NACA TN 3669

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3669

PERFORATED SHEETS AS A POROUS MATERIAL FOR DISTRIBUTED SUCTION AND INJECTION

By Robert E. Dannenberg, Bruno J. Gambucci,
and James A. Weiberg

Ames Aeronautical Laboratory
Moffett Field, Calif.

Washington
April 1956

Q

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3669

PERFORATED SHEETS AS A POROUS MATERIAL FOR DISTRIBUTED SUCTION AND INJECTION

By Robert E. Dannenberg, Bruno J. Gambucci,
and James A. Weiberg

SUMMARY

Measurements were made of the resistance to air flow of a series of perforated metal sheets having open areas ranging from less than 1 percent up to 41 percent. The results showed that the permeability of a perforated sheet is governed principally by its open-area ratio. The number of holes per square inch, the sheet thickness, and the shape of the individual holes had little or no effect on permeability.

As a porous material for boundary-layer-control applications by means of distributed suction or injection, punch-perforated sheets can be made to any desired permeability. For these applications it is usually necessary to have different permeability at different locations. To achieve a gradient permeability, the size and/or spacing of the holes in successive rows can be varied commensurately with the prescribed variation in permeability. Gradient permeability also can be achieved with uniformly perforated sheets combined with some form of resistance backing to furnish the gradient effect.

INTRODUCTION

In wind-tunnel and flight applications of various aerodynamic systems using distributed suction or injection, two types of material arrangements have been used in the porous region. In one type, a single material (e.g., sintered metals) provides both the outer surface and the control of porous-flow resistivity. The other type is a composite or sandwich arrangement of two or more different materials which, in combination, have properties not possessed by a single material.

The physical properties of the material used in the porous region for any aerodynamic type of system involving either distributed suction or injection must fulfill certain basic requirements which are more or less independent of the type of application. These requirements for a porous material or for any combination of different materials include the following:

1. Control of permeability (i.e., the ability to produce a prescribed permeability which is uniform throughout a given area or which varies in a prescribed manner).

2. Sufficiently wide range of permeabilities to accommodate the flow requirements.

3. Adequate strength for the specific application.

4. Adaptability to conventional attachment methods.

Other properties such as

1. Perforation pattern[1] or pore size

2. Surface roughness

3. Formability

4. Thermal properties

5. Availability in sheet size to meet the specific application

6. Resistance to corrosion

7. Susceptibility to clogging

are also of specific interest, but the relative importance of these latter properties depends on the application.

Little information is available as to the suitable ranges of permeability for applications other than for lift control and for stabilization of the laminar boundary layer. These latter systems have been investigated in detail (refs. 1 to 5) and the range of permeability required is noted in figure 1.

Perforated metals as a porous material for aerodynamic application offer many advantages, particularly from the standpoint of strength and in providing for a smooth and wave-free surface. Joints, splices, and discontinuities could be eliminated by perforation of only the section of the skin in the region in which suction or injection is required. The tendency to clog is greatly reduced because the holes are straight through the sheet and do not tend to trap foreign particles, and also because the holes can be of relatively large diameter (0.02-inch or greater) as compared to the minute passageways through fibrous or sintered compacts. From a

---

[1] In this report the pattern is distinguished from roughness in that a smooth sheet which has been perforated with a particular arrangement of holes is considered to have a certain pattern, whereas roughness has the usual connotations of a granular or sandpaper-like surface.

fabrication standpoint, perforated sheets are available in a wide variety of sizes and are easily formed and attached by conventional methods.

The investigation reported herein was conducted in order to ascertain the resistance to air flow through thin multiholed sheets and to establish which quantities are most important in determining the permeability characteristics of perforated materials. Some examples are presented illustrating the use of punch-perforated sheets for distributed-suction application.

NOTATION

A	frontal area of porous sample, sq ft
g	acceleration due to gravity, ft/sec^2
H	total pressure upstream of porous material, lb/sq ft
Δh	pressure drop across porous material, in. of water
Q	volume flow, at free-stream density, through porous material, cu ft/sec
t	temperature, °F
v	suction air velocity, normal to the surface of the porous material, $\frac{w}{\rho g A}$, ft/sec
w	weight rate of air flow, lb/sec
ρ	mass density of air, slugs/cu ft

FLOW CHARACTERISTICS OF PERFORATED SHEETS

Die-Punched Holes

Punched perforation patterns are commercially available in an almost endless array of round, square, and elongated hole shapes with straight, staggered, or diagonal spacings (ref. 6 or 7). Almost any type of metal sheet can be punched. For aerodynamic uses the sheet thickness is governed by the strength requirements of the particular type of installation.

At the present time,[2] the smallest round hole available in a commercially punched stainless steel sheet is 0.020 inch. For an aluminum sheet, the smallest diameter is 0.018 inch. For round-hole patterns, the thickness of a stainless steel sheet that can be punched is limited to approximately one-half the hole diameter. In aluminum, the thickness can about equal the diameter.

The resistance to air flow normal to the surface of various punch-perforated sheets is presented in figure 2 for a range from 0.6-percent to 41-percent open area. All flow-resistance characteristics presented in this report were determined experimentally by the method described in reference 8. Specimens were installed between flanges in a 5-inch-diameter pipe so that the flow through the sheet was in the same direction as the punching action which perforated the sheet. (The upstream face of each specimen was open to the atmosphere.) There was no appreciable effect on the results when the sheet was tested in the reverse direction.

It can be noted from figure 2(b) that punch-perforated sheets show a wide range of permeability. The number of holes per square inch decreases rapidly in the small open-area ratios. For example, to obtain a 1-percent open area with a 0.023-inch diameter hole (sheet 2, fig. 2(a)) requires only 24 holes per square inch with a center-to-center distance of 7/32 inch.

Drilled Holes

A greater range of round-hole sizes is available if drilled holes rather than punched holes are used to produce a perforated sheet. Hole diameters as small as 0.003 to 0.006 inch are obtainable. Holes less than 0.0135 inch (No. 80 twist drill) require pivot drills with special equipment. Sheet thickness in stainless steel is limited to about twice the pivot drill diameter. A 1-percent open area can be obtained with 69 holes per square inch by use of a 0.0135-inch drill, or with 259 holes per square inch by use of a 0.007-inch pivot drill (sheets 5 and 6 in fig. 5(a), respectively).

The resistance to air flow of a number of drilled sheets with open areas ranging from 0.25 to 7.7 percent is presented in figure 3(b). The test setup was similar to that used for the punch-perforated specimens except that the diameter of the specimen holder was reduced to 3 inches. The size of the test specimen was reduced primarily due to the time required to drill the smaller holes (0.007-inch diameter). Each hole in itself was not difficult, but only 30 to 50 holes could be drilled per hour.

---

[2] Vendors of perforated metal materials were contacted by mail to determine the limitations to hole size and sheet thickness.

Other Methods of Producing Small Holes

Other processes of obtaining a multiholed sheet with a large number of small holes include electrolytically deposited metals, acid etching of metals, and rolling of wire mesh cloths. The latter process has been studied in detail by the NACA Lewis Laboratory in connection with transpiration-cooling applications (ref. 9). In connection with high-lift and drag-control systems, the use of rolled metal cloth has the disadvantage that the rolling process must be controlled with extreme care to obtain the desired permeability, thereby making the problem of reproducibility difficult.

Photographs of multiholed sheets are shown in figure 4 together with the respective flow characteristics. The electrolytically deposited metal specimens shown in figure 4 represent standard stock patterns (ref. 10). The etched sheet[3] shown in the figure is a material intended for a nonaerodynamic application. Other types of acid-etched sheets can be fabricated in certain kinds of stainless steel and in softer metals, whereas electrolytically deposited sheets are limited to the softer metals. In both cases the perforation patterns (hole size, shape, and arrangement) are optional. In the electrolytically deposited sheets shown in figure 4(a), the holes are not straight-sided as in punched or drilled sheets, but are slightly tapered. For the etched sheets the perforations are etched through from both surfaces simultaneously, resulting in a hole which is slightly venturi-shaped. Neither type of sheet is strong enough to support usual aerodynamic loads and would require a supporting structure.

FACTORS AFFECTING PERMEABILITY

The primary factor affecting the quantity of air flow through a perforated sheet for a given pressure differential appeared to be the open-area ratio. Secondary factors such as the number of holes per square inch, the sheet thickness, and the shape of the individual holes had a considerably smaller effect on the flow characteristics. Neither the shape of the sheet (flat or curved) nor a small change in the upstream pressure appeared to affect the flow characteristics. Certain of the secondary factors, however, enter into the final selection of a perforated sheet for practical application.

The dependence of the flow resistance of a perforated sheet on the percentage of open area can be noted in figures 2(b) and 3(b). The small changes in flow characteristics resulting from variation in the number of holes per square inch or the sheet thickness are exemplified in figures 5 and 6, respectively. Some of the data from figures 2, 3, and 5 were used in figure 7 to indicate more clearly the governing effect of open area on

---

[3] Samples of etched sheets were obtained from the Buckbee Mears Company, St. Paul 1, Minnesota.

the flow quantity passing through a perforated sheet. The flow-resistance characteristics presented in figures 2 to 7 are useful for design purposes and would be expected to apply for sheets with perforation patterns other than those investigated.

CONTROL OF PERMEABILITY

Controlled permeability is necessary in any application where the power required for boundary-layer control is an important item. In systems where a porous material is used in a region with a gradient in the external pressure distribution, minimum flow for a specific application generally necessitates that the permeability of the porous material be varied in a prescribed manner. The permeability of a uniformly perforated sheet can be regulated by the size and/or spacing of the holes so as to effect complete control of the flow resistance. In the range of permeability suitable for lift control applications (fig. 1), the flow requirements are such that the open area of a perforated sheet would vary from about 5 percent to less than 1 percent. To achieve a gradient in permeability, the size and spacing of the holes in successive rows can be varied commensurately with the prescribed variation in resistivity.

One method of obtaining a gradient permeability is by the use of nonuniform perforations, that is, unequal hole size and variable spacings. Two arrangements of gradient permeability are shown in figures 8 and 9. Rows of holes were drilled in the sheets with uniform spacing but with varying sizes as noted in the figures. The size of the holes in each row or group of rows determined the percentage open area or permeability of each segment of the sheet. Based on the percentage of open area, suction-velocity distributions were calculated by interpolation from figure 3. The ratio of the area of a given permeability to the total area was taken into account to compute the volume rate of flow. The computed and measured volume rates of flow were compared (for equal values of Δh). Complete agreement between the calculated and measured flow quantities was found. (See figs. 8 and 9).

