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Very Long Trains – Phase II Rack Tests

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14. ABSTRACT
In Phase II of this research project, FRA sponsored Wabtec to perform train air brake tests on long trains at their facility in Wilmerding, Pennsylvania, between January 2021 and March 2021. The air brake rack simulated trains with up to 200 control valves using a conventional (i.e., head-end power only) configuration. Test results, summarized by Wabtec in a separate report, were shared with Sharma & Associates, Inc. (SA), who performed detailed analysis from June 2021 to November 2021 at its office in Countryside, Illinois, to understand the issues of brake signal propagation, brake pipe pressure reduction, brake cylinder (BC) pressure buildup, and false gradient braking on VLTs. The data analysis revealed that there were slightly slower response times and slightly reduced brake cylinder pressures as the train length increased, with leakage levels further contributing to the differences. When subsequent brake applications were made without waiting for the brake pipe pressure at the rear of the train to fully recover, the likelihood of unintended brake releases were higher with longer trains. Such situations can be avoided by making the second application appropriately deeper than the first application.

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Very Long Train, VLT, Air Brake System, Distributed Power

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1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
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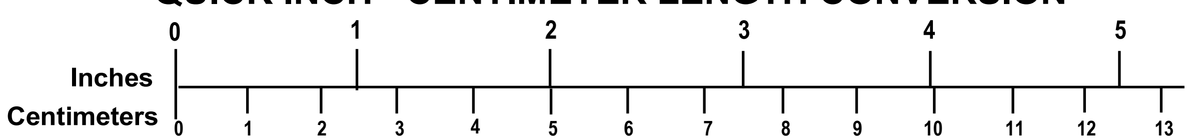

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Contents

Illustrations

Tables

Executive Summary

The operation of long trains (termed Very Long Trains or VLTs for purposes of this report) is governed by the railroad's air brake and train handling instructions, as well as the education, training, and supervision of operating crews. While there are no federal or state statutes governing train length, the Federal Railroad Administration (FRA) reviews and monitors train performance and accepted practices for VLT operations through tests and simulations to confirm the safe performance of the air brake system as well as resulting train dynamics. FRA initiated a multi-phase collaborative study of VLT operations steered by a Test Review Committee (TRC) comprised of FRA, Class I railroads, labor unions, and air brake equipment manufacturers, with a specific focus on brake system performance and train dynamics considerations.

In Phase II of this research project, FRA sponsored Wabtec to perform train air brake tests on VLTs at their facility in Wilmerding, Pennsylvania, between January 2021 and March 2021. The air brake rack simulated trains with up to 200 control valves using a conventional (i.e., head-end power only) configuration. Test results, summarized by Wabtec in a separate report, were shared with Sharma & Associates, Inc. (SA), who performed detailed analysis from June 2021 to November 2021 at its office in Countryside, Illinois, to understand the issues of brake signal propagation, brake pipe (BP) pressure reduction, brake cylinder (BC) pressure buildup, and false gradient braking on VLTs.

The research team found that in a train with minimum leakage, service applications produced about the same brake cylinder pressure in trains of 100 vs. 200 cars. This applies to comparisons of both the last car BC pressures and the train average BC pressures. For the high leakage condition, 60 cubic feet per minute (CFM), BC pressures were lower in the longer train. Last car BC pressure with a full-service application was 3.6 psi lower in the 200-car train than in the 100-car train, and the train average BC pressure was 2.7 psi lower in the longer train. A similar reduction in BC pressures in the longer train were seen with a 15 psi brake application. The test data also showed longer BC pressure buildup times during full-service brake applications in the longer 200-car train as compared to the shorter 100-car train for similar leakage conditions.

The time for the brake system to completely recharge and stabilize after a release in the 200-car train was approximately three times longer than the recharge time for the 100-car train (longer recharge times require longer wait in cycle braking situations to avoid potential unintended brake release situations). A 200-car train took up to 2.5 times longer to recharge after a running release compared to the 100-car train. This slower response should be noted and planned for in handling VLTs after a running release.

