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Final Report

OPTICAL TECHNIQUES FOR STUDY OF BLOWERS

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ABSTRACT

The possibility of applying aerodynamic optical techniques to the study of blower and spout operation became of interest in early 1954. The facilities and experienced personnel at the Aircraft Propulsion Laboratory of the University of Michigan made it possible to run preliminary tests there, and this report covers such tests.

The primary purpose of this series of tests was the gathering of information and experience on the applicability of optical techniques to blower investigations. A secondary purpose was possible comparison of gas flows through blowers of different design.

Optical techniques, both shadow and schlieren spark photography, are informative and could be designed for study of blowers in actual service on wood-forming, either on research or factory machines. Systematic studies with optical techniques would assist in understanding gas flows, turbulence, and energy exchange during the wool-forming process.

Increasing primary air flow through the blowers increases induced air flow sufficiently to deflect the primary air jets and prevent direct impingement. Some other observations are given in the detailed comments on the negatives, although many of them cannot be explained with present knowledge of the flows.

OPTICAL TECHNIQUES FOR STUDY OF BLOWERS

EXPERIMENTAL WORK

Shadowgraph, schlieren and interferometric techniques are commonly used for examing density gradients in gas flow. The simplest system optically is the shadow system, in which light from the source passes through the region to be studied and falls on a photographic plate. A density gradient in the test region deflects the light rays passing through the test region, the amount of deflection being directly proportional to the magnitude of the density gradient. If a uniform density gradient exists throughout the region studied, there will be uniform illumination of the photographic plate. If the density gradient is not uniform, however, there will be a change in illumination on the photographic plate, this change being proportional to the derivative of the amount of deflection, or proportional to the second derivative of the density.

In the schlieren technique, the change in illumination of a photographic plate is directly proportional to the density gradient, or to the first derivative of the density in a direction perpendicular to the schlieren knife edge. A diagram of the "balanced" mirror system employed in these tests is shown in Fig. 1. Light from the source is reflected from the first parabolic mirror so that parallel light passes through the region to be studied, is focused by a second parabolic mirror, and illuminates a photographic plate. A knife edge, located at the focal point of the second parabolic mirror, intercepts those light rays which are deviated by density changes in the region to be studied. This interception is responsible for the change in illumination at the photographic plate. The sensitivity of the schlieren system is inversely proportional to the size of the light source in the direction perpendicular to the knife edge, directly proportional to the amount of light cut off at the knife edge, and directly proportional to the focal length of the second parabolic mirror.

An interferometer requires a more complex and delicate optical system, but provides directly a measure of density. The initial parallel light beam is split into two beams, one of which passes through the region under

study, the other serving as a reference. The two beams are then recombined and interference fringes show the density in the test region. A knowledge of gas compositions and pressure distribution permits determination of temperature distribution. The University of Michigan interferometer is of the Mach-Zehnder type with 8-inch mirrors. Such an instrument appears at the moment to be impractical for blower studies and no tests were made with it.

Blowers were installed in the schlieren system (Fig. 1) at the location marked "nozzle." Photographs were made while light passed through the space between the opposing rows of slots and parallel to the rows, and while light passed perpendicular to the rows and to the central plane of gas flow. With the light parallel to the slot rows the interaction of the primary jets could be seen, but the primary jets themselves could not be distinguished. Light perpendicular to the slot rows clearly showed each pair of opposing primary jets, but the body of the blower blocked off the zone of interaction. All schlieren photographs after negative 3 were made with the knife edge horizontal at about 50 percent cutoff. Shadowgraphs were made by removing the knife edge from the schlieren system. All photographs are by the "open-flash-shut" method. The room is darkened, the film uncovered, the one-microsecond light flashed, and the film covered.

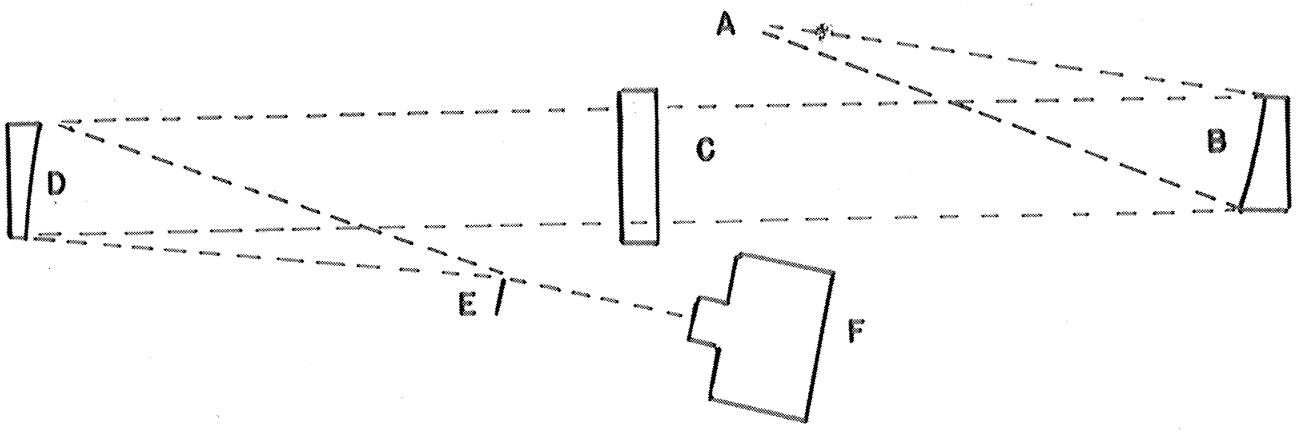
Most of the work was performed on four factory-type blowers; the 119-, 94-, 59-, and 49X-slot. These were photographed in both positions at three primary air pressures: 50, 100, and 200 psi. Both shadow and schlieren photographs were made in most of these combinations. A 59-slot blower with an 8-degree skirt and a 5-slot experimental blower were briefly tested. Two 94-slot blowers with 3/32-inch radius curvature on the top and with 5/32-inch radius were compared.

