LOCOMOTIVE BLAST PIPES AND CHIMNEYS.

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In this paper the author feels that he is, to a certain extent, re-opening a somewhat neglected field of investigation. In the comparatively early days of railways, several experiments were conducted with a view to ascertaining the most advantageous proportions, etc., for the draught producing apparatus, but of late years, in spite of the great increase in the loads that have to be hauled and the speeds that have to be maintained, this important subject seems to have been almost entirely neglected.

For the sake of clearness the paper has been divided into two parts, viz. :—

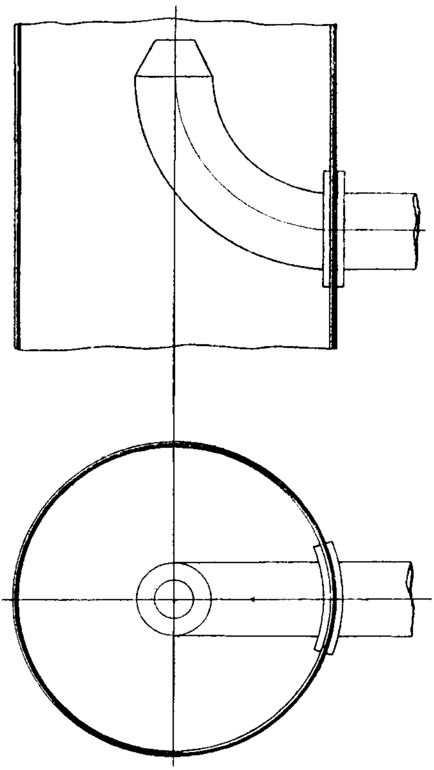
1. The Blast Pipe.
2. The Chimney and Petticoat Pipe.

1.—THE BLAST PIPE.

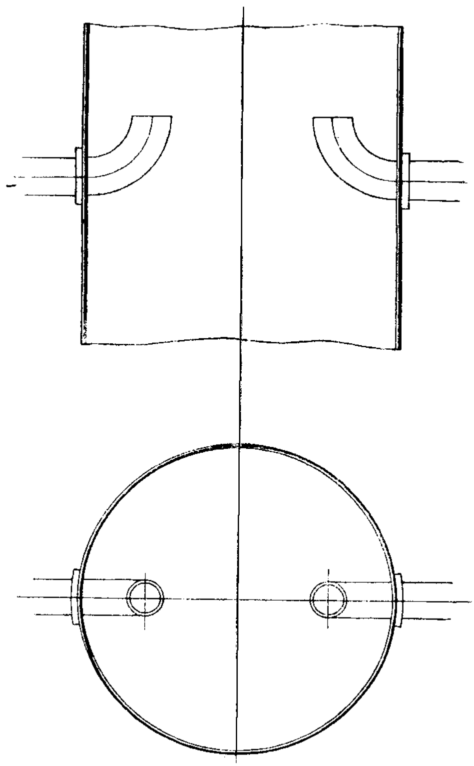
The object of the blast pipe is to utilise the waste exhaust steam from the cylinders for the production of an artificial draught, which will cause a rapid combustion of the fuel in the firebox, and on this the good steaming of the engine depends. Its origin is somewhat obscure, for although, in 1803, Richard Trevithick built the first engine in which the exhaust steam from the cylinders was turned into the chimney, it is not generally thought that he realised the advantages attendant on the use of the steam blast, and he cannot therefore be said to have been the inventor. It is interesting to note, however, that in 1827 Hackworth's "Royal George" was fitted with a blast pipe in the chimney, which was provided with a contracted orifice, Fig. 1, and at the same date Stephenson was still using two ordinary exhaust steam pipes, Fig. 2. However this may be, the latter employed the blast pipe on the "Rocket" during the Rainhill trials, and there is no doubt that the success of this engine was due in a large measure to the use of this fitting.

The action of the blast is, at speeds from about 25 m.p.h. upwards, that of a continuous jet of steam drawing the gases with it by means of the friction of its sides, although at speeds below this a plunger action takes place, as there is an appreciable interval between the exhausts.

EXHAUST STEAM PIPES IN USE IN 1827



TREVITHICK'S
FIG. 1.



STEPHENSON'S
FIG. 2.

In main line engines, both passenger and goods, the former is the action which predominates, and should therefore be taken into account, while in shunting engines for use in yards, etc., the latter is the action which must be considered, although in practice a compromise between the two is usually made. The foregoing considerations influence chiefly the design of the chimney and will be dealt with under that heading.

One of the most important items in the design of a blast pipe is the selection of a suitable diameter for the orifice, and in determining this it is necessary to exercise careful judgment, as it is a case of deciding between two evils. By this is meant, that if the diameter of the orifice is too small, back pressure on the piston will result, together with an excessive consumption of fuel, which is drawn through the tubes in a half burnt state. On the other hand, if the nozzle is too large, the draught will be impaired and the boiler will not steam properly. In short, the diameter of the orifice should be made as large as possible, consistent with the good steaming of the boiler.

It has been stated in the past, and the opinion is still held to-day by a number of locomotive engineers, that it is impossible to determine by calculation alone the most suitable diameter for a blast orifice for a given engine, and that the only method is by experiment. This idea is upheld to a certain extent by observations of actual practice, for one frequently finds two engines identical in every other respect except in the diameter of the blast orifices, which may differ by as much as half an inch. This is due, no doubt, to the varying class of coal supplied to the sheds to which the engines are allocated.

According to D. K. Clark, in "Railway Machinery," 1855, the area of the blast orifice is regulated by the following four items:—

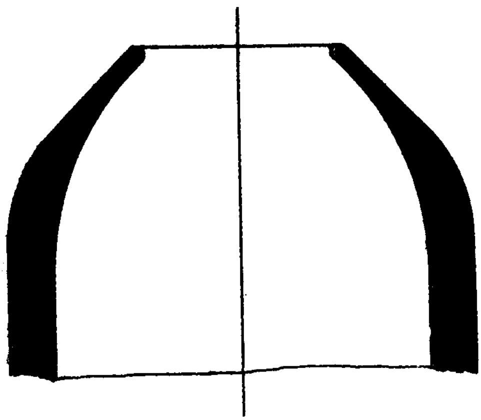
(1) Grate area.
(2) Heating surface of the tubes.
(3) Cross sectional area of the chimney.
(4) Cubic capacity of the smokebox.

The first two of the above are of paramount importance, but the others are generally neglected. The same authority also states that being mainly regulated by the dimensions of the boiler, the size of the orifice is practically independent of the size of the cylinders. It is also stated, by the way, that the finish of the orifice influences the results to a considerable degree, very superior results having been obtained from a nozzle finished to an angle on the outside, as shown in Fig. 3, leaving an edge one sixteenth of an inch thick and slightly turned over from the inside. The idea of the bevel is presumably to enable the smoke, etc., to come into contact with the steam more readily as it leaves the orifice.

On the subject of the diameter of orifices, some very complete experiments were made in Germany about 20 years ago by Messrs. Von Borries and Tröske, as a result of which the following formula was derived:—

When d = dia. of blast orifice in inches,
R = area through tubes in sq. ins.,
S = grate area in sq. ins.,

$$\text{then } d = .156\sqrt{\frac{S \times R}{S + .3R}}$$



CLARK'S BLAST ORIFICE

FIG. 3.

According to Meyer, the most suitable area for a single orifice is 1/200th of the grate area in sq. ins., and results obtained by this rule agree closely with American practice. The area of the orifice should be larger or smaller according as the fire is shallow or deep, because if the fire is deep, a greater vacuum will be necessary to draw the air through the grate and vice versa.

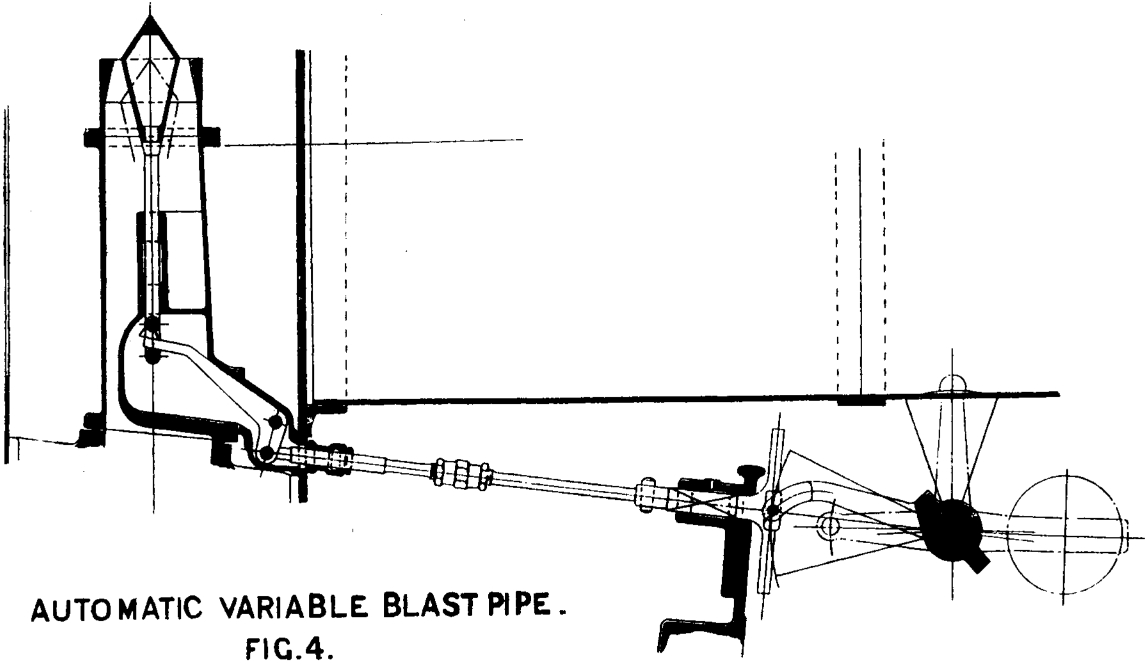
Molesworth gives the diameter of the blast orifice from .35 to .4 times that of the cylinder, but this gives rather large proportions. A comparison of the diameters of the cylinders and blast pipes of the six comparatively modern engines, Table I., shows that the ratio of orifice to cylinder varies from a minimum of .25 in the case of the L. and Y. and G.N. tank locomotives, to a maximum of .3 in the case of the G.N. express engine.

Since the conditions under which an engine has to do its work are continually varying, it is impossible to obtain a definite proportion for the diameter of the orifice, which will give the best results under all circumstances, and to overcome this difficulty, what are known as variable blast pipes have been devised. Theoretically they are correct, but in practice great trouble is experienced in keeping them in working order, owing to the corrosive action of the smokebox gases. However, if the mechanism in contact with the gases is left fairly loose, and not made too good a fit, it will be found that they give satisfactory results. They are also, of course, open to abuse at the hands of careless drivers, who, to save themselves trouble in keeping steam, will always use the smallest aperture, with consequent waste of fuel.

The simplest class of variable blast pipe is that invented by the late Mr. G. Macallan of the G.E.R., to all the main line engines of which, the author believes, the device is fitted. It consists simply of a hinged cap having an orifice about 25 per cent. smaller in diameter than that of the fixed pipe, but with this design only one variation is obtainable. (See JOURNAL for October, 1916.)

Another device is that introduced by the Variable Blast Pipe Co., and is shown in Fig. 4. A cone mounted on a vertical spindle was placed in the orifice, so that by raising or lowering the cone the area of the orifice could be increased or decreased at will. The spindle passed through a gland in the bottom of the smokebox, and was connected by means of cranks and rods to the weigh-bar shaft, thus enabling the area of the orifice to vary with the point of cut-off. The practice of coupling the variable gear to the weigh-bar shaft is, in the author's opinion, a very commendable one, as once set, it works automatically and is entirely independent of the enginemen. Experiments carried out on four different engines fitted with this type of blast pipe showed an average saving of 7.61 per cent. per train mile and 8.37 per cent. per engine mile over four corresponding engines fitted with the ordinary pipe.

In America and on the European Continent, where rectangular orifices are in use, their area is easily adjusted by the simple expedient of hinging two of the sides. This apparatus was introduced by Messrs. Wallace and Kellog, of Altoona, Wisconsin, and is connected to the valve gear.



AUTOMATIC VARIABLE BLAST PIPE.
FIG. 4.