The team also found that as train lengths increased there were slightly slower response times and slightly reduced BC pressures, with leakage levels further contributing to the differences. When subsequent brake applications were made without waiting for the BP pressure at the rear of the train to fully recover, the likelihood of unintended brake releases were higher with longer trains. Such situations can be avoided by making the second brake application appropriately deeper than the first application.

1. Introduction

In Phase II of this research project, the Federal Railroad Administration (FRA) sponsored Wabtec to perform train air brake tests on long trains (termed Very Long Trains or VLTs for purposes of this report) at their facility in Wilmerding, Pennsylvania, between January 2021 and March 2021. The air brake rack simulated trains with up to 200 control valves using a conventional (i.e., head-end power only) configuration. Test results, summarized by Wabtec in a separate report, were shared with Sharma & Associates, Inc. (SA), who performed detailed analysis from June 2021 to November 2021 at its office in Countryside, Illinois, to understand the issues of brake signal propagation, brake pipe pressure reduction, brake cylinder (BC) pressure buildup, and false gradient braking on VLTs.

1.1 Background

While there are no federal or state statutes governing train length, FRA reviews and monitors train performance and accepted practices for VLT operations through tests and simulations to confirm the safe performance of the air brake system as well as resulting train dynamics. FRA initiated a multi-phase collaborative study of VLT operations steered by a Test Review Committee (TRC) comprised of FRA, Class I railroads, labor unions, and air brake equipment manufacturers, with a specific focus on brake system performance and train dynamics considerations.

FRA sponsored a VLT study comprising four phases, in a logical sequence designed to gain maximum benefits as data and understanding of the system behavior became available after each phase. An overview of the scope of work for each of these phases is described below.

- Phase I: Investigate expected air brake performance of VLTs through modeling, using longitudinal train dynamics software capable of simulating air brake system and train dynamics, such as coupler forces and slack action due to train handling. This phase determined the need for further research; no publication was generated from this phase.
- Phase II: Conduct a series of air brake rack tests with up to 200 control valves and quantify the air brake performance of the VLT for Head End (HE) only train configuration.
- Phase III: Perform tests on a stationary VLT with 200+ cars, with both HE and Distributed Power (DP) configurations, to understand the impact of high leakage conditions at various air brake applications.
- Phase IV: Conduct tests on a moving train to capture dynamics resulting from braking operations and train handling.

This report discusses Phase II of the research.

1.2 Objectives

The Phase II objective was to conduct a series of air brake rack tests simulating the air brake system in VLTs with up to 200 brake control valves. The air brake rack tests were designed to simulate a conventional train (i.e., head-end power only) configuration. The tests were conducted to understand the issues of brake signal propagation, brake pipe pressure reduction, BC pressure buildup, and false gradient braking on VLTs.

1.3 Overall Approach

1.3.1 Test Equipment

A brake rack consisting of conventional pneumatic freight brake equipment was configured for up to 200 cars. Each train configuration had an equal number of ABDX and DB-60 control valves that were distributed uniformly with 50 feet of brake pipe between valves. The team used AAR-certified equipment conforming to AAR S-463, "Test Rack, 150-Car, Freight Brake," with appropriate modifications for 200 cars. Each configuration was instrumented and used a data acquisition system.

1.3.2 Test Configurations

Three different train lengths were tested: 100 cars, 150 cars, and 200 cars. Each train configuration was tested under three different leakage conditions: minimum leakage, 60 Standard Cubic Feet Per Minute (SCFM) of air flow, and 60 SCFM air flow with a 15-psi gradient between the head end and rear end. The leakage was distributed as uniformly as possible, but some combinations of train length and leakage required leakage to be concentrated, either in the front or rear of the train, to meet the mandated limits of 60 scfm and 15 psi gradient.

