chambers. While most anechoic chambers can be built by simply installing wedge blocks on the inside walls of an acoustically designed building shell, the GTWT chamber requires special consideration for air flow through one wedge wall and construction of at least two wedge supporting walls within the building shell. The air-breathing wall must be designed and built by cooperation between the acoustical company and the design engineers at ARL. It is important that the RFP chamber specifications provide for quality safeguards. The quality control procedures will be the responsibility of ARL engineers who will test components prior to acceptance of deliveries. The addition of the two internal wedge-supporting walls required the assistance of architects within the University to determine the building modifications necessary to accept the wedge structure. L. R. Quartararo [2] pointed out that although the outer walls were made of sand-filled concrete block for acoustic isolation, the building roof was too thin to attenuate adequately outside noise and could not support any additional reinforcement. Thus, the two major cost items necessary for completion of the chamber are the cost of the internal wedge treatment and structure and the cost of necessary building modifications. In addition to the major expenses, reconfiguration of the AFRF to accommodate two duct silencers and possibly a new auxiliary blower requires an allowance for extra expenditures. An additional allowance has been made for turbulence control measures. The cost of a portable scaffold for use inside the chamber is included here since it is necessary for the intended operation and adjustment of the chamber.

The total estimated cost is $330,000.

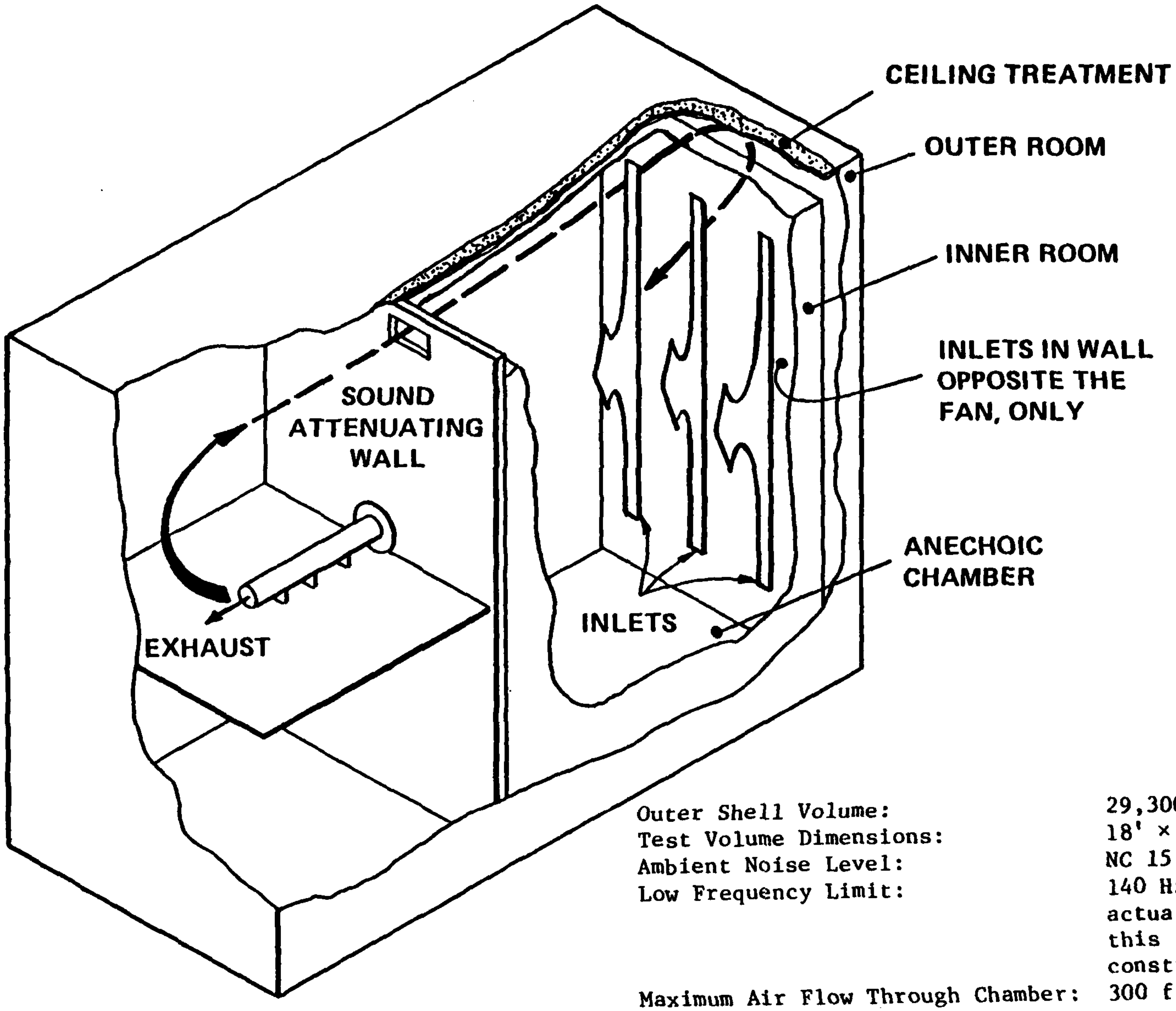
References

1. Bruce, E. P. The ARL Axial Flow Research Fan -- A New Facility for Investigation of Time-Dependent Turbomachinery Flows. ASME Paper No. 74-FE-27 (1974).

2. Quartararo, L. R. Inflow Ducting in High-Volume-Flow Subsonic Anechoic Chambers. ARL/PSU TM 83-177, Applied Research Laboratory, The Pennsylvania State University (12 October 1983).

3. Nilsen, A. W. Analysis of the Unsteady Pressures in a Turbulent Jet. M.S. Thesis, Department of Aerospace Engineering, The Pennsylvania State University (September 1969).

ANECHOIC CHAMBER



Outer Shell Volume:	29,300 ft^3
Test Volume Dimensions:	18' × 23' × 32'
Ambient Noise Level:	NC 15
Low Frequency Limit:	140 Hz [chamber performance may actually be satisfactory below this frequency due to chamber construction details]
Maximum Air Flow Through Chamber:	300 ft^3 per second = 24 lb/sec

Figure 1. Anechoic Chamber showing Sound Attenuating Wall and Air Return Path.