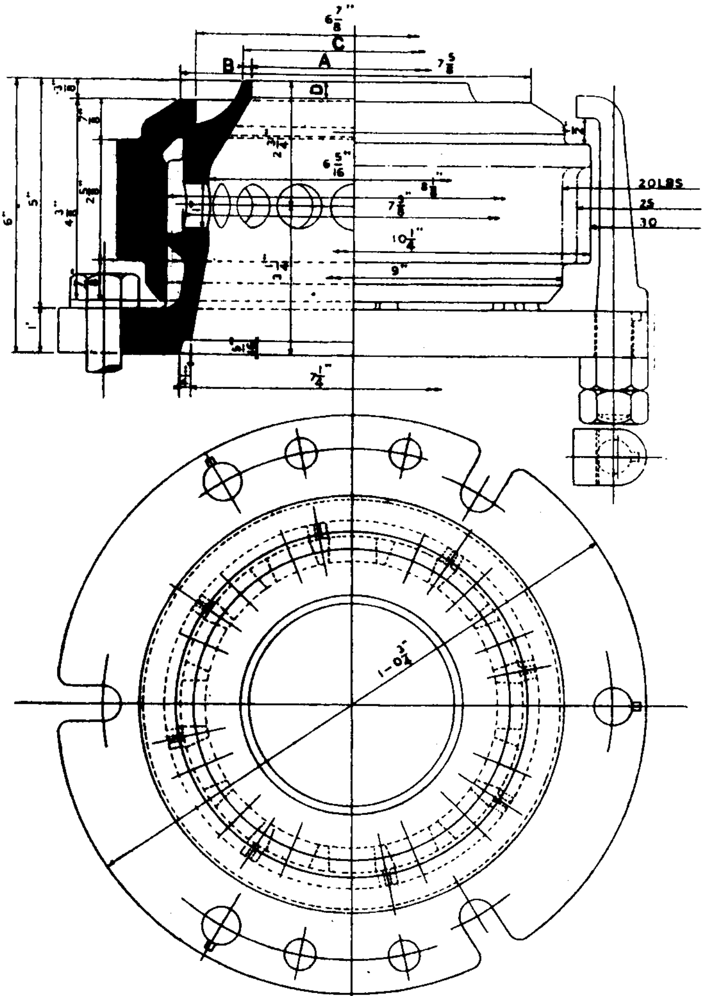
It has been tried with complete success on the Duluth and Iron Range R.R. in America. The engines of this company which are so fitted have a reversing quadrant with fourteen notches on each side of the centre, and the orifice is set to vary half an inch with each notch, so that a difference of 7 sq. ins. is obtained between mid and either full gear positions. The engines are or were (the author does not know whether they are still running) said to be the best for steam on the line, pulling heavier loads, and consuming less fuel than any of the others.

It is said that one of the engines, on which the trials were carried out, showed a saving in fuel of from £13 5s. 6d. to £21 16s. 6d. per month for eight months, the cost of the coal being approximately 11s. 8d. per ton. This, however, seems a large amount, so the statement must be taken for what it is worth. They also made from 5½ to 10 miles per ton above the average.

The most recently invented variable attachment is that invented by Mons. L. Marèchal, of the P.L.M. Railway of France, and styled "The Clover type exhaust gear." It consists of three triangular wings which taper at the bottom to knife edges, the whole arrangement being movable in a vertical direction. It is claimed for this device that engines fitted with it can pull at the same speed 15 per cent. more load than other engines of the same class fitted with the ordinary types of blast pipe. This apparatus was illustrated and described in the April, 1917, issue of the JOURNAL.

Some locomotives utilise a part of the exhaust steam for feed-water heating, etc., and when this is the case, the blast pipe orifice must be smaller than usual in order to produce a sufficient draught with a reduced amount of steam. When, however, the engine is being worked at its fullest capacity, or no exhaust steam is being used, the contracted orifice will cause a considerable back pressure and an excessive draught, with the consequent detrimental results.

To overcome this difficulty, the following arrangement has been successfully adopted on the G.W.R. About 2 inches below the orifice, 16 1-inch holes are drilled round the circumference of the pipe. Normally these are closed by a weighted collar, known as a "jumper," the weight of which varies from 17 to 30 lbs., according to the class of engine (Table 2); but when the pressure in the pipe becomes excessive, *i.e.*, above the 17 or 30 lbs., as the case may be, the collar is raised, thus uncovering the holes which remain open until the pressure drops again. By this means the area of the orifice is increased by about $12\frac{1}{2}$ sq. ins. This device is shown in Fig. 5.



DIMS A VARIES FROM $4\frac{1}{2}"$ TO $5\frac{5}{8}"$
" B MUST BE $\frac{3}{16}"$ FOR ALL DIAMS.
" D " " " " " "
MAX. " C = 6"

G.W.R JUMPER BLAST PIPE

FIG. 5.

With reference to the vacuum obtainable in the smokebox, Molesworth gives the following formula :—

When d = dia. of the blast orifice in inches,
D = ,, chimney ,,
p = gauge pressure of steam in lbs. per sq. in.,
E = vacuum obtainable in inches of water,
then $E = (37 \times d^{1.662} \times p^{.8}) \div D^2$.

Experiments carried out by the New York Central R.R. of America have clearly shown that it is not necessary for the jet, either blower or exhaust, to fill the chimney in order to obtain a vacuum. These tests were carried out on an engine fitted with two $\frac{3}{4}$-inch blower nozzles, both of which, when turned on full, did not more than half fill the chimney, leaving a clear annular space between the jet and the chimney walls.

The following readings were taken with one jet only, turned on full, and show the vacuum obtained in inches of water :—

Inside the smokebox door	1.5in.
Under the chimney	1.45in.
In front of the tubeplate	1.1in.
In centre of firebox, 12in. above grate ...	.4in.

Prior to these experiments, when the ordinary round orifice was in use, it was found that what should have been a circular jet was flattened out at the upper extremity of the chimney to a rectangular one, crowding and overflowing as it were at the side, and leaving a good space at both back and front. It was also noticed that at slow speeds the engine "cross-exhausted." After correcting the exhaust steam passages to remedy the last mentioned trouble, a rectangular orifice was fitted to the blast pipe to produce a jet with a clear space between it and the chimney walls. This arrangement was duly tried with highly satisfactory results, and is now, the author understands, the standard on that particular line.

These experiments resulted in the following conclusions:

(*a*) The blast pipe must be designed so as to eliminate "cross-exhausting."

(*b*) The form and size of the jet must be such as will leave a space between it and the sides of the chimney at the top, so that there is room for the entrained gases to pass into the atmosphere.

(*c*) Great care must be exercised in setting the blast

TABLE I.

Engine.		Cylinders.	Heating Surface in sq. feet.			Grate.	Dia. of	Ratio of dia. of orifice to dia. of cylinder.
Railway.	Type.	Dia. × Str.	Tubes.	Firebox.	Total.	Area in sq. ft.	orifice.	
		in. in.					in.	
L. and S.W.	4-4-0	19 × 26	1,222	328	1,550	24	5	.263
G.C. ...	4-6-0	19½ × 26	1,778	133	1,911	26	5	.256
L. and Y. ...	2-6-2/T	19 × 26	1,877	162	2,039	26	4¾	.25
G.N. ...	0-8-2/T	20 × 26	1,302	136	1,438	24.5	5	.25
G.N. ...	4-4-0	17½ × 26	1,130	120	1,250	21	5¼	.3
L. and N.W.	4-4-0	19 × 26	1,848	161	2,009	22.5	5¼	.276

TABLE II.—LEADING DIMENSIONS OF THE JUMPER BLAST PIPE FOR DIFFERENT CLASSES OF G.W.R. LOCOMOTIVES.

Boiler	Engine Class	Type	Blast Pipe				
			Superheater		Non-Superheater		
			Dia.	Ring	Dia.	Ring	
			in.	lbs.	in.	lbs.	
S/1	4,000	4-6-0	5¼	22	—	—	Engines with boilers having wide waterways to have 5⅛in. dia. and 25lbs. ring.
	2,900	4-6-0	5¼	22	5⅜	22	
	2,800	2-8-0	5¼	20	5⅜	20	
	103 and 104	4-4-2	5⅛	25	5¼	25	
S/2	3,100	2-6-2/T	5	25	5⅛	25	Engines with boilers having wide waterways to have top ⅛in. less in dia. than shown in table, but min. dia. must be 4¾in.
	3,300 to 3,455	4-4-0	4⅞	20	5	20	
	4,100 to 4,168	4-4-0	4⅞	20	5	20	
	7, 8, 14 and 16	4-4-0	4⅞	20	5	20	
	2,221 to 2,250	4-4-2/T	5	20	5⅛	20	
S/3	3,600	2-4-2/T	4¾	20	4⅞	20	
	3,521 to 3,560	4-4-0	4⅞	20	5	20	
S/4	3,100	2-6-2/T	5⅛	25	5¼	25	
	4,200	2-8-0/T	5¼	20	5⅜	20	
	3,800	4-4-0	5⅛	22	5¼	22	
	4,300	2-6-0	5⅛	20	5¼	20	
	3,700 and 3,719	4-4-0	5	20	5⅛	20	
	2,600	2-6-0	5⅛	20	5¼	20	
S/5	4,400	2-6-2/T	—	—	4¾	17	
	4,500	2-6-2/T	4¾	17	4¾	17	
	3,800	2-6-2/T	—	—	4¾	—	
	4,600	4-4-2/T	—	—	4⅞	20	
S/6	111	4-6-2	5⅝ single row	25	—	—	
113th lot	3,252 to 3,291	4-4-0	4⅞	20	5	20	
	—	—	4¾	20	double	row	
146th lot	102	4-4-2	5	20	—	—	
2,301 class	3,521 to 3,560	0-6-0	4¾	20	4⅞	20	
	—	0-6-0/T	4¾	20	4⅞	20	
Std. Goods	—	0-6-0	4¾	20	4⅞	20	

TABLE III.—L. & Y.R. BLAST PIPE AND COWL EXPERIMENTS.

No.	Dist. of orifice below centre line of boiler.	Dist. between orifice and bottom of cowl	Length of cowl	Dia. of orifice	Dist. between blast orifice and bottom of chimney.	Heightofchim ey		Dia. of choke of chimney	Taper of chimney	Average speed in m.p.h.	Average cut off in percentag of strok	Average steam pressure in lbs. per sq. in.	Average vacuum in inches of water		Load behind draw-bar in tons.
						Exte nal	Internal						Top row of tubes	Bottom row of tubes	
	in.	in.	in.	in.	in.	in.	in.	in.					in.	in.	
1	14¼	9	23½	4¾	30	28¼	13½	12½	1.4in. per foot outwards towards the top.	34.4	36.2	168.5	2.3	3.5	160
2	14¼	12½	17½	4¾	30	28¼	13½	12½		37.6	31.37	175.4	2.75	3.75	160
3	14¼	No	cowl	4¾	30	28¼	13½	12½		38.4	26.6	176.5	1.66	3.166	160
4	2¼	No	cowl	4¾	18	28¼	13½	12½		40.2	36.2	164.6	2.5	3.5	160
5	8¼	9½	17½	4¾	24	28¼	13½	12½		38.6	30.1	174.3	3.875	4.375	200

The above tests were carried out on a 2-4-2 tank engine; wheels, 5ft. 8in. dia.; cylinders, 18in. by 26in.; 220 1¾ inch tubes; heating surface of tubes 1,086 sq. ft., and of firebox 107 sq. ft.; grate area, 18¾ sq. ft.; cubic capacity of extended smokebox, 111,390 cub. ins.

TABLE IV.—DIAMETER AND POSITION OF BLAST PIPE ORIFICE IN RELATION TO TUBEPLATE FOR VARIOUS CLASSES OF LOCOMOTIVES OF THE L. & N.W.R.