Illustrative forms of installation for punch-perforated sheets incorporating their own permeability are shown in figures 10(a) and 11(a). Such installations should be simple to incorporate in an aircraft-type structure. The porous region could be punched in the same sheet that forms the adjacent areas of the outer skin, and the usual type of rib structure could be used for support.

Perforated sheets of about 5-percent open area have a permeability more or less equivalent to that indicated by the right-hand edge of the shaded area noted in figure 1. Sheets of 5-percent open area are limited to a maximum of 190 holes per square inch by the smallest dies available (0.020-inch diameter). Any increase in the number of holes per square inch or in the hole diameter increases the open-area ratio. Sheets with open areas greater than about 5 percent have a permeability which is too large and lies outside the range of interest as noted in figure 1. In certain applications, however, the use of more open surface sheets (30 to 40 percent) with up to 600-900 holes per square inch may be desirable. To be able to use these more open sheets and still maintain economical suction power operation, the porous-flow resistance must be increased by some sort of resistance backing to bring the permeability within the limits indicated in figure 1.

A special type of resistance backing consisting of a phenolic-bonded fibrous-glass compact was developed at the NACA Ames Laboratory. Designed to serve as an underlying porous material in composite assembly with a perforated surface sheet, the compact provides for precise permeability control (uniform or gradient). Details of the fibrous-glass compacts are given in references 8 and 11.

Forms of installation for perforated sheets in composite type of assembly are illustrated in figures 10(b) and 11(b). In the type of assembly shown in figure 10(b), the outer perforated sheet and fibrous-glass compact are removable, thus allowing for interchange with compacts of different permeability without change in the surface perforation pattern. The method of assembly allows the backing sheet to be joined to ribs or other members without the necessity for blanking off corresponding areas of the porous surface.

COMPARISON WITH OTHER POROUS MATERIALS

As a porous material, perforated sheets have a wide range of permeability and can be made to almost any desired uniform or gradient arrangement. For comparative purposes, the range of permeability obtainable with granular and fibrous types of materials is shown in figure 12 along with the corresponding range of permeability obtainable with perforated sheets of various open areas. The maximum permeability shown in figure 12 (100-percent open area) represents for the incompressible case the condition of flow in which the pressure difference is equal to the dynamic pressure of the induced air velocity, $\frac{1}{2}\rho v^2$. The minimum permeability shown in the figure (corresponding to that of a sheet with 1/4-percent open area) is representative of a nonaerodynamic application of an extremely dense material for filtration use. This limit may be considered as about the minimum value of permeability required in any type of porous material. The minimum permeability required for aerodynamic application, particularly for boundary-layer control, would be expected to correspond to about the permeability of a 1-percent open area perforated sheet (fig. 12). The permeability requirements noted in figure 1 for lift control and for drag reduction at subsonic speeds can be covered by use of perforated sheets as the porous material, with the open area varying between approximately 1 percent and 7 to 11 percent. Permeability requirements in the more porous range, up to the maximum permeability in figure 12, will probably be for applications in which the prescribed inflow velocities will be of the order of a few percent of a supersonic free-stream velocity.

The flow-resistance characteristics of perforated sheets with straight-through holes were found to be basically different from those of granular or fibrous types of materials with labyrinth-like passageways. For the latter types of materials the flow velocity increased linearly with the pressure difference across the material (refs. 8 and 12); whereas for perforated sheets the flow velocity increased approximately as the square root of the pressure difference. This dissimilarity in flow characteristics of porous regions having labyrinth type of passageways and those having straight-through holes could have an important effect on the performance of suction or injection systems at off-design conditions. As illustrated in figure 13, for two systems having the identical design conditions, a change in the pressure across the porous surface would produce a greater change in the flow quantity for the surface with labyrinth-like passageways than for that with straight-through holes. Since the basic requirement of suction and injection systems generally is to maintain a specified flow quantity, a system using a perforated sheet material in the porous region would have the advantage of being less sensitive to pressure changes than one using granular or fibrous materials.

CONCLUDING REMARKS

Measurements were made of the air-flow resistance characteristics of perforated metal sheets with straight-through holes. The primary factor affecting the flow resistance of a perforated sheet was found to be the open-area ratio. The number of holes per square inch, the sheet thickness and the shape of the individual holes had little or no effect on the permeability in the range of variables tested.

As a porous material, punch-perforated sheets can be made to any desired permeability. For gradient permeability, the punched sheets can be used either (1) alone, with a nonuniform perforation pattern to provide the gradient variation or (2) with a uniform perforation pattern, to provide the outer surface of a composite or sandwich type of assembly in which a second underlying porous material (e.g., fibrous-glass compacts) furnishes the gradient variation.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Feb. 6, 1956

REFERENCES

1. Bray, Richard S., and Innis, Robert C.: Flight Tests of a Leading-Edge Area Suction on a Fighter-Type Airplane With a 35° Sweptback Wing. NACA RM A55C07, 1955.

2. Debeau, D. E.: Gordon, S. A., Badertscher, R. F., and Swager, W. L.: Evaluation of Porous Materials for Boundary-Layer Control. Progress Rep. 1, Battelle Memorial Institute, Columbus, Ohio, Mar. 1955.

3. Dannenberg, Robert E., and Weiberg, James W.: Effect of Type of Porous Surface and Suction Velocity Distribution on the Characteristics of a 10.5-Percent-Thick Airfoil With Area Suction. NACA TN 3093, 1953.

4. Braslow, Albert L., Burrows, Dale L., Tetervin, Neal, and Visconti, Fioravante: Experimental and Theoretical Studies of Area Suction for the Control of the Laminar Boundary Layer on an NACA 64A010 Airfoil. NACA Rep. 1025, 1951.

5. Head, M. R., Johnson, D., and Coxon, M.: Flight Experiments on Boundary Layer Control for Low Drag. British R.A.E. Rep. Aero 2541, Mar. 1955.

6. Anon.: Perforated Materials. General Catalog No. 62, The Harrington and King Perforating Co., Chicago, Ill., 1954.

7. Anon.: Perforated Metals. Catalog No. 8, Charles Mundt and Sons, Jersey City, N. J., 1954.

8. Dannenberg, Robert E., Weiberg, James A., and Gambucci, Bruno J.: A Fibrous-Glass Compact as a Permeable Material for Boundary-Layer-Control Applications Using Area Suction. NACA TN 3388, 1955.

9. Donoughe, Patrick L., and McKinnon, Roy A.: Experimental Investigation of Air-Flow Uniformity and Pressure Level on Wire Cloth for Transpiration-Cooling Applications. NACA TN 3652, 1956.

10. Anon.: Lektromesh Specification Sheet. The C.O. Jelliff Mfg. Corp., Southport, Conn., 1955.

11. Anon.: Bulletin V-102, Varapac, BLC Porous Materials Co., Box 502, Palo Alto, Calif., 1955.

12. Dannenberg, Robert E., Weiberg, James A., and Gambucci, Bruno J.: The Resistance to Air Flow of Porous Materials Suitable for Boundary-Layer-Control Applications Using Area Suction. NACA TN 3094, 1954.

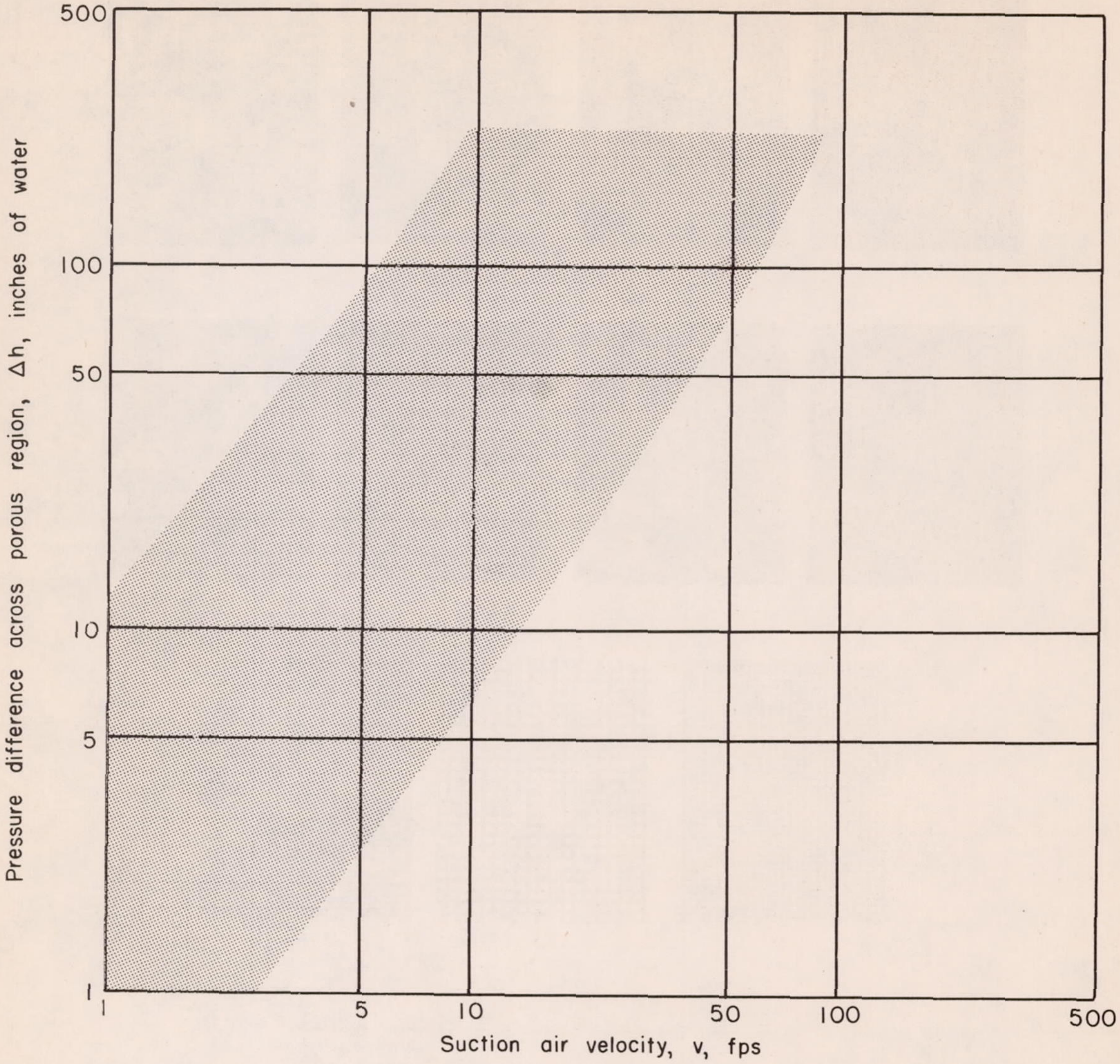
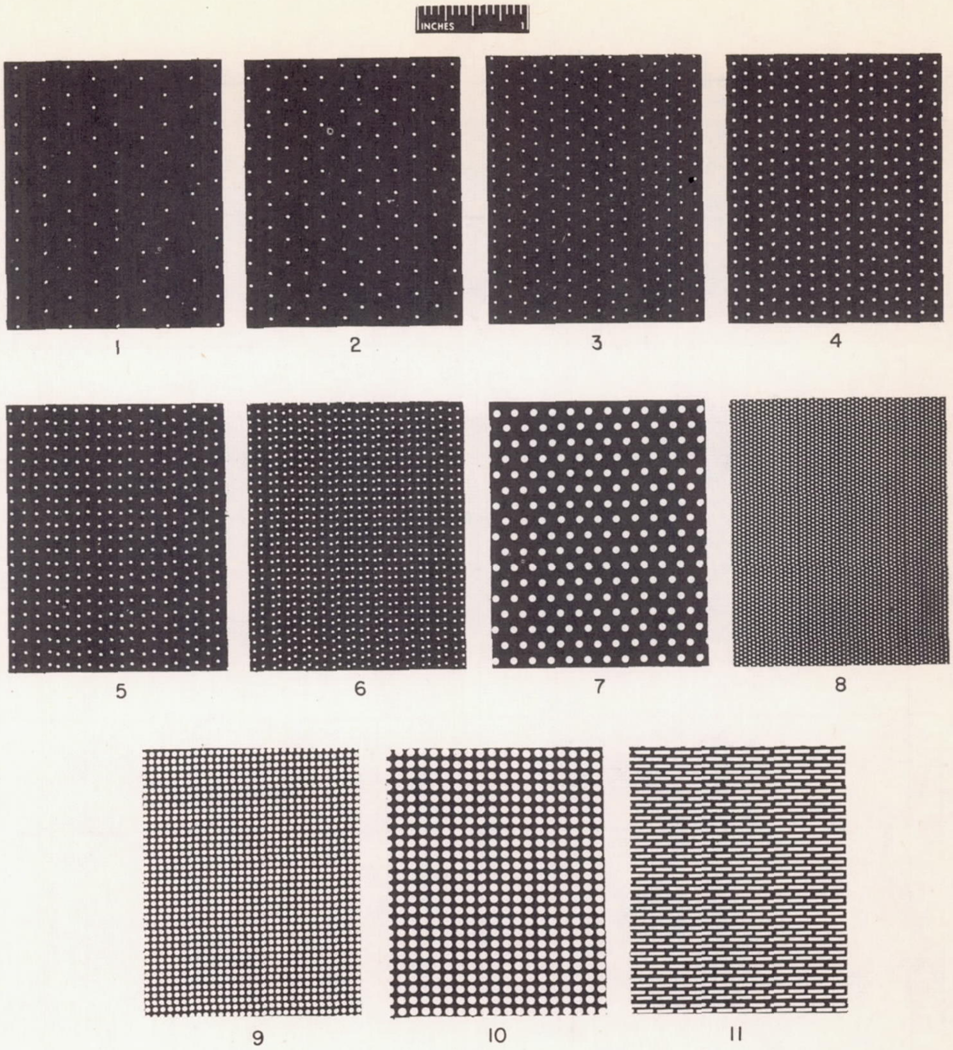


