Thesis.

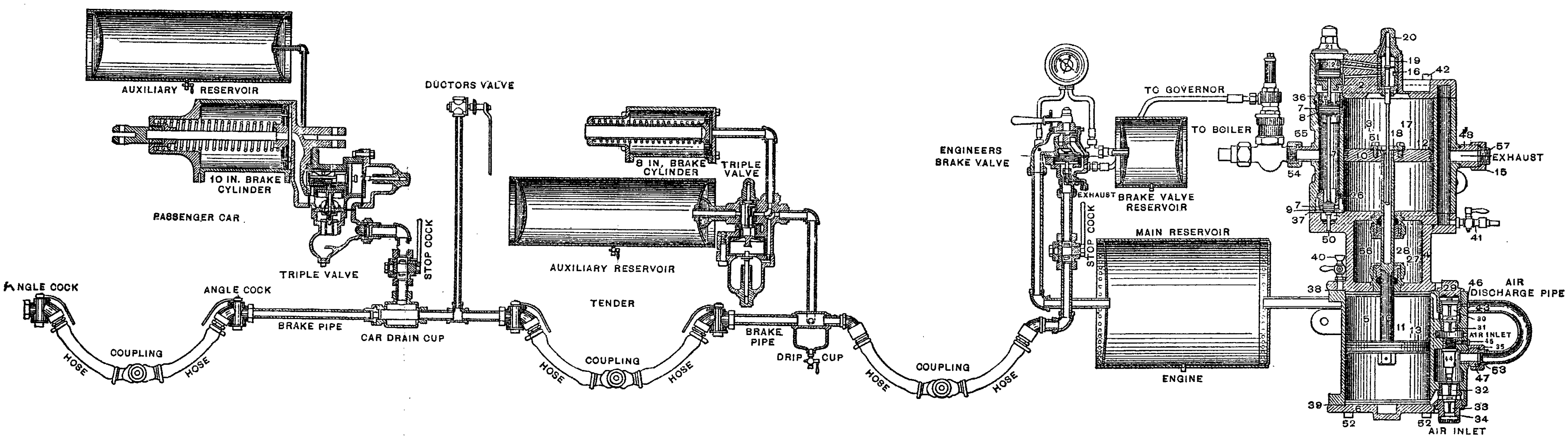
The Development of the Air Brake

Blaine H. Miller Course I 1904.

There is probably no part of the equipment of an up to date railroad more interesting and important than the braking equipment. The railroads are the largest common carriers and their field of action penetrates every part of the world. It is necessary in handling trains, that the engineer should have absolute control of his train. The safety of life and property is demanded by the traveling public. When one notices the ease with which trains are handled today and compares the number of accidents to the number of people carried, his natural impulse is to inquire into the methods of train handling. The efficiency of train handling today is largely brought about by the air brake. Of course there are other elements entering into the subject of train handling. This Thesis deals only with the air brake, and traces its development from its introduction to the present date. The Westinghouse air brake has been taken as a model, because it more nearly, according to best authority, represents the perfect air brake, than any other used.

Plate A.

.L ARRANGEMENT OF THE AIR-BRAKE EQUIPMENT ON THE ENGINE, TENDER AND PASSENGER CAR.



The air brake is a brake worked by compressed air. The first form was the straight air brake, and was invented in 1869 by George Westinghouse. The parts necessary to operate the straight air brake were an air pump, a main reservoir, a valve called the three way cock used to control the application and release of the brakes, a train pipe and brake cylinders. The main reservoir pump and engineers valve were located on the engine, while the train pipe and brake cylinders were on the car. The braking power in this system was stored in the main reservoir on the engine. The brakes were applied by changing the position of the three way cock on the engine, so as to allow the main reservoir pressure to flow into the train line.

The train line, connected directly with the brake cylinder, allowed air to pass into the cylinder, forcing out the piston and applying the brake.

This style of brake was unsatisfactory for several reasons. First, the tendency of the brake was to apply soonest at the head of the train. When the application of the brakes was sudden, the slack in the train running ahead would cause severe shocks and damage. In case of bursting hose, the brakes could not be set as the air would pass through the opening into the atmosphere. Third: In long trains the main [reservoir pressure would] equalize with the train line pressure and brake cylinder pressure. The resultant pressure would be very low on account of the large space to be filled. This made it necessary for the engineer to allow the air pump to compress air into the train line and brake cylinders, so that before the maximum braking power was obtained, the train would be stopped.

