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On the Resistance of the Atmosphere to Railway Trains, and a Means of Lessening the same. By H. BESSEMER, C. E.

The amount of absolute resistance of the atmosphere, to bodies moving through it at high velocities, is still a moot-point, and perhaps in no branch of engineering have we greater discrepancies in opinion, as to the actual loss resulting from this cause. Dr. Lardner, who devoted a good deal of attention to the point in question, arrived at the conclusion, that the atmospheric resistance offered to passenger trains moving at 30 miles per hour, was 15 lbs. per ton of the gross weight of the train, or $1\frac{1}{2}$ times the whole amount of the resistance caused by all the other power-absorbing forces combined. It is easy to see, however, that this mode of calculation must be anything but correct, as the resistance will vary, not according to the greater or less weight of the train, but as the greater or less area exposed to the direct atmospheric resistance, together with the shape of the front or leading carriage. The most generally acknowledged rule is, that at a speed, for example, of 35 miles per hour, the resistance is 6 lbs. per square foot. This is convincingly confirmed by a series of experiments entered into by Mr. Bessemer, who has devoted his attention to this greatly neglected question. He says,

“In my experiments before referred to, I fitted up an apparatus consisting of a horizontal wheel supported by a vertical shaft which was

driven by bevel gear, and connected to a steam engine. The horizontal wheel was keyed firmly to the shaft, and carried upon it a second wheel made of wrought iron, and free to move upon the shaft. This second wheel was placed above the first, and supported upon it by small anti-friction wheels of steel attached to the upper one, so that the upper horizontal wheel could revolve with exceedingly little force. One of Salter's spring balances was attached, by its opposite ends, to one of the arms of each wheel, so that the two wheels were made to move in concert, excepting when any opposing force was applied to the progress of the upper wheel, when the spring balance served to indicate the amount of such opposing force. But as the indications could not be read off during the experiment, I attached to the index a pencil tracer and card, so that when the apparatus was at rest, the resistance which had been indicated on the card could be read off.—Matters having been thus arranged, a model carriage of wood, on a scale of one-sixth the size of those in use upon railways, was attached to the light iron wheel, and the apparatus put in motion. The amount of resistance opposed to the passage of the carriage through the air, was ascertained by the wheel on which it was placed moving on its friction rollers, and indicating on the spring balance the number of the pressure. The speed was gradually augmented from the time of starting, in each experiment; and when the number of revolutions per minute was attained, which was equal to the number of miles per hour previously determined on for each series of experiments, the speed was gradually diminished, till the carriage was brought to a state of rest, when the indication on the card was copied off, and the same experiment twice repeated, so as to obtain, in all cases, the mean of three experiments. The first series indicated a resistance of 2.1 lbs. per square foot of front surface of carriage, at 20 miles per hour; a resistance of 3.2 lbs. at 25 miles per hour; a resistance of 4.5 lbs. at 30 miles; a resistance of 6.1 at 35 miles; a resistance of 10.0 at 45 miles per hour. The last was the highest rate of speed which the apparatus was capable of moving at, without danger of derangement; and the resistance at this rate per superficial foot of frontage of carriage amounted exactly to 10 lbs. I took this speed as the basis of my subsequent experiments, because the various pressures, being expressed in round numbers, will impress themselves more distinctly on the mind than if decimals were used. Having thus ascertained that the pressure amounted to exactly 10 lbs., on the end of the model carriage of 1 foot square, a second carriage was placed between the buffers left open, as is the present practice on railways. The two carriages being put in motion, at the selected rate of 45 miles per hour, the resistance indicated as the mean of three experiments, was 14.1 lbs., so that, striking off the decimal, we have 4 lbs. resistance per superficial foot of the second carriage. A third carriage was connected before, and the experiment proceeded with in a similar manner. The indication was now 18 lbs., showing an addition of 4 lbs. for the third carriage. Three more carriages were successively added, and the result in each case was precisely 4 lbs. per superficial foot. A train of six carriages being thus connected, the spring balance indicated 30.5