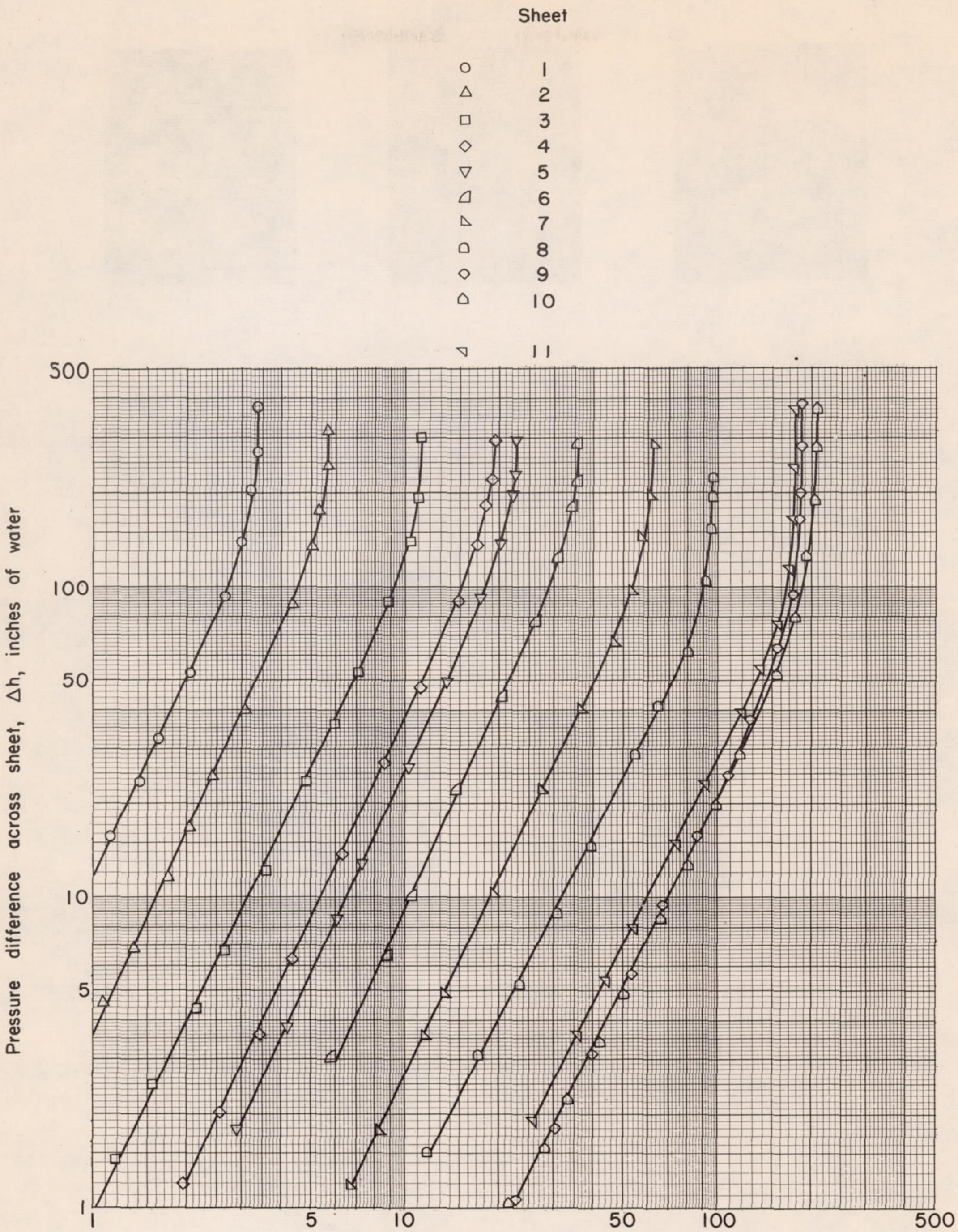
Figure 1.- Range of permeability of interest for materials used in the porous region of systems using area suction for high lift or for stabilization of the laminar boundary layer.



Sheet	Hole diam., in.	Holes per sq in.	Percent open
1	0.023	14.5	0.60
2	.023	24.1	1.0
3	.023	47	2.0
4	.026	57.6	3.0
5	.026	73.7	3.9
6	.023	134	5.6
7	.050	57	11
8	.020	714	23
9	.045	233	37
10	.079	83	41
11	Slot 0.020 × 0.115	140	30

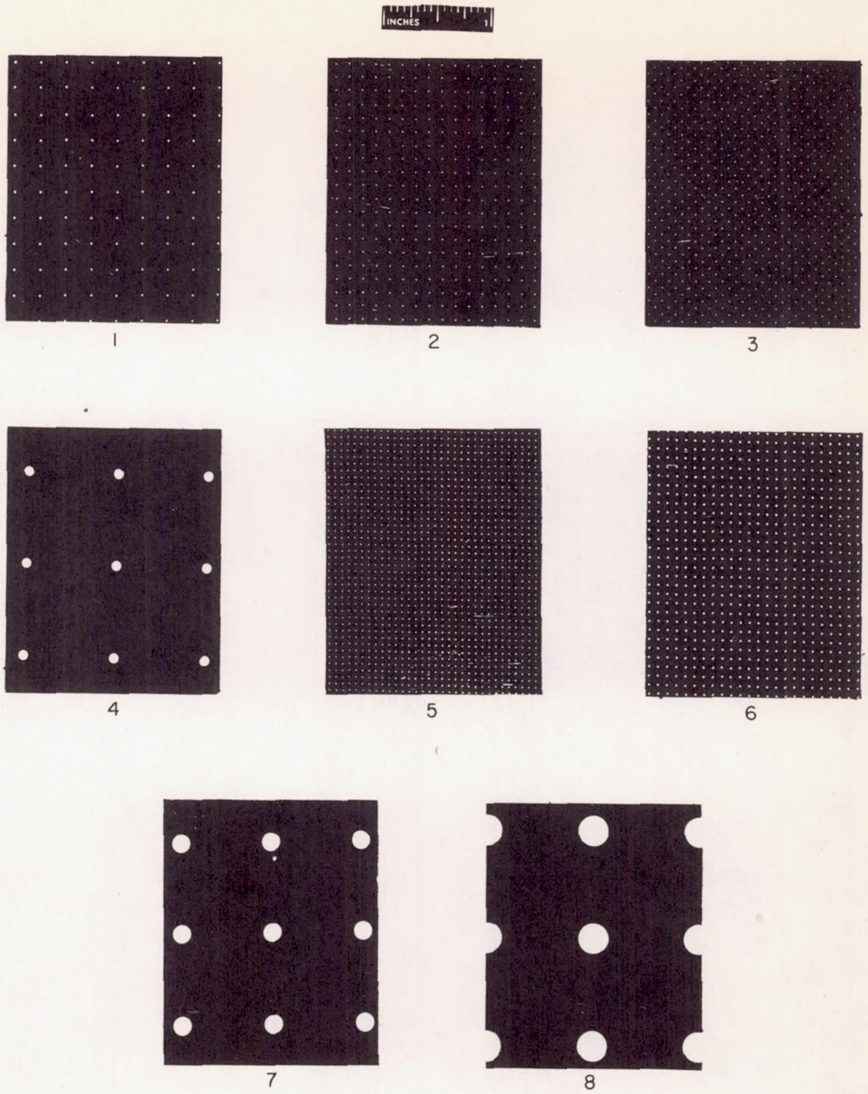
(a) Perforation description.

Figure 2.- Details of the perforation pattern and the resistance to air flow of various metal sheets with die-punched holes; thickness = 0.016 inch.