RESULTS

Ninety photographs were made on July 20 and 21, 1954. Ten failed to produce good negatives and one was spoiled in developing. In most cases duplicates were made at each set of conditions. All good negatives are appended to copy number 1 of this report. The complete data sheet and detailed comments on all negatives are in the Appendix.

DISCUSSION

Figures 2 and 3 (negatives 1 and 2, respectively) show the effect of orientation of the knife edge in schlieren photographs. The density



A- SPARK-GAP LIGHT SOURCE
B- FIRST PARABOLIC MIRROR
C- NOZZLE
D- SECOND PARABOLIC MIRROR
E- KNIFE EDGE
F- CAMERA

Fig. 1. Parabolic Mirror Schlieren System

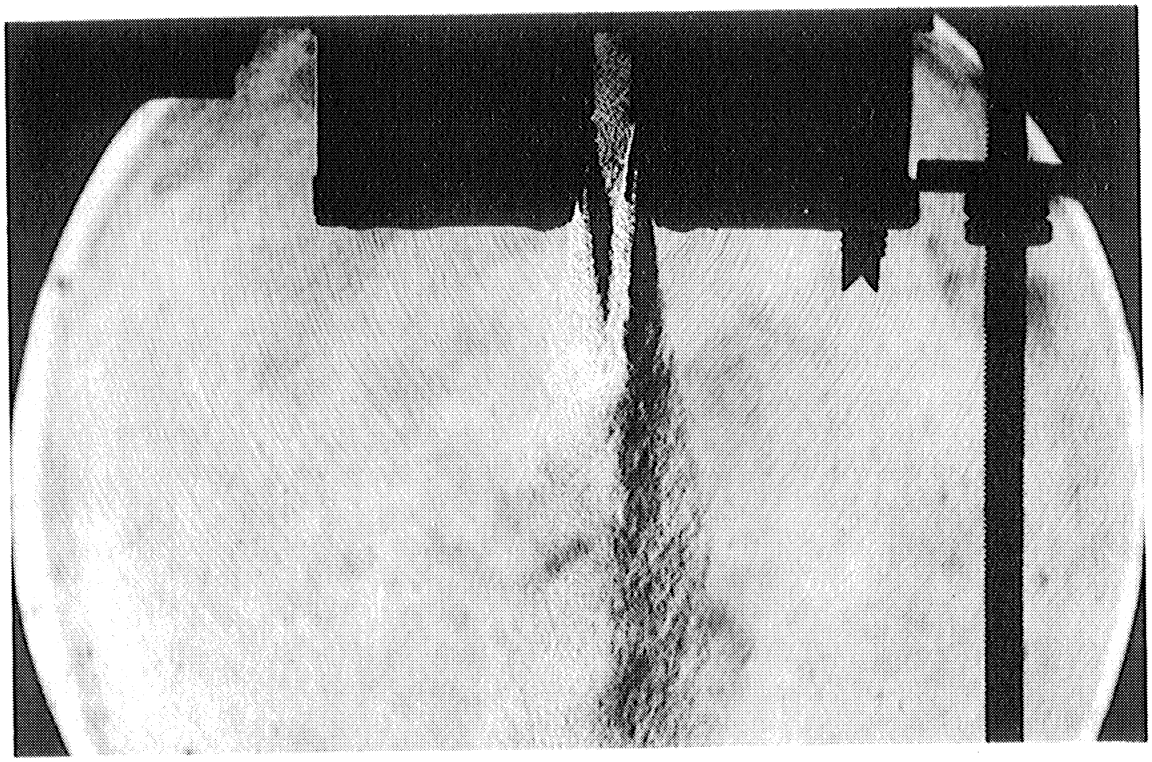


Fig. 2. 119-Slot Blower, 100 psi, Knife Edge Vertical (Negative 1)

gradients appear only perpendicular to the knife edge — vertical in negative 1 and horizontal in negative 2. The background atmosphere is relatively uniform except for dust flecks and the concentric rings which are slight pressure fluctuations corresponding to sound waves originating at the blower discharge. Negative 1 shows the angle of expansion of the primary jets and the apparently complete mixing of opposing primary jets within a short distance below the blower. Negative 2 shows the same angle of expansion, and more clearly shows the primary jets before they appear to lose identity. A sharply defined jet boundary persists almost to the bottom of the blower, although pressure gradients have begun to spread to the surrounding air. Both pictures are of a 119-slot blower at a primary air pressure of 100 psi.

Figure 4 (negative 7) shows the same blower at a primary air pressure of 200 psi. The doubled air flow is inducing more air from the top of the blower down through the space between the slot rows, but the velocity through the slots is not changing. The result is greater deflection of the primary air jets — so much that they do not impinge directly but become essentially parallel before disintegrating. The overall angle of expansion remains the same, however.

Figure 5 (negative 11) is a shadowgraph at the same conditions as Figs. 2 and 3. Much more detail is visible in the primary air jets, but the expansion portion is difficult to see.

Figures 6 and 7 (negatives 27 and 28) are schlieren photographs of a 49X-slot blower at 100 and 200 psi. Turbulence is greater than for the 119-slot blower at the same pressures, and the primary air jets disintegrate more quickly. At 200 psi the initial jets from the 49X appear broken and irregular, which is probably the result of delivery of air by the center slots down along the skirt (similar to the deflection at 200 psi in the 119-slot blower) and by the end slots toward the center. The overall angle of expansion is approximately the same for both blowers.

Figure 8 (negative 39) is a shadowgraph of a 59-slot blower at 100 psi. Comparison with Fig. 5 (negative 11) shows sharp impingement and very little deflection of the primary jets in the 59. Apparently, less air is induced through the top of the blower.

Figures 9 and 10 (negatives 51 and 52) are schlieren photographs of a 94-slot blower at 100 psi and 200 psi respectively. Comparison with Figs. 3 and 4 (negatives 2 and 7) shows much the same flow relation. The 119-slot blower gives less of an angle of impingement, but at 200 psi neither blower shows significant direct impingement of the jets.