1.3.3 Data Collection

The tests were conducted in Wabtec's facility in Wilmerding, Pennsylvania, between January and March 2021. The air brake rack tests simulated a VLT with up to 200 control valves on a conventional (i.e., head-end power only) configuration. Train average BC pressure build-up (a function of time) was used to compare the stopping ability of various train configurations. The main factors that can influence the development of a train's average BC pressure, and hence the train's stopping ability, are:

- Brake signal propagation time to rear of train
- BC build-up time at rear of train
- Brake pipe gradient (difference in brake pipe pressure between the first locomotive at the head end and the last car)
- State of brake system recharge – brake application initiated with insufficient reservoir recharge can lead to reduced cylinder pressures or unintended brake release

Brake Pipe (BP), BC, Auxiliary Reservoir (AR), and Emergency Reservoir (ER) pressures were collected at five car locations, equally spaced throughout the train:

- first car
- car at one quarter point
- car at middle of train
- car at three quarter point
- last car

The four different pressures, three brake signal propagation times, and the recharge time, as defined below, were collected.

- Application propagation time: duration between BC pressure reaching 0.5 psi on the first car and the last car
- Release propagation time: duration between when the locomotive handle is moved to release position and when the BC pressure starts to exhaust from the last car's retaining valve
- Last car BC release time: duration between when the locomotive handle is moved to release position and when the BC pressure in the last car is reduced to < 3 psi
- Recharge time: time interval between when the locomotive handle is put in release position and the last car reservoir pressure reaches to within 2 psi of its original (fully charged) pressure.

1.3.4 Test Cases

For each test, the brake rack was initialized with cylinders released and reservoirs fully charged to the extent possible given the specified brake pipe leakage (i.e., steady state conditions), unless specified otherwise. A series of test was conducted for each of the nine train configurations (three different lengths and three different leakage conditions). These tests included 8 psi minimum application, 15 psi application, 30 psi full service application, emergency application, false gradient tests, and others (see Table 1).

Train Length (# of Cars)	BP Leakage	Minimum, release and recharge	15 psi reduction, release and recharge	Full service, release and recharge	Graduated application, 6 to 10 psi	Graduated application, 15 to 17 psi	Emergency from fully charged state	Emergency from partial service application	Emergency after service release	False Gradient braking
100	minimum	x	x	x	x	x	x	x	x	x
	60 cfm	x	x	x	x	x	x	x	x	x
	60 cfm/ 15 psi gradient	x	x	x	x	x	x	x	x	x
150	minimum	x	x	x	x	x	x	x	x	x
	60 cfm	x	x	x	x	x	x	x	x	x
	60 cfm/ 15 psi gradient	x	x	x	x	x	x	x	x	x
200	minimum	x	x	x	x	x	x	x	x	x
	60 cfm	x	x	x	x	x	x	x	x	x
	60 cfm/ 15 psi gradient	x	x	x	x	x	x	x	x	x

Table 1. Test matrix of the nine train configurations

A full service application in normal railroad practice is defined as a BP pressure reduction of 26 psi. In the air rack tests performed by Wabtec, a 30 psi reduction in BP pressure was made to assure that equalization between BC and AR was attained, providing maximum BC pressure.

For the 200-car train length, additional conditions were tested in which 15 percent of the control valves (i.e., 30 cars) were non-functional (the maximum number of cars allowed to have non-functioning brakes in a 200-car train). Three different conditions were created with the non-functional control valves placed in various positions along the train and tested with the nine train configurations.

1.4 Scope

The Phase II project scope was to conduct a series of air brake rack tests with available maximum train length configuration of at least 200 valves, to understand the issues of brake signal propagation, BP pressure reduction, BC pressure buildup, and false gradient braking. These tests were conducted on a conventional train (i.e., head-end power only). This document provides details of the analysis performed on the test results and summarizes the findings.

1.5 Organization of the Report

This report is structured as follows:

Section 2 explains the fundamentals of the Air Brake System.

Section 3 presents detailed analysis of the test results for the following test parameters and conditions: Application Propagation Time, BC Pressure Buildup Time History, Release Propagation Time, Last Car BC Release and Recharge Time, and Stepped Reduction and False Gradients.

Section 4 summarizes the findings.