Ref.	Class of Engine	Dia. of orifice	Horizontal dist. of centre of orifice from tubeplate	Vertical dist. of orifice below centre of top row of boiler tubes.	Length of Chimney.	Dia. of Chimney at Throat.	Tubes.	Heating Surface.		Grate Area.	Cylinders.
								Tubes.	Firebox.		
		in.	in.	in.	in.	in.					
A^{1}	6′ 6″ 2-4-0 "Precedent," 2-cyl. simple	4¾	16½	2	39	16	—	980.3	103.3	—	17″ × 24″
A^{2}	6′ 0″ 2-4-0 "Whitworth," ,, ...	4¾	16½	2	—	16	—	—	—	—	—
A^{3}	7′ 0″ 4-4-0 "Jubilee," 4-cyl. compound	4⅝	21¼	7½	34	16	225 1⅞″	1220.5	159.1	20.5	15″, 20½″ × 24″
A^{4}	7′ 0″ 4-4-0 "Renown," 2-cyl. simple	5¼	21½	10¾	28½	16	225 1⅞″	1220.5	159.1	20.5	18½″ × 24″
A^{5}	7′ 0″ 4-4-0 "Alfred the Great," 4-cyl. compound ...	4⅝	21¼	6¼	28½	15	—	Total...	1507.7	—	16″, 20½″ × 24″
A^{6}	4′ 6″ 2-4-2/T and 2-4-0/T side tank	4⅞	14½	2¼	42	16	170 1⅞″	—	—	—	17″ × 20″
A^{7}	5′ 6″ 2-4-2/T side tank	4¾	16½	2	42	16	198 1⅞″	—	—	—	17″ × 24″
A^{8}*	4′ 3″ 0-8-0 coal, superheater	5¼	23	10½	24	16	159 1⅞″, 24 5″	2004.3	146.7	23.6	20½″ × 24″
C^{1}	5′ 0″ 0-6-2 side tank	4½	16¼	2¼	39	16	198 1⅞″	980	103.5	17.1	18″ × 24″
C^{2}	5′ 0″ 0-6-0 express goods	4¾	16¼	2¼	39	16	198 1⅞″	980	103.5	17.1	18″ × 24″
D^{1}	4′ 3″ 0-6-0/T special tank	5	13	1½ (above)	52	16	198 1⅞″	Total...	1074.6	17.1	17″ × 24″
D^{2}	4′ 3″ 0-4-2/T shunter	4¾	16½	½ (above)	28½	16	195 1⅛″	Total...	967	15	17″ × 24″
D^{3}	4′ 3″ 0-6-2/T side tank coal engine...	4¾	13	2¼	45	16	198 1⅛″	960.2	94.6	17.1	17″ × 24″
D^{4}	4′ 3″ 0-6-0/T saddle tank ,, ...	4¾	13	2¼	28½	16	198 1⅛″	981	87.3	17.1	17″ × 24″
D^{5}	5′ 0″ 0-6-0 special DX ,, ...	4¾	16½	2¼	45	16	198 1⅛″	980	94.6	17.1	17″ × 24″
D^{6}	4′ 3″ 0-6-0 small ,, ...	4¾	13	2¼	45	16	198 1⅛″	960.2	94.6	17.1	17″ × 24″
E^{1}	4′ 3″ 2-8-0 and 0-8-0 4-cyl. compounds (small boiler) ...	4¾	43⅞	6	31	15	—	1630	123	20.5	15″, 20½″ × 24″
E^{2}	4′ 3″ 2-8-0 4-cyl. compound (large boiler)	5½	23	10½	24	16	—	1979	146.75	23.6	15″, 20½″ × 24″
E^{3}	4′ 3″ 0-8-0 coal engine	5¼	30	10¾	24	16	—	Total...	2125.75	—	20½″ × 24″
E^{4}	4′ 3″ 0-8-0 ,, (small boiler)	4¾	45⅝	3¼	24	16	—	Total...	2043.25	—	19½″ × 24″
E^{5}	4′ 3″ 0-8-0 ,, (large boiler)	5¼	31½	10¾	34	16	—	Total...	1489	—	19½″ × 24″
E^{6}	5′ 0″ 4-6-0 4-cyl. compound	4¾	43⅞	6	28½	16	—	1630	123	20.5	15″, 20½″ × 24″
E^{7}	4′ 3″ 0-8-2/T shunter tank	5¼	38	11½	24	16	—	Total...	1953.25	23.6	20½″ × 24″
F^{1}	6′ 6″ 4-4-0 "Precursor"	5¼	22⅜	13	24	16	—	1848	161	22.4	19″ × 26″
F^{2}	6′ 0″ 4-4-2/T ,, side tank	5¾	22½	13	22	16	296, 310 1⅞″	1848	161	22.4	19″ × 26″
F^{3}	6′ 0″ 4-6-0 "Experiment"	5	22½	13	22	16	279 1⅞″	1908	133	25	19″ × 26″
F^{4}	5′ 0″ 4-6-0 express goods	5¼	22½	12½	22	16	—	1841	144	25	19″ × 26″
G^{1}*	6′ 6″ 4-4-0 "George V.," superheater	5⅜	23⅞	11½	24	16	—	Total...	1849.65	22.4	20½″ × 26″
G^{2}*	5′ 6″ 4-6-2/T side tank ,, ...	5⅛	23¼	8½	24	16	—	1195.6	138	23.9	20″ × 26″
G^{3}*	6′ 0″ 4-6-0 "Prince of Wales," superheater	5⅜	25 3/16	11	22	16	—	Total...	1897.5	25	20½″ × 26″
J*	6′ 6″ 4-6-0 "Claughton," superheater	5¼	35	14	20	16	—	2060.8	171.2	30.5	(4) 16″ × 26″

NOTE.—For superheater engines, marked thus *, the vertical distance is that below centre line of top superheater smoke tubes.

pipes, petticoat pipes and chimneys, so that their respective axes are all in the same straight line.

(*d*) All exhaust steam joints must be perfectly tight.

(*e*) If the size of the chimney will not allow condition (*b*) to be fulfilled, it will pay to enlarge it sufficiently.

The author commends items (*c*) and (*d*) of the above to the careful consideration of the running staff, as he knows from experience that these points are frequently neglected.

The Pennsylvania Railroad employ on their latest engines a special class of exhaust nozzle 7¼in. in diameter. The casting is formed with four radial projections having a knife edge on the under side, and it is claimed that this arrangement splits up the exhaust and makes it fill the chimney more effectively (Fig. 6).

In connection with the class of orifice described in the preceding paragraph, the object of which, by the way, is at direct variance with the results and conclusions of the New York Central tests, it is stated on good authority that it is doubtful whether bridge or semi-bridge pieces are of any real utility, beyond the advantage that may be obtained in some cases by their action in correcting the slightly 8-shaped form of the exhaust, which is generally due to poorly designed blast pipes.

The plan of the jet of exhaust steam as it leaves the orifice is not, as is commonly supposed, that of an inverted frustrum with *straight* sides, but between the orifice and the point where it first strikes the chimney, the sides of the frustrum are composed of *two slightly concave curved* lines.

During some experiments made to ascertain the pressures existing in the centre of the exhaust jet the following readings were obtained :—

At a point 12in. above the orifice	...	59.3 lbs. per sq. in.
,, 24in. ,, ,,	...	44.6 ,, ,,
,, 6in. below the top of smokebox ...	...	28.5 ,, ,,

It was also ascertained that the pressure diminished rapidly as the gauge was moved from the centre to the outside of the jet, and the velocity correspondingly decreased from 576 to 292ft. per sec.

It is generally believed that the efficiency of the jet is unchanged, provided the weight of steam exhausted per unit of time is equal, whether the engine is working at a late cut-off, with heavy exhausts at long intervals, or at an early cut-off, with lighter and more frequent blasts. It has been ascertained by experiment that a given weight of steam emitted from the orifice will displace about two and a half times its own weight of hot gases, according to the following formula in which

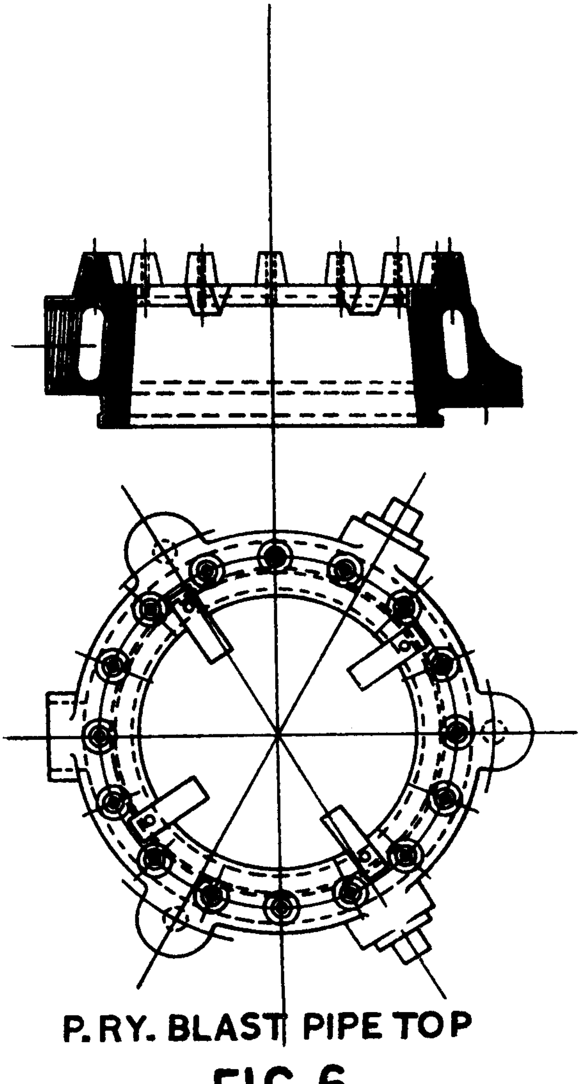
G = wt. of gases displaced in lbs.
W = wt. of steam emitted from orifice in lbs.
A = area of blast orifice in sq. ins.
S = cross-sectional area of chimney in sq. ins.
T = cross-sectional area through tubes in sq. ins.
L = a constant = 4.

$$\text{Then } G = W\sqrt{\frac{2\left(\frac{T}{S}\right)^2\left(1-\frac{A}{S}\right)}{\frac{A}{S}\left\{L+2\left(\frac{T}{S}\right)^2\right\}}}$$

When the "breeches" blast pipe is used it is necessary that the fork should be located about 18in. below the orifice, or the steam will shoot right and left alternately from the top of the chimney, according to the cylinder which is exhausting. This action of the exhaust in impinging on the walls of the chimney is very detrimental thereto in the matter of wear and tear, and is therefore to be avoided.

The height of the blast pipe varies considerably, but in this country the usual practice has been, until recently, to place the orifice just above the level of the top row of tubes. Experiments have shown that the higher the blast orifice the more fire will be burnt at the front end of the firebox, and vice versa. As a result of this, several attempts have been made to design blast pipes which will give a more equal distribution of the draught over the tubes, and the best known of these is the "Vortex" blast pipe, designed by Mr. W. Adams, late Locomotive Supt. of the L. and S.W.R. In this form of pipe (see the JOURNAL for October, 1916), the blast is emitted from an annular orifice surrounding a hollow cylindrical space in the middle of the pipe. An opening in the side of the pipe opposite the lower rows of tubes serves to communicate the hollow space with the smokebox, so that the gases from the lower tubes are drawn up through the centre of the blast pipe. It is claimed that this class of pipe causes an even flow of air through the firebox and reduces the back pressure considerably.