Fourth: The effect of friction on the flow of air from the main reservoir through a long train line made this brake slower.

The air brake as discribed, made several gains over the hand brake previously in use. With a train of fifty air brake equipped cars, a full and harder set brake was obtained on the whole train, more quickly than a hand brake could be set on a single car. Since trains handled on heavy grades have to be slowed down for the purpose of recharging, the air supply, the wheels are given a chance to cool. With hand brakes on heavy grades, the shoes grind against the wheels all the way down, heating the wheels to so high a temperature that they often break. Air brakes there for give us increased speed with greater safety.

The second form of air brake was the automatic brake. This was also invented by George Westinghouse in 1873. The difference in the equipment of the straight air and automatic brake, was that the automatic had beside the train line and brake cylinder, a plain triple valve and an auxiliary reservoir. There were two gains made in the automatic brake over the straight air brake.

First: The necessary braking power for each car regardless of the length of the train, was stored in the auxiliary tank under each car. Thus the brakes could be set very quickly compared to the action of the straight air brake.

Second: If the train parted, the triple valves would automatically apply the brakes. This could not be done with the straight air brake.

The essential feature of the automatic was the triple valve, known as the plain triple. It was located on the car at the junction of the train line, auxiliary, and brake cylinder. The valve was called a triple because it automatically did three things namely: charge the auxiliary, apply the brakes and release them.

When an engine was coupled to a car not charged, the triple valve was coupled to the main train line by a hose. The pressure from the train line passed through the triple and into the auxiliary. The air would flow into the auxiliary until the pressures in the train line and auxiliary were equalized. To set the brakes the train line pressure was reduced. This caused the piston in the triple valve to move down and open a port into the brake cylinders. Another reduction of pressure then had to be made to set the brakes harder. These reductions could be made until the pressures in the brake cylinder and auxiliary were equal, at which point the brakes would have their maximum power. To release the brakes it was necessary to pump air into the train line. This forced the triple piston up to a point where it released the pressure on the auxiliary. This auxiliary pressure being lowered, the brakes were released. With the old style triple valve the auxiliary could be charged in about seventy seconds to seventy pounds pressure.

The main objection to the plain triple was that it often took some time to release the brakes, as the air pump would not charge the auxiliaries equally.

The plain triple valve could also be used as an emergency brake. By suddenly reducing the pressure, the triple piston opened a large port.

into the brake cylinder, which set the brakes immediatly. The braking power in emergency was no greater than in service application. Plain triple valves are very little used today except on engines and tenders. Their use on cars is confined principally to those equipments put on before the introduction of the quick acting triple valves.

The plain triple was satisfactory so long only as it was used in service application. It was most unsatisfactory with emergency application on a long train. In the emergency application the head brakes were set so much sooner than those in the rear, that the slack of the train ran ahead and often did great damage. It was therefore necessary that some improvements be made, so that the brake could be depended on in both service and emergency application. To this end the quick acting brake was introduced.

The quick acting triple valve was invented in 1887 by George Westinghouse Jr. Two advantages were gained by this invention over the plain triple valve.

First: It enabled the engineer to set the brakes throughout the train before the slack had a chance to run ahead and do damage.

Second: It not only enabled the engineer to set the brakes quicker, but it enabled him to set them harder, thus permitting a quick stop and consequently a higher safe speed for trains.

In service application there was no difference in the action of the plain triple and quick acting triple valves, except the additional ports placed in the slide valve of the quick acting triple, and which are only used in emergency. It is therefore evident that these two kinds of valves scattered throughout a train would work perfectly together.

A check valve was added to the quick acting triple. This might be called an emergency valve. It acted only in case of a break in the hose coupling or train pipe, in which case it caused all brakes to be set, instead of allowing the air to escape into the open.

It has been said that in the case of the quick acting triple the brakes were set harder in emergency. It would therefore seem that they would be corrospondingly harder to release. This is true in the case of the quick acting triple, but not true for the plain triple.

With the quick acting triple air from the train line helps set the brakes in emergency, and the pressures equalize higher. Therefore the train line pressure must be made higher to overcome the auxiliary pressure and force the triple piston to release position.

There has been some question as to whether the emergency will work after a partial service application has been made. It is much harder to get quick action after the service application has been made. The quick action depends on the amount of reduction that has been made in service and upon the piston travel. In no case can we gain as much after a small service reduction has been made, as we could if a sudden reduction were made when the auxiliarys were fully charged and the brakes released. After a light reduction a gain over the pressure obtained in full service can be made by going to the emergency position, if the piston travel is of fair length. By using the emergency after a partial service application, we would get full service more quickly, even though we made no gain in pressure.