(b) Flow-resistance characteristics.

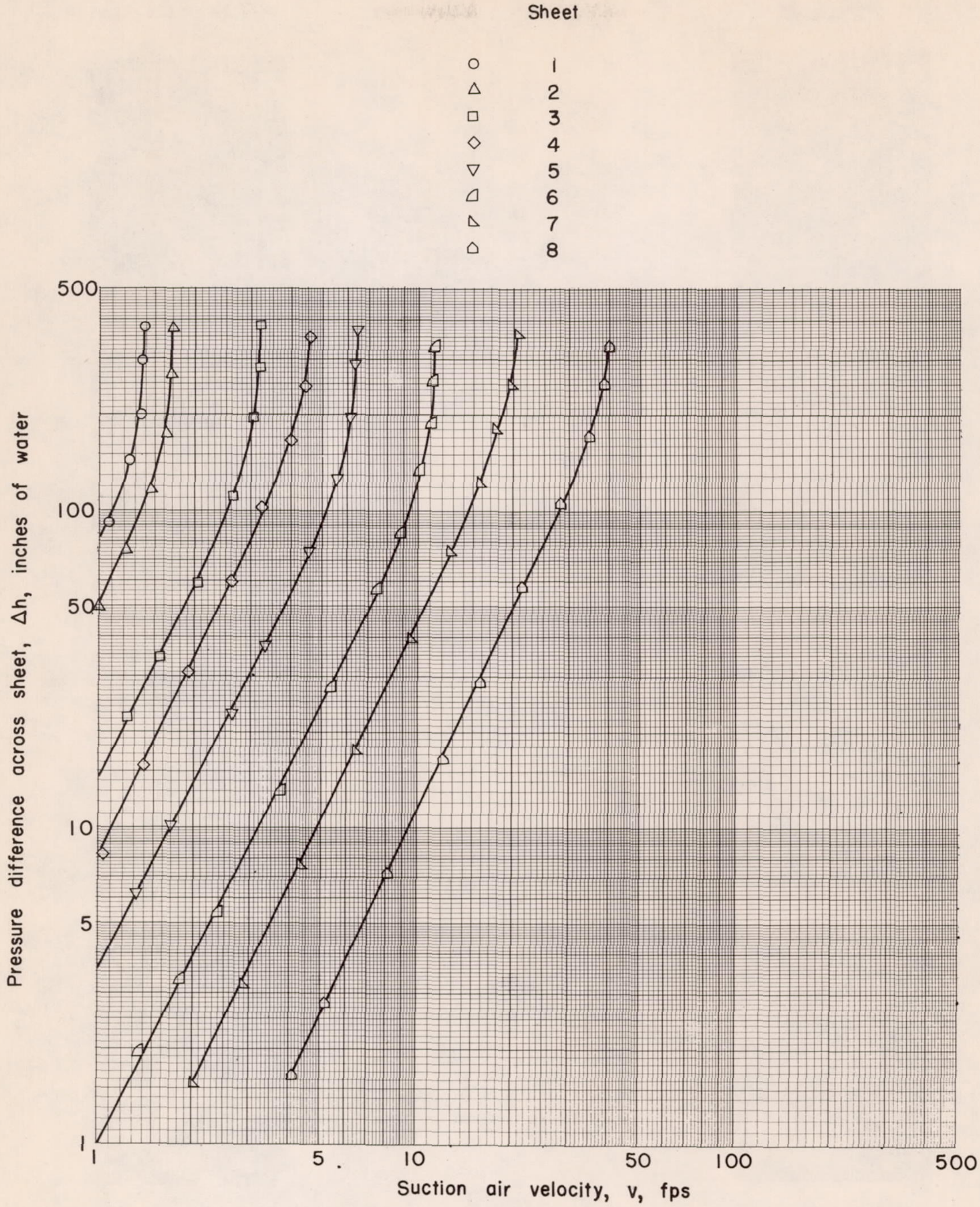
Figure 2.- Concluded.



Sheet	Hole diam., in.	Holes per sq in.	Percent open
1	0.0135	17.5	0.25
2	.007	64.9	.25
3	.007	129.8	.50
4	.0937	1	.87
5	.007	259.6	1.0
6	.0135	139.8	2.0
7	.196	1	3.83
8	.277	1	7.67

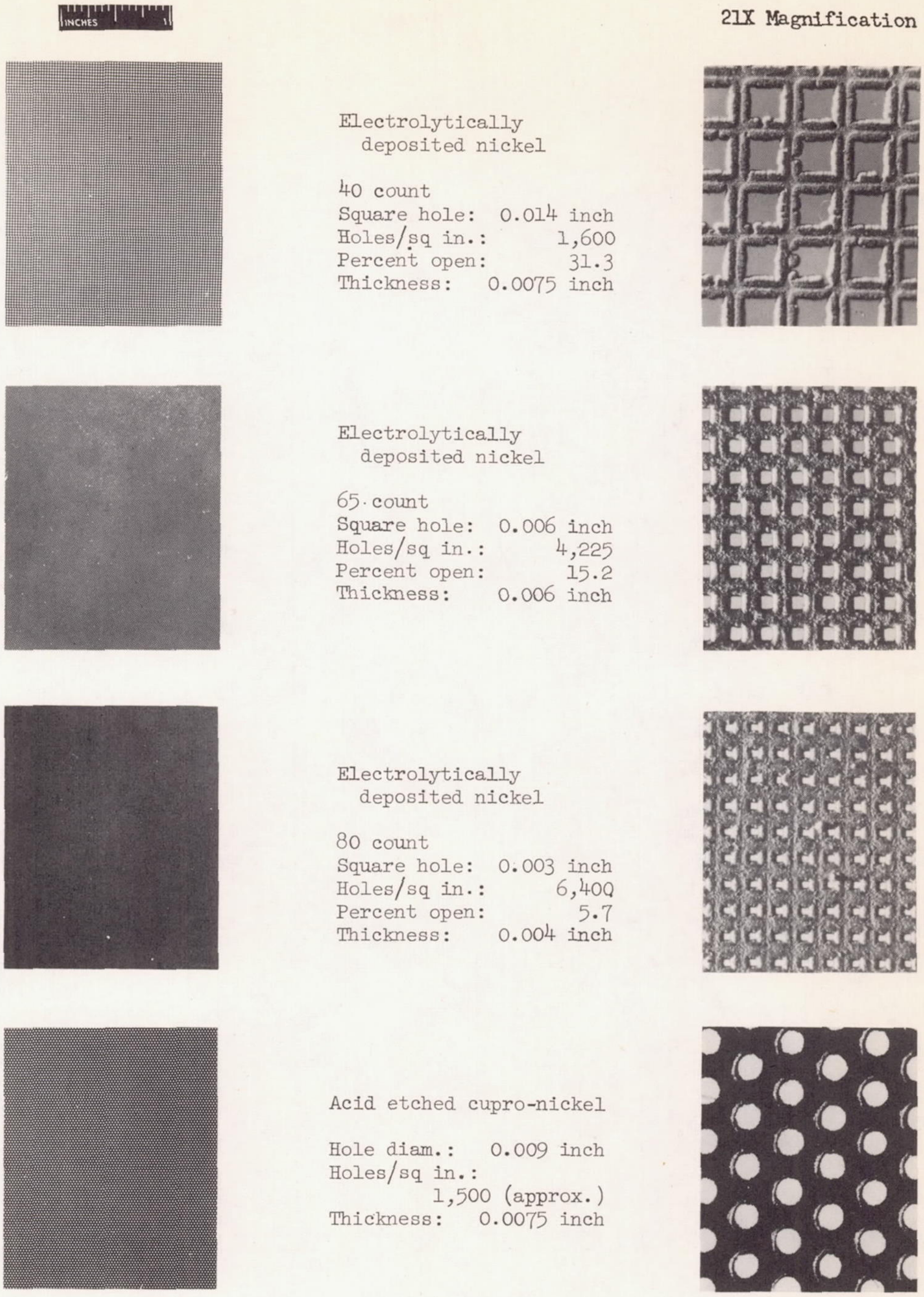
(a) Perforation description.

Figure 3.- Details of the perforation patterns and the resistance to air flow of various brass sheets with drilled holes; thickness = 0.016 inch.



(b) Flow-resistance characteristics.

Figure 3.- Concluded.



Electrolytically
deposited nickel

40 count
Square hole: 0.014 inch
Holes/sq in.: 1,600
Percent open: 31.3
Thickness: 0.0075 inch

Electrolytically
deposited nickel

65 count
Square hole: 0.006 inch
Holes/sq in.: 4,225
Percent open: 15.2
Thickness: 0.006 inch

Electrolytically
deposited nickel

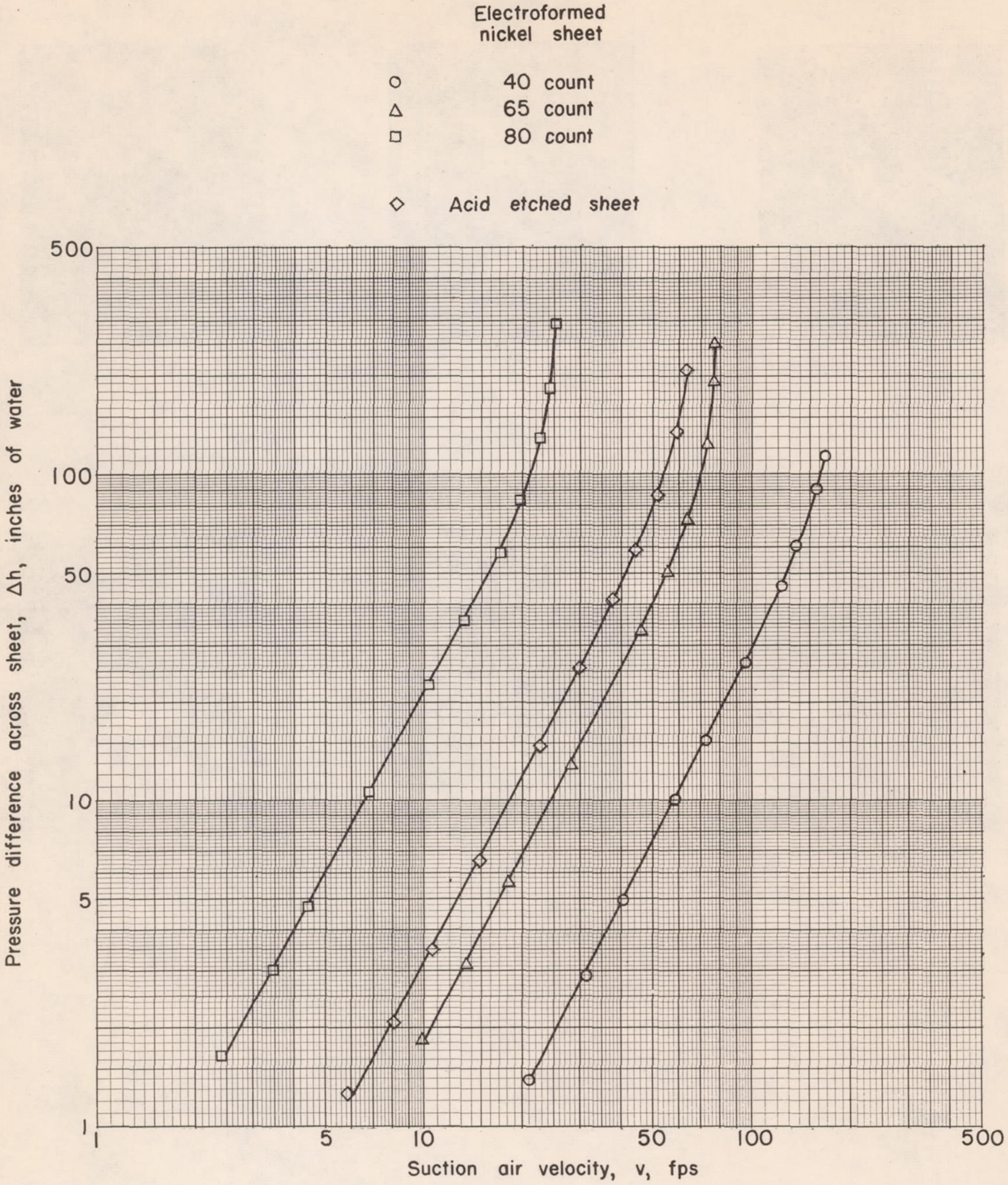
80 count
Square hole: 0.003 inch
Holes/sq in.: 6,400
Percent open: 5.7
Thickness: 0.004 inch

