ready to put more of these castings in service, and with the present predominance of lightweight bolsters, it would appear very desirable to equip perhaps a limited number of cars with more of the lightweight side frames.

This development of lightweight steel castings for freight cars is not confined to side frames and bolsters. It may be of interest to add here that quite a number of cars are also equipped with lightweight couplers, draft yokes, striking castings, and body-bolster center braces.

Tables 2, 3, and 4 of this discussion giving results of tests of 50-ton, 70-ton, and 90-ton alloy-cast-steel truck bolsters are presented to supplement the results tabulated by the author. Figs. 1, 2, and 3 of this discussion show a 50-ton, 70-ton, and 90-ton alloy-cast-steel bolster, respectively, after testing.

F. G. Lister.[3] The interesting and timely data furnished in this paper is worthy of careful consideration. The freight-car truck has been the subject of a great deal of thought for a good many years, and more so in the last few years since the railroads have speeded up their trains, requiring more attention to the bolsters, truck frames, and brake rigging than ever before. The service is more severe. Heavier and more frequent braking has thrown more strain on the bolsters and side frames.

The truck frame, in its evolution from the old arch bar to the present U-section cast-steel frame, has undergone many changes, and not until the dynamic-testing machines were developed by the manufacturers of steel frames and research work commenced in connection with the design of the frames was it possible to distribute the metal through the structure to uniformly control the stresses encountered in actual road service. However, this meant a cast-steel side frame of heavy sections, making the extra weight undesirable. Because of this fact consideration has been given to the use of alloy steels.

It is admitted that a worth-while saving in weight at no sacrifice of strength can be made by use of alloy steels in both truck side frames and bolsters. Alloy steels of high strength and dependability have been available for many years, but these have been too expensive to justify their use in freight-car construction. The problem resolves itself into the selection of an alloy steel which has high strength, ductility, and good casting properties and which at the same time is reasonable in cost. Fortunately, the last two years have seen the development of a number of new alloy steels which meet these requirements with a considerable degree of success. In these steels, high physical properties are obtained through use of the cheaper alloying elements such as silicon, copper, and manganese, with or without the addition of small amounts of chromium or nickel. When the experimental work now under way has been completed, several of these now low-priced alloy steels should find a useful place in car castings for the reduction of dead weight, and this should be especially true for truck bolsters and truck side frames.

Author's Closure

Mr. Stertzbach may be correct in believing that the reappearance of the separate journal box is to be expected only in special cases, but the steady increase in operating speeds of freight equipment has forced more careful consideration of the efficiency of journal-box lids and dust guards. The day has passed when it can be reasonably held that a dustproof lid joint may be made between a pressed-steel lid and a rough cast box face or that oil can be retained and water kept out by means of a simple basswood dust guard floating in a cored dust well. It avails little if an improved dust guard makes a water- and oil-tight seal around the axle, if there is no equally tight seal between the guard itself and a machined surface at the rear end of the box. The machining of the front and back ends of a separate journal box should be less expensive than the corresponding machining of boxes cast integral with a side frame, and this is the basis for the author's original statement. With separate boxes there would be the further advantage of angular flexibility in a horizontal plane between journal box and frame, thereby avoiding damaging contacts between journal bearings and the inside of the box.

As to the spring mounting of side frames, Mr. Stertzbach evidently had in mind provision for full spring travel over the boxes, and the elimination of the spring-mounted bolster as was done in the "Verona" truck. The author was not considering the elimination of the bolster springs, but their retention of present travel with the addition of short-travel springs over the boxes in order that the frames themselves would be protected against fatigue and the individual wheels made more responsive to track irregularities as a very definite protection against derailments in high-speed service.

The author is in agreement with Mr. Stertzbach that the requirement of a fatigue test for each order of side frames would be unworkable, but the present tentative requirements of the A.A.R. for nonstandard lightweight frames provide for a fatigue or dynamic initial test on four frames and a similar test after the production of the first one thousand frames. The specification later states: "As soon as a sufficient background of dynamic- and static-test experience has been gained with lightweight side frames of various designs and materials to warrant future acceptance on the basis of static tests only, ... no further dynamic tests will be required, except in the case of frames of substantially different design or material which have not previously passed a dynamic test."