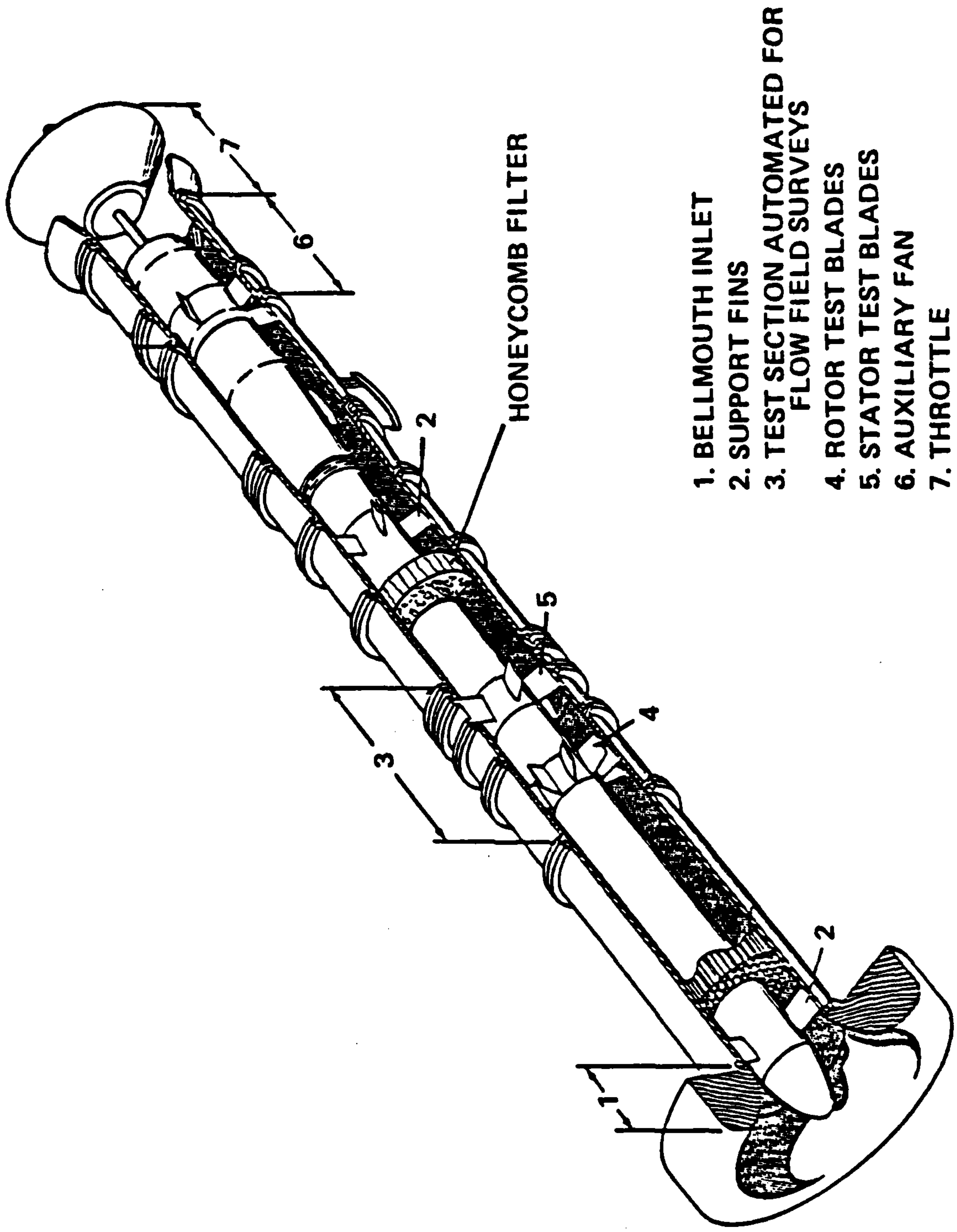
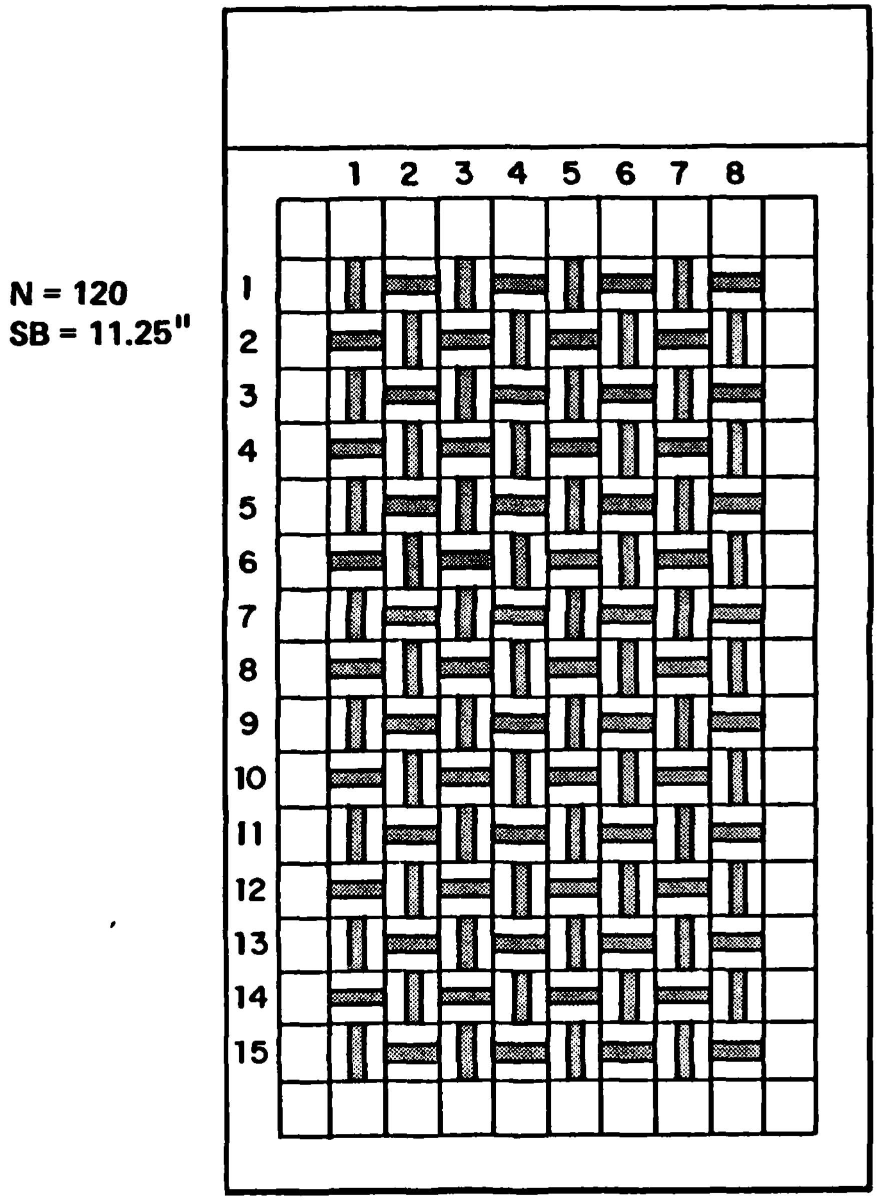


Figure 2. Axial Flow Research Fan.



Anechoic Chamber Rear Wall
24" Wedge Depth

Figure 3. JHP - 1 Air Inlet Wall Wedge Layout - Center Wedge Adjustable - Ideal Layout