lbs., but, as before stated, I throw off the decimal, and thus obtain 10 lbs. resistance for the first carriage, and four pounds for each of the five following carriages, making 20 lbs. resistance for the intermediate carriages, or $\frac{4}{10}$ as much pressure on each of the last carriages as was exerted on the first. Having arrived at this important result, the next stage of experiments, and that on which depended entirely the success of the plan I had devised in my mind, for reducing the atmospheric resistance on the ends of the intermediate carriages, was now to be tried. For this purpose, I had five small hoods of wood, made to fit into, and fill up, the intervals between the ends of each carriage. One of these hoods was placed in between the first and second carriages of the train of six, which thereby presented externally the appearance of a double carriage, without any vacancy or space between them, for the atmosphere to impinge against. The train was now brought up to 45 miles per hour, and the mean of three experiments showed a diminution of 4 lbs. in the general resistance. A second space was then filled in, which resulted in another reduction of 4 lbs.; the remainder of the spaces were then successively filled up, with a like result in each case. The train presented, at last, the appearance of one immensely long carriage, without any break or interval to catch the air, and thus arranged, the whole train suffered only a resistance of 10 lbs., being precisely the same as that of a single carriage, and clearly demonstrating, that, in the case of a train of six carriages, $\frac{2}{3}$ of the atmospheric resistance could be saved, by merely filling up the intermediate spaces.

“The next point to be ascertained was, how much farther the remaining 10 lbs. could be reduced: with this view, two more carriages were constructed; the ends were of a wedge form, like the bow of a ship, that is, the floor and roof of the carriage were pointed like the bow, while the sides of the carriage were left perpendicular, thus forming a sort of equilateral triangle, with its base attached to the parallel sides of the carriage. It was my intention to place one of these carriages at the fore, and the other at the after part of the train; one of them was accordingly placed in front, and the train brought to a velocity of 45 miles per hour. The pressure indicated, was now reduced from 10 lbs., to 6.3 lbs., although seven carriages were used. This was the first of three experiments intended to be made to get a mean, but, unfortunately, in the second experiment with these seven carriages, the centrifugal force was so enormous, that one of them became detached, and abutting against a side wall, formed a solid obstruction to all the rest, and the result was the destruction of the whole train of carriages. I was thus prevented from making the farther trial with the wedge-shaped carriage placed at the stern. I had intended to put my apparatus again in order, for the purpose of trying this last-named experiment, and also with a view of ascertaining the most advantageous form of wedge, but pressure of business prevented this being done at the time, and I have not since had leisure to resume the inquiry. However, I have clearly demonstrated this much—that the resistance of the atmosphere to railway trains, is exerted on the ends of each of the carriages forming a train, and amounts, in each

case, to $\frac{4}{10}$ of the power exerted on the first; and also, that, by filling the intermediate spaces between the carriages, this pressure on them will be most materially diminished."

The care with which these trials have been conducted, leaves no doubt as to the accuracy of the results; their tendency will, no doubt, be to induce practical engineers to probe deeper into the details of the best forms for carriages, with a view to the diminution of the propulsive power, so ably discussed by our author. The experiment of the filling up of the spaces between the carriages, opens up to us consequences of a more serious aspect than we were before aware of. Mr. Bessemer appends a series of tables, setting forth the diminution of the resistance, with his wedge-shaped carriages, and filled up spaces, as compared with the widely separated, and flat fronted ones of the ordinary construction; the loss of power, in the latter case, being based upon the observations both of Dr. Lardner, and Mr. Robert Stephenson. According to the formula of the latter gentleman, the resistance of three trains, of 10, 15, and 20 carriages respectively, moving at 35 miles per hour, with a gross weight of 40, 60, and 80 tons, experiences a detrimental resistance, including all sources, of 1200, 1800, and 2400 lbs., whilst, by the use of Mr. Bessemer's modified carriages, the same conditions are represented by 574, 781, and 986 lbs. of total resistance. In the express trains, where the speed is increased to 60 miles per hour, the total opposing forces amount to 2800 lbs., while the author contends that his proposed practice would reduce this down to 922 lbs., or less than one-third.