Table 1 of Mr. Stertzbach's discussion specifically refers to alloy frames and bolsters applied to domestic service in 1936. In addition, the Gould Coupler Corporation furnished lightweight alloy frames and bolsters for four hundred Brazilian cars.

Square-Edged Inlet and Discharge Orifices for Measuring Air Volumes in the Testing of Fans and Blowers[1]

R. E. Sprenkle.[2] In his recommendations to the Power Test Committee No. 10 on Centrifugal and Turbo-Compressors and Blowers of the A.S.M.E. of the use of thin-plate orifices for testing fans and blowers in place of the more expensive flow nozzle or the more elaborate procedure of making pitot-tube traverses, as was originally intended, the author has performed a valuable service to industry. Not only has he verified the splendid work initiated by Ebaugh and Whitfield,[3] but he has extended this work to cover the discharge orifice as well. As a result of this work,[1] the author has found the orifice to be just as accurate as the flow nozzle, and that a test can be made much faster than when using a pitot tube. Therefore, there is no justification for the use of any other device than the orifice, especially when it is apparent that the cost of a thin-plate orifice for ducts as large as are required for fan testing is but a fraction of that for the same size nozzle.

It is perhaps unfortunate that the physical aspects of the

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[3] Superintendent of motive power, St. Louis-San Francisco Railway, Springfield, Mo. Mem. A.S.M.E.

[1] Published as paper AER-58-7, by Lionel S. Marks, in the November, 1936, issue of the A.S.M.E. Transactions.

[2] Mechanical Engineer, Bailey Meter Company, Cleveland, Ohio. Mem. A.S.M.E.

[3] "The Intake Orifice and a Proposed Method of Testing Exhaust Fans," by N. C. Ebaugh and R. Whitfield, Trans. A.S.M.E., vol. 56, December, 1934, paper PTC-56-3, pp. 903–912.

orifice as well as the data obtained should have been compared only with the V.D.I. orifice and its coefficients in this paper, when there exist today unexcelled data on the American orifice. The writer refers not only to the many excellent papers previously given before this Society on characteristics of the American types of orifices, but also to the A.G.A.–A.S.M.E. Orifice Committee report.[4] In this report are data which are even more complete than the V.D.I. data in so far as practical application is concerned. It is true these data do not cover the discharge or the inlet orifice, but on the other hand, neither do the V.D.I. data. As the author has stated, the V.D.I. specifications for discharge orifices are exactly the same as for duct orifices. Therefore, the writer believes that a comparison of the author's studies with the latest A.G.A.–A.S.M.E. data[4] will be of considerable value in ascertaining if orifices as prescribed by the joint A.G.A.–A.S.M.E. Committee can be used successfully as discharge orifices.

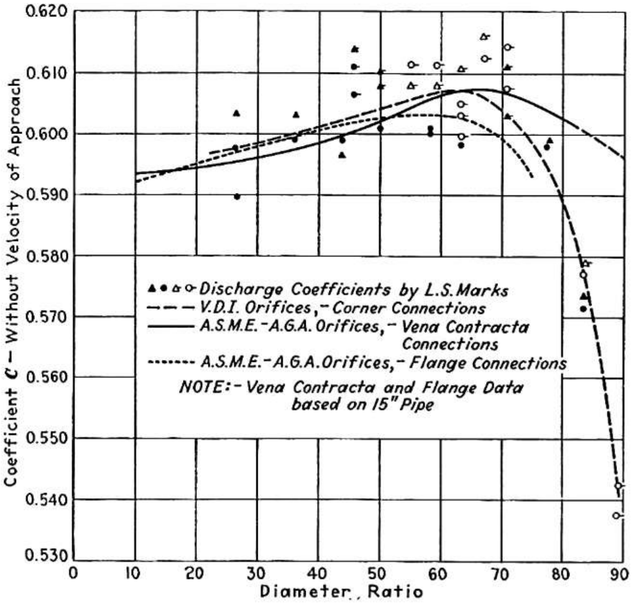

FIG. 1

First of all in considering this comparison it should be understood that while the author states that his orifices are of a modified V.D.I. type, they are in reality the same as our American orifices using flange connections as recommended by the American Gas Association, and which are included in the report.[4] In fact, the author's orifices conform as closely to the American as to the V.D.I. pattern which incidentally the writer believes is a fortuitous circumstance.