2. Air Brake System Fundamentals

Figure 1 shows a basic piping diagram of a freight car braking system [1]. Train brakes are fully charged when the brake pipe, auxiliary reservoir and emergency reservoir are all charged to the feed or the regulating valve setting of the locomotive, which is typically 90 psi in a freight train. The control valve shown in the figure is the heart of the brake system. The control valve applies and releases brakes by sensing the difference in pressure between the BP and AR. If the pressure in the BP is lower than the AR, the brakes will apply. If the pressure in the BP is higher than the AR, the brakes will release. The control valves react to a small difference in pressures between BP and AR, usually about 1.5 psi or greater.

Due to leakage and other factors causing a BP gradient, the rear of the train may not be fully charged. For a train with head end power only (i.e., without a distributed power unit or air repeater), the maximum permissible leakage is 60 CFM according to 49 CFR § 232.205 for Class I brake test – initial terminal inspection [2]. A train equipped with at least one DP unit or an air repeater unit providing a source of BP control air from two or more locations must not exceed a combined flow of 90 Cubic Feet Per Minute (CFM). The pressure gradient must be within 15 psi to comply with 49 CFR § 232.103, which says the pressure in the rear of the train shall not be less than 75 psi. If these conditions are met and the BP, AR, and ER are charged to the same pressure, the rear of the train not being fully charged does not constitute an undercharge. An undercharge occurs if the ARs are not charged up to the same pressure as the BP at that car. The control valve, sensing BP pressure to be higher than AR pressure, will keep the brakes released. A BP reduction may or may not apply the brakes on these cars. If the BP pressure after the brake application remains higher than the AR pressure, the brakes will not apply. For this reason, an adequate BP pressure at the rear of the train does not necessarily indicate the train is charged as required. The ARs can be replenished by the main reservoir in the locomotive only when the brakes are released. The AR pressure does not increase as quickly as the BP pressure because it must flow through a restricted charging port in the control valve.

If no air is fed into the BP from the locomotive, BP leakage will gradually reduce the BP pressure until the control valves assume a service application position and apply brakes. If BP leakage is within the regulatory limits and the engineer's automatic brake valve is in the proper position, sufficient air will flow into the BP to prevent a leakage application. This is because of the "pressure maintaining" feature of the automatic brake valve in the locomotive. In the pressure maintaining portion of the automatic brake control valve, air will flow at a slow rate into the BP to compensate for leakage after a reduction has been made. For example, during a minimum brake application, ER pressure will be reduced by 8 psi, with corresponding reduction in the BP pressure. When left in this position, the brake valve will maintain BP pressure around 82 psi, allowing air to flow into the BP if necessary to compensate for any leakage.