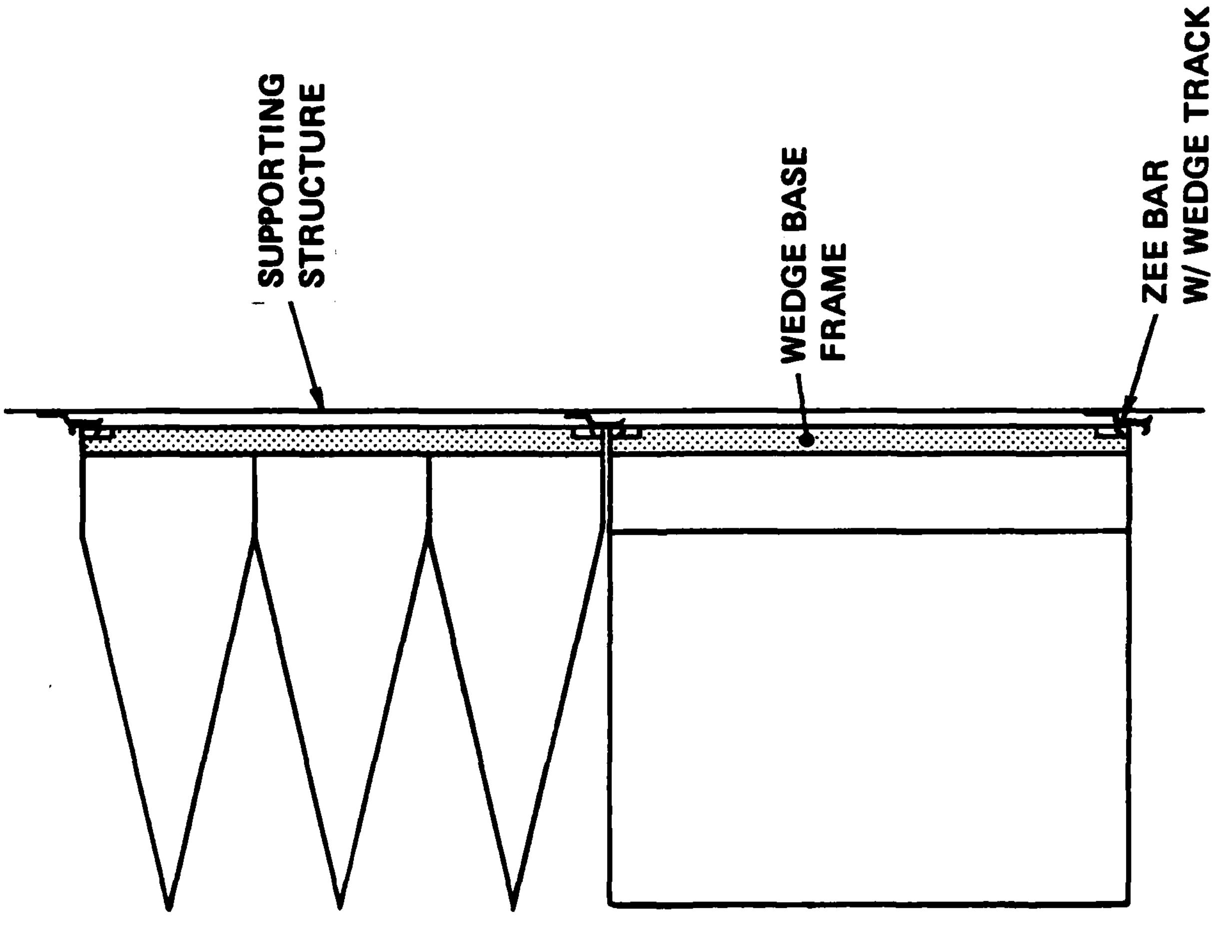


Figure 4. Peak Wedge Details.

Anechoic Chamber Rear Wall
24" Wedge Depth

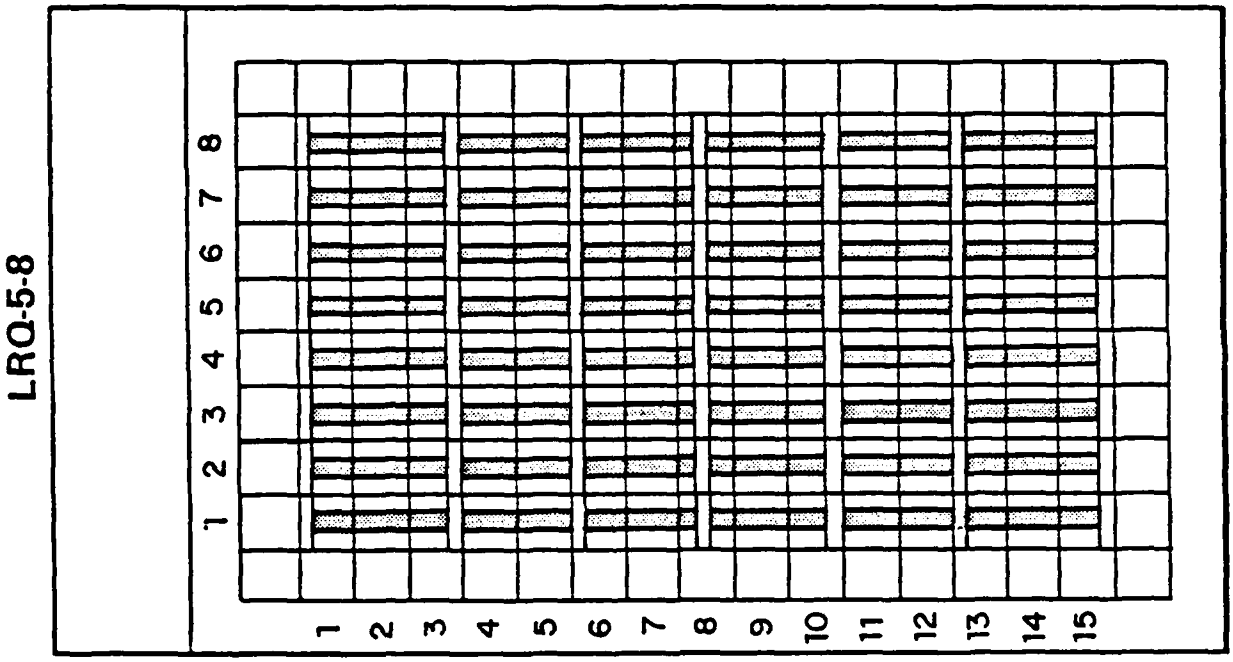


Figure 5. LRQ-5-8 Air Inlet Wall Layout.