In order to throw the triple into quick action the reduction on the train line must be made so that the train line pressure will get into the brake cylinder before the pressure from the auxiliary. The auxiliary pressure gets in a small amount as the service port in the slide valve passes the port leading to the cylinder. However the air from the train line reaches the cylinder first. The size of the ports used in emergency to let auxiliary pressure into brake cylinder and that of those used in service application are different, the service ports being larger. This is so as to hold back the auxiliary pressure in emergency and allow as much air as possible to enter the brake cylinders from the train line.

It may seem from what has preceded that the triple valve is a very sensitive piece of mechanism. This however is not true, and experience has shown that the action is remarkable considering the poor treatment this piece of machinery receives. The triple needs no more care than any other piece of machinery to keep it doing first class work.

Dust and cinders sometimes stop up the ports in the triple valves and and cause some auxiliaries to be more fully charged than others. This makes some brakes set quicker than others, and sometimes the reduction of pressure cannot be made quick enough to get quick action. One triple valve going in action makes a reduction and starts the next triple and so on throughout the train. Even in the case of several triples being out of order the brakes would still work, so efficient and sensitive are the valves.

Should the engineer fail to make reductions in the air pressure after once starting to set the brakes, the air coming ahead from the back of the train would kick off the head brakes. Water in the train line often causes trouble as it freezes the pipes. It comes from leaks in the air pump.

The triple valve depends largely for its usefulness on the springs used. A weak spring might fail to close the valve and all valves would go into quick action, setting the brakes on the entire train. This is true in the case of short trains, but not necessarily so on long ones. On a short train with gradual train line reduction, air is triples being out of order the brakes would still work, so efficient and sensitive are the valves.

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Probably the most common cause of brakes being set accidentally is a sticky valve. The valve when sticky will not respond to a light reduction of pressure. When it does move, it jumps and the sudden blow compresses the graduating spring and makes the valve quick acting. This sets all the valves on the train, regardless of their position in the train.

The Westinghouse freight equipment is somewhat different than the passenger equipment. In the first place it is smaller. The auxiliary reservoir is connected directly to the brake cylinder. While the appearance of the freight equipment is different the principle is about the same as in the passenger.

Of late years the call by the traveling public for higher train speed, rendered it necessary to insure the safety of life and property. To meet this demand, the high speed brake was introduced and adopted. This brake is about thirty per cent. more efficient than the ordinary quick action brake. It is used on such trains as the Empire State Express, the Black Diamond, and the Congressional Limited. The average percent of braking power to light weight on a passenger car equiped with the quick action brake is about ninety. With the new high speed brake this percentage is about one hundred twenty five. It might seem that such a high braking power would flatten the car wheels. However these brakes are only used when the train is moving at a very high speed. There is an automatic reducing valve used with the high speed brake, which gradually reduces the brake cylinder pressure so that when the speed of the train is decreased, the brake cylinder pressure has also been corrospondingly decreased to the sixty pound limit, as used by the ordinary quick action grake.

It is safe to use a higher braking power with the train running fast, because the faster the wheels turn the greater the inertia of the wheels, which friction of the wheeds has to overcome before they will stop revolving.

There were some tests made in England, called the Westinghouse Galton tests, which proved that the faster the tread of the wheel moved against the brake shoe, the less the friction between the two. As the speed decreases the friction increases. The friction of the wheel and rail remains constant, regardless of the speed of the train. The train line and auxiliary pressures carried with the high speed brake are about 110 pounds. The auxiliary and brake cylinder when set in emergency equalize at about 85 pounds pressure. This 85 pounds pressure is reduced to the safe pressure of 60 pounds for slow speed, by means of an automatic reducing valve which will be explained later.

It may be well now to take up in detail the other necessary parts of an uptodate air brake equipment.

The main reservoir is located on the engine between the frams back of the cylinder saddle. It should be located, if possible, at the lowest point in the air brake system, so as to have all dirt and oil in the system drawn into it, as it is easier to remove it there.