Acid etched cupro-nickel

Hole diam.: 0.009 inch
Holes/sq in.:
1,500 (approx.)
Thickness: 0.0075 inch

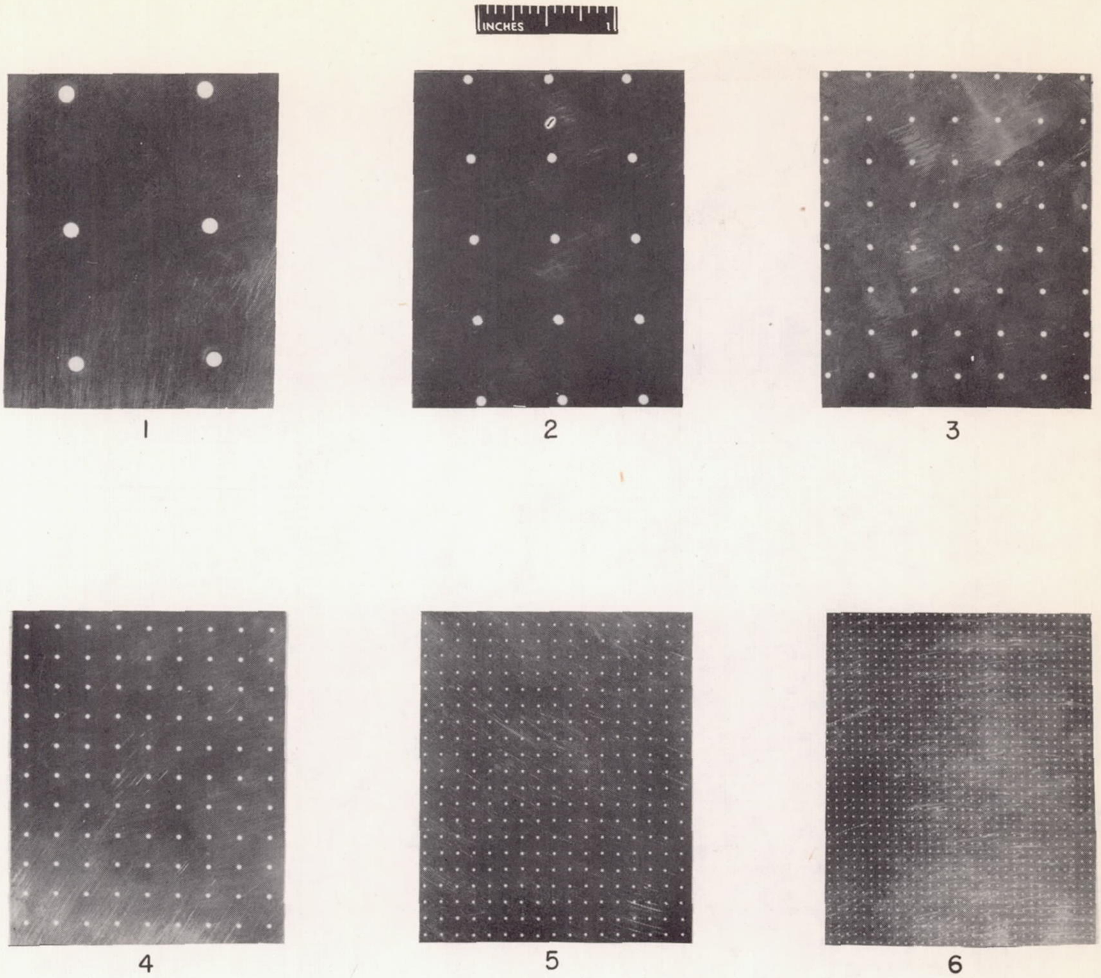
(a) Perforation description.

Figure 4.- Details of perforation patterns and the resistance to air flow of electrolytically deposited and etched metals.



(b) Flow-resistance characteristics.

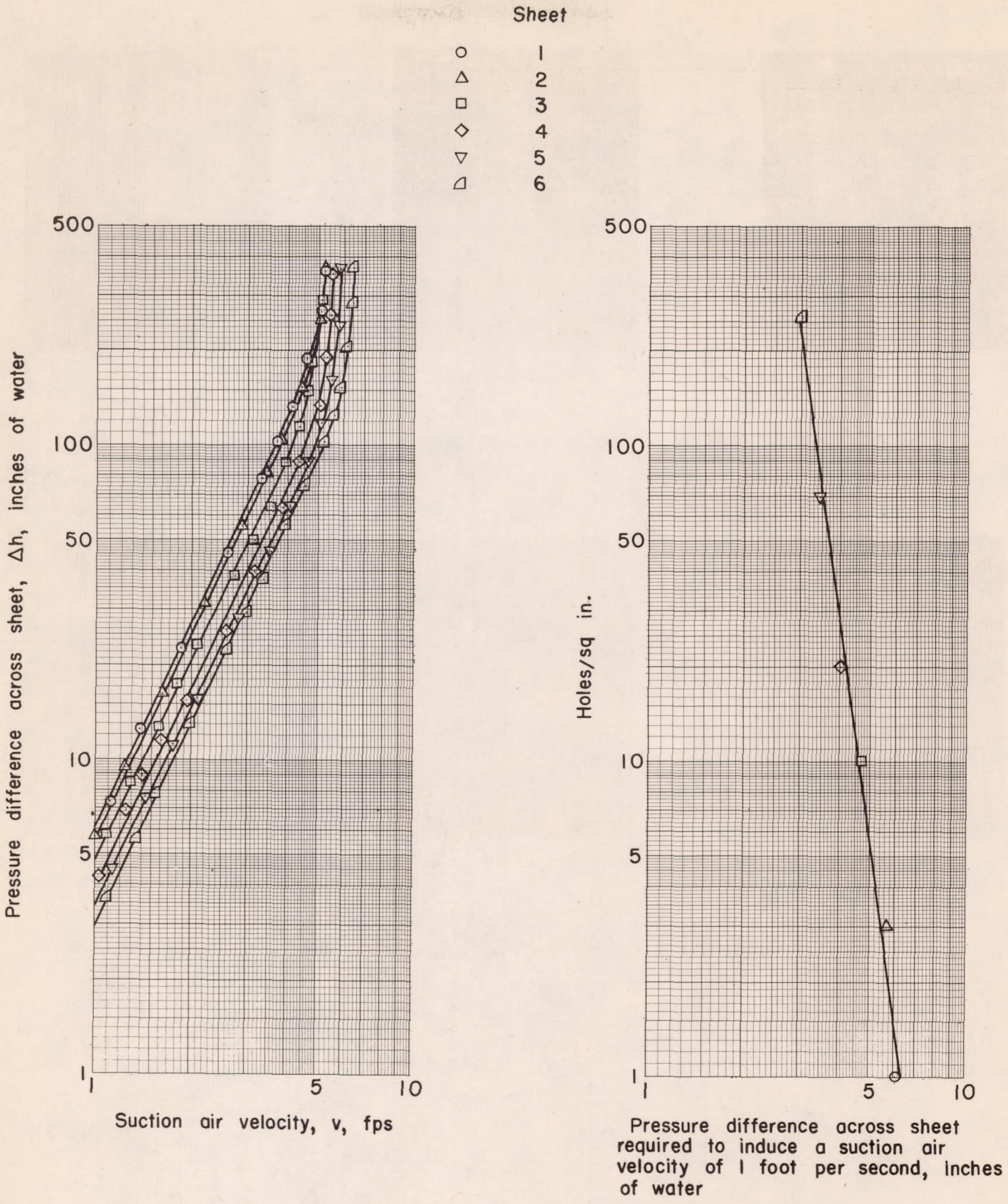
Figure 4.- Concluded.



Sheet	Hole Diam., in.	Holes per sq in.	Percent open
1	0.113	1	1
2	.0635	3	1
3	.036	10	1
4	.025	20	1
5	.0135	69.9	1
6	.007	259.6	1

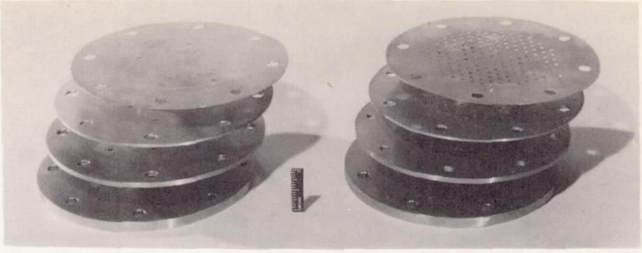
(a) Perforation description.

Figure 5.- Effect of number of holes per square inch on the resistance to air flow of drilled brass sheets with an open area of 1 percent; thickness = 0.016 inch.