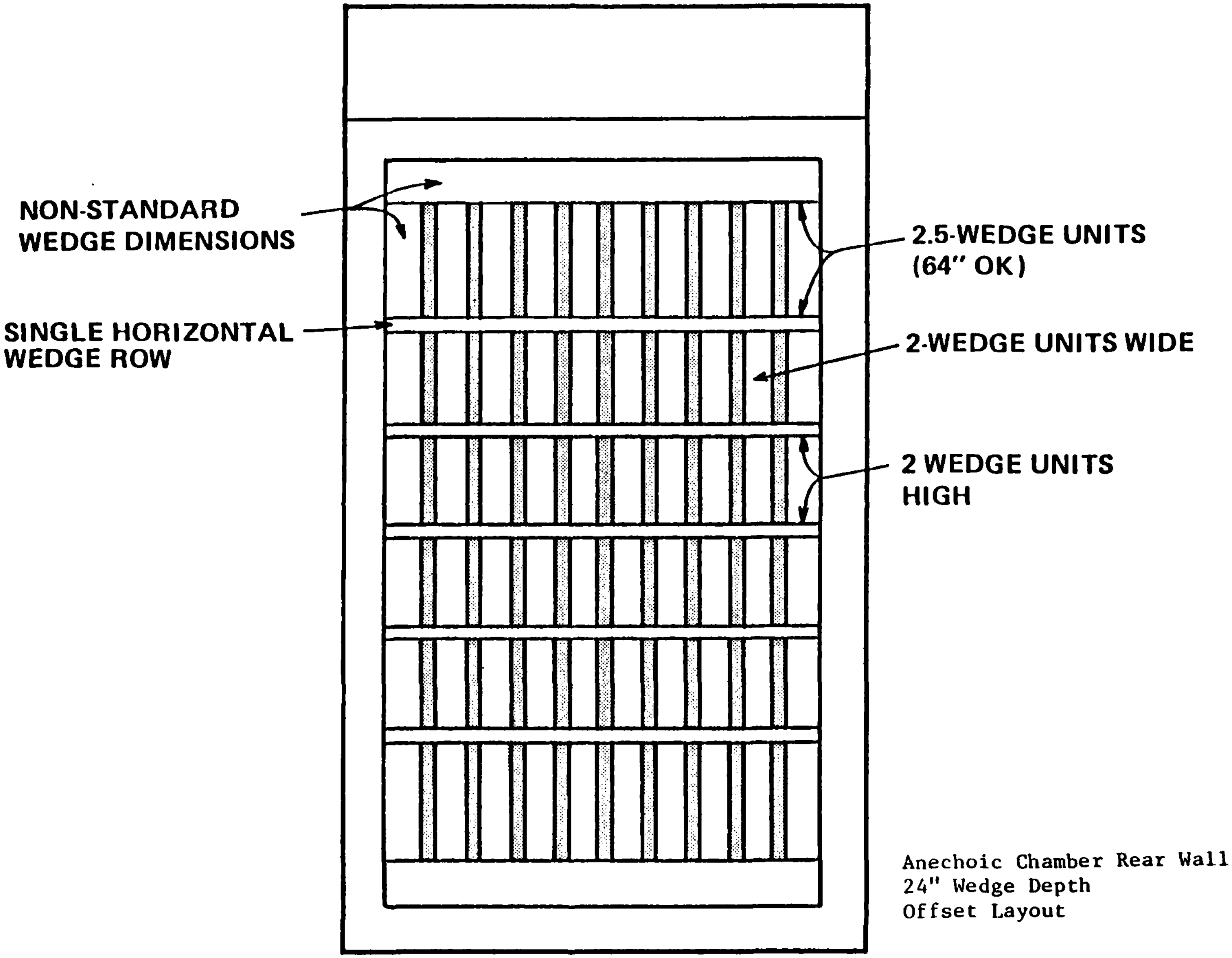
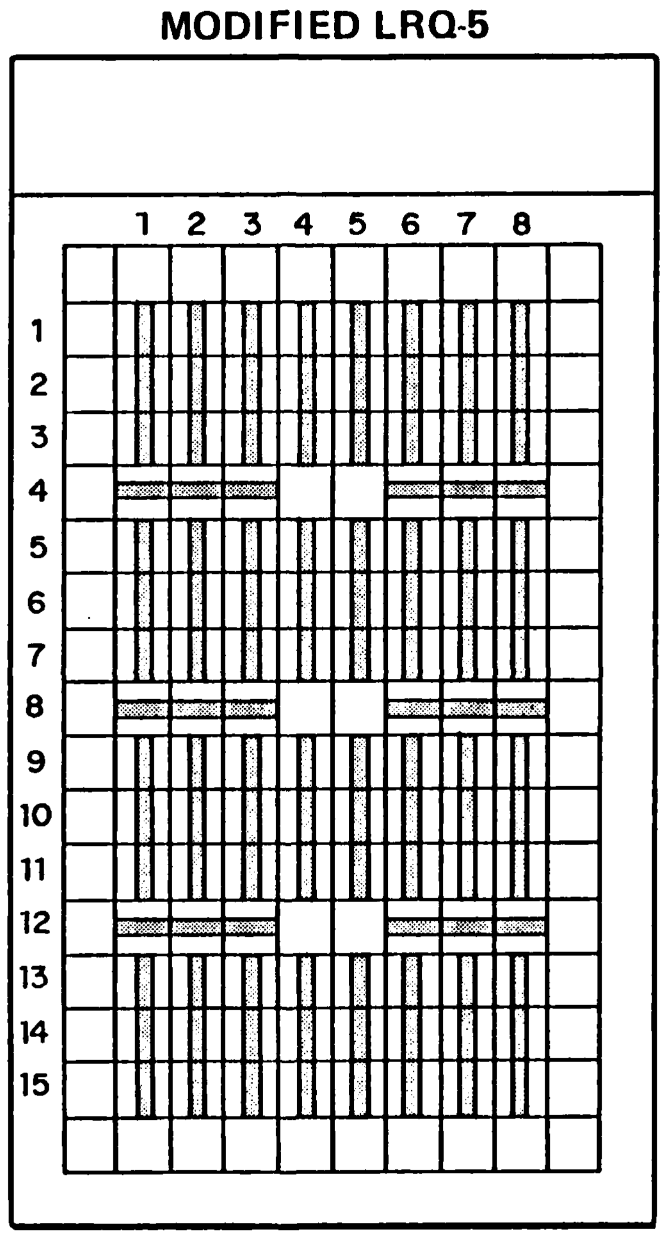
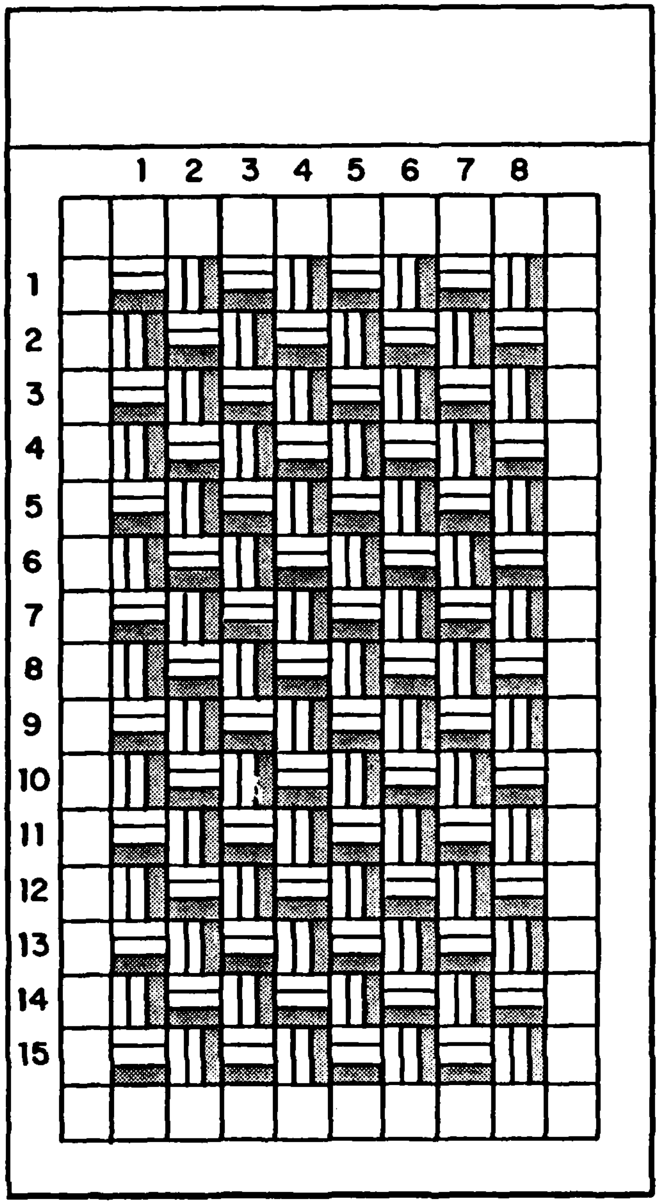


Figure 6. LRQ-5-9 Air Inlet Wall Layout.