Figure 11 (negative 57) is a schlieren photograph perpendicular to the slot rows of a 94-slot blower at 100 psi. The identity of the individual jets is sharply defined for some distance below the bottom of the blower. The angle of expansion at the end is about 6 degrees.

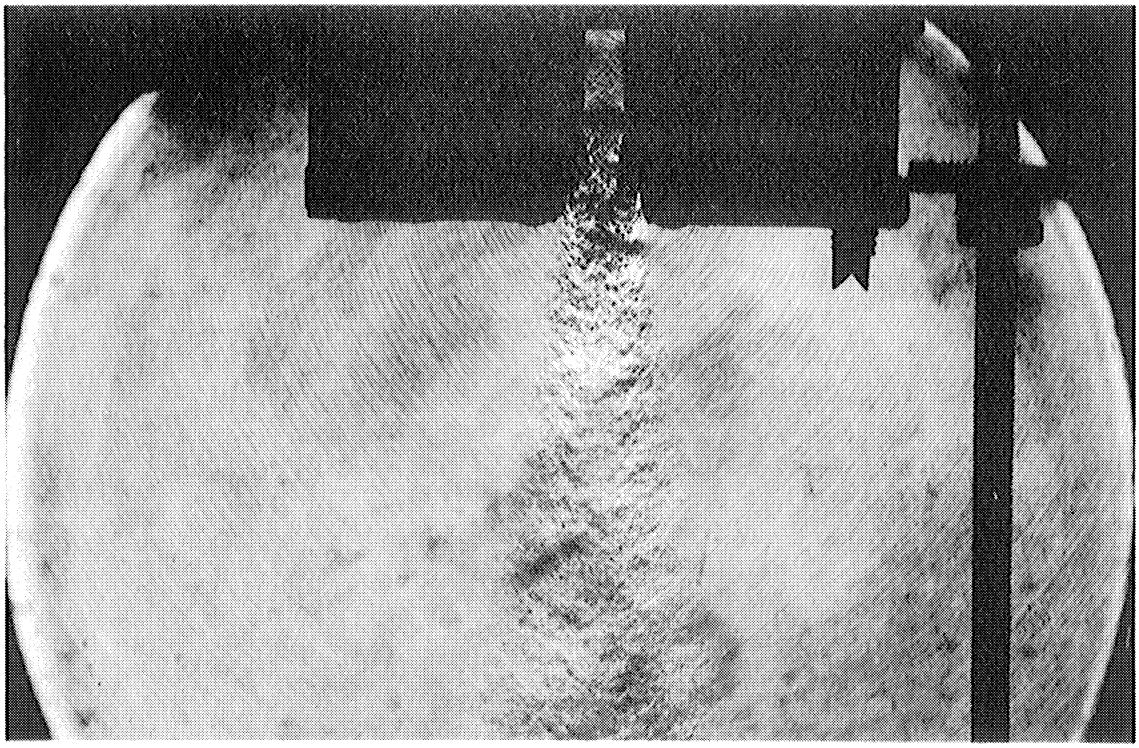


Fig. 3. 119-Slot Blower, 100 psi, Knife Edge Horizontal (Negative 2)

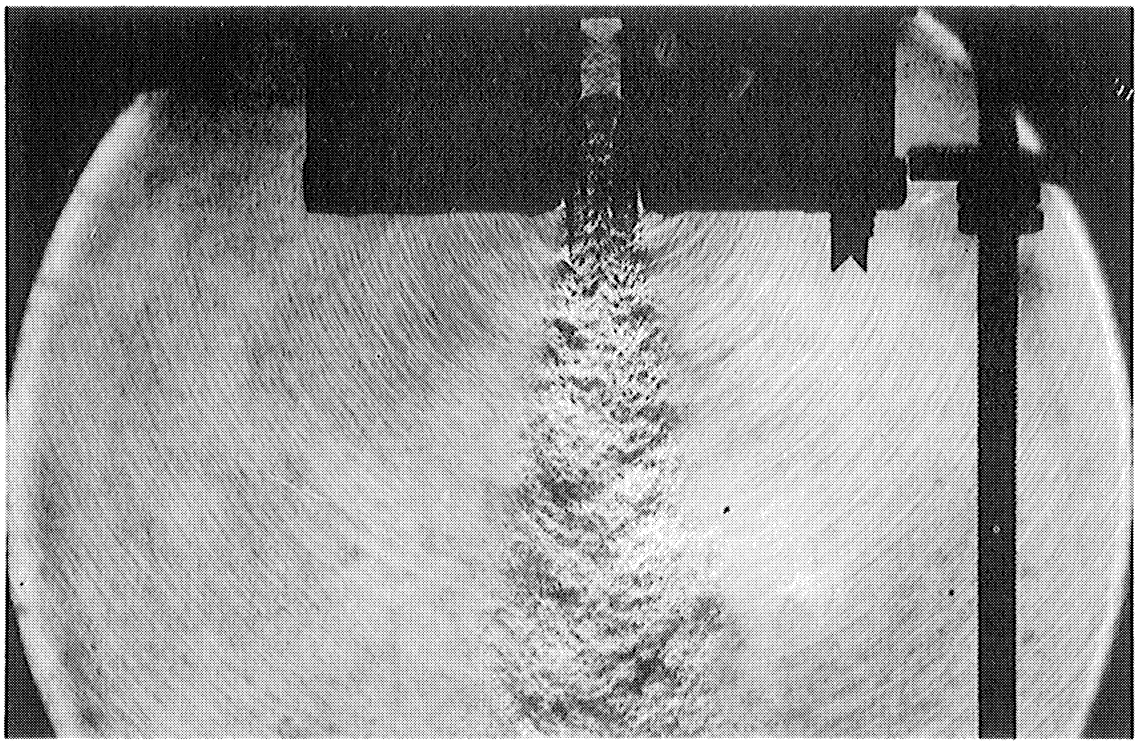


Fig. 4. 119-Slot Blower, 200 psi, Schlieren (Negative 7)