It is important to state at this time that the best way of plotting orifice coefficients is to show the discharge coefficients alone without including the velocity of approach, also to use diameter ratio instead of area ratio. By so doing the real characteristic of the device is shown, that is, it reveals whether the actual discharge coefficient is stable with increasing or decreasing diameters ratios, or whether it changes rapidly and thus becomes unstable. On the other hand, the inclusion of the approach-velocity factor with the discharge coefficient covers up such trends in such a way that they are not readily discernible. It is important to know the magnitude of such changes in coefficient value as it is inadvisable to use an orifice having an unstable coefficient if perfect dependence is to be placed upon its results.

Curves showing coefficients of discharge for A.S.M.E. orifices using vena-contracta pressure connections, for A.G.A. orifices using flange connections, and for the V.D.I. orifices using corner connections, all without the approach-velocity factors, are shown in Fig. 1 of this discussion. As is well-known, vena-contracta connections are placed one diameter preceding and in the plane of the smallest jet area following the orifice, whereas the flange connections are placed 1 in. preceding and following the orifice. The location of the V.D.I. corner connections is very clearly illustrated in Figs. 2 and 3 of the paper. The curves in Fig. 1 of this discussion show that the characteristics of the three types of orifices are practically the same up to a diameter ratio of 60 per cent, and that there is little to choose from in favor of either type up to that point. However, the curves begin to separate quite widely beyond the 60 per cent diameter-ratio point, and it will be noted that the coefficients of both the A.G.A. orifice with flange connections and of the V.D.I. orifice with corner connections begin to drop quite rapidly. This is one reason why the A.G.A.–A.S.M.E. report[4] has not recommended the use of flange connections for orifices of about 75 per cent diameter ratio.

In contrast to the sharp drop of the coefficient curves for both the V.D.I. and the flange-connection types, the curve for the vena-contracta orifice is comparatively flat, with about the same slope for diameter-ratios above and below 70 per cent. There is no reason, therefore, why orifices using vena-contracta connections cannot be used with certainty up to diameter ratios of 0.825. In fact, vena-contracta orifices of such maximum sizes are used extensively in commercial practice, and with very satisfactory results.

The author's data, taken from Fig. 4 of the paper and corrected to the basis of discharge coefficients alone, are plotted in Fig. 1 of this discussion. The magnitude of the spread between individual points may suggest the scale used in this plotting is too large. However, this is the same scale used in making the preliminary analysis of the A.G.A.–A.S.M.E. vena-contracta data referred to previously (the final scale used in presenting these data was $2^1/_2$ times larger than this).

If each one of the author's points could be given equal weight, it would appear that the discharge-coefficient curve for discharge orifices could be about 0.3 per cent above the V.D.I. curve between the diameter ratio of 45 to 70 per cent. This would still come within a ±1.5 per cent tolerance. In fact, the use of either kind of pressure connection, namely, corner (V.D.I.), flange (A.G.A.) or vena-contracta (A.S.M.E.), would still place all of the author's data within this tolerance. The writer is firmly of the opinion, however, that the use of the vena-contracta connections would enable this tolerance to be reduced to at least ±1 per cent, and would allow the use of a larger range of diameter-ratio orifices with a smaller chance of involving an unknown error due to the rapid change in the characteristic value.

Ronald B. Smith.[5] The author has concerned himself with a potentially important problem in the field of low-pressure flow. In both this country and in Europe there have been demands, within the last three years, for test-code recommendations on thin-plate inlet and exit orifice installations. In the United States the response has been deferred; in Europe the problem has been met by increasing the tolerance on the available tests. Whatever the method of attack an atonement for ignorance appears to be important in the beginning. A tolerance increasing with the area ratio at least for discharge orifices seems rational, for if the scattering of tests at the low ratios as indicated in Fig. 4 of the paper is the result, as the author suggests, of distorted

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[4] Report of the American Gas Association and A.S.M.E. Joint Orifice Coefficient Committee, The American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y., 1935.

[5] Turbine Engineering Department, Westinghouse Electric & Manufacturing Company, South Philadelphia, Pa. Jun. A.S.M.E.

inlet-velocity profile, the effects will be more serious as large area ratios are used. The pressure differentials are more frequently smaller with high area ratios, which also enhances the possible error. At present it seems probable that an orifice in a pipe or at the end of a pipe can never be used with as low a tolerance for fan or reciprocating-blower tests as it may for water or steam measurements unless effective damping can be secured.