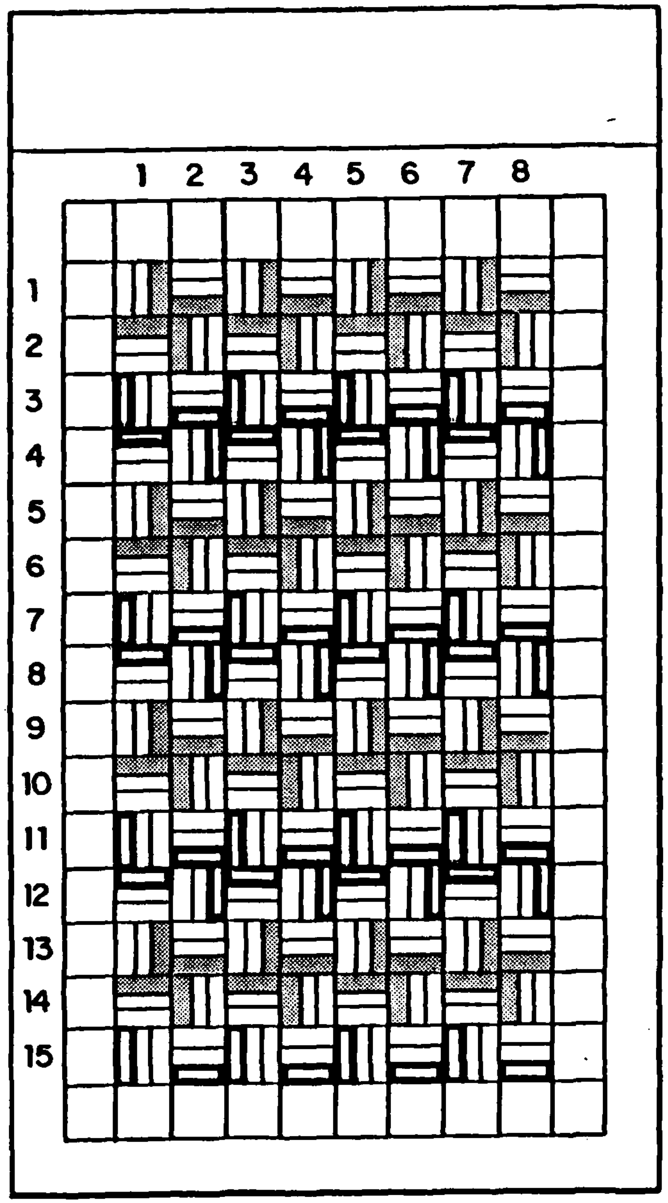
Anechoic Chamber Rear Wall
24" Wedge Depth

Figure 7. Modified LRQ-5 Air Inlet Wall - All Openings are Same Size.



Anechoic Chamber Rear Wall
24" Wedge Depth

Figure 8. JHP - 2 Inlet Configuration based on Standard Two-Peak Wedge Units.



Anechoic Chamber Rear Wall
24" Wedge Depth

Figure 9. JHP - 3 Inlet Configuration based on Standard Two-Peak Wedge Units.

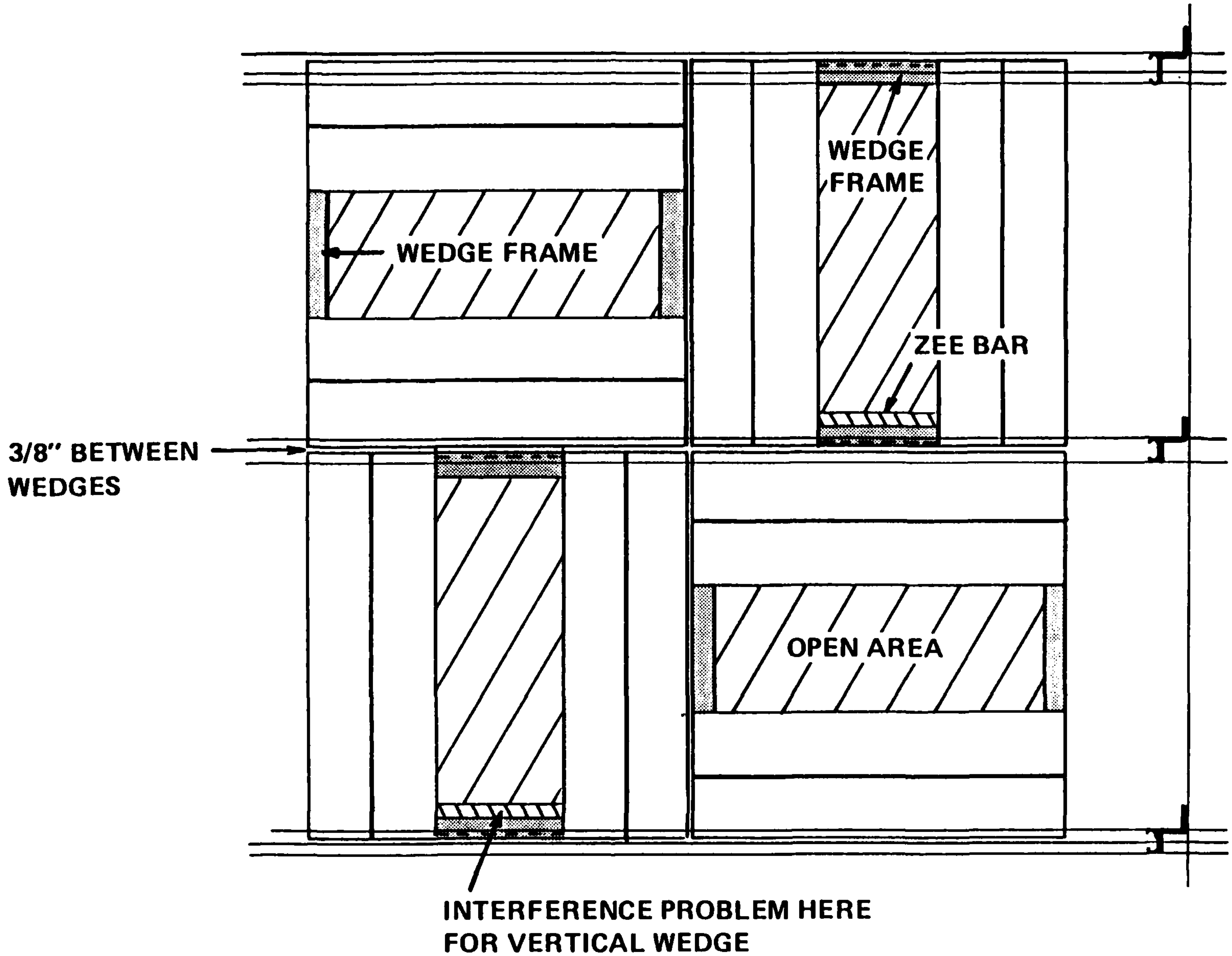
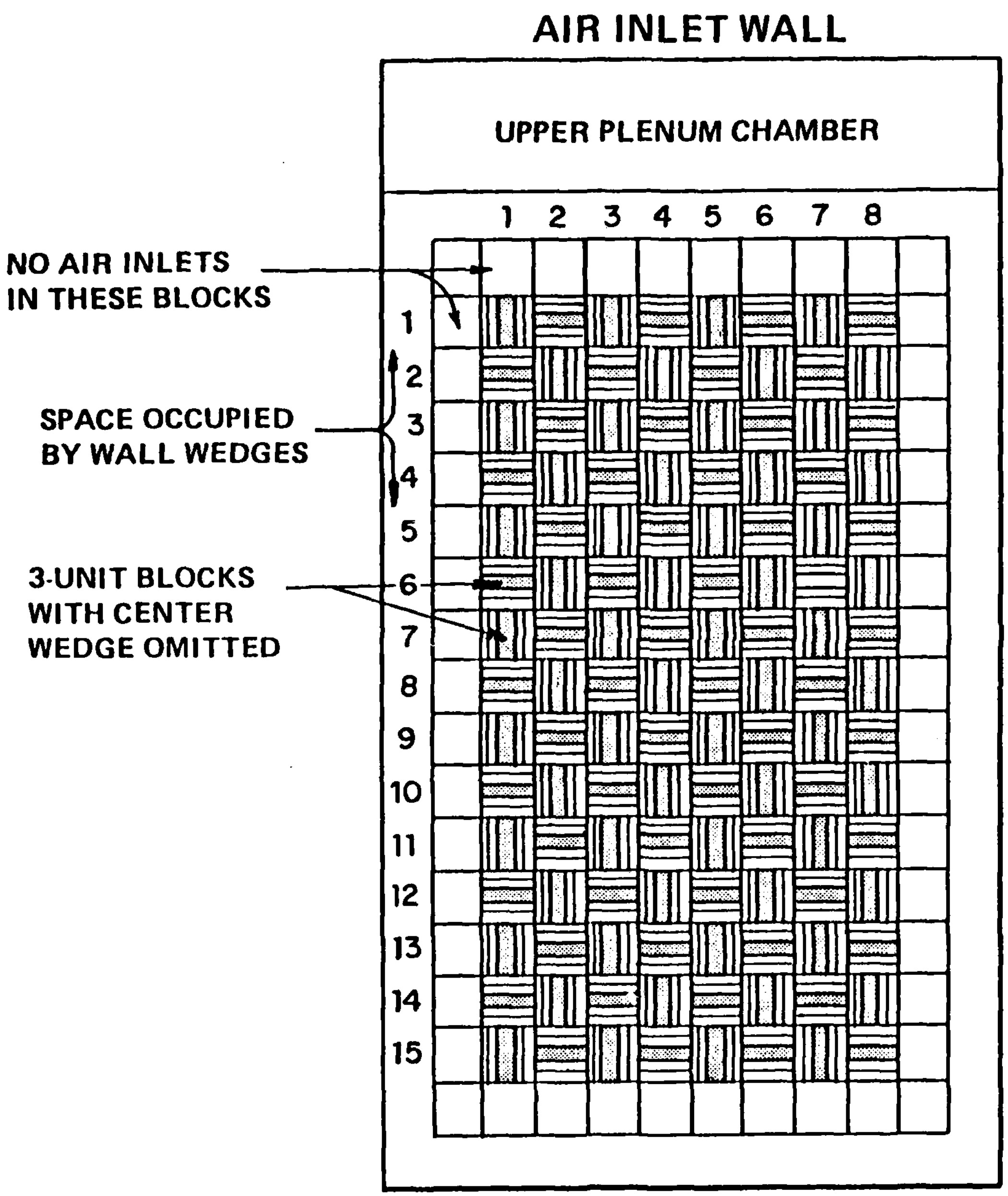