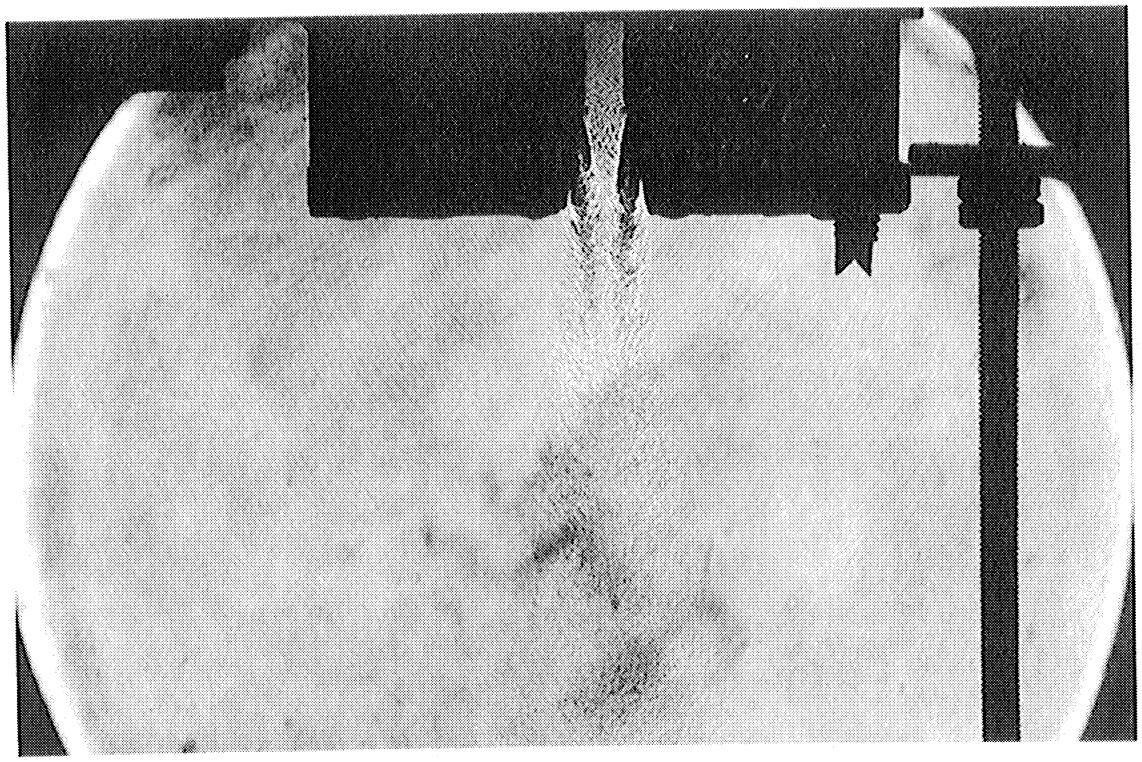


Fig. 5. 119-Slot Blower, 100 psi, Shadow (Negative 11)

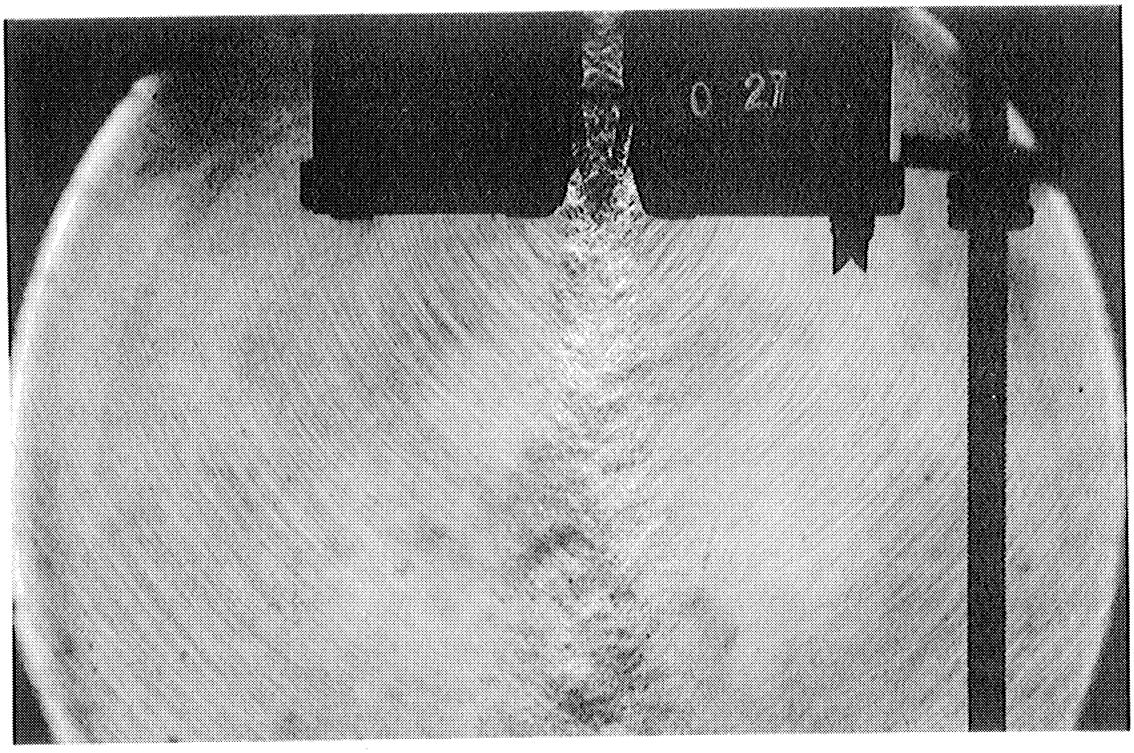


Fig. 6. 49X-Slot Blower, 100 psi, Schlieren (Negative 27)