In July, 1897, the late Mr. F. W. Webb, then Locomotive Engineer of the L. and N.W.R., built the first of the



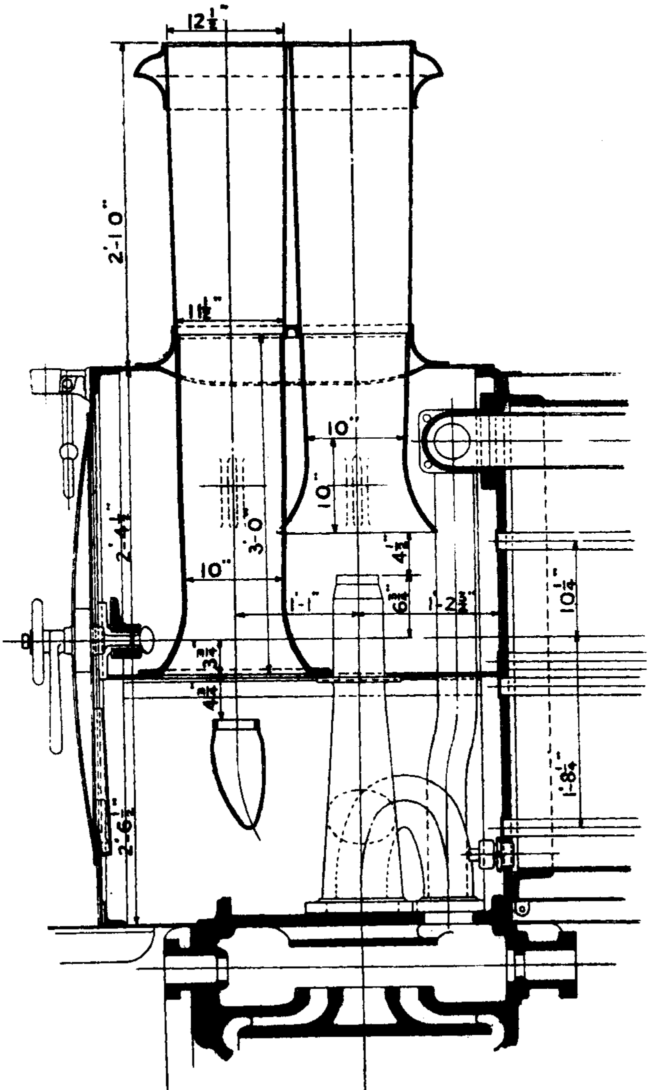
P. RY. BLAST PIPE TOP

FIG. 6.

well-known 4-cylinder compound express engines, "Black Prince," No. 1902, and in order to enhance its steaming qualities, fitted it with what was practically a double smokebox (see Fig. 7). The smokebox was divided into two compartments by a horizontal plate, so that half the tubes discharged the gases into the upper and half into the lower compartments, each division being provided with a separate blast pipe and chimney (see also Fig. 8). The exhaust steam from the right hand low-pressure cylinder discharged into the upper chamber, and that from the corresponding left hand cylinder into the lower one, the chimney of which extended down to the division plate. By this arrangement of blast pipes, etc., it was hoped to effect a more equal distribution of the draught over the whole of the tubes, and thus obtain a more efficient heating surface. This engine, however, did not run for long in this condition and was soon altered to have the ordinary type of smokebox, in which state it is still running to-day. Mr. Hughes, of the L. and Y.R., carried out, a few years ago, on one of his 2-4-2 type tank engines, some very interesting experiments in order to ascertain the most suitable height for the blast pipe and cowl. These experiments are fully described in Mr. Hughes' paper on "Horwich Locomotives" (Inst. of Mech. Engineers), from which Table 3 has been compiled. From this it will be seen that the last test, No. 5, was the most satisfactory as regards both the highest vacuum and the least variation of the draught at the top and bottom rows of tubes. The high steam pressure and low vacuum maintained in No. 3 is explained by the weather being very favourable, thus enabling the engine to be worked at an earlier cut-off and with less demand on the boiler.

In the course of some trials conducted on the old M.S. and L.R. in 1850 by Mr. Peacock, the Locomotive Supt., the records of which are given in Clark's "Railway Machinery," it was found that the most advantageous position for the orifice was 18in. below the roof of the smokebox, which places it just above the level of the top row of tubes.

In recent years, however, the adoption of high pitched boilers of large diameter has, owing to the loading gauge remaining unaltered, necessitated the use of extremely short external chimneys, and as a consequence they have had to be extended downwards inside the smokebox. This, in turn, has made it imperative to shorten the blast pipe, the particulars of which, in the following two engines, are good instances of how its height varies inversely as the diameter



SMOKE BOX ARRANGEMENT 4CY. COMP. L.&N.W.R.
FIG. 7.

of the smokebox, and consequently as the height of the external chimney.

	High pitched L. & Y.R. 2-6-2/T.	Low pitched N.L.R. 4-4-0/T.
	in.	in.
Height (internal) of smokebox...	86	60
Height of external chimney ...	$22\frac{1}{4}$	43
Depth of internal chimney ...	$30\frac{1}{2}$	$3\frac{1}{4}$
Distance between roof of smokebox and orifice	$42\frac{1}{2}$	7
Distance of orifice from centre line of boiler	12 below	23 above

In the case of the first five engines referred to in Table I., the ratio of the distance of the orifice below the roof to the height of the external chimney ranged from .48 to .82 with an average of .63, but these values vary too much to be of any use.

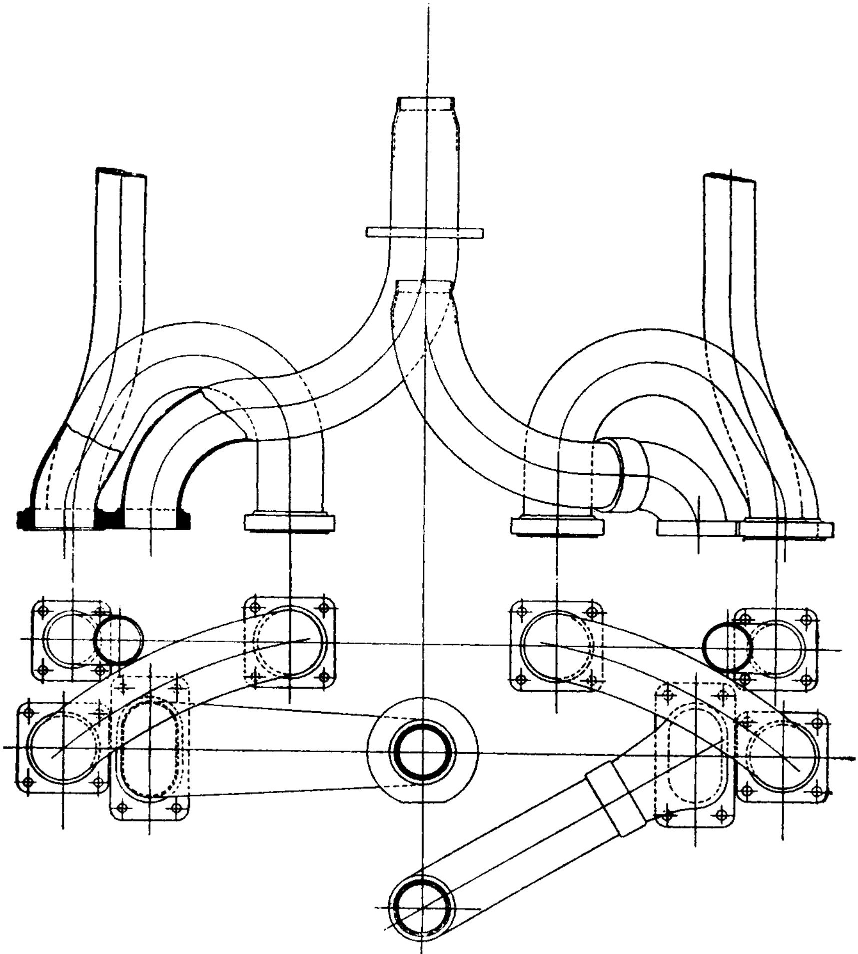
Another important point to be observed in designing a blast pipe is that of making the passage of the exhaust steam from the ports to the orifice as direct as possible and free from bends. In some modern types of engines, especially those fitted with one or other of the various forms of superheater, the chimney must be placed forward of the centre line of the cylinders in order to clear the header, and the blast pipe must be bent in order to bring the orifice under the chimney aperature. In cases such as this, where bends are inevitable, they should be made as easy as possible.

While the single orifice is in sole use in Great Britain and on the Continent, the double orifice, Fig. 9, finds considerable favour in America, the advantage, of course, being that the exhaust of the one cylinder does not interfere with that of the other. On the other hand, there is the grave disadvantage that neither orifice is concentric with the base of the chimney, but this difficulty may be overcome by having the one exhaust nozzle surrounding the other, after the style of the vortex blast pipe.

The remaining item that has not been considered is the distance of the centre of the orifice from the tubeplate. This is governed chiefly by the circumstances mentioned, to suit which the location of the orifice must be arranged.

Mr. Hughes, of the L. and Y.R., has, in addition to the tests mentioned previously in connection with the height of the blast pipe, made further experiments to ascertain the most advantageous position of the orifice in relation to the tubeplate, and has come to the conclusion that the most suitable location for it is about midway between the smoke-box door and the tubeplate.

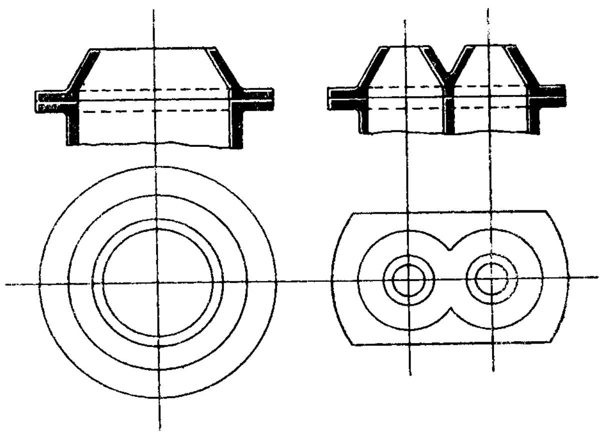
In the opinion of the author, the further the orifice is away from the tubeplate the better, since any sparks that may be drawn through the tubes have an opportunity of falling to the bottom of the box, before being ejected into the atmosphere.



BLAST & STEAM PIPES 4CY. COMPOUND L&NWR.
FIG. 8

In Fig. 10 are shown the various types of blast pipes in use on the L. and N.W.R., and Table 4 shows their most important particulars.

Blast pipes do not call for much attention in the running shed except that the orifice should be watched to avoid "scaling." The internal diameter of the orifice is frequently reduced by half an inch or more, as it becomes made up with scale, resulting in a detrimental effect on the economical working of the engine. The method of dealing with this is to remove the pipe and build a fire under it, when the scale will be burnt off.



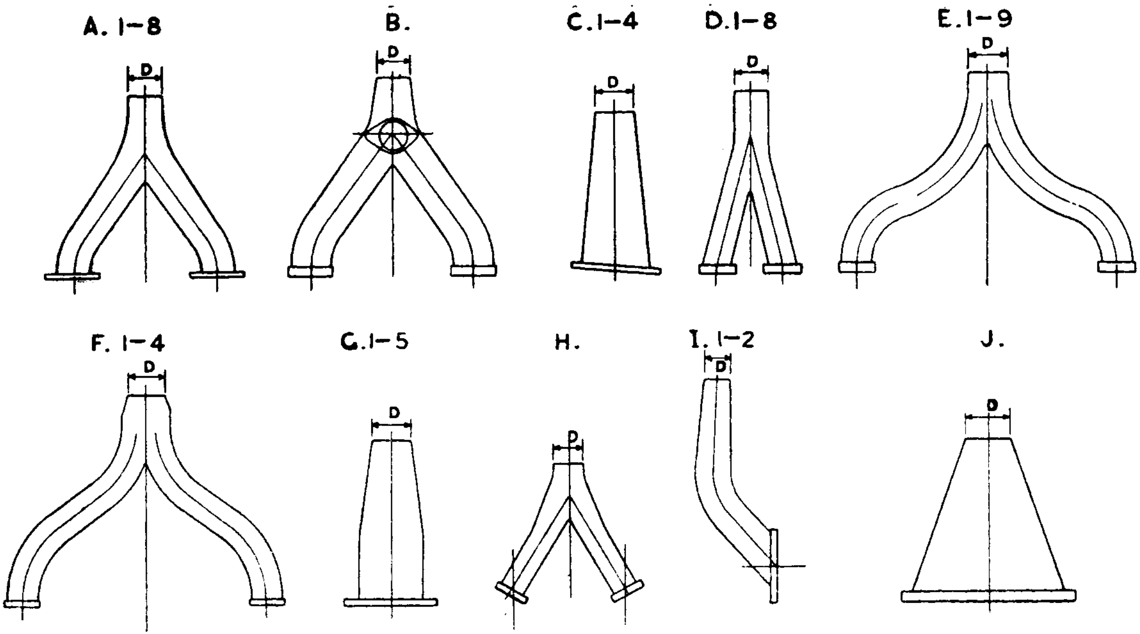
SINGLE & DOUBLE ORIFICE

FIG. 9.

When their engines are steaming badly, drivers sometimes place a hook or other object in the blast pipe. This practice is very objectionable, as such objects are liable to work loose, fall down the pipe, and damage the valves. The usual method of reducing the area of an orifice is by securing a ring, either iron or copper, preferably the latter, to the inside circumference, and it is found that this method gives complete satisfaction.

II.—THE CHIMNEY AND PETTICOAT PIPE.

In considering the design of locomotive chimneys, it should be borne in mind that the draught is mainly dependent on the mechanical action of the blast and not, as in



L. & N.W.RY. BLAST PIPES.

FIG. 10.

stationary engines, on the lesser density of a column of hot air.

As mentioned previously, Part I., the blast has two distinct actions, viz., (1) the jet, and (2) the plunger, which occur respectively at fast and slow speeds.