Figure 10. Air Inlet Wedge Details.



Anechoic Chamber Rear Wall
24" Wedge Depth

Figure 11. Air Inlet Wall. Ideal Layout.

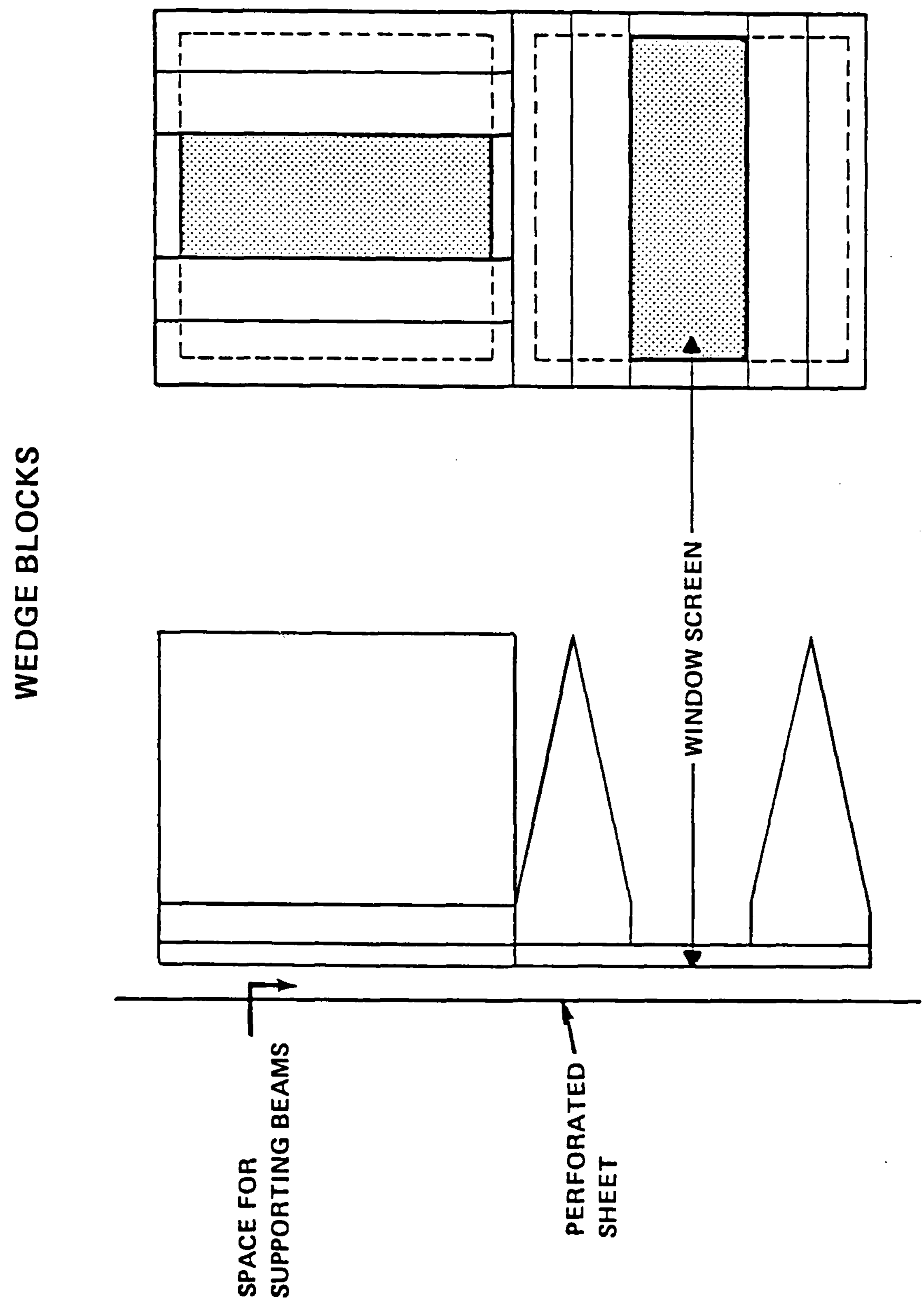
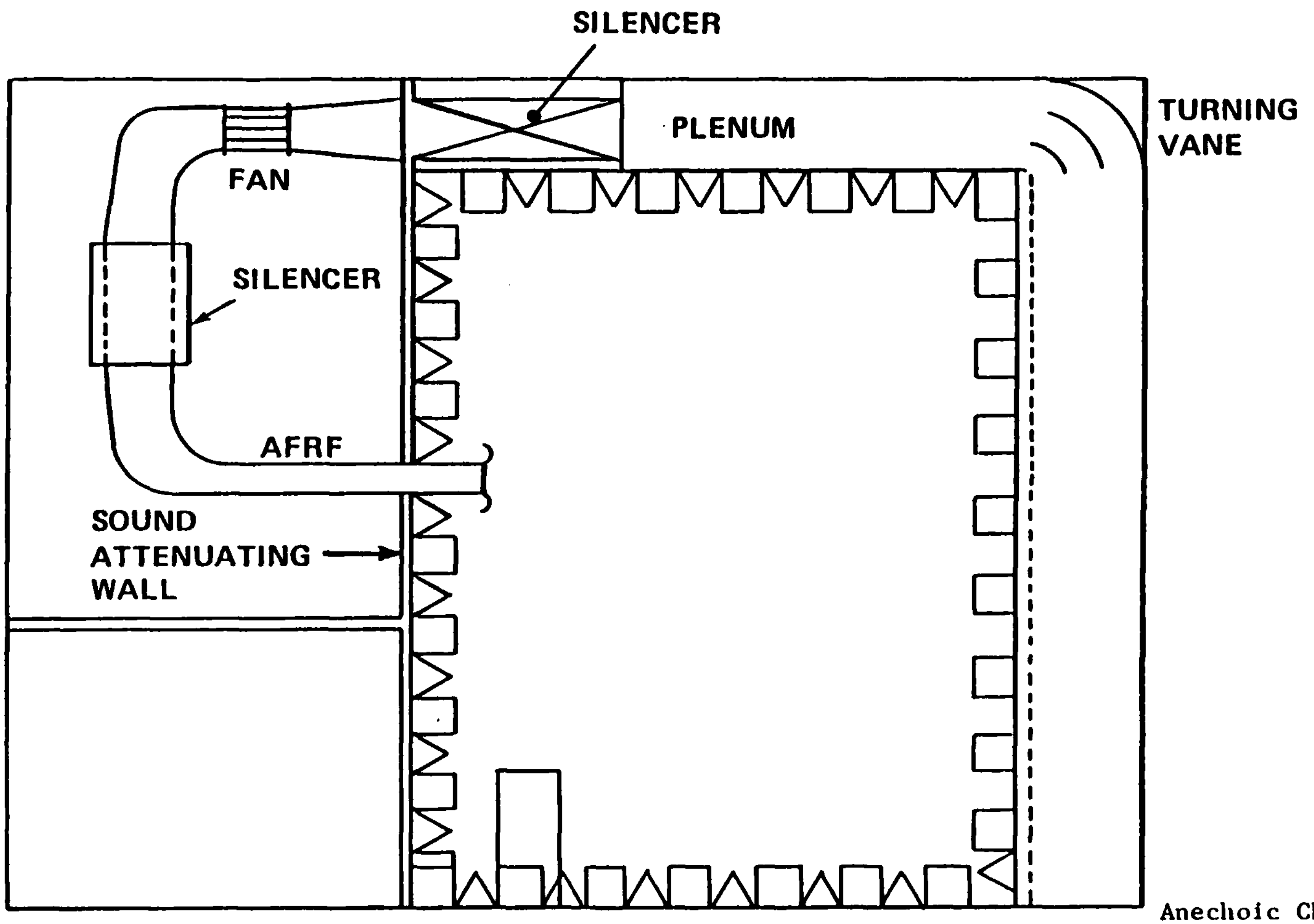