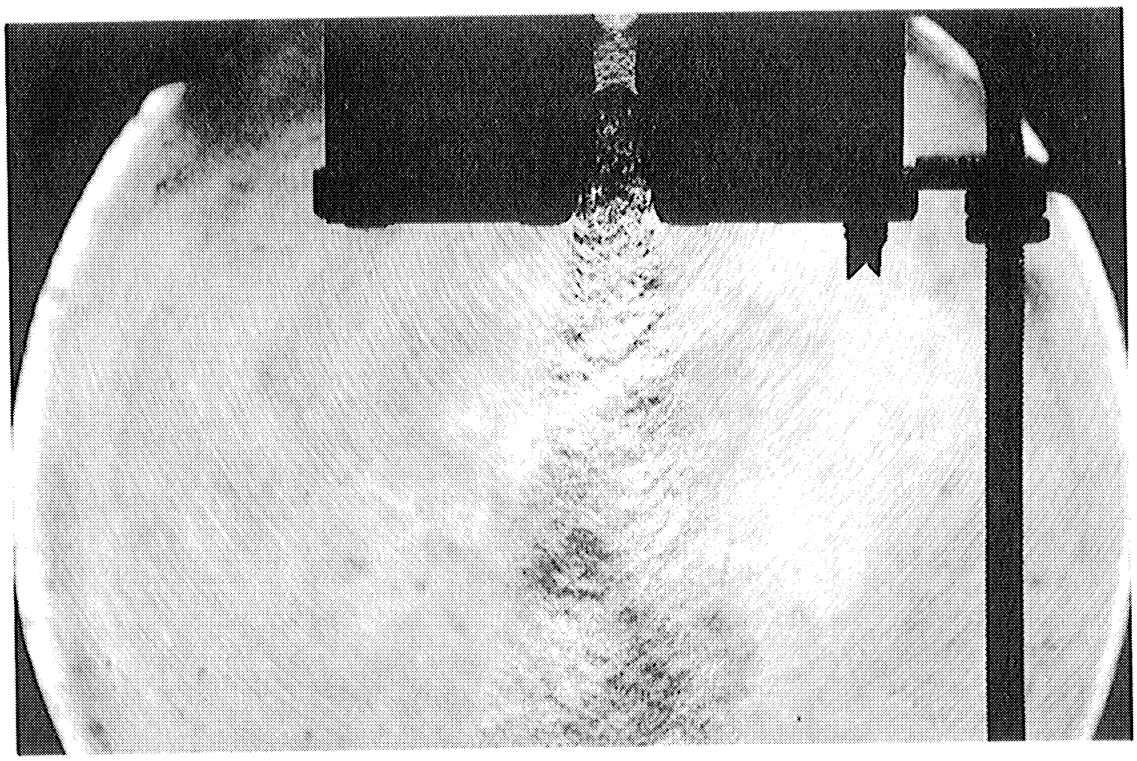


Fig. 7. 49X-Slot Blower, 200 psi, Schlieren (Negative 28)

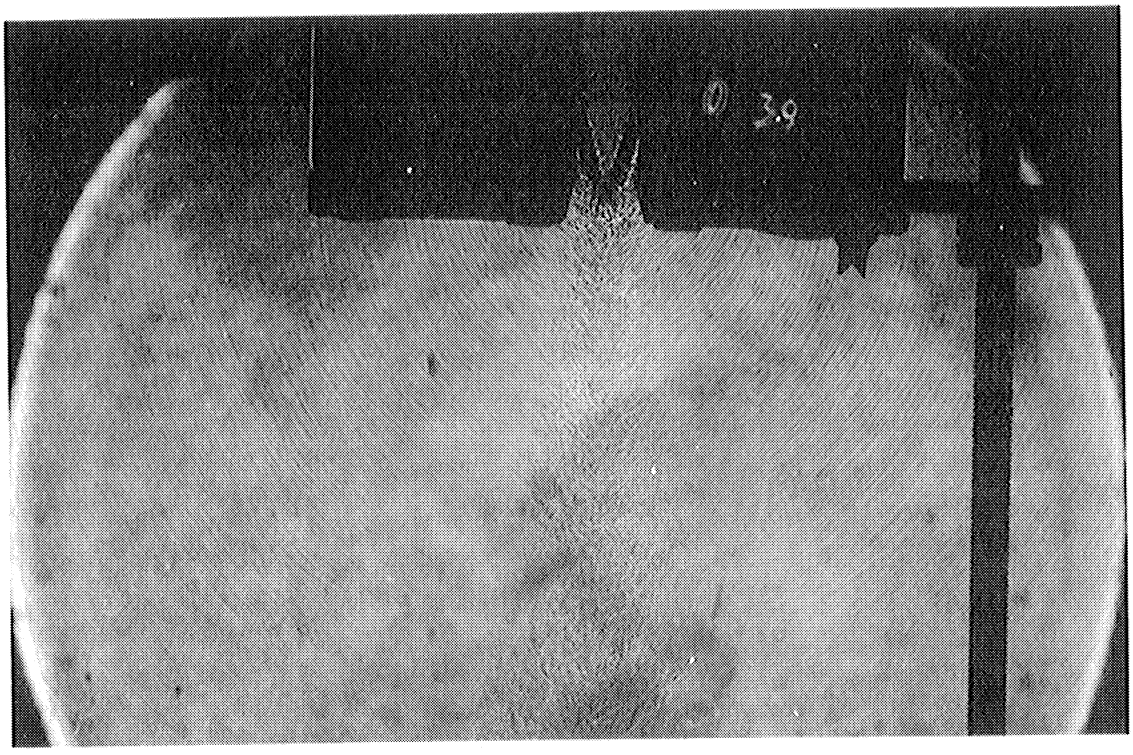


Fig. 8. 59-Slot Blower, 100 psi, Shadow (Negative 39)