The air leaves the pump it goes to the main reservoir. The main reservoir pressure begins at the pump and ends at the engineer's valve. It is usually kept at about 90 pounds pressure, except in mountainous country and on high speed brakes, where it of course runs higher. The reservoir should have a capacity of not less than 20000 cubic inches. In any case it should be large enough to equalize the pressure on the train line, so that it will insure the prompt and certain release of the brakes after they are set. In freight service larger reservoirs are required as there are more auxiliaries to be charged. A large main reservoir is most essential after an emergency application and especially so after a break in the train. The main reservoir acts as the storehouse, in which to keep a reserve pressure to release the brakes and charge the auxiliaries. If the main reservoir is too small, the pump will get too hot. Small reservoirs mean high pressures, and the higher the pressure the more the heat generated in compressing the air. Again the pump has to work faster to charge the auxiliaries. When it works too fast, it does not have time to take in a full cylinder of air at each stroke, and hence loses its efficiency.

The engineers brake valve is a sort of a transfer station for the compressed air. The air is stored in the main reservoir and its future action is controlled by the engineers brake valve subject to the needs of the service. The brake valve controls not only the main reservoir air supply, but all air that may be stored in the auxiliaries and train line. The origonal engineers brake valve was the three way cock. This was used with straight air, with the plain automatic, and for some time by a good many roads with the quick acting brake. It was however not sufficiently sensitive, and there was great danger of throwing the brake into emergency at times least

desired.
Reductions in pressure were then made by instinct or sound. An engineer having a long train today and a short one tomorrow, could not do good braking, as the valve was nothing more than a plug valve.
If the reductions were a trifle too heavy, the triple valves would be thrown into quick action. The reductions could not be made too slowly, or the air would blow through the escape valves into the brake cylinders. If the air escape from the train line was suddenly checked, the air from the rear of the train would ahead and kick off the head brakes. What was needed, was a valve which would mechanically make the desired reduction in train line

pressure, regardless of the length of the train.

A new valve was designed so that it would ensure a volume and pressure in the main reservoir, sufficient to release all brakes. To this end the valve was designed, so that it would keep twenty pounds more pressure in the main reservoir, than in the train line. This improved valve was naturally called the twenty pound cock instead of the three way cock. Instead of a plug and socket, the valve consisted of a valve body in which there was a top valve and spring and a main valve and spring, the purpose of the springs being to hold the valves in place. The top valve controls the opening to the atmosphere. The main valve controls the openings from the main reservoir to the train pipes. With the handle in release position, the main valve allows the passage of air from the main reservoir to the train pipe through two large ports. When the handle is turned to the first notch, all air must pass the feed-valve and go through two small openings into the train pipe. The valve should be set in this position while train is running. The rest of the work done by this brake valve is in principle the same as the three-way cock. When the handle is turned to the third notch, it opens the train pipe and allows the air to escape into the atmosphere, setting the brakes. There is one position of this valve which closes all ports. This is used in case the train breaks in two, or when the brakes have been set from the conductors valve, so that the air will not escape from the main reservoir

A new device for automatically assisting the engineer to apply the brakes moderately and with more skill, is the engineers brake and equalizing discharge valve. This valve closely resembles the engineer's brake valve just described. The chief differance is that the valves in this brake valve are held to their seats by air, instead of springs. The main purpose of this new valve is to insure a more easy and uniform application of the brakes throughout the entire length of train.

By a gradual reduction of pressure from the train pipes the air did not rush ahead violently from the rear cars and kick off the head brakes. In place of the main valve and top valve of the twenty pound cock a rotary valve was substituted. Below the rotary valve is the air chamber, or valve body, to which is attached a small air tank, to add capacity. The rotary valve controls the ports. When the handle is turned to release position, the air is given a free passage from the main reservoir to the train line. When the handle is in the second notch or position, the air flows to chamber, and small auxiliary reservoir, and also on top of the piston valve, keeping it to its seat.

Another position of the handle relieves the air from the train pipe and sets the brakes. This valve is very useful in double heading and on mountain grades.

There is a device on every car which enables the conductor to stop the train. This is known as the conductors valve. The device consists of a valve and spring, enclosed in a case. The spring holds the valve to its seat. The valve is worked by a lever, to which a chord may be attached and hung in the car, where it is most convenient. By pulling the chord and moving the lever the valve moves from its seat and allows the air from the train pipe to escape, setting the brakes in consequence. As soon as the chord and lever are released the spring automatically places the valve on its seat and shuts off the flow of air from the train pipe. In applying the brakes, the conductors valve should be held open until the train comes to a stop. Conductor's valves are only used in case of possible accident.