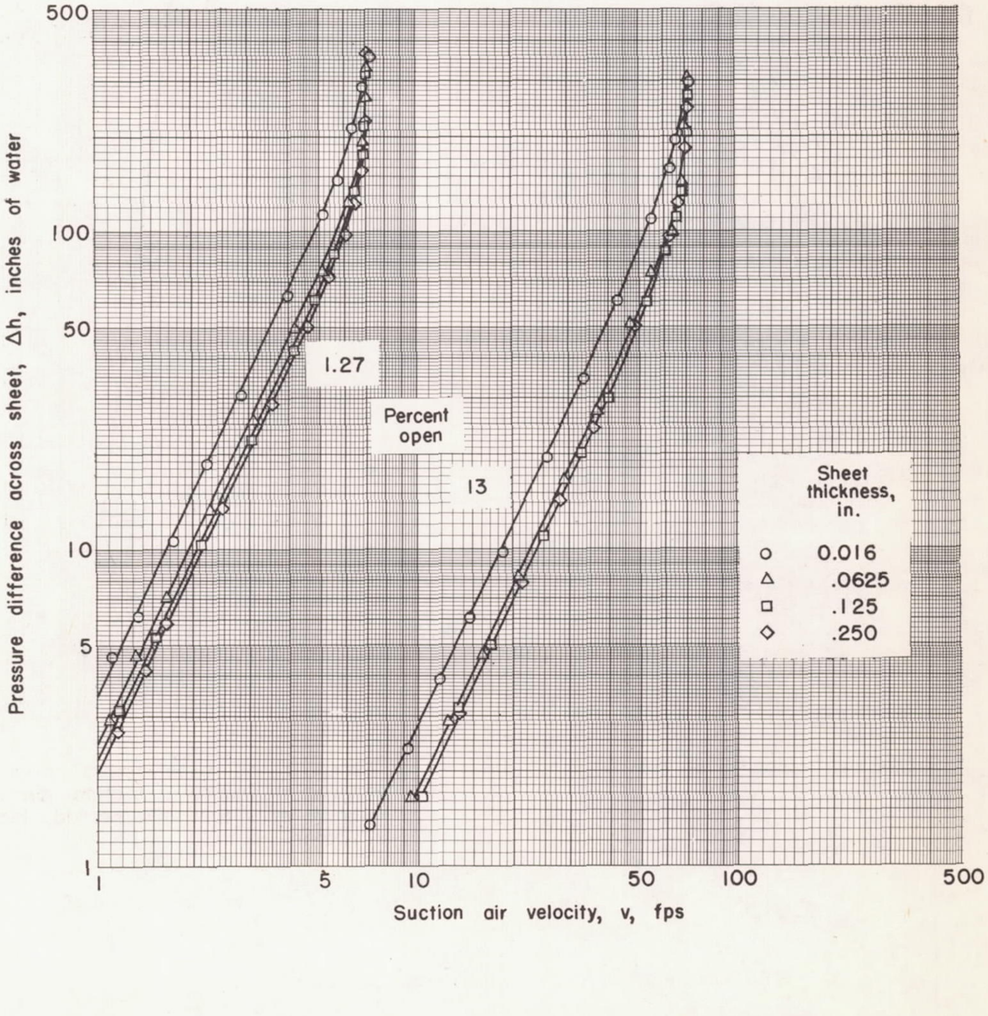
(b) Flow-resistance characteristics.

Figure 5.- Concluded.



Hole diam.:	0.113 inch	Hole diam.:	0.0935 inch
Holes/sq in.:	1	Holes/sq in.:	18
Percent open:	1.27	Percent open:	13

(a) Perforation description.



(b) Flow-resistance characteristics.

Figure 6.- Effect of sheet thickness on the resistance to air flow of various drilled brass sheets.

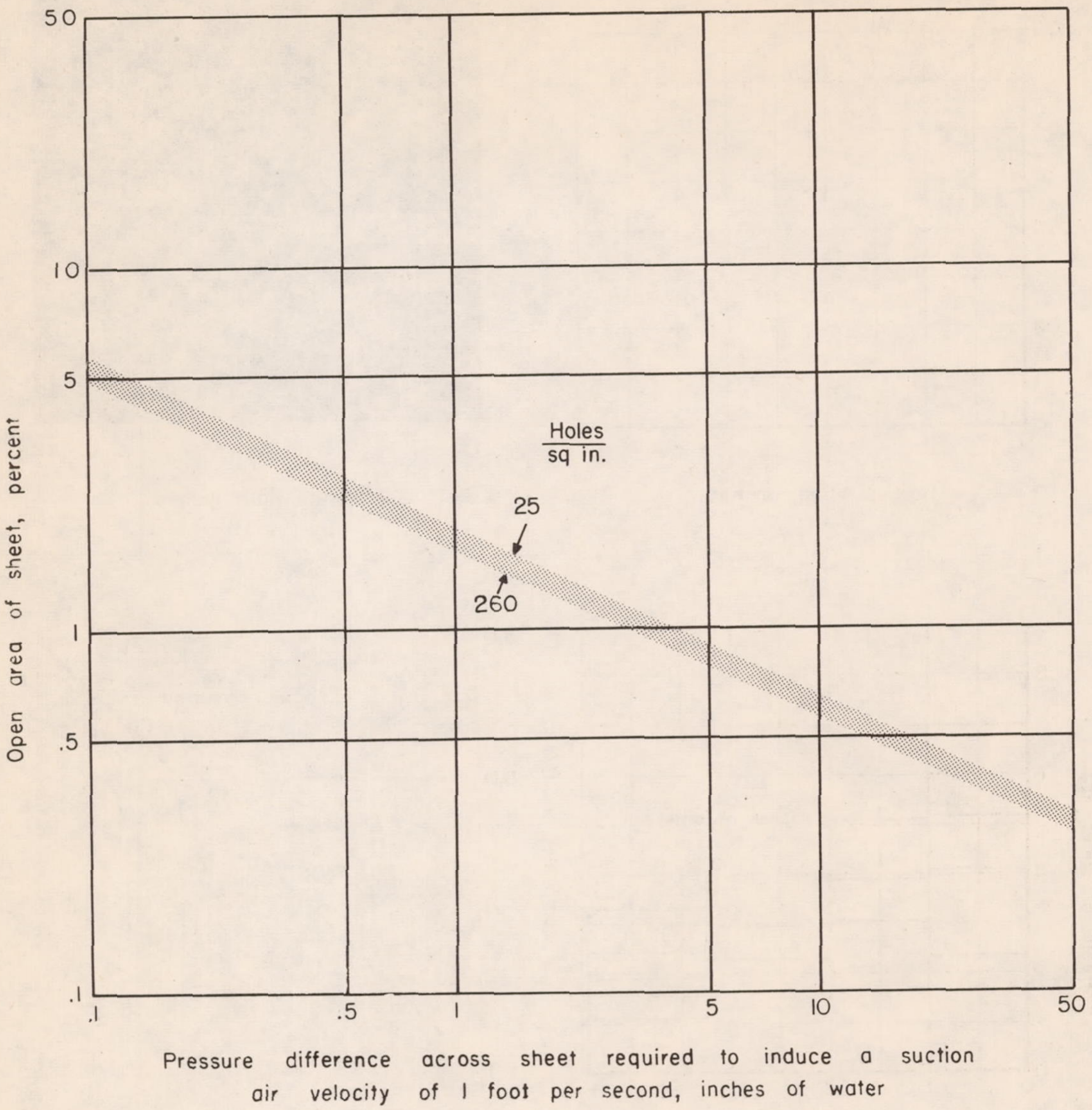


Figure 7.- Correlation of air-flow data with different open-area ratios for drilled brass sheets; thickness = 0.016 inch.

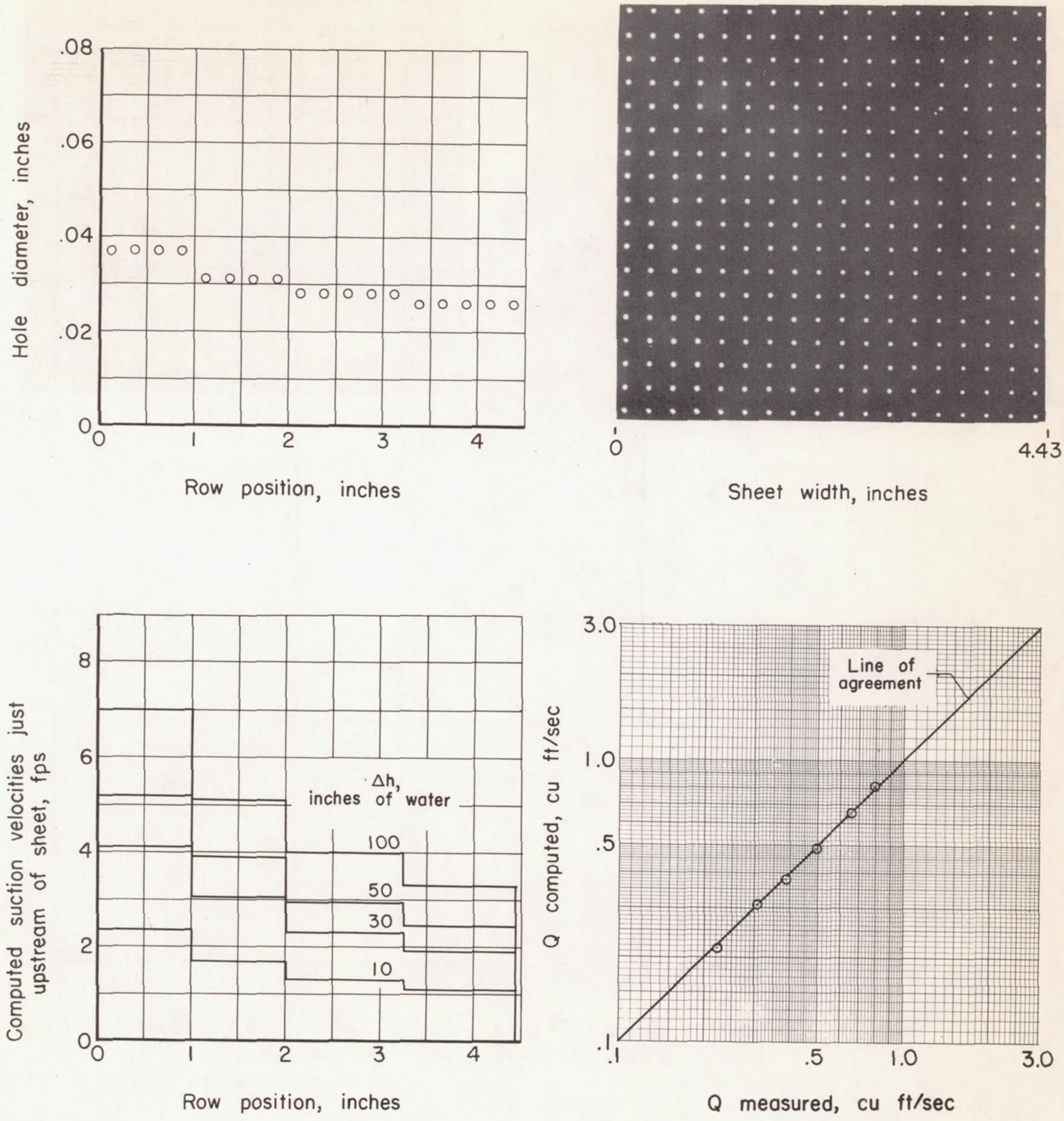


Figure 8.- Drilled brass sheet with stepped arrangement of permeability; open-area variation from 1.72 percent to 0.85 percent; 16 holes per square inch; thickness = 0.016 inch.