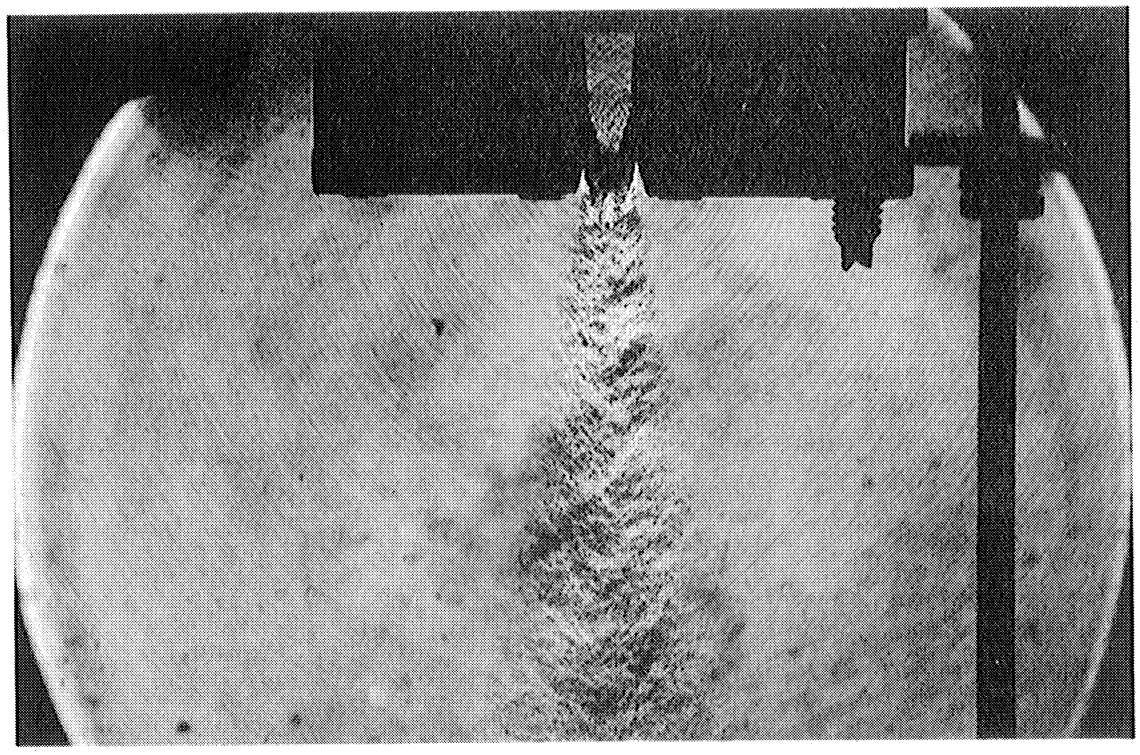


Fig. 9. 94-Slot Blower, 100 psi, Schlieren (Negative 51)

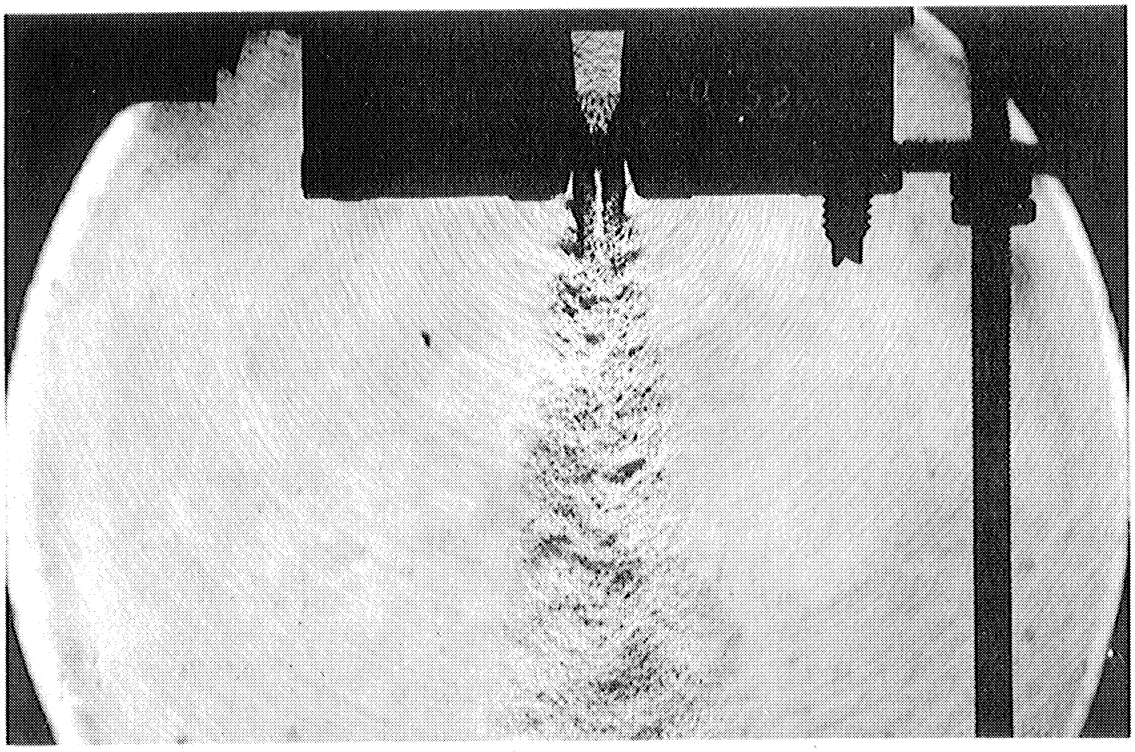


Fig. 10. 94-Slot Blower, 200 psi, Schlieren (Negative 52)

Figure 12 (negative 67) is a schlieren photograph perpendicular to the slot rows of a 49X-slot blower at 100 psi. This blower is designed to deliver the air jets at an angle in this view, but the angle is not apparent although the jets can be identified. Except at the ends of the slot rows, the jets are moving straight down.

All blowers show about the same overall angle of expansion from observation along the slot rows, but views perpendicular to the slot rows show variations from contraction to about 10-degree expansion. The variation is not consistent enough for explanation from these photographs.

All views along the slot rows show a definite change in flow characteristics of the induced air at the change in cross section where the slots discharge. Apparently, a sudden acceleration of the induced air and a corresponding decrease in pressure occur.

In examining all the photographs made by these techniques, the lack of focusing must be kept in mind. Everything in the parallel portion of the light beam is in focus and no depth is apparent.

ACKNOWLEDGEMENT

The assistance of Robert E. Cullen and James A. Nicholls in adapting the schlieren system for this study is appreciated.