The problem of orifice-plate thickness is a question of importance. It should not vibrate, and it should be sufficiently stiff so that it does not deflect. Even with small pressure difference when plates are 60 in. in diameter and only $^1/_{16}$ in. thick, the deflection may not be insignificant. In Europe this question has been viewed more seriously than here.[6,7] Would it not be better to specify a minimum plate thickness and cylindrical-orifice length as a function of the pipe diameter rather than to suggest the use of $^1/_{16}$- or $^3/_{32}$-in. plates without an upper limit on duct size?

In this connection the European experiments[8] indicate that the length of the cylindrical edge and the plate thickness affect the discharge coefficient oppositely. The data apply to corner taps which are essentially those employed by the author. It has been found that if the cylindrical length were about one third of the plate thickness, the effects are compensating for area ratios as high as 0.7. When the plate is less than $0.04D$, where D is the pipe diameter, the orifice length and the plate thickness may be identical without noticeable effect on the coefficient. The author's experiments seem to fall within this range, but with smaller ducts, unless a geometric ratio is chosen, they may be subject to error.

The decision to measure the differential pressures with pipe taps located 1 in. upstream and downstream from the orifice plate is a noteworthy break from European convention. The use of pressure chambers in large pipes is not only costly but unwieldy. If taps are located symmetrically around the periphery of the pipe and the pressure readings compared, it has frequently been possible to determine irregularities in the approaching stream and to correct them before testing. This is a distinct advantage for fan-test work. Rather than an arbitrary location of the taps at 1 in. upstream and downstream, the writer favors geometrically similar installation requirements with the dimensions as functions of a linear variable, say the pipe diameter. For the size tested by the author it is apparent that the choice of 1 in. lies within $0.01D$ and $0.03D$ from the pressure plate. Since this is essentially the tolerance allowed by the V.D.I., the author's comparison with the European standards should agree. Had the 1 in. dimensions been employed for ducts of 16 in. diameter, and for large area ratios, the impact pressure rise that occurs near the corner[9] would hardly have begun and differences in the coefficient of as great as 2 per cent may actually be found if this 1-in. location be adhered to. The upstream location at 1 in. is satisfactory for ducts larger than 30 in. diameter, but in smaller sizes it is sufficiently far away from the orifice so that the pressure reading will be affected by the impact built up in a variable manner depending on the area ratio. Would it not be better to accept either the corner tap or the location $1D$ upstream, and thus be rid of the difficulties?

After a study of the pressure distribution downstream of the orifice,[3] it would seem that the agreement between the author's studies and Stach's[10] on inlet orifices is more fortuitous than rational. Between a corner tap and a $0.4D$ downstream tap there may be as much as 3 per cent difference in the pressure, or possibly 1.5 per cent in the discharge coefficient. In mentioning Stach's tests it may be well to point out several possible errors. Stach's measurements are relative, inasmuch as they were made by calibrating the flow through the inlet and exit orifices with other nozzles installed in a standard manner in the line. However, the distance between the in-line meters was 18 pipe diameters which is not sufficient to be certain of damping the discharge eddies and thus preventing the discharge of one meter affecting the entrance to another. In addition the nozzles, some as small as 4 in., were made from sand castings with an uncertain amount of machining, and finally the area ratios for some nozzles were larger than 0.45 which is a region that has since been found in error[7] by as much as 0.5 per cent.

Although the author makes no mention of the use of the discharge nozzle, it may be well to point out a difficulty apart from the cost that makes the orifice more suitable. At the end of a line, most frequently when discharging a fluid or gas into one of different viscosity there is, particularly for low-pressure flows, a tendency for the flow to leave the throat of the nozzle and to form an appreciable contraction. This appears to be the result of a pressure which may be slightly less than atmospheric at the point where the nozzle profile changes from a curve to a straight throat, and where the flow temporarily leaves the wall. If noticed, this transient difficulty may be overcome by temporarily disturbing the outlet flow with a plate or by working a wire around the nozzle throat, but the uncertainty of its presence is a distinct disadvantage to the use of a discharge nozzle. A somewhat similar difficulty has been found by the writer, even when the nozzle is discharging fluids of the same viscosity (air into air) if the exit pipe is only 4 or 5 diameters long. Since the pressure within the pipe may be less than atmospheric, on account of the downstream build-up, outside air may break in and thus disturb the downstream pressure reading. The difficulty may be overcome when discharging to air by using a long exit pipe or by installing a downstream valve.