The mode in which he proposes to effect the filling up of the spaces between each carriage of the train, is clever and easy of application. Each end of the carriages is fitted up with a hood, or flexible covering of leather, or gutta percha, similar to the ordinary collapsible coverings of pleasure carriages. The frame of the hood is attached, by hinges, to the projecting head of the buffer, and is strengthened from within, by suitable diagonal braces. The whole may be brought into a small compass, when out of use, by the joints, which permit the upper ends of the supporting frames of the leather to fall inward, towards the end of the carriage. With reference to the absurd practice of crowding the carriage roofs with luggage,* Mr. Bessemer remarks very pointedly:—

"From what has been said, it will be clear, that the practice of putting luggage on the roofs of the carriages, is a most preposterous mode of conveyance. Take, for example, a portmanteau three feet in length, by one foot high, presenting a surface of 3 superficial feet: at 30 miles per hour, this gives a resistance of 13.5 lbs., and assuming, as before, (which is really more than ample,) that 10 lbs. will draw a ton, we have a resistance, caused by this single portmanteau, equal to a weight of 2880 lbs. inside the carriage! And if we apply this rule to express trains, moving at 60 miles per hour, the resistance increasing as the square of the velocity, we have $2880 - 2 \times 2 = 11520$ lbs., or little more than 5 tons, as the equivalent load inside the carriage. According to

* This mode of carrying baggage is not practised in the United States—here it is all carried in a separate car, and under lock and key.

the method I have proposed, of closing up the spaces between the carriages by elastic hoods, these will form convenient space for the stowage of luggage, and where they would be secure from rain or dust."

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The Late Failure of the Chester Bridge.

The newspapers of the day will have informed our readers of the primary details of this lamentable occurrence. A variety of opinions exist as to the true cause of the giving way of the girders, but the results are quite sufficient to place us on our guard against too great a reliance upon Cast Iron employed in the manner it is here. The account of the accident, as furnished by a resident in the locality, is as follows:

The Chester and Holyhead Railway is carried along from the Chester station, by the side of the Roode, on a handsome viaduct, and crosses the River Dee at the extremity of the Roode, nearer the city than the celebrated one-arch stone bridge, erected by Harrison, of Chester, over that river, at the other side of the Roode. The Dee railway bridge is a flat-girder bridge of iron, divided into three spans by two massive stone piers, at equal distances in the stream; and each span is formed of three lengths of cast iron beams or girders, joined together with bolts, with a semi-circular iron cap over each joint, and the beams being further trussed on the sides by tension or suspension rods, consisting of a number of parallel wrought iron plates. The beams or girders are in the rib of 2 in. metal; in the flange $2\frac{1}{2}$ in. Each beam weighs probably 30 tons. Like the Menai suspension-bridge, this one has, or rather had, two roadways, the one used for the up trains and the other for the down trains; and each roadway was carried over the river on two parallel lengths of the beams we have been describing. The roadway and rails used for the trains from Ruabon, &c., to Chester is still entire and uninjured; that used for trains from Chester to Ruabon is uninjured for two-thirds of its length (viz., the two spans nearest Chester), and for the remaining third, only one of the two parallel beams supporting the roadway (viz., the outside one next to Roode) has given way, the other remaining apparently uninjured. The length of beam between the abutment and the next pier (95 ft. span) has three joints in it, and each joint is secured in various ways, viz., by bolts, lugs underneath it, with clips, &c. The accident was seen by a little boy who was fishing in the river, on the Wrexham side, near the bridge. Hearing a train coming, he naturally looked up, and on its crossing the span nearest to him, he heard a crashing noise for two or three seconds, and then, as he says, he saw the four carriages come down into the river "in a string." From the rails to the surface of the water, at the time of the accident (in the then state of the tide), is a distance of about 30 ft. (and not, as some accounts have stated, 120 ft.) The account of Clayton, the engine-driver, the only individual on the train who passed over safely, is as follows:—When passing over the third