Figure 12. Two Adjacent Wedge Blocks showing Air Inlet Detail.

AFRF CONFIGURATION



Anechoic Chamber
GTWT
1/8" = 1 ft

Figure 13. Proposed AFRF Configuration.

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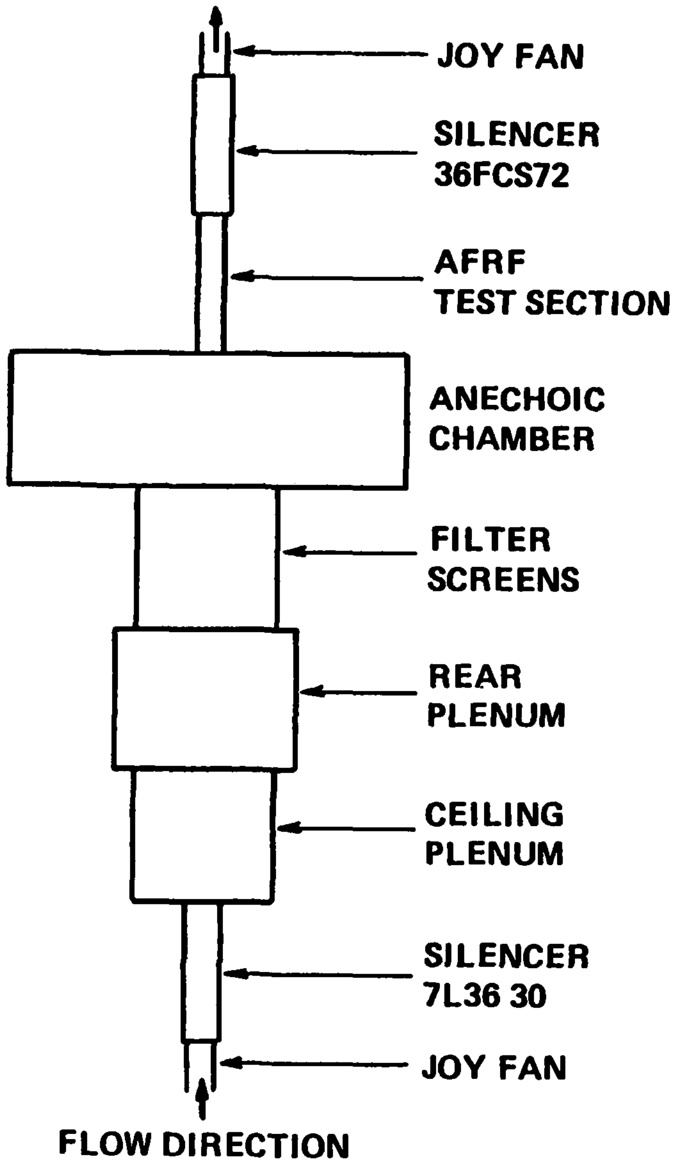
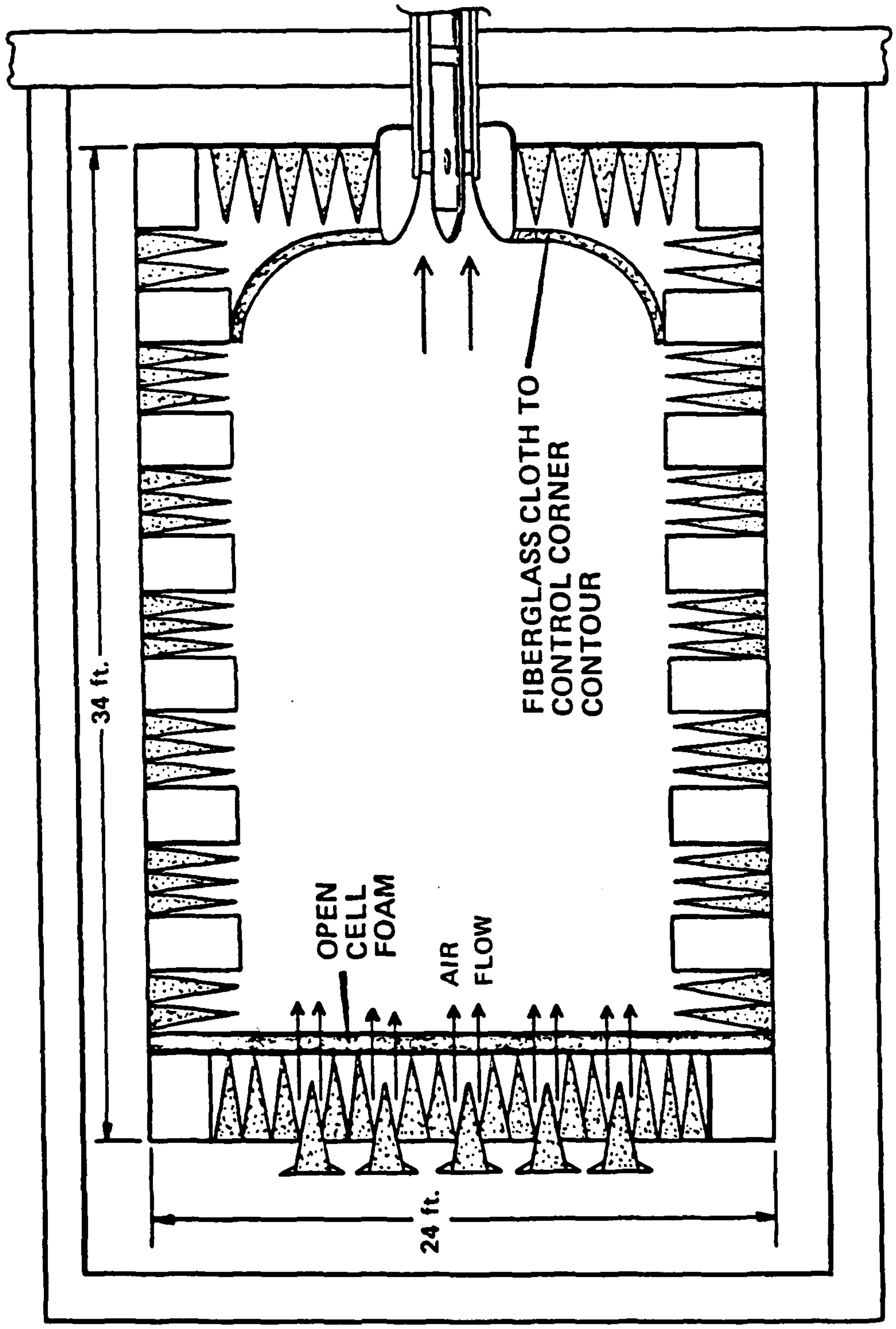