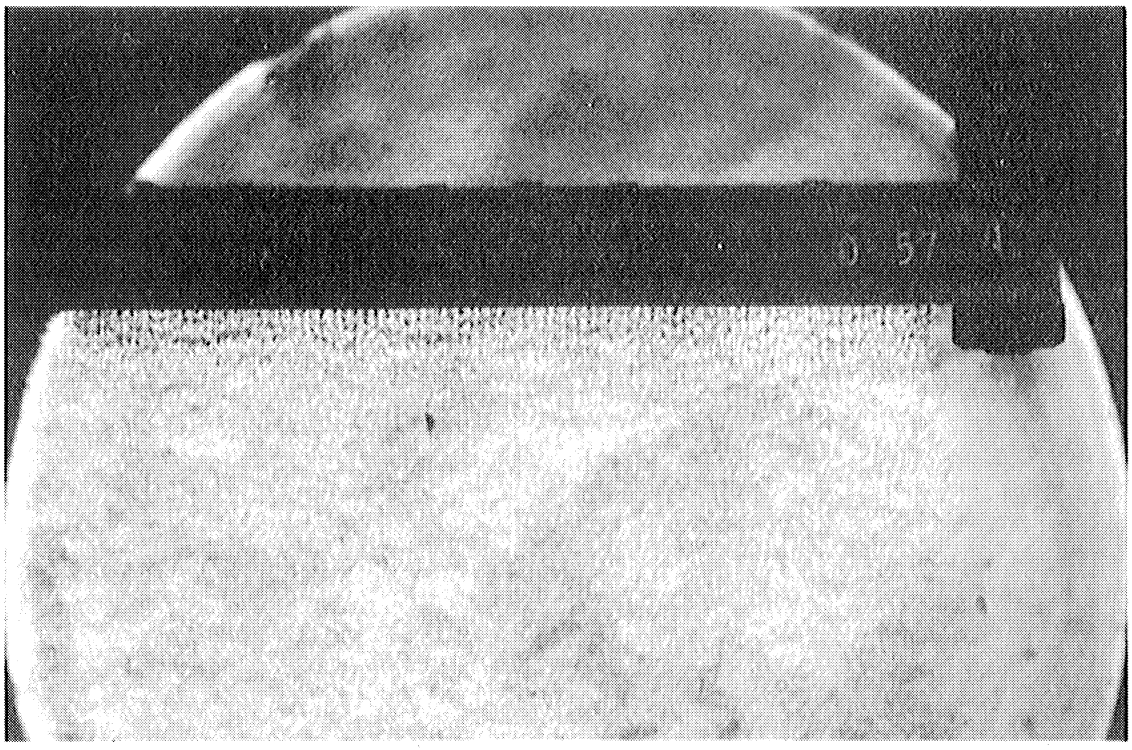


Fig. 11. 94-Slot Blower, 100 psi, Schlieren Perpendicular (Negative 57)

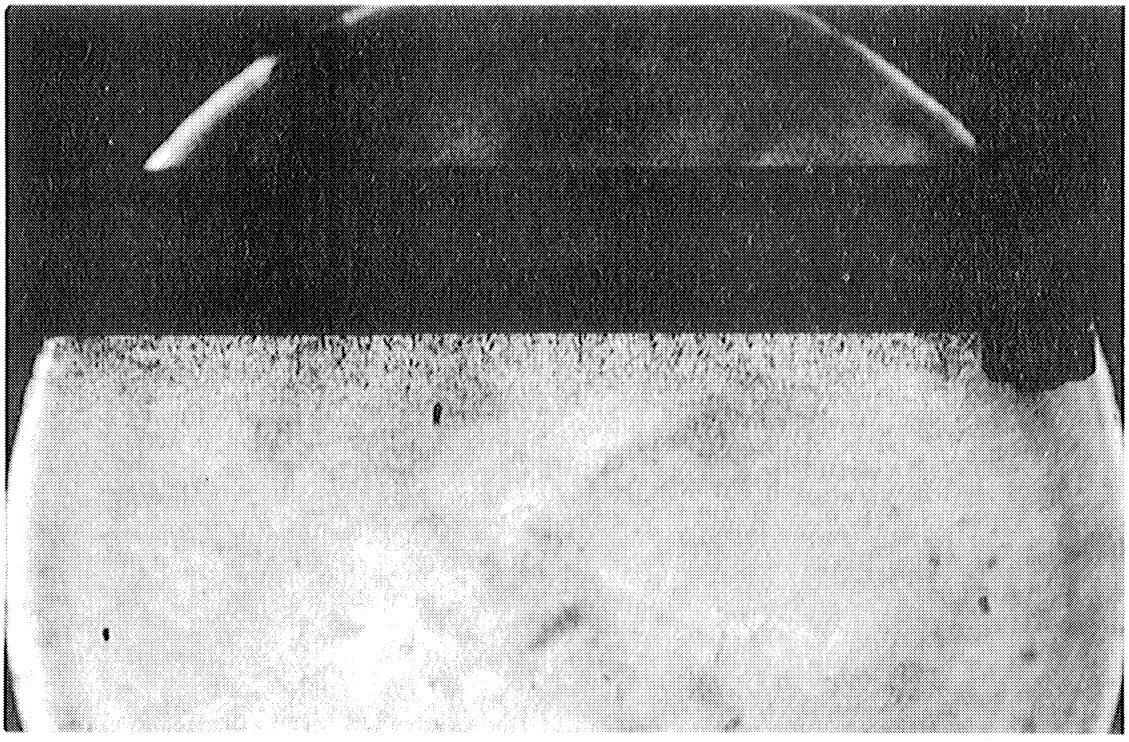


Fig. 12. 49X-Slot Blower, 100 psi, Schlieren Perpendicular (Negative 67)

APPENDIX

DATA SHEET

(see page 13 for explanation of terms)