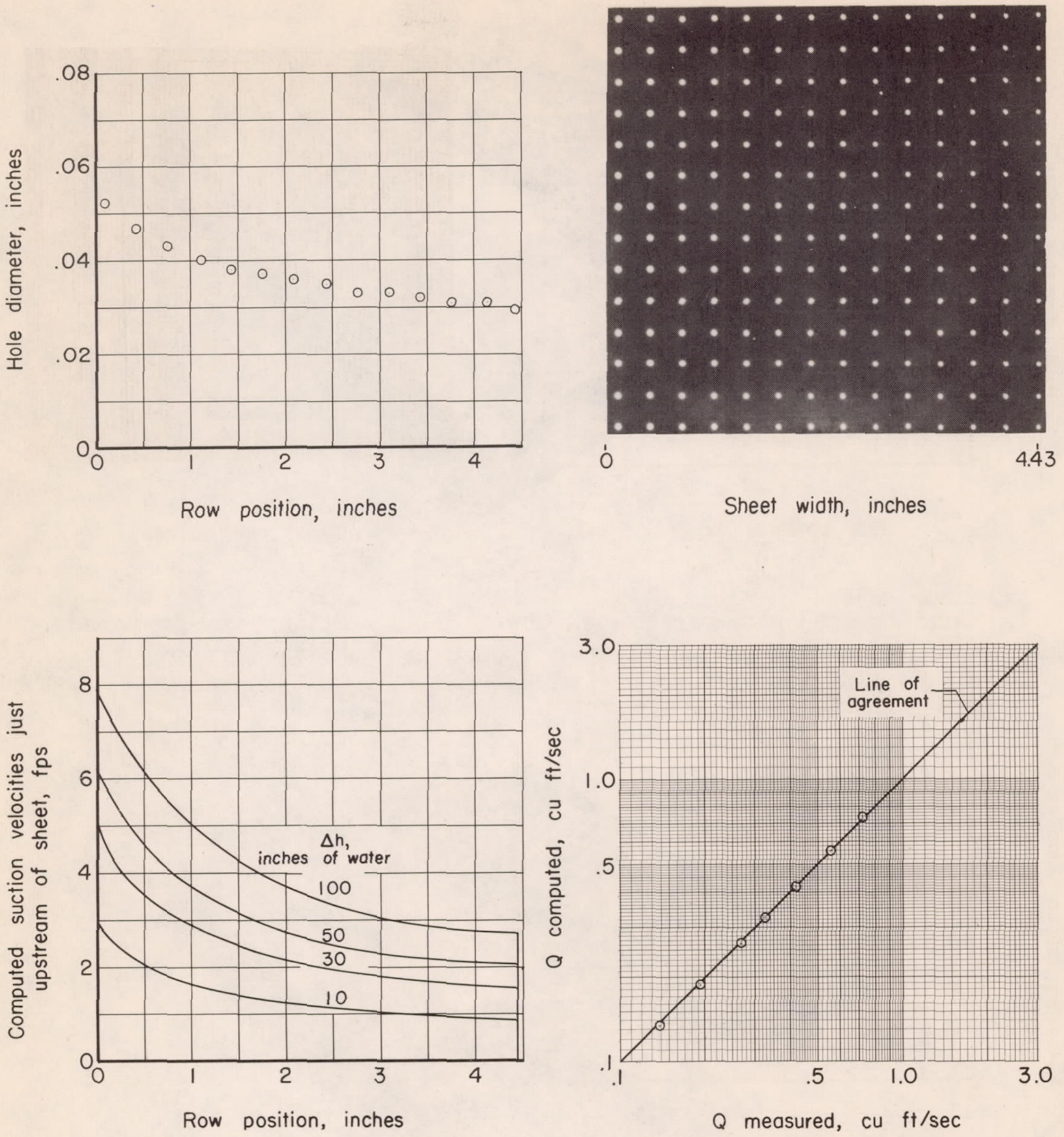
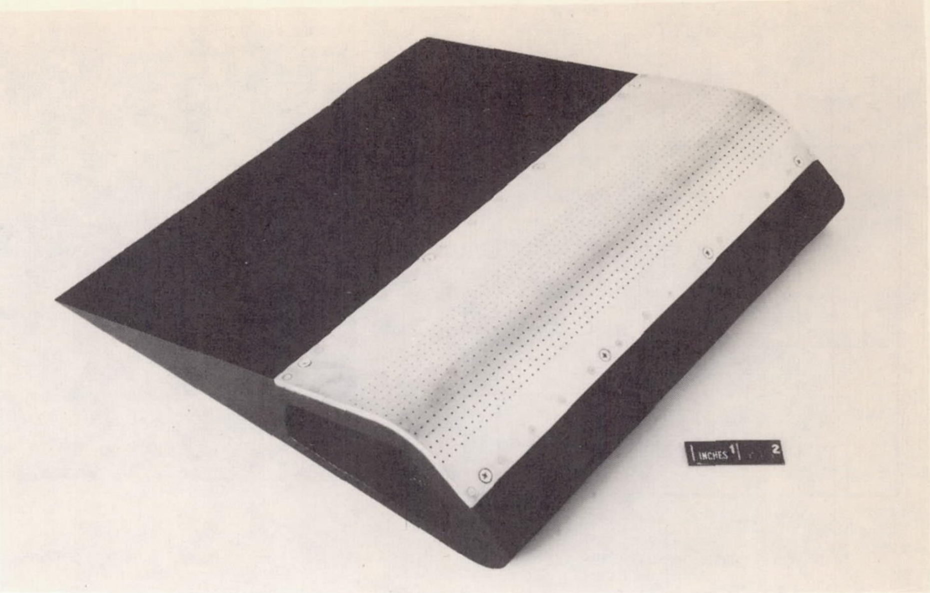
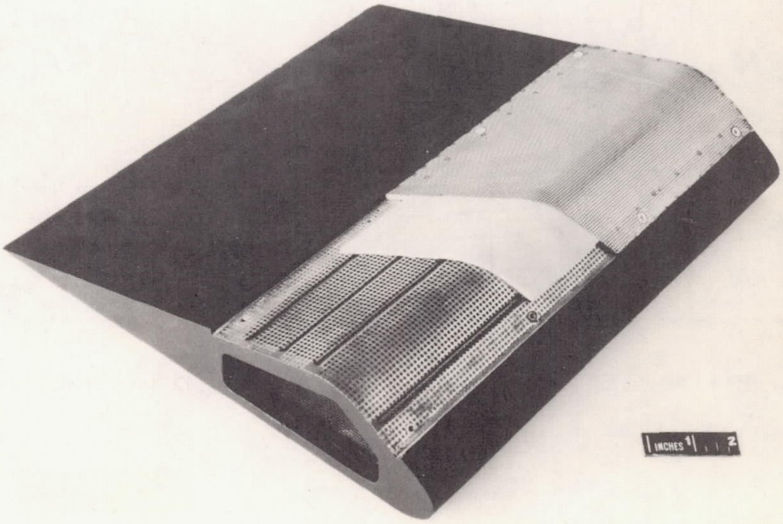


Figure 9.- Drilled brass sheet with tapered (multistepped) arrangement of permeability; open-area variation from 1.91 percent to 0.68 percent; 9 holes per square inch; thickness = 0.016 inch.



A-21080

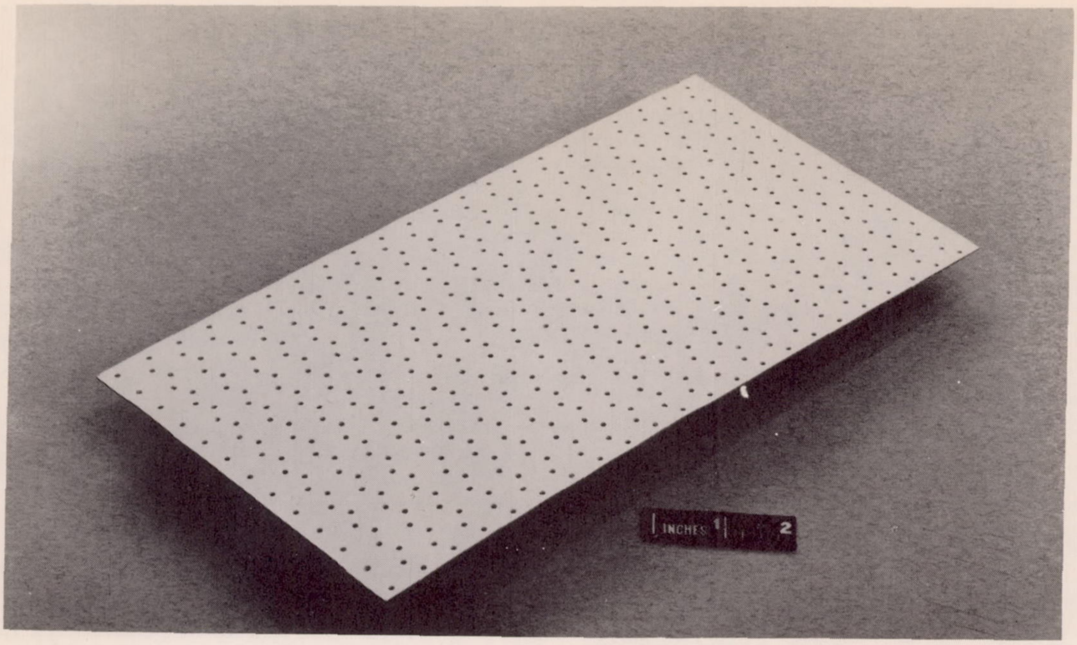
(a) Nonuniformly punch-perforated sheet incorporating its own gradient arrangement of permeability. Open area decreases from 3.7 percent at the leading edge to 2.0 percent at the trailing edge.