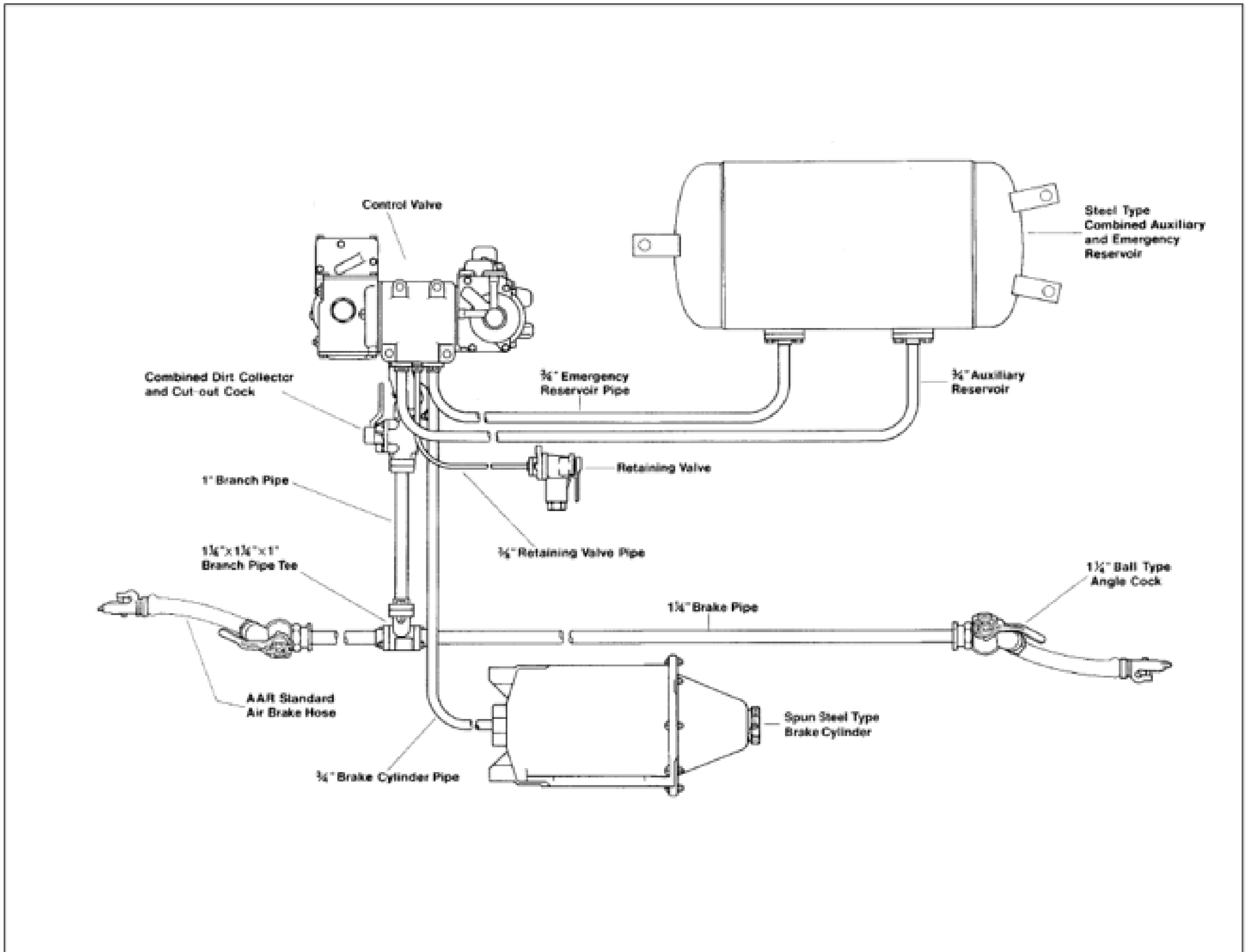

Figure 1. Freight Brake Equipment Piping Diagram (Courtesy: New York Air Brake)

3. Data Analysis

The research team chose a representative subset of test cases from Wabtec's air rack test report to gauge air brake performance in VLTs. As mentioned previously, the results are summarized and discussed in terms of propagation time for brake application and release, last car BC release time, and last car reservoir recharge time for various brake applications and leakage conditions. The team conducted this analysis to evaluate the braking system performance of VLTs, specifically in comparison to the performance of a conventional 100-car train.

For a given leakage condition in the train, average leakage levels per car are lower for longer trains. For the 60 CFM case, the average leakage per car for a 100-car train is 0.6 SCFM and for a 200-car train is 0.3 SCFM. To comply with CFR requirements, longer trains will need to have less leakage per car. In other words, a 200-car train comprised of two 100-car trains at the CFR limit for leakage will not comply with federal regulation.

The air rack tests simulated train configurations with HE only power; DP trains were not simulated. Full service brakes were implemented as a 30 psi BP pressure reduction and not 26 psi in Wabtec's air rack tests.

3.1 Application Propagation Time

Application propagation time is the duration between BC pressure reaching 0.5 psi on the first and last car. The propagation time for brake application is shown in Figure 2 for the tested leakage conditions and various brake applications on both 100-car and 200-car trains. The propagation time for brake application times approximately doubles between 100-car and 200-car trains for a particular leakage and brake application scenario, including the emergency brake application. For the same brake application and leakage conditions, the application propagation time is approximately proportional to the train length. For a given 100-car or 200-car configuration, leakage has marginal impact on brake signal propagation time for minimum and service applications and very little impact for the emergency application.