Negative	Blower	Position	Air Pressure	Photo.	Remarks
1	119	Parallel	100	Schl	Knife-edge vertical, 50% cut-off
2	(4847-4046)	Parallel	100	Schl	Knife-edge horizontal, 50% cut-off
3	(4847-4046)	Parallel	100	Schl	Knife-edge horizontal, 75% cut-off
4	(4847-4046)	Parallel	100	Schl	Plate added on top of blower to simulate bushing. No apparent effect, but plate left on.
5	(4847-4046)	Parallel	100	Schl	
6	(4847-4046)	Parallel	100	Schl	
7	(4847-4046)	Parallel	200	Schl	Higher pressure shows jets longer but deflected more. Same angle of expansion.
8	(4847-4046)	Parallel	200	Schl	
9	(4847-4046)	Parallel	200	Schl	
10	(4847-4046)	Parallel	100	Shad	
11	(4847-4046)	Parallel	100	Shad	Better definition of jets, less definition of expansion zone.
12	(4847-4046)	Parallel	200	Shad	
13	(4847-4046)	Parallel	200	Shad	
14	(4847-4046)	Parallel	50	Shad	
15	(4847-4046)	Parallel	50	Shad	50 psi gives lower turbulence, more direct impingement of jets (15 spoiled in developing).
16	(4847-4046)	Parallel	50	Schl	
17	(4847-4046)	Parallel	50	Schl	

Negative	Blower	Position	Air Pressure	Photo.	Remarks
18	49X	Parallel	50	Shad	
19	(7915)	Parallel	50	Shad	Much turbulence. Primary jet
20	(7915)	Parallel	100	Shad	appears irregular at 200 psi.
21	(7915)	Parallel	100	Shad	Jets disintegrate sooner than
22	(7915)	Parallel	200	Shad	in 119, mixing is complete
23	(7915)	Parallel	200	Shad	sooner.
24	(7915)	Parallel	0	Shad	
25	(7915)	Parallel	50	Schl	
26	(7915)	Parallel	50	Schl	
27	(7915)	Parallel	100	Schl	Angle of expansion about 20°.
28	(7915)	Parallel	200	Schl	
29	(7915)	Parallel	200	Schl	
30	59	Parallel	50	Schl	
31	(N8737)	Parallel	50	Schl	
32	(N8737)	Parallel	100	Schl	
33	(N8737)	Parallel	100	Schl	Underexposed.
34	(N8737)	Parallel	200	Schl	
35	(N8737)	Parallel	200	Schl	
36	(N8737)	Parallel	50	Shad	
37	(N8737)	Parallel	50	Shad	Sharp impingement of jets, much
38	(N8737)	Parallel	100	Shad	turbulence at 200 psi. Angle
39	(N8737)	Parallel	100	Shad	of expansion about 24°.
40	(N8737)	Parallel	200	Shad	
41	(N8737)	Parallel	200	Shad	
42	94	Parallel	50	Shad	
43	(N6299)	Parallel	50	Shad	Sharp impingement of jets, ex-
44	(N6299)	Parallel	100	Shad	cept at 200 psi, where jets de-
45	(N6299)	Parallel	100	Shad	flect and are parallel for long
46	(N6299)	Parallel	200	Shad	distance.
47	(N6299)	Parallel	200	Shad	
48	(N6299)	Parallel	50	Schl	
49	(N6299)	Parallel	50	Schl	
50	(N6299)	Parallel	100	Schl	Angle of expansion about 24°.
51	(N6299)	Parallel	100	Schl	
52	(N6299)	Parallel	200	Schl	
53	(N6299)	Parallel	200	Schl	
54	(N6299)	Perp.	50	Schl	
55	(N6299)	Perp.	50	Schl	
56	(N6299)	Perp.	100	Schl	Slight identity of jets at 50
57	(N6299)	Perp.	100	Schl	psi, sharp identity at 100 and
58	(N6299)	Perp.	200	Schl	200. End expansion about 6°.
59	(N6299)	Perp.	200	Schl	

Negative	Blower	Position	Air Pressure	Photo.	Remarks
60	(N6299)	Perp.	50	Shad	
61	(N6299)	Perp.	50	Shad	
62	(N6299)	Perp.	100	Shad	
63	(N6299)	Perp.	100	Shad	
64	(N6299)	Perp.	200	Shad	
65	(N6299)	Perp.	200	Shad	
66	49X	Perp.	100	Schl	Sharp identity of jets at 100
67	(N7915)	Perp.	100	Schl	psi but not at 200 psi. Ends
68	(N7915)	Perp.	200	Schl	show angle, but center jets
69	(N7915)	Perp.	200	Schl	move straight down.
70	59	Perp.	100	Schl	
71	(N8737)	Perp.	100	Schl	
72	(N8737)	Perp.	200	Schl	Negatives useless; see 74-77.
73	(N8737)	Perp.	200	Schl	
74	(N8737)	Perp.	100	Schl	Sharp identity of jets. 5°
75	(N8737)	Perp.	100	Schl	contraction at end at 100 psi,
76	(N8737)	Perp.	200	Schl	0° at 200 psi.
77	(N8737)	Perp.	200	Schl	
78	119	Perp.	100	Schl	
79	(N4847)	Perp.	100	Schl	Slight identity of jets. Slight
80	(N4847)	Perp.	200	Schl	contraction at end.
81	(N4847)	Perp.	200	Schl	
82	59	Perp.	100	Schl	Slight identity of jets. 10°
83	(8°skirt)	Perp.	200	Schl	expansion at end.
84	5	Perp.	100	Schl	Sharp identity of jets.
85	5	Perp.	200	Schl	Turbulence between jets.
86	5	Perp.	200	Schl	
87			Not Taken		
88	94(5445)	Parallel	200	Schl	No apparent change.
89	3/32 rad.	Parallel	200	Schl	
90	94(5307)	Parallel	200	Schl	No apparent change.
91	5/32 rad.	Parallel	200	Schl	

NOTE:

Blowers are indicated by slots, with serial number given at first usage.

Positions are parallel—light beam parallel to slot rows—and perpendicular (perp)—light beam perpendicular to slot rows.

Air pressures are indicated as pounds per square inch gauge.

"Photo." indicates the type of photography employed—shadow (shad) or schlieren (schl).