Considering the jet action, the length of the chimney is of little or no importance, since the longer the chimney the greater the frictional resistance, which is to be avoided. This is quite evident if one considers the gases to be entrained, as is really the case, in very small air pockets situated round the circumference of the jet. If the chimney is comparatively long and the jet completely fills it, say half way up, it will be seen that the air pockets" are, as it were, "squeezed" out before reaching the top of the chimney. Taking this into consideration, it should be the aim of the designer to have the chimney high enough to enable the jet of steam with its entrained air to fill it just at the top. This difficulty may also be overcome by giving the chimney a taper corresponding to that of the exhaust jet.

In respect of the plunger action, it will be noted that if the steam is allowed to escape into the atmosphere through too short a chimney, the interval between the exhausts, short though it may be, will be sufficient to allow the air to rush back into the smokebox, thus having a negative effect on the work already done. This difficulty can be overcome only at the expense of the freedom of exhaust from the cylinders, viz., by contracting the blast orifice.

By thus reducing the orifice, the time taken by the exhaust to reach the atmosphere is considerably prolonged, so that one exhaust is entering the bottom of the chimney by the time the last portion of the preceding one has escaped at the top. This effect, however, only takes place at low speeds, as the velocity of the steam is due to its expansion, whereas at high speeds the piston is forcing the steam out by its own velocity.

With reference to the question of parallel versus taper chimneys, it is interesting to note that two of the leading locomotive engineers in this country have, after exhaustive tests, come to opposite conclusions, the one having decided that the parallel type is the more efficient and the other the taper type, so there is apparently plenty of room for investigation in this direction.

The well-known American investigator, Dr. Goss, has, as a result of his experiments, derived formulæ for the design of chimneys, which are based on the height available for the chimney and the diameter of the smokebox. Formerly it was the practice to make the diameter of the chimney the same as that of the cylinders, although there was really no connection between the two.

The results of the experiments are given in the following formulæ:—

When D = dia. of chimney in inches.
S = dia. of smokebox ,,
H = height of chimney ,,

(a) When the blast orifice is on the centre line of the boiler,

$$D = .246 + (.00123\,H)\,S.$$

(b) Further experiments showed that with a taper chimney the least diameter need not vary with the change in height, thus,

$$D = .25\,S.$$

(c) The preceding formulæ apply only when the orifice is on a level with the centre line of the boiler. In those cases where it is above the centre line,

$$D = (.246 + .00123\,H)\,S - .19\,c$$ for parallel chimneys,

(d) $D = .25\,S - .16\,c$ for taper chimneys.

(e) When the orifice is below the centre line,

$$D = (.246 + .00123\,H)\,S + .19\,c$$ for parallel chimneys,

(f) and $D = .25\,S + .16\,c$ for taper chimneys.

In the last four formulæ, c is the distance between the blast pipe orifice and the centre line of the boiler.

Unfortunately these experiments were carried out on an engine placed on a testing plant in a building, and therefore no account could be taken of the rush of air through the dampers, due to the motion of the engine, thus rendering the results useless for all practical purposes.

The following formulæ were deduced as a result of the experiments conducted by Messrs. Von Borries and Tröske, and are based on the diameter of the blast orifice:—

(a) If h = height of top of chimney above orifice of a straight pipe,
and d = dia. of blast orifice,
then $h = 14\,d$.

(b) When D = dia. of top of chimney, then $D = 3.8\ d$.

(c) When D^1 = dia. bottom of chimney would have, were it extended downwards to the level of the orifice, then $D^1 = .65\ D$.

(d) When c = height of smallest dia. of chimney above the blast orifice, then $c = .4\ h$.

It was also ascertained that the correct taper for a chimney was approximately 1 in 12, and its length should be equal to three or four times its smallest diameter.

Experiments have shown that the cross-sectional area of a straight chimney may be made, with advantage, about 12 times that of the blast orifice, and taper chimneys may be increased in area at the base about 12 per cent. in excess of that of straight chimneys. It has also been shown that the base of straight chimneys should be from 30 to 36 inches above the top of the blast orifice.

It is generally assumed that in the chimney the vacuum around the jet tends to solidify it and thus prevent contact with the chimney until it reaches the top, and this view is to a certain extent supported by the results of experiments conducted by the American Master Mechanics' Association. These tests showed that the jet does not fill the chimney at or near the bottom, but only at the top. Indeed, the latter should be preferably the case. When making calculations for the design of petticoat pipes, these facts should be remembered.

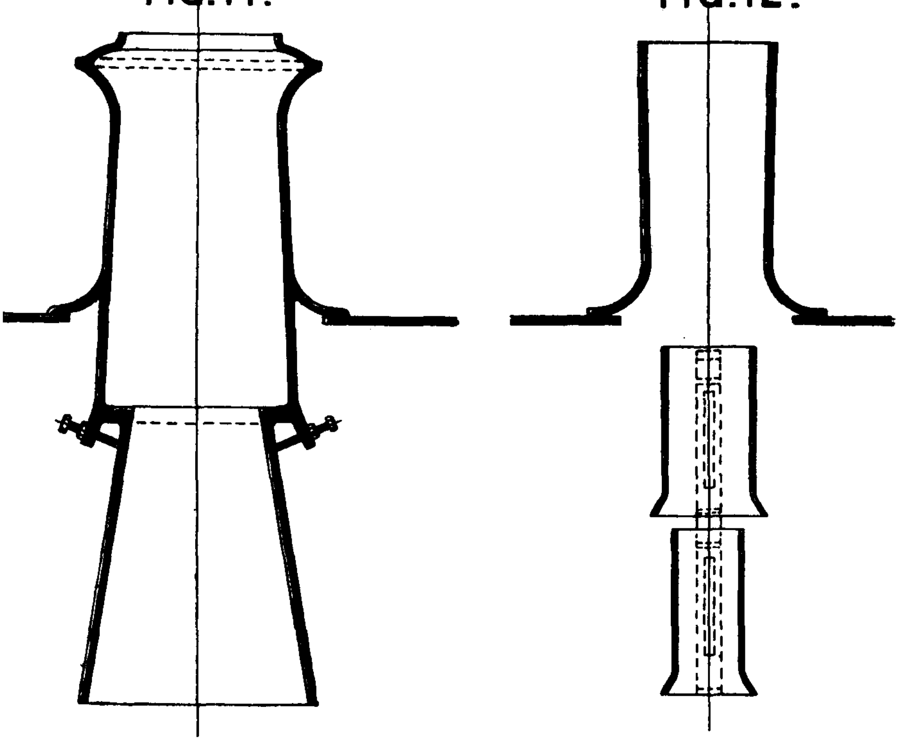
Readings of vacuum gauges in inches of water, show that the vacuum between the wall of the chimney and the jet at the given positions are as follows:—

	inches.
One-third of the length of chimney from its top	1.5
Mid-way ,, ,, ,, ,,	2.52
Seventeen inches from its base	3.61

These readings point to the fact that the larger the annular space surrounding the jet the higher the vacuum, and vice versa. A reading taken at a point mid-way between the roof of the smokebox and the orifice on a line with the centre of the brick arch, showed that the vacuum at that position was 2.54 inches of water. The vacuum may be increased by raising the boiler pressure or increasing the weight of steam exhausted per unit of time.

When the position of the blast orifice is below the centre line of the boiler, a petticoat pipe or cowl, Fig. 11, is interposed between it and the chimney. This is, in some cases, fastened up tightly against the base of the chimney, forming with what is practically an airtight joint, a downward extension or internal chimney. In other cases, one

FIG. 11. FIG. 12.



ARRANGEMENT OF PETTICOAT PIPES

or more cowls are suspended from the smokebox roof by means of slotted hangers, as shown in Fig. 12. They are arranged in a telescopic manner, annular spaces being provided between each cowl and between the top one and the chimney. This arrangement is more frequently applied to simple than to compound engines, in order to obtain a reduction in the comparatively high pressure exhaust of the former. In compound engines the chimney is frequently extended downwards to within about 2 feet of the orifice.

Experiments carried out on the L. and Y.R. have shown that the best results with cowls are obtainable when the bottom of the cowl was $1\frac{1}{4}$ inches above the centre line of the boiler. They should be flared at the lower end to slightly over four times the diameter of the blast orifice. They should also be made to taper from $\frac{1}{2}$ inch to 1 inch per foot, the largest diameter being at the top. The smallest diameter should be approximately a quarter of that of the boiler barrel.

The efficiency of the petticoat pipe is mainly due to its forming a larger orifice through which the exhaust steam jet must pass, thereby augmenting its induction action by solidifying it, it being neither essential nor desirable that the jet should come into actual contact with it.

To obtain the best results the smoke should have free access to the chimney. This may be done if the orifice is in a high position, by providing the base of the chimney or cowl with a bell mouth, or by placing the orifice below the chimney a distance about equal to the diameter of the latter.

In conclusion, the author hopes that the paper will be productive of a good discussion, as the subject is one on which an extremely small amount of information is available.

APPENDIX.

L. & N.W.R BLAST PIPE EXPERIMENTS.

1. *Specially Shaped Blast Pipes in Engines fitted with Spark Arresters.*—In consequence of the "Experiment" class engines fitted with spark arresters not steaming satisfactorily, a blast pipe was tried having the bush fitted 3in. down from the top of the pipe, in order to cause the steam to strike the chimney 3in. lower. It was found with this blast pipe that the steaming of the engine was greatly improved, and all the "Experiment" engines fitted with the Crewe type of spark arrester have since been similarly fitted.

2. *Special Blast Pipe Bush for the "Precursor" Class.*—In May, 1909, a special bush was fitted in the blast pipe of a "Precursor" engine. It was made $5\frac{3}{8}$in. in diameter, the idea being to reduce the coal consumption, and also the back pressure in the cylinders, thus allowing the engine to run more freely. This engine was kept under observation for some time, but no difference was noticed in the

coal consumption as compared with engines of the same class fitted with standard blast pipe bushes.

It was then decided to open some standard bushes from $5\frac{1}{4}$in. to $5\frac{3}{8}$in. diameter. This was done, and the engines fitted with the $5\frac{3}{8}$in. diameter bushes proved quite satisfactory.

As the special bush was more expensive to make and no particular advantage was derived, it was decided that the present standard bush should remain, but be made $5\frac{3}{8}$in. in diameter.

In December, 1910, it was decided to revert to the original standard blast pipe of $5\frac{1}{4}$in. diameter for these engines, the reason given being that the engines were then continually taking assistance, which was not the case when they were first turned out, and this was attributed to the blast pipe having been opened out to $5\frac{3}{8}$in.

3. *Rectangular Blast Orifice for "Experiment" Engine No.* 2630.—When this engine left the works, the area of the blast orifice was $26\frac{1}{2}$ sq. ins. ($6\frac{5}{8}$in. × 4in.). This was 7 sq. ins. over the standard bush. It was only with difficulty that sufficient steam could be maintained to work light express and local trains, and on several occasions time was lost. The area was then reduced to 24 sq. ins. ($6\frac{3}{8}$in. × $3\frac{3}{4}$in.) and this effected a considerable improvement in the steaming, which was quite free enough for light express work, but was far from good enough for heavy trains. Moreover, the fire had to be watched most carefully all the time, and an excessive damper opening was required.

It was not considered to be worth the expense to fit a still smaller bush, and it was therefore decided to put a standard blast pipe in the engine.

4. *Variable Blast Pipes.*—A "Precursor" tank engine (4-4-2), No. 1164, was fitted in 1910 with an arrangement for altering the area of the blast pipe orifice from the footplate. This consisted of a large torpedo placed vertically in the mouth of the blast pipe, so that when moved in an upward direction the area was increased, and vice versa.

The apparatus was also fitted to a number of "George the Fifth" and 5ft. 6in. six-coupled superheater side tank engines, but was subsequently removed from these and the standard type fitted.

It remained on engine 1164 until August, 1915, when the blast pipe was found to be worn out, and as the gearing had apparently not been used for some considerable time it was removed.

DISCUSSION.