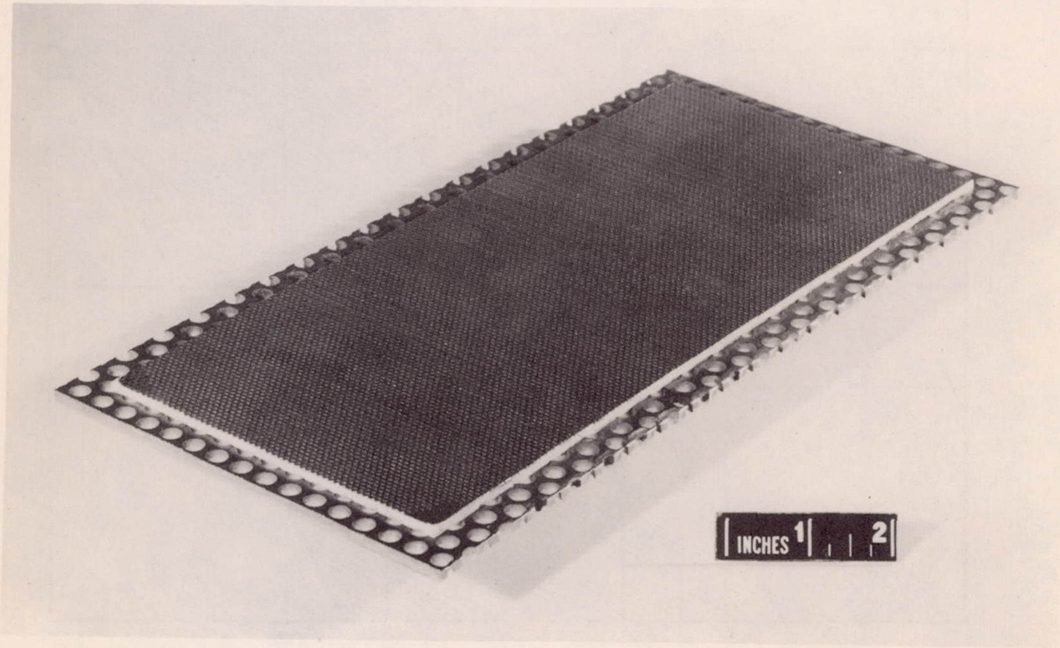
A-21081

(b) Composite assembly of punch-perforated sheets enclosing a fibrous-glass compact. Compact provides for gradient permeability. Open area of surface sheet equals 37 percent.

Figure 10.- Illustrative form of installations for a porous region on a flap application. Both installations have the same distribution of gradient permeability.



(a) Single sheet incorporating its own permeability. Open area equals 5.4 percent.



(b) High-strength assembly with sheets bonded to fibrous-glass compact. Compact provides for permeability. Open area of surface sheet equals 27 percent.

Figure 11.- Illustrated forms of punch-perforated sheets used as a porous surface. Both installations have equal and uniform permeability.

░ Range of permeability for:

1. Perforated sheet and woven wire cloth materials with an open area of less than about 7 percent.
2. Perforated sheet and woven wire cloth materials with an open area of about 11 percent or greater and in composite assembly with a second, more dense, underlying material (ref. 11).
3. Filter papers (ref. 12).
4. Felt cloths (ref. 12).
5. Granular and sintered metals (ref. 12).
6. Fibrous-glass compacts (ref. 8).

▨ Range of permeability for:

1. Perforated sheet and woven wire cloth materials with an open area ratio of about 11 percent or greater.

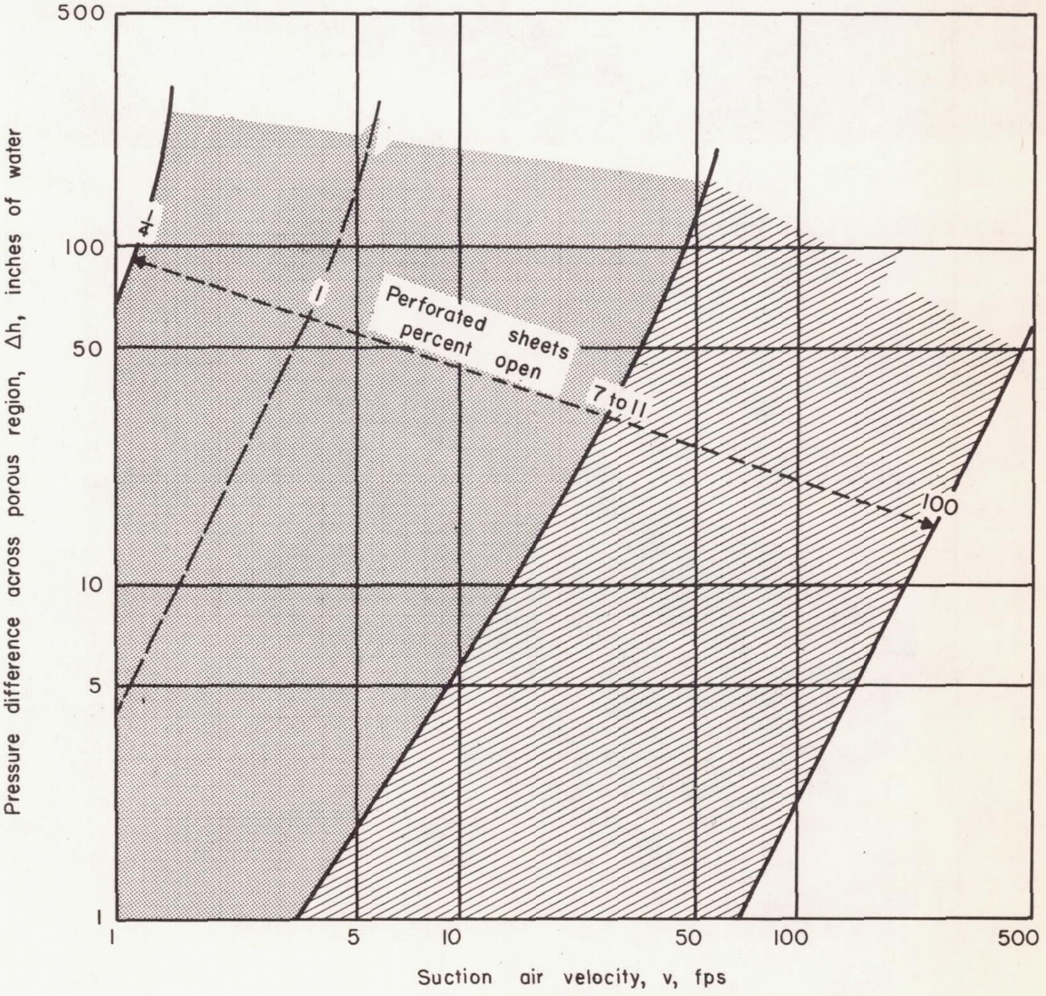


Figure 12.- The range and the limits of permeability obtainable with different kinds of porous materials for normal flow, $H = 2116$ lb/sq ft; $t = 70^\circ$ F.

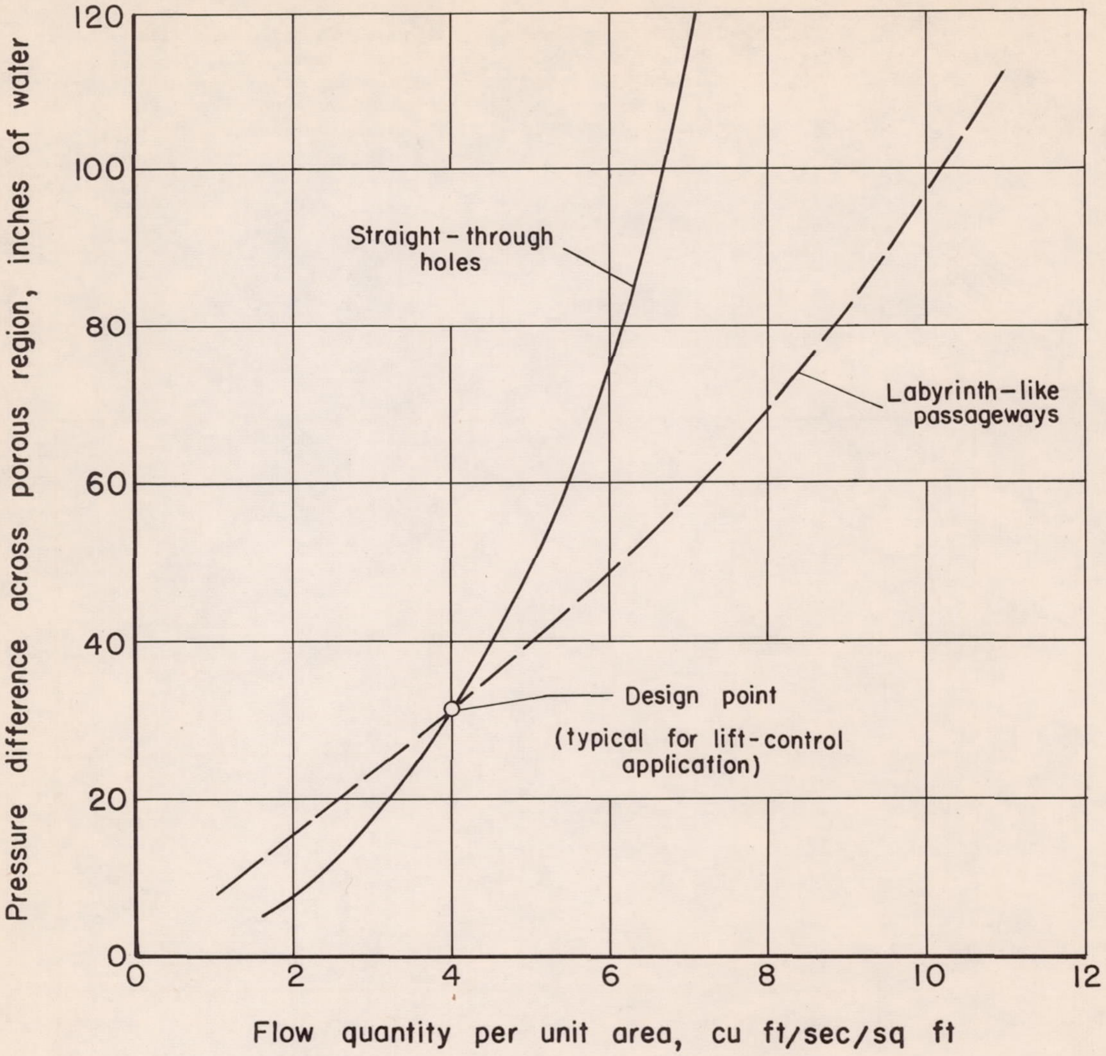


Figure 13.- Variation of suction flow quantity with pressure difference across a porous region with either straight-through holes or labyrinth-like passageways.