In connection with the high speed brake equipment the reducing valve was spoken of. This reducing valve consists of a piston and spring. Any air in the brake cylinder is free to reach the top of the piston in the reducing valve. As long as the tension in the spring is greater than the brake cylinder pressure on top of the piston the valve will not move. When brakes are full set, the pressure is greater than the tension in the spring. The piston is therfore forced down, and carries the slide valve with it, which opens a port, allowing the brake cylinder pressure to escape into the atmosphere. The reducing valve is very useful, as by simply adding it to the present quick acting equipment, we can turn this equipment into high speed brakes. Certain additions have to be made on the engines however. A duplex pump is used and two trainline governers are added. Reducing valves are connected to the tender and driver brake cylinders. These are arranged with cutout cocks, so that the engine may be used with "high speed" brake or with the ordinary quick action brake.

Another interesting and very

useful piece of mechanism is the air pump. It is located on the engine and consists of an engine and pump, that is, an air cylinder and a steam cylinder. These two cylinders are connected by a casting to which both are bolted. A piston passes through the center piece connecting the steam and air cylinders. The casting is fitted with a packing box so that when properly packed, there can be no flowing of steam in to the air or of air into the steam cylinder. The steam, working the the piston, is regulated by a piston valve called the main valve and which is located in the walls of the steam cylinder. The main valve is in turn regulated by a reversing piston, which is located above it. After the pump is started, the main piston, as in any steam engine, regulates the valve motion. Steam to work the pump, is admitted to the main valve on one side of the steam cylinder and is exhausted after use on the opposite side. The exhaust is carried to the atmosphere through the smoke stack of the locomotive. The air pump consists simply of a piston acting as a plunger. The movement is identical with the steam piston. Two sets of valves, self acting, control passages of air to the main reservoir and atmosphere. They are called the upper and lower discharge valves and receiving valves. When the air piston moves away from the upper end of the cylinder, the upper receiving valve opens and air follows the suction, or the vacuum, formed, until the piston commences its return stroke, when the upper valve closes and the air is forced into the main reservoir through the upper discharge valve. As the receiving valve closes automatically when the air is being discharged into the main reservoir, so the discharge valve acts in the same manner in retaining the pressure in the main reservoir.

The air pump is controlled by a pump governor. The object of the governor is to automatically shut off the supply of steam to the pump when the air pressure in the train line and reservoirs has reached the allowable limit, forming the basis for which the maximum power of the brake is designed. Excessive pressure which may result in the sliding of the wheels is thus avoided.

The link between the differant appliances which form the air brake equipment, is the train line, or main air pipe. This starts at a connection with the main reservoir, runs to the engineers brake valve, from whence it goes under the tender to each of the cars. The connections between cars are made with flexible rubber hose and air tight couplings. The main pipe is tapped under each car by pipes to the triple valve and conductor's valve. Some roads put a device on each car to apply the brakes in case the car jumps the track. This consists of a valve with a long handle pointing downward; the end of the handle being about two inches above the ties. When the car jumps the track the handle strikes the ties, opens the valve in the train pipe and in letting the air escape, sets the brakes.

At each end of the car is a stop cock. These cocks are for the purpose of confining the air to the appliances on the car, when necessary to uncouple cars in service. These cocks should always be open when the train is connected and in service. A dummy coupling is located at the end of each car, so that when the hose is not coupled to another hose, it can be connected to the dummy, keeping it free from dust and cinders.

Thus far air brake equipment on cars only has been considered. There are also brakes on locomotives.

Opinion differs regarding the economy of using driver brakes for general service and on many roads they are considered an emergency brake. The usual outcome of using them for emergency only, is to strip off the tires, which necessitates sending the engine to the shop for repairs. The driver brake with straight air is bad practice, as it has to be worked independent of the train brake. Some driver brakes have been applied by pipe connection to the triple valve of the tender so that the auxiliary on tender would furnish braking power for both engine and tender. This generally proved a weak inefficient method. The best way of working driver brakes, is to have them on the same system with the car brakes, which make them act in conjunction with the car brakes. This insures a moderate, but not too hasty application of the brake. There are many reasons for having the engine exert a percentage of the braking power, in proportion to its weight compared with the total weight of the train. Since this is the case driver brakes should become part of the continous train brake, and exert braking power for all stops. Each engine should therfore be equipped with its own triple valve and auxiliary reservoir.