	AREA FT^2	VELOCITY FT/SEC
JOY FAN	2.9	103
SILENCER 36FCS72	7.1	42.3
AFRF TEST SECTION	2.4	125
ANECHOIC CHAMBER	680	0.44
FILTER SCREENS	90	3.33
REAR PLENUM	144	2.1
CEILING PLENUM	96	3.1
SILENCER 7L36 30	7.5	40
JOY FAN	2.9	103

Figure 14. Air Flow Path showing Cross-Sectional Areas to Scale.



APPLIED RESEARCH LAB P.S.U. Turbulence control

Figure 15

APPENDIX A: ADJUSTMENT MECHANISM

A proposed adjustable wedge mechanism is shown in Fig. A.1. The movable wedge is mounted on a plate with pipe flanges at opposite ends. Short pieces of pipe are fitted through the plate and screw into the underside of the pipe flanges. These short pipes are selected to slide over the longer supporting pipes which, in turn, are mounted on the plenum side of the main chamber wall. Pipe caps on the ends prevent the movable wedge from sliding off the support mechanism. Friction is sufficient to hold the wedge in position since the entire mechanism mounts horizontally. The wedge can be adjusted from inside the chamber by grasping the wedge by its hardware cloth covering.

The initial position of the these wedges can be set to 90 square feet open area by use of the following formula:

$$SB = \frac{15A}{N} \qquad \text{(A1)}$$

where

SB is the set-back position in inches,

A is the desired open area in square feet, and

N is the number of adjustable openings.

Zero set-back is the position where the wedge shoulder just closes the opening. This will put the wedge base approximately four inches back of the supporting wall. The length of the short sliding pipe section can be selected so that the opening is just closed when the movable platform is closest to the supporting wall.

If the wedge frame flanges are taken into account, the usable opening is smaller and the set-back formula becomes

$$SB = \frac{17A}{N} \ . \qquad \text{(A2)}$$

If the set-back is measured from inside the chamber, the wedge peaks will be displaced by an additional depth of about four inches [the actual shoulder height] so that the formula becomes

$$SB = 4 + \frac{17A}{N} . \qquad (A3)$$

After the initial installation, the wedges should be set to provide 90 square feet of open area. Then, during initial tests, the wedges can be adjusted to control air flow. Modifications to this mechanism may be necessary to adapt it to some of the wall configurations described in this report.

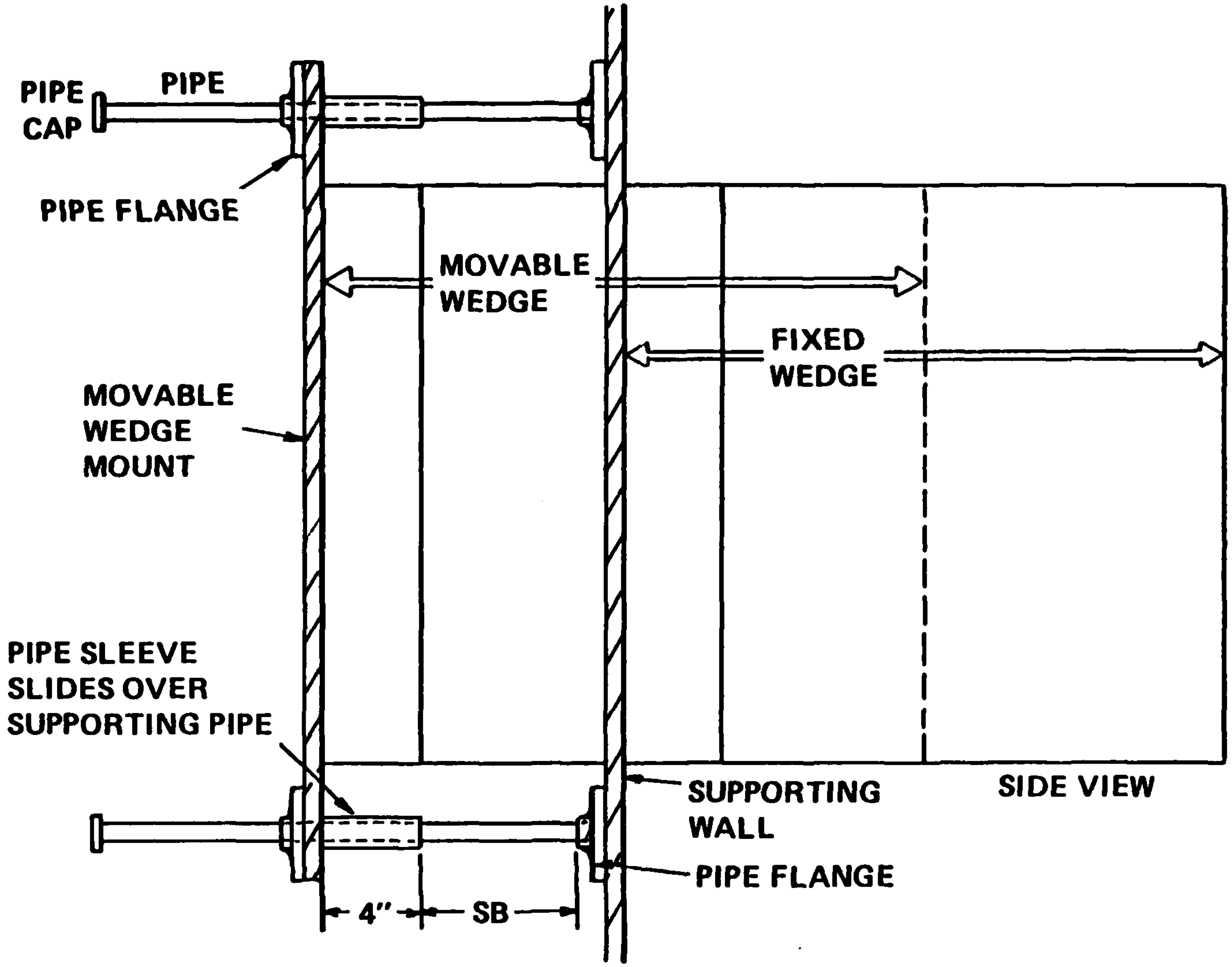


Figure A.1. Proposed Adjustable Wedge Mechanism.

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