G. L. Tuve.[11] The recognition of square-edged orifices as one of the code methods for use in fan testing would indeed be a welcome simplification, and the author has done a real service in obtaining data to support his statement that "the square-edged orifice is a very reliable device for measuring air."

After using thin-plate orifices in several hundred fan tests over a period of 15 years, the writer is thoroughly convinced of their practical value. For low duct velocities the pitot tube is often of little use, and the orifice is a welcome alternative; in any test work it is certainly desirable to have two methods of measurement available for occasional checking. Much test work is done with a false sense of security regarding the accuracy of results, and it is interesting to note that in order to come within a tolerance of 1.5 per cent on pitot-tube measurements, the author states that the micromanometer was necessary.

The author departs somewhat from American practice in plotting the orifice discharge coefficients with approach factor included and by plotting against orifice area ratios instead of against orifice diameter ratios. American engineers also prefer to use a more limited range of orifice sizes because of certain disadvantages of the very large or very small ratio sizes. Again, the pressure connections used in this country are not usually those

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[6] "Calibration of an Orifice," by H. W. Swift, *Philosophical Magazine*, series 7, vol. 8, no. 51, October, 1929, pp. 409–435.

[7] "Orifice Discharge Coefficients for Viscous Liquids," by G. L. Tuve and R. E. Sprenkle, *Instruments*, vol. 6, November, 1933, p. 201.

[8] "Neuere Mengenstrommessungen zur Normung von Düsen und Blenden," by R. Witte, *Forschung auf dem Gebiete des Ingenieurwesens*, vol. 5A, 1934, p. 205.

[9] "Die Strömung durch Düsen und Blenden," by R. Witte, *Forschung auf dem Gebiete des Ingenieurwesens*, vol. 2A, 1931, pp. 245–291.

[10] "Die Beiwerte von Normdüsen und Normblenden im Einlauf und Auslauf," by E. Stach, *Zeit. V.D.I.*, vol. 78, 1934, pp. 187–189.

[11] Professor of Heat-Power Engineering, Case School of Applied Science, Cleveland, Ohio. Mem. A.S.M.E.

specified by the German standards. A wealth of data on coefficients published by or with the cooperation of the A.S.M.E. Fluid Meters Committee, has been apparently overlooked by the author. While these data refer largely to pipe orifices, the V.D.I. coefficients were also obtained on pipe or duct orifices.

Fortunately, in the diameter-ratio range of 0.3 to 0.75 (0.09 to 0.56 area-ratio range), the coefficients from the Orifice Committee report,[4] from the V.D.I., or from the A.G.A.-A.S.M.E. cooperative project at Ohio State University, all agree within less than 1 per cent. Hence, it makes little difference which is used. Moreover, the data from these sources indicate that either vena contracta, flange, or corner taps may be used without exceeding the tolerance of 1.5 per cent.

Tests have been made in the laboratories of the Case School of Applied Science, Cleveland, Ohio, in which both pipe and discharge orifices have been compared against the pitot tube, venturi meter, and heat balance (heating coil in the air stream). In addition to confirming the findings of the author, one additional conclusion is worth mentioning, that is, when an orifice coefficient deviates for some reason from standard, it is almost always high rather than low, as evidenced also by the 18 points above, and only eight points below, the curve in Fig. 4 of the paper. From this standpoint, it would seem more logical to set the tolerance limits as + 2.5 per cent and —0.5 per cent, rather than ± 1.5 per cent.

Author's Closure

Two of the discussers of this paper express some surprise that the author has not compared his results with those reported by the A.G.A.-A.S.M.E. Orifice Coefficient Committee[4] but has chosen instead to compare with the coefficients contained in the V.D.I. rules. No other procedure was actually practicable, since the American coefficients apply only to pipe or duct orifices. It is true that the V.D.I. rules give identical coefficients for discharge orifices and duct orifices and that no experimental justification for this identity is offered. The experimental work on discharge orifices used by the Germans appears to have been that of Stach[10] which gave discharge coefficients for a discharge orifice differing from the V.D.I. coefficients for duct orifices. In the V.D.I. rules, discharge orifices are given a tolerance larger than the tolerance proposed for duct orifices; this procedure may be a confession of uncertainty as to the true values of the discharge-orifice coefficients or may be an attempt to include the Stach coefficients up to an orifice area ratio of about 0.6. The fact that the V.D.I. rules give identical coefficients for the discharge orifice and the duct orifice does not appear to the author to justify the assumption that these two coefficients are in fact identical and consequently does not appear to him to justify an assumption that the values of the American coefficients for duct orifices can be considered to apply to discharge orifices.