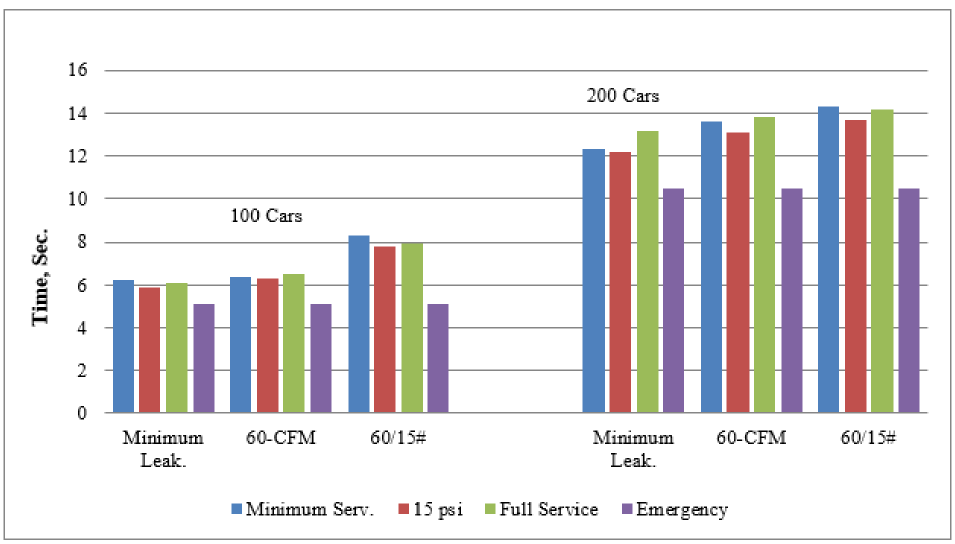

Figure 2. Brake Application Propagation Time

3.2 Brake Cylinder Pressure Development

The BC pressures from data on the first car, the car at one quarter point, the car at the middle of train, the car at the three quarter point, and the last car are averaged and plotted in Figure 3. The average BC pressures are shown for various leakage conditions and brake applications in the figure. As expected, the average BC pressures are lower with increasing leakage. For example, there is a 7.5 percent reduction, from 40 psi to 37 psi, in the average BC pressure as the leakage increased from a minimum leakage condition with a flow of around 10 CFM to a higher leakage condition with a flow of 60 CFM in a 100-car train after a 15 psi brake application. The average BC pressure reduction is 12.5 percent for the 60 CFM/15 psi leakage condition in comparison to the minimum leakage for the same 100-car train after the 15 psi brake application. As seen from the bar chart, the change in average BC pressure is not very significant between the 100-car and 200-car configurations for the same leakage condition. The test data for BC pressure development show that the stopping ability of the train as indicated by the average BC pressure is affected more by leakage condition than the train length. The effect of leakage is in the range of 7 to 10 percent for the 60 CFM leakage condition and 12 to 20 percent for the 60 CFM/15 psi leakage condition.