The cost of equiping a locomotive with a complete air brake appliance is about two hundred seventy five dollars: tender, sixty dollars: passenger car, one hundred dollars and freight car forty five dollars.

It will be seen from the above figures that the equipment is rather expensive. It has been suggested that the brake mechanism be simlified and the cost reduced corrospondingly. The demand however has not been so much for cheaper mechanism but for greater results. As the development of air brakes has been progressive in results, it would not be wise to accept a poorer brake for the sake of saving a few dollars.

There were a number of tests made some years ago, which show how quickly air brake trains can be stopped with quick acting brakes. The train used in these tests consisted of fifty 60000 pounds capacity box cars. The light weight of each car was

30000 pounds. The tests were ten in number. The following is the description of the tests.

1. Emergency stops train running at twenty miles an hour.
2. Emergency stops train running at forty miles an hour.
3. Applying brakes while train was standing still, to show rapidity of application.
4. Emergency stops train running at forty miles an hour.
5. Service stops and time of release. Exhibition of smoothness of ordinary stop and time of release.
6. Hand brake stops at twenty miles per hour, with five brakemen on train
7. Breaking train in two.
8. Emergency at twenty miles per hour

the brake leverage having been increased to give the quickest stop possible.

9. Emergency stop at forty miles per hour, using same leverage as in (8)

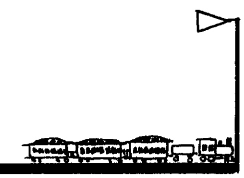
10. A train of twenty freight cars and a train of twelve ordinary passenger cars, running beside each other along parallel tracks, each being about the same weight and length of train and the brakes applied at the same time. This shows the relative stopping power of the old and new brake.

The summary of the results of these test is given on the next page.

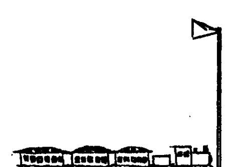
Place of Test	Downgrade ft per mi	First			Second			Fourth			Sixth			Seventh			Eighth			Ninth			Tenth		
		Miles Speed	Feet Dis.	Seconds Time	Miles Speed	Feet Dis	Seconds Time	Miles Speed	Feet Dis.	Seconds Time	Miles Speed	Feet Dis.	Seconds Time	Miles Speed	Feet apart Distance	Seconds Speed	Miles Speed	Feet Distance	Seconds Speed	Miles Speed	Feet Distance	Seconds Time	Miles Speed	Feet Distance	Seconds Time
St. Paul	13.6	19	172	7	36	490	15	20 / 37	200 / 583	-- / --	- - -	- - -	- - -	25	100		20	109		37	327				
Chicago	Level head wind	22	184	10	37	480	15	20 / 34	162 / 470	11 / 15	19	1700	62	20	59		20	120	6	32	272	11			
St. Louis	52.8	20	176	11	36	507	18	35	502	17	21	2115	178	23	61		20	109	6	38	377	11			
Cincinatti	50.0	25	184	12	35	592	17	37	573	17	21	1925	75	22	32		20	102	6	41	425	12			
Cleveland	40.0	26	265	12	43	718	20	38	636	17	23	1686	65	25	45		20	96	6	40	375	11			
Buffalo	32.2	21	214	12	40	679	19	39	648	19	20	1000	48		59		20	93	6	40	414	13			
Albany	35.0	20	158	10	36	560	18	37	580	19	21	1035	54	22	62		19	78	5	40	358	12			
New York	53.0	23	203	12	41	614	20	41	672	20	21	2137	85		43		22	91	6				38	319 / 547	12 / 17
Philadelphia	44.0	23	264	14	36	593	19	36	579	18	18	1889	75	22	35		20	87	6				49	697 / 932	19 / 23
Washington	52.0	19	159	10	42	694	21	20	1643	67	42	718	21	23	58		21	81	6	40	359	11			
Pittsburg	47.0	26	194	11	40	649	21	40	673	20	20	1720	72				20	95	6				45	494 / 890	14
Boston	40	20	158	10	36	560	18	37	580	19	20	1342	60		180		19	78	5	40	358	12			

Summary of results of tests

The following figure gives an idea of the advancement in air brake appliances. The three figures represent to scale stops made by the same train at the same rate of speed but equipped as indicated. It takes twice as far to stop a train going at 40 miles an hour, three times at 50 and 5 times at sixty, as it does if the speed of the train be 30 miles an hour.



1886 Plain Automatic Brake



1887 Quick action brake

1896 High speed brake.