The President: Gentlemen,—I am very glad to be present this afternoon to be able personally to congratulate the author on the interesting and useful paper he has just read to us. The preparation of the detail of such a paper entails much research and trouble on the part of the author, but the study of a subject such as he has chosen is in itself a very valuable educational training. The Council of this Institution is always glad to receive papers from the Graduates, and I am sure I voice the opinion of the Council and all others present here this afternoon in thanking Mr. Dunn for his paper. The subject of the paper refers to two items in the construction of a locomotive which play a very important part in the success or otherwise of any particular type. Unless an engine is a free steaming one, it is not economical, and certainly becomes a nuisance to everyone from the fireman to the superintendent, in fact it becomes a "report collector." I do not suppose there are many parts of the locomotive which provide greater opportunities for debate. There are such very strong differences of practice even on locomotives of practically similar type in other respects. An engine has to be made to steam with a light train and also with a heavy train, and in the latter case a much larger volume of steam passes up the chimney, and there is a greater pull on the fire. The design, however, of the blast pipe may be correct and very satisfactory for one method of firing but not for another, and again, the "steaming" of an engine may be improved by using the back damper instead of the front damper in engines fitted with two ashpan dampers. I mention these little matters as they point to the advisability of practical tests being made and carried out in actual service before the final position and dimension of the blast pipe is decided upon in any new type.

The author stated, and rightly, that the presence of an exhaust injector had a bearing on the diameter of the blast pipe orifice, due to the fact that there is less back pressure.

Personally, I am very much against variable blast pipes consisting of the hinged type, because in addition to the difficulty of getting them worked intelligently, there is also the chance of the cap not coming down "truly," and thus deflecting the blast wrongly.

Your President last year was Mr. Maunsell, of Ashford, and I am sure members will be interested to know that the two new types of locomotives recently put into traffic on the South Eastern and Chatham Railway are most excellent "steamers," not only with heavy trains, but with light loads, which is saying a good deal, because it is not easy to make engines "steam" well under both conditions. I hope Mr. Clayton, who is here this afternoon, will give the meeting some details of the dimensions and also of the equipment of the smokebox generally of the two classes of engines I have referred to, because I can say from personal experience they are excellent "steamers," and so the information will be of great interest to the Institution.

Mr H. W. Dearberg: I am sure we all second what has just been said about the good paper we have had, especially as it has come from a Graduate. I think it is all our wish to encourage this sort of work, particularly so as the Graduates very often bring forward subjects which older engineers might consider elementary.

One point on which I cannot quite agree with the author, is that sufficient experimental work has not been done on this question. I think all locomotive engineers, at least those who have had a good deal of running experience, know very well what it means to have the blast pipes and the smokeboxes and grate areas in good proportions, and I think many engineers have done a good deal in this matter.

Passing on to the formula of Von Borries and Tröske, this gives a diameter of blast pipe that is much too small, and the coefficient would be far better if it were increased to .168. I took a standard engine which I knew to be a good "steamer," and by this formula the result gave a blast pipe $3\frac{5}{8}$in. in diameter; the actual engine is steaming well with a $4\frac{3}{4}$in. blast pipe, so I think the coefficient could very well be altered to .168.

I have here some results of experiments taken from a standard engine, which I think were probably amongst the most exhaustive experiments ever carried out. They show that the ordinary blast pipe fulfils all necessary requirements, and that it is not necessary, under ordinary circumstances, to go in for variable blast pipes at all. There is rather a good deal of it, so I will merely give a few extracts.

The load was 347 tons, including engine and train (these experiments are about 20 years old), and the distance over which the experiments were carried out was $29\frac{1}{4}$ miles, diameter of blast pipe $4\frac{3}{4}$in., orifice level with top row of tubes, chimney 18in. diameter and 3 feet long, grate area

20.65 square feet, area through the tubes 3.43 square feet, cylinders 18¼in. × 26in., wheels 6ft. 6in. in diameter.

Starting up an incline of 1 in 264, the vacuum taken in the centre of the chimney halfway up was 10in. water pressure, with a cut-off of 44 per cent., the steam exhausting at 78 per cent., boiler pressure 140lbs. Level with the middle row of tubes, halfway between the blast pipe and the smokebox door, the vacuum was ¾in.; level with the top row of tubes, halfway between the tubeplate and the blast pipe, 3in.; level with the bottom row of tubes, halfway between the tubeplate and the blast pipe, 3in.; back of brick arch, second row of tubes from bottom, 3in.

Again, selecting a speed of 55 miles per hour, engine going down grade of 1 in 264, centre line of chimney 3⅛in., vacuum level with top row of tubes ½in.; level with top row of tubes, halfway between tubeplate and blast pipe, 1¼in.; level with bottom row of tubes, halfway between tubeplate and blast pipe, 1¼in.; back of brick arch, second row of tubes from the bottom, ½in.; just inside fire door $^1/_{16}$in.; back of ashpan ⅛in.; centre of ashpan ⅛in.; cut-off 25 per cent.; steam exhausting at 66 per cent. Temperature in smokebox in first case 525° F., in this case 500° F. This shows that an ordinary blast pipe was doing its work well, and suiting the steaming qualities to the load.

On another occasion, with the same engine, but with a 237 tons load, on a rising grade of 1 in 264, cut-off 22 per cent., and exhausting at 64 per cent., the centre line of the chimney showed only ¼in. vacuum; at middle row of tubes, halfway between blast pipe and smokebox door, ½in.; level with top row of tubes, halfway between tubeplate and blast pipe, 1¼in.; level with bottow row of tubes, halfway between tubeplate and blast pipe, 1¼in.; back of brick arch, at second row of tubes from bottom, 1in.

On a very opposite occasion to this, when the engine was finishing its trip, with cut-off at 17 per cent., the vacuum in the centre of the chimney was $^1/_{16}$in.; level with the middle row of tubes, halfway between the blast pipe and the smokebox door, ⅛in.; level with top row of tubes, halfway between tubeplate and blast pipe, ½in.; level with bottom row of tubes, halfway between tubeplate and blast pipe,½in.; back of brick arch, second row of tubes from bottom, ¼in. The vacuum in all cases was measured by the water gauge. The steam pressure in all these cases was practically within the blowing-off point, 140lbs., and varied only about 5lbs. I think, if you will take notice of these figures, you will see how the vacuum automatically comes down to suit the running conditions, and in a case like this it shows the blast pipe to have been very well considered in the first place, also the area of the grate and tubes. I consider that it also shows quite clearly that, with proper proportioning, it is not necessary to resort to a variable blast pipe under average circumstances.

I think that the diameter of the blast pipe should be based upon the grate and tube area, for this reason; the amount of steam passed up the blast pipe must always depend on the evaporative capacity of the boiler, and this should be the real basis. If you base calculations on the cylinders you are liable to be rather out, because possible changes of boiler have not been taken into account.

I have some more figures here of a large number of standard passenger engines, in which it is very interesting to compare the grate areas in square feet with the area in square inches of the blast pipe. These particulars are of modern engines.

25 sq. ft. grate area,	area in sq. in.	of	blast	pipe	21.6
24	,,	,,	,,	,,	19.6
23	,,	,,	,,	,,	19.6
23	,,	,,	,,	,,	19.6

These two latter engines have exactly the same proportions but belong to different lines. Another engine has 26 sq. ft. of grate area and area of blast pipe 17.7 sq. in. This is a great reduction. In one case of a modern four-cylinder engine, which consumes a good deal of fuel and is not at all a free-running engine, the area of fire grate is 31.5 sq. ft., blast pipe only 19 square inches of area. I think that was largely the cause of the trouble. Taking some old passenger engines, several have averaged for 17 square feet of grate area, from 17 to 17.7 square inches of blast pipe area. I think that accounts for a great many of the older engines being notable for free-running; they had such a large proportion of area of blast pipe to area of grate.

Another point that struck me is that the author speaks of the gases escaping up the sides of the chimney. This might be theoretically correct and fairly true in practice, but I think, if you will take the trouble to notice an engine actually throwing sparks, the sparks generally come from the centre of the exhaust. I have watched an engine for many miles, and I have generally found the majority of solid matter to be shot straight up the centre of the exhaust.

This leads me to believe that the steam should fill the chimney just the same as the steam should fill the cone of a vacuum exhaust ejector.

As regards the shape of the chimney, I cannot record anything very different from other people's experiences, but I have found that, with straight chimneys, one slightly smaller at the top will certainly improve the steaming of many engines, rather than a chimney tapered the other way. Moreover, as regards diameter, I think if the diameter be increased too much, a bad steaming engine results. I know of one class of engine fitted with a smaller chimney which gave no more trouble and the blast pipe did not have to be altered. I think the steam should always fill the chimney, and so obtain a larger vacuum.

Mr. C. Salter-Whiter (S.E. and C. Railway): I think from the results of experiments that it is necessary that the steam should fill the chimney, and that on the South Eastern and Chatham Railway it has been borne out that, if the chimney is not filled or very nearly filled, a bad steaming engine results. Recently it was decided to standardise the number of lengths of chimneys. Formerly there were about 15 or 20 different lengths of chimneys of the same diameter, and we decided to try and reduce this number if possible. With a little alteration in length, never more than a few inches, we reduced the number to seven, and at the same time all the spark arresters were removed and cones and short blast pipes replaced by longer blast pipes. It was also intended not to use any petticoat pipes at all. Thus, in one or two instances the new chimney was shorter, for if the next longer chimney had been fitted it would not have cleared the loading gauge; but the new blast pipes were longer than those with which the engines had been previously fitted. The consequence was, the engines in question did not steam well, although in their original condition they were very free steaming engines for their size. The only cause which I could see, particularly as no other alteration whatever had been made, was that there was too large an annular space at the top of the chimney between the chimney walls and the outside of the jet, and this seems to prove that when this is the case a better steaming engine does not always result.

Referring to the conditions prevailing before the experiments were carried out by the New York Central Railroad, the author states that the steam jet from the circular blast pipe altered, as it neared the top of the chimney, to a rectangular shape, and left a space between it and the chimney walls at the back as well as the front of the chimney.

I cannot quite see how the jet can change from the circular form, which must be the shape at the blast pipe orifice, to a rectangular form at the top of the chimney. I quite understand perhaps that it is somewhat beaten back by the wind at the front, which would, in the absence of a capuchon, or wind screen, tend to force it over to the back of the chimney, but the author states that there was also an annular space at the back, which I cannot account for. Perhaps some member with more experience could explain this. Again, the author states that the sides of the jet took a slightly curved concave form. I was always under the impression that the sides of the jet were perfectly straight, and enclosed an angle of about 8 degrees. It was on this figure that the experiments I have just described were based, and it was found in practice to be very nearly right. I can understand it curving after it leaves the chimney, but between the blast pipe orifice and the top of the chimney I do not see what conditions prevail to cause it to take a curved form.

I may say that all S.E. and C.R. standard chimneys are parallel, 16in. internal diameter and are made of cast iron, and in some cases, where it is not possible to use a long blast pipe owing to the shortness of the chimney, a long petticoat pipe is used in conjunction with a short blast pipe. We used to have 15in. diameter chimneys for 17in. and 17½in. cylinder engines, but now all standard engines are fitted with a 16in. diameter chimney. The diameters of the blast pipe orifices only vary ¼, from 4¾in. to 5in. So far as I am aware, these are the only two sizes of blast pipe orifices in use on the standard engines, other than steam carriages and small shunting engines. The standard petticoat pipe is about 14½in. diameter at the top and tapers down to 14in. minimum diameter, which point is about 12in. from the lowest extremity. From the minimum diameter it is bell-mouthed out to 21in. diameter at the bottom. Tender engines are sometimes fitted with chimneys having a capuchon about 1½in. high, on the front half of the circumference, in order to eliminate back draughts as much as possible, and I think that the results obtained with them fully justify their existence on chimneys of all main line engines, which do most of their running in fore gear. Local passenger tank engines are seldom if ever fitted with capuchon chimneys.

Mr. Sanderson (The Baldwin Locomotive Works): The author states, quoting I believe from Meyer, that the most suitable area for a single orifice is 1/200th of the grate area in square inches, and that this rule closely agrees with American practice. The character of the fuel used governs the size of the grate. For the same boiler capacity, cylinder sizes and driving wheel diameter—take for example an engine 20in. × 24in. cylinders—the grate areas might have to be very different. For instance, with anthracite coal the grate area might be about 50 square feet, American practice—1/200th would give a nozzle of 6⅞in. diameter. For the same engine burning bituminous coal, the grate area might be 30 square feet—5¼in. diameter. If you go into wood fuel, you would use a grate for the same size engine perhaps 12 or 14 square feet—only $3^5/_{16}$in. If you go into oil fuel, there is no grate at all! So that, when you refer to American practice, you have to be a little bit more definite as to just what practice you are referring to, as there is great variety of it and great variety in the fuel used.