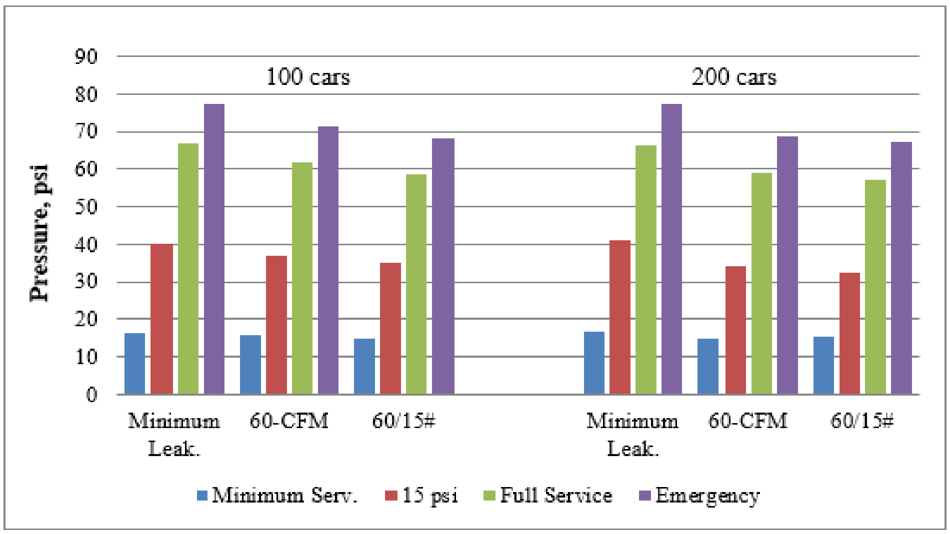

Figure 3. Comparison of Average BC Pressures

Figure 4 plots the average time for BC pressure development across the four braking cases for the three leakage conditions and the two train lengths.

There is significant increase in the average time between 100-car and 200-car configurations. As an example, the time increases by 91 percent from 52 seconds in the 100-car configuration to 100 seconds in the 200-car configuration for the 15 psi service brake application and the 60 CFM leakage condition. The time for BC pressure development is affected by the train length.

The final BC pressures in the last cars are plotted in Figure 5 for the various cases considered. As shown in the figure, the final last car BC pressures are independent of train lengths. The lower last car BC pressure with significant leakage reflects the impact of increased air flow demand and the resulting increase in gradient on both 100-car and 200-car trains.