Another point on which two of the discussers agree is in expressing a preference for the use of pressure measurements taken at the vena contracta. The author fails to perceive any application of this to the case of a discharge orifice and thinks that the discussers must have had in mind duct orifices or possibly inlet orifices. The solid-line curve of Fig. 1 of this discussion has no applicability to the author's tests.

There is also criticism of the use by the author of orifice area ratio (as used also by the Germans) rather than the orifice diameter ratio. The use of orifice area ratio appears to be preferable since it spreads out the curve in the region of higher values of the ratio which is also the region of most rapid variation of the discharge coefficient.

Mr. Sprenkle suggests that the best way to plot orifice coefficients is to show the discharge coefficients alone without including the velocity of approach. The author is entirely in agreement with him on this point and has incorporated values of the coefficient, so defined, in Table 1 of the paper. The plottings, it is true, are on the basis of the coefficient which includes the velocity of approach and this was done in order to make a direct comparison with the German coefficients. These coefficients have been adopted by the International Standards Association and it seems to the author desirable to conform as far as possible in the method of presentation of results. It has, moreover, the minor advantage of simplifying calculations for discharge.

Mr. Smith comments on the lack of definiteness in the recommendations contained in the paper for orifice plate thickness. What he has to say about the influence of the length of the cylinder edge and of the plate thickness is correct and is taken care of in the V.D.I. rules. For the range of duct diameters which the author had in mind, on which he had carried out investigations, and which are of interest in fan and blower tests, the two elements to which he calls attention become unimportant. Any moderate variation from the dimensions suggested by the author would have an entirely negligible influence on the discharge coefficient.

The status of inlet orifice coefficients is rather curious. The results obtained by Stach, by Ebaugh and Whitfield, and by the author all agree in giving an identical discharge coefficient. This consistency is puzzling because the pressure differentials on which they are based are different, Stach having used a corner tap while the other two investigations used pressure taps at a distance of 0.4 times the duct diameter downstream from the orifice. A difference in the pressure differentials measured at these two places is certain; its value is indicated in the paper of Ebaugh and Whitfield, and is stated by Mr. Smith. That the author's results agree with those of Ebaugh and Whitfield is not an inconsistency, since the same location of the pressure tap was used in both cases. The reasons for the agreement with Stach may possibly be those suggested by Mr. Smith.

Professor Tuve calls attention to the scattering of values of the discharge coefficients and to the fact that the coefficients are generally high as compared with the V.D.I. values. The discharge coefficients were obtained by comparison with volumes determined from pitot-tube traverses, the latter having previously been compared with calibrated-nozzle discharge measurements. It is the author's experience that pitot-tube traverses in fan ducts have a marked tendency to give values which are too high. This may result from swirling motion of the air, from pulsations, and from the pattern of the velocity distribution. As the calculated values of the orifice discharge coefficients reflect directly any errors in the pitot-traverse measurements, the author is inclined to regard the scattering of points shown in Fig. 1 of this discussion as being due primarily to errors in the pitot-traverse readings and not to variations in the orifice discharge coefficients. Unfortunately this belief is not susceptible of proof.

Undercooling in Steam Nozzles[1]

Charles H. Coogan, Jr.[2] Under a grant from the faculty research committee of the University of Pennsylvania, the writer is studying the phenomena which occur in the steam-jet air pump. The apparatus used by the writer consists mainly of a framework in which nozzle and sliding diffuser plates of various shapes may be placed. These various metal plates are placed between two pieces of 10 × 29$^1/_2$-in. glass which are parallel and $^{13}/_{16}$ in. apart. The customary search tube is so

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[1] Published as paper FSP-58-6, by J. T. Rettaliata, in the November, 1936, issue of the A.S.M.E. Transactions.

[2] Instructor in Mechanical Engineering, University of Pennsylvania, Philadelphia, Pa. Jun. A.S.M.E.