Now, later on in the paper, the author states that the blast pipes with double orifices find considerable favour in America. Permit me to assure him that there are no main line engines built nowadays to modern designs with double orifice blast pipes.

The "Vortex" pipe he refers to has been experimented with again and again. I had a whole lot of this to do myself. They have not lived past the first test or two.

It may interest members to know that in certain of the tests made by the Master Mechanics' Association some years ago, and referred to by the author, the chimneys were drilled with small holes from the bottom to the top. Small sliding pipes were put in through these holes. The ends were turned down and it was arranged that the test would be started with all the pipes pulled out close against the inside of the chimney. As soon as the engine was running under constant conditions the pipes were pushed in $^1/_{16}$in., and then another $^1/_{16}$in., they would show smoke. By and by, as the pipes were pushed far enough in to reach the confines of the exhaust jet, it would be mixed with steam, and then it would show all steam. In that way they were able to draw an exact diagram of the shape of the exhaust. A curious thing was found which has reference to the shape spoken of by the author, that the exhaust assumes. Within certain limits—I do not mean for extreme proportions—within certain reasonable limits, the exhaust jet will adjust itself to the shape of the chimney. It will follow it. They always found this jacket of smoke around the jet of steam clear up right close to the top. There was always an envelope, as shown by these pipes, of smoke unmixed with steam, following up the jet.

Now in connection with the nozzle, here referred to as the Pennsylvania recent pattern, I have in my office a report from Mr. Young, Engineer of Tests, and some correspondence I have had with Mr. Young, which shows very clearly that it is not the purpose of this device to fill the stack so much as to roughen the exhaust. The exhaust was too smooth. It did not get hold of the smoke and take it up with it, and what they were doing was to roughen the surface of the jet so that it would grip, as a coarse file would grip when going through cotton wool, and carry the smoke along with it by friction. That was the purpose of this splitting up of the surface, of the surface only, of the jet. They found a considerable advantage in it and their tests were very, very thorough. I think there were 29 series of tests run with one engine. Then the tests were repeated with engines of other classes, going as high, I believe, as 16in. and 17in. of vacuum in the smokebox and developing something like 58,000lbs. drawbar pull. I repeat, it was not so much to fill the stack as to roughen the surface of the jet and thus make it act on the smoke more by friction and carry the smoke along with it.

I think those points might be interesting in connection with these matters.

Mr. Clayton (S.E. and C. Railway, Ashford): I am sure Mr. Dunn deserves great credit for the very able paper he has placed before us this afternoon. Like other speakers before me, I hope there will be more Graduates who will read papers before the Institution. It should be very encouraging to them that one of their number can get up what I can call a very instructive paper on this interesting question of blast pipes and chimneys.

Probably no other subject has received the attention of locomotive engineers in the past to the same extent as this. I should like to say first of all that, in my opinion, vacuum in the smokebox represented by inches of water is somewhat of a snare and a delusion. Over and over again experiments have shown that we may get engines which do not steam and will yet show a good vacuum, and, on the other hand, you get engines showing a very poor vacuum and yet they steam very well. There are so many problems involved in it, from entrance of air into the ashpan, sizes of air spaces in grate, position of brick arch, area through tubes, position of the blast pipe with respect to tube-plate, size of blast orifice, size of chimney, and the relation that all bear to each other. I do not think any locomotive engineer could devise a formula to take care of all these points. The first essential is that the engine must be designed with ample proportions as regards heating surface, grate and tube area, cylinder volume, etc., and all the parts such as ashpan, brick arch, blast pipe, etc., in correct relation to each other, as experience and knowledge of existing engines prompt. After this, actual test will show how the engine steams, and by a little adjustment here and a little adjustment there, you eventually succeed in making the engine so that it can maintain itself along the road. As we all know, it is not a bit of good to the traffic department if it cannot keep time, and no one knows it more than our President, and when he says that an engine has been evolved that does steam well, you may take it from me that it is so.

I may tell you that at first the engines he has referred to were not good "steamers." The first experiments showed we had got something slightly wrong. We certainly made sure of one good point—we got the blast pipe well away in front of the tubes. A blast pipe pushed against the tubes is very detrimental. It just plays on the centre of the tube area and causes sparks to be thrown. The gases must have a nice even flow from all the tubes, and in the particular engines referred to this point has received special attention. We had also a cone in the chimney, as this was the practice based upon experience with other engines on the system, but the engines did not steam very well. First we removed the chimney cone altogether and left the main chimney plain. The steaming of the engines immediately improved by fifty per cent.

We could not maintain in the first instance more than about 150lbs. of steam. By just removing the inside cone altogether and leaving nothing between the top of the blast pipe and the chimney orifice, the engine easily held about 170lbs. That was a very gratifying change for the better. We next tried reducing the orifice slightly, about ⅛in. diameter. That had no apparent effect—if anything it was rather worse. It is generally thought that, by reducing the blast orifice, one can get a fiercer draught upon the tubes, and that should therefore have put the matter right; but it did not. We went back to the original orifice and tried again—results much the same. The engine was however certainly improved since it was originally turned out. We came to the conclusion then that there was too great an annular space between the blast cone and the chimney at the top, so that the air could probably get back again into the smokebox, so we put in an inside liner which was not anything like the reduction of the first cone, and, strange to say, struck it just about right. The engine is fitted with exhaust injector, so that we have one of the factors the author mentions in his paper that affects the question. The engines now are found to steam perfectly and under practically all conditions. We did not make many experiments, but it is a fact that the results were obtained by just a little consideration here and there and not trying more than one thing at a time. If you alter several things at once you do not know which has effected the improvement when this takes place; but by altering one thing only at a time, you are sure of your ground as the experiment proceeds.

With regard to back pressure, that is another snare and delusion. Look at any indicator diagram taken from a locomotive, and tell me if there is any appreciable back pressure shown which can be traced to the small orifice. The engine has so much fuel to turn into heat units and you must get it out in work in order to get the train along. Within small limits, a reduction on the orifice does not apparently affect the indicator diagrams.

With regard to the variable blast pipe arrangement which the author has shown us, I have little respect for it, for two reasons. Firstly, one main line company in this country which took over a section of line where many of the engines were so fitted, began by removing this automatic variable blast gear. Secondly, it is a complication, and the simpler you can keep your locomotive the better. These things are all liable to give trouble, and although it is automatic, yet the complication is not probably worth the little theoretical benefit you get from it. Now automatic variable blast pipes are all right if you have a coal premium, but you must have a coal premium, because the drivers won't use them judiciously—they will always use the opening they can get along with best on the road, and it is generally the smaller orifice.

It is a fact, I think, that the exhaust steam should not fill the chimney, but there should be an annular space of 1in. to 1½in. round the cone of steam. Professor Goss, in America—no one has done more in experimenting in this way—showed us that the cone of the blast is rather a series of balls coming out of the blast nozzle until you get very high speeds when they follow one another so quickly that it has become practically a straight-sided cone with recesses which entrain the air and gases from the smokebox, etc. In the injector cone, the steam jet must not fill the orifice into which the water is drawn, otherwise the water could not get in, and the same thing applies, I believe, to the blast pipe.

With regard to the Pennsylvania arrangements—"nibs" we called them on the Midland—sometimes it was found that one, two, or four, round the blast pipe, just to roughen the column of steam and make the smoke and gases as it were "catch on" to it, had a very good effect.

With regard to this wonderful $7\frac{1}{4}$in. blast pipe on the Pennsylvania Railroad, I wonder what was the size of the engine. Perhaps the author would tell us in his reply.

Mr. Sanderson: The engine referred to had cylinders 25in. × 32in.

Mr. Clayton: If it was such a big engine with 25in. cylinders, then we have nothing to compare with it.

I hope we shall have more Graduates responding to the high spirit and thorough manner in which Mr. Dunn has presented this paper.

I should be sorry to think that I had given the impression that this question of the blast pipe and chimney can only be settled by rule-of-thumb. I want particularly to be understood first of all as saying that the engine must be designed with ample and proper proportions as regards cylinder capacity, grate, heating surface, tube area, relation of blast orifice to tube area, size of chimney and blast orifice, etc., etc. This was instanced in the case of the engine referred to as being a good "steamer." It has good proportions of grate area, for its heating surface and cylinder capacity and the relation of grate, brick arch, tube area, superheater capacity, blast pipe and chimney were properly thought out. This is proved, I think, by the fact that so little subsequent alteration was required to make the steaming of the engine perfect.

Mr. Sanderson: There is one more thing I would like to mention. I think it belongs to this discussion, and has not been referred to by any of the speakers, nor in the paper. I believe that the tests made by Professor Goss and by the Master Mechanics' Association and at the St. Louis Exposition and by the Pennsylvania Railroad, all show that the lowest position in which you can possibly get the exhaust nozzle is the most effective, in that there is a greater distance for entrainment or friction between the jet and the smoke before it enters the stack. Of course, the danger of throwing fire is increased, but in our country we use spark arresters devised to overcome that; the low position has been found the most effective for the same size nozzle and stack diameters for producing entrainment. That point I think was not brought out.

Mr. Dearberg: There is one other point I might raise while we are on this subject, that is with reference to the firebars. I think they have a very important bearing on the working of an engine, especially engines working for considerable distances. I have found that if the firebars are very deep, or too close together, a greater blast will be required to make the engine steam, especially towards the end of the journey, for the simple reason that clinkers have a tendency to collect down between the bars and choke the air spaces. This was the case in one particular engine. By putting in bars less deep, only half the depth, and spacing them a little wider apart, the defect was remedied and it was not necessary to alter the blast pipe. In its original state the engine steamed pretty well at first, but towards the end of the journey it became a very bad steaming engine. It took some time to find this out, but when altered it made quite a good "steamer."

Mr. Kelway-Bamber: We have had an excellent paper and a useful discussion. We have heard of two recently constructed locomotives which are said to steam well and to respond very satisfactorily to all service conditions.

If we could know something of those conditions, *e.g.*, the weight and speed of the trains, the distance hauled, the grades negotiated, and gross and net ton mileage per trip, it would greatly enhance the general interest of the paper.

The President: Incidentally, I might say that the goods engine, which is of the 2-6-0 type, is conveying about 85 loaded goods wagons on fairly easy gradients, but at comparatively fast speeds. The passenger engine, which is a 2-6-4 tank engine, has worked a boat train to Folkestone, 71 miles without a stop and over fairly heavy gradients out of London. When working an inspection coach on a certain journey, running at high speeds, she steamed just as well.

Mr. G. F. Burtt (L.B. and S.C. Railway): The author of this interesting paper states that two engines, identical in every respect except in the diameter of blast pipe orifices, may vary by as much as ½in.; this appears a very wide range, and the author might perhaps give us an instance of such a difference.

Regarding the variable blast pipe gear, the advantage of uniform blast is very questionable; a heavy blast at starting is an advantage.

I remember some years ago that Mr. Kirtley (L.C. and D. Railway) employed a rectangular variable blast pipe in his early 4-4-0 engines, but it was not worked from the footplate.

With reference to the experiments on the New York Central, it is stated that the exhaust is not required to fill the chimney to obtain a vacuum; this needs a little further explanation.

I should like the author to explain the reference to "cross exhausting." This seems to be quite a novel operation.

The Adams' "Vortex" pipe was fitted to the standard passenger (Gladstone or 0-4-2 type) and to a 0-6-0 goods engine on the L.B. and S.C. Railway many years ago, and was highly satisfactory, and is still used on these two classes. These engines have 18¼in. x 26in. cylinders with the steam chest underneath and the exhaust passing up between the cylinders.

Mr. Salter-White referred to the "capuchons" not being fitted to tank engines, as they run in both directions. This could be got over, as is or was done on the Belgian State Railways, by making the capuchon a loose piece to revolve round the chimney, so that the driver can turn it to suit the direction in which the engine is travelling.

Mr. Rodgers (L.B. and S.C. Railway): Mr. Dunn's paper on the blast pipe has been very comprehensive, and we are very pleased to have this subject brought to our notice again, because it is one of those important items which seems to elude locomotive engineers when coming to a final conclusion as to what is best. I think myself that the conditions of the smokebox, its volume, with the relations of height, diameter of chimney and petticoat to blast pipe, have a great deal to do with the size of the cap and its position in relation to the tube levels. You find in many cases that a blast pipe is up to and sometimes above the top row of tubes, and the engine steams very well, such as the Adams' blast pipes which Mr. Burtt has just referred to on the Stroudley B class engines. These blast pipes are still retained on those engines simply because they are doing excellent work. But one cannot look for good steaming with a small or large nozzle unless the smokebox is kept in proper condition. If there is a drawing of air through any part, then, of course, immediately the steaming qualities of the engines deteriorate, and many complaints come in from engines failing to maintain steam for that reason.

The quality of coal used has also very much to do with the diameter of the nozzle. Where you get friable coal, then the small diameter nozzle has a tendency to pull the small particles right through the tubes and cause great waste of fuel.

The diameter and length which might suit one district will not suit another, and I am of the opinion of the late Mr. Burnett that it is only by actual trial that we are able to arrive at the proper diameter, length, and position of the blast pipe and its nozzle.

Professor Dalby, in his "Steam Action," deals with the same subject as Mr. Clayton mentioned in speaking of Professor Goss's American testing plant experiments. I only wish to mention it in the meantime because it is part and parcel of the subject.

I am inclined to think that there is something more than the mere filling of the chimney with the exhaust. We have simply looked for a jet of steam *filling* the chimney, and entraining the gases and causing the vacuum in the smokebox. That I think is not quite the whole of the argument, as Mr. Clayton has pointed out.

Mr. Maitland (L.B. and S.C. Railway): I have had a little experience of the differences in blast pipes, and I would specially endorse Mr. Clayton's views as to the necessity for the inner liner for the chimney or the petticoat of the chimney to be fitted absolutely true to the chimney and blast pipe, and also that they should be properly designed. I think a great deal, though not all, of the trouble which in the past has been attributed to blast pipes, also trouble with the engines not steaming because the blast pipe was not of the proper size, could be found in defects either in the design or the fitting of the liner in the chimney. At the same time that does not in any way detract from the importance of the question of the correct size of the blast pipe. I am convinced that the only satisfactory way of arriving at the proper diameter of the blast pipe is by actual practical observation. Conditions differ so much in certain ways, not only conditions depending upon the fuel, but also in regard to the amount and kind of work the engine has to do. In many cases engines are called upon to start away from bad and difficult places, particularly with goods trains, and they become, if one might say so, "winded," or thoroughly short of steam. They do not appear to possess the capability of recovering themselves, and therefore the kind of work is one factor which I think should be taken into account when the design of the blast pipe is considered.

We seem to get the right results in practice, but as regards the theory of blast pipes we do not seem to get much further, and therefore I welcome Mr. Dunn's paper as a very valuable contribution on a subject which has for many years seemed to puzzle the theoretical views of engineers.

CORRESPONDENCE.

Mr. Smith Mannering (L.B. and S.C. Railway): The author of the paper states that the important subject of blast pipes and chimneys has been almost entirely neglected by locomotive engineers. Surely the subject is of such vital importance to the successful steaming of an engine that they do not neglect the matter, but on the contrary, give all the attention to it that it rightly deserves. The author has made a special study of this interesting question, and his paper has been very carefully and thoughtfully mapped out. He deserves, therefore, great credit for his paper and the manner in which he has so thoroughly dealt with the subject.

I should like to mention the keen interest which Mr. Macintosh, of the Caledonian Railway, took in this subject when he was Chief Locomotive Engineer of that Company. This engineer once mentioned to me the arrangement of blast pipes in his express 4-4-0 main line engines running between Glasgow and Carlisle. He pitched these pipes $^5/_{16}$in. forward I think. I had a trip from Glasgow to Carlisle and back on one of these locomotives. The driver told me that his blast pipe had been pitched forward $^3/_{16}$in. at first, but whilst a great improvement was noticed in hill climbing, the results were not so good in level running; the pipe was therefore thrown out another $\frac{1}{8}$in., making $^5/_{16}$in. all, with the result that he could do anything with the engine afterwards. Some of you may have heard of this arrangement on the Caledonian Railway, since the author does not mention it. I do not know of any other locomotive engineer who has tried this experiment. Mr.

Macintosh was most emphatic as to the benefit of this arrangement on the Caledonian engines. The reason, no doubt, of the success of this arrangement was the centralisation of the exhaust steam in its passage through the chimney at high speeds and of the consequent effects of air resistance, which in the ordinary central relation between the blast pipe and chimney would have a tendency to cause the exhaust steam to cling to the back of the chimney and cripple the desired effect of filling it.

The Author, in reply to the discussion, said: I must thank you all very much for the kind manner in which you have received my paper. The subject is not by any means an easy one to deal with, owing to the lack of available information and the great differences of opinion in practice.

The President stated that bad steaming engines were uneconomical and a nuisance, and I can thoroughly endorse what he has said in that connection. As to the necessity of practical tests being made, this must be admitted, but more reliable theoretical data are desirable from the point of view of the designer, and these should be obtainable. The President does not appear to be in favour of the hinged type of variable blast pipe, but although I have had no experience of them myself, I believe they are very satisfactory on the G.E.R. The particulars of the working conditions of the two new S.E. and C.R. engines are very interesting, and I think 85 loaded goods wagons is an extremely good load for a 2-6-0 type engine. On the L. and N.W.R. the average load for the 0-8-0 superheater engines is 80 loaded wagons.

Mr. Dearberg does not agree with me that insufficient experimenting has been done. I should rather have said that very little information is available, because one can find very little indeed anywhere with regard to results of British blast pipe experiments. Mr. Dearberg has given us particulars of some experiments, Stroudley's I believe, which show very good results indeed for an ordinary blast pipe, the best, in fact, I have seen. With reference to the comparison of grate areas in square feet to blast orifice areas in square inches, there does not, on the whole, appear to be much chance of establishing a definite relation between the two.

The same speaker says he has watched an engine throwing sparks for several miles, and that he had come to the conclusion that most of the solid matter came up through the centre of the exhaust. This would most probably be the case with *solid matter*, since the pressure of the jet, as stated in the paper, is greatest at its centre. With reference to the *smoke* escaping between the jet and the chimney walls, Mr. Dearberg will, I am sure, not mind if I maintain the statement in the paper. In this connection reference may be made to the tests described by Mr. Sanderson. Certainly the exhaust jet should fill the chimney for the *last half inch or so at the top*, but not for its full length. Mr. Dearberg mentions a very interesting fact in stating that the depth and spacing of the firebars influences the steaming of an engine; this is a point well worth consideration.

Mr. Whiter's account of the difficulties experienced by the S.E. and C.R. after standardising their chimneys, is very interesting and shows how much care has to be taken in designing blast pipes and chimneys. I obtained particulars of the tests on the New York Central R.R. from one of the American papers, I believe the "Railway Mechanical Engineer." I agree with Mr. Whiter that the fact that there is a space at the *back* of the jet seems rather strange. But I may add that the article in question was illustrated with sketches showing the shape of the jet in relation to the chimneys, so there is no doubt as to the correctness of the information.

In connection with the shape of the exhaust jet, perhaps the term "concave" is hardly correct, "indentations" being a better word. The sides of the jet are *approximately* straight lines, and it is interesting to know that the assumption that these are at an angle of 8 degrees with the vertical has been found in practice to be very nearly correct. Prof. Goss (see Mr. Clayton's remarks) says that the exhaust jet consists of a number of balls merging at high speeds into what is practically a straight line, the spaces between the convex surfaces being the "indentations" referred to.

The particulars of the S.E. and C.R. blast pipes, petticoat pipes and chimneys are very useful, and we are indebted to Mr. Whiter for them. I am sorry I did not mention the "capuchon," or wind deflector, in the paper, as it is a very useful device, and as Mr. Whiter says, fully justifies its existence. On the line with which I am connected chimneys are not sent out to the steam sheds with "capuchons," which are fitted only as an expedient in the case of bad steaming engines.

I thank Mr. Sanderson for drawing attention to American practice. The formula quoted in the paper was for coal burning engines. I note that no modern American engines are now equipped with double blast orifices. In referring to the " Vortex " blast pipe, I presume he means the double exhaust arrangement with one nozzle surrounding the other and not the Adams patent " Vortex " blast pipe. The tests of the Master Mechanics' Association prove conclusively that the smoke forms a jacket round the exhaust steam jet. With reference to the Pennsylvania R.R. blast pipe (Fig. 6), it is interesting to learn that the idea of the semi-bridge pieces is not to fill the chimney but rather to roughen the outer surface of the exhaust jet, so that it has a better grip on the gases.

Mr. Sanderson mentions four different experiments which have shown that the lower the blast orifice the better, although the danger of fire-throwing is increased. From Table IV. of the paper it will be seen that in the engines at present running on the L. and N.W.R., the distance of the orifice below the centre line of the top flue tubes varies from 2 to 18 inches, and no spark arrester is in general use.

Mr. Clayton seems to have given up the idea of formulæ for smokebox arrangements and to depend almost entirely on following up the design of existing engines. With reference to the new engines of the S.E. and C.R., the alterations made in order to obtain better results are very interesting, particularly the fact that the reduction of the orifice by ⅛in. had no apparent beneficial effect, but rather the reverse. Mr. Clayton's experience shows again the necessity of having the chimney of the correct diameter at the top. It is interesting to hear that he does not consider that the size of the blast orifice within small limits influences the back pressure to any appreciable extent, since this is to a certain extent contradictory to general opinion.

With reference to the automatic variable blast pipe (Fig. 4), Mr. Clayton apparently does not believe in it, but the reasons he gives for his disapproval do not seem to me to be very sound. His first reason is that the Midland Company, when it took over the London, Tilbury and Southend Railway, removed the variable blast pipes from the engines of the latter, although they had been in use for a number of years. If they were not successful, why had the Tilbury engineers continued to use them? Moreover, why were their latest 4-6-4 tank engines fitted with them? His second reason is that it is a complication, the little benefit to be derived from which renders it hardly worth installing. I grant that it is a complication, but the figures quoted in the paper seem to me to render it worth while.

Evidently Mr. Clayton does not entertain the same dislike for the non-automatic variable blast pipe provided a coal premium is in vogue. The necessity for the latter is quite apparent as the carelessness of many modern enginemen is proverbial, and they would certainly generally use the smallest orifice. In my opinion the automatic type is much preferable, and as regards the smokebox, it is not more complicated. Moreover, it is not necessary to adopt that expensive luxury—a coal premium.

I thank Mr. Bamber for his kind remark and quite agree with him in thinking that further particulars of the new S.E. and C.R. engines and the conditions under which they work would enhance the value of the discussion.

Mr. Mannering, like several previous speakers, thinks my opening remarks are not in accordance with facts. I would refer him to my reply to Mr. Dearberg. Mr. Macintosh's novel experiments and results are very interesting.

In reply to Mr. Burtt, I remember examining the blast pipes of two of our "George the Fifth" engines and noting that the blast pipe of one of them was fitted with a copper liner a quarter of an inch thick, making a difference in the diameter of half an inch. I may say I have not come across a similar instance before or since. While on this question, it might be of interest to members to know that the most troublesome engines in the way of steaming on the L. and N.W.R. are the 0-6-0 18in. cylinder side tank passenger and express goods engines. These engines, both piston and flat-valved, have many different heights of pipe and diameters of orifice, and these details are continually being changed. Mr. Burtt refers to the rectangular variable orifice in use on the L.C. and D.R. some years ago, and I believe that in order to operate this gear it was necessary to open the smokebox door and do it by hand, but in this I am open to correction.

I am asked to explain the statement made in connection with the New York Central tests that "it is not necessary for the exhaust to fill the chimney in order to obtain a vacuum." These tests showed that although there was an annular space throughout the entire length of the chimney, a vacuum was obtained, as shown in the paper. This does not agree with much that has been said here this afternoon, and shows that in spite of the existence of an annular space at the top of the chimney sufficient air could not get back into the smokebox in order to destroy the vacuum.

Mr. Burtt also asks me to explain the term "cross-exhausting," by which I mean the discharge of the left side exhaust from the right side of the chimney top and vice-versa, an operation which takes place when the legs of "breeches" blast pipes converge very near the orifice. The Belgian State Railway tank engine "capuchon" arrangement is very interesting, although it is another of those dreadful complications about which we have heard so much.

As Mr. Maitland says, we do not seem to progress much further in the theoretical part of the question, although in practice we do not do so badly. Of course, the conditions under which the engines are to work are an important factor and must always be taken into account.

In conclusion, I will say that had the paper been presented in normal times it would no doubt have been more up-to-date, for I have been unable to obtain particulars of some fairly recent experiments I had wished to include, owing to the universal shortage of staff. I thank the members for their kind remarks and for the very interesting discussion.