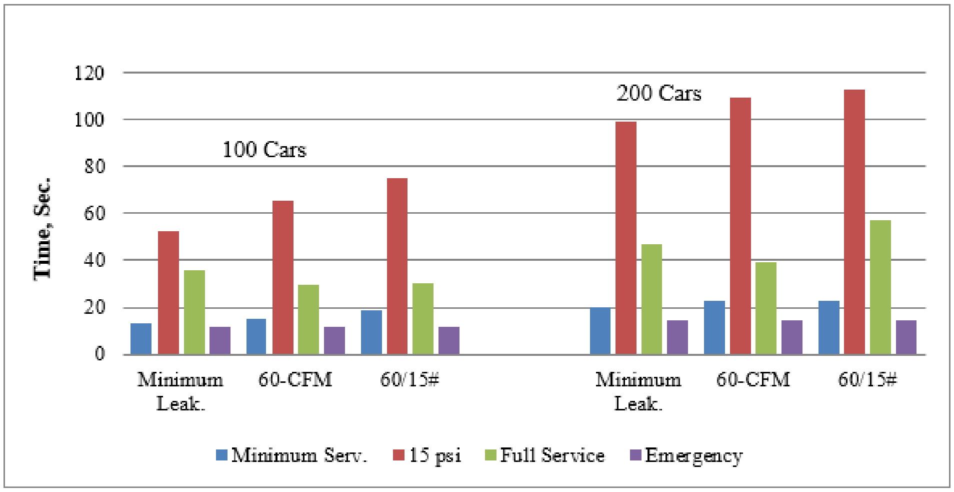

Figure 4. Comparison of Time for Average BC Pressure Development

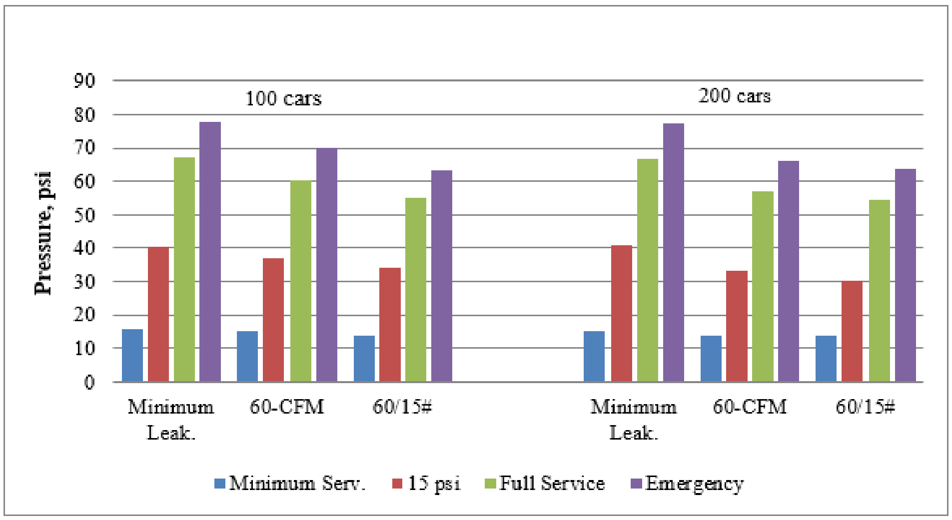

Figure 5. Last Car Final BC Pressure

The last car BC pressures and build up times for the 100-car configuration with 60 CFM leakage after a minimum application are shown in Table 2. The column labeled "initial" is the propagation time, which is the time between the locomotive engineer moving the handle to minimum application position and the BC pressure starting to build up. The "12 psi" column in the table is the buildup time to develop 12 psi BC pressure and includes the propagation time. The "final" column is the final BC pressure for the specific brake application.

The buildup time for getting to 12 psi in the first car BC is 17.1 seconds (see Table 2) for the 100-car configuration. This is greater than the time for the four other cars. The time for the BC pressure buildup in the last car is 15.3 seconds, which is less than the times for the first and 75th cars. The time for the 100-car train configuration with minimum leakage from Test 1-100 is reported as 11.7 seconds for the first car and 13.8 seconds for the last car (Appendix G, Page G1-2 in the test report).

Table 2. Test 13-100, Minimum Application, Release and Recharge (60 CFM)

	BC Development			Release and Recharge	
	Initial	12 psi	Final	Cylinder<3psi	Reservoir w/in 2 psi
Car #	Sec.	Sec.	psi	Sec.	Sec.
1	0.7	17.1	16.0	11.9	18.6
25	2.7	13.9	17.6	18.3	137.1
50	5.1	14.4	15.8	36.6	248.5
75	6.2	16.0	14.9	53.6	283.7
100	7.2	15.3	15.2	53.4	297.6

The results in Table 3 for a 200-car train configuration from Test 13-200 shows the BC pressure development time for the 100th car is less than the first car, and for the 200th car is greater than the 100th car.

Table 3. Test 13-200, Minimum Application, Release and Recharge (60 CFM)

	BC Development			Release and Recharge	
	Initial	12 psi	Final	Cylinder<3psi	Reservoir w/in 2 psi
Car #	Sec.	Sec.	psi	Sec.	Sec.
1	0.7	22.9	15.2	11.4	18.4
50	6.5	30.8	14.6	31.5	351.2
100	8.3	18.0	16.8	73.4	689.9
150	12.4	21.2	14.9	111.0	805.3
200	14.3	20.4	13.9	106.8	843.6

The test results in terms of BC pressure development, release, and recharge for 100- and 200-car train configurations with the 60 CFM and 15 psi gradient leakage conditions are shown in Table 4 and Table 5, respectively. The time for 12 psi pressure development at the 100th car is less than the first car for both the 100-car and 200-car configuration. These results are similar to the results from Test 13-100 in Table 2.

Table 4. Test 25-100, Minimum Application, Release and Recharge (60 CFM/15#)

	BC Development			Release and Recharge	
	Initial	12 psi	Final	Cylinder<3psi	Reservoir w/in 2 psi
Car #	Sec.	Sec.	psi	Sec.	Sec.
1	0.7	21.4	15.4	11.6	18.1
25	3.1	12.5	16.5	18.4	116.8
50	6.7	23.0	14.7	33.9	215.0
75	8.8	18.9	13.3	60.2	288.3
100	9.1	17.7	13.8	60.9	300.9

Table 5. Test 25-200, Minimum Application, Release and Recharge (60 CFM/15#)

	BC Development			Release and Recharge	
	Initial	12 psi	Final	Cylinder<3psi	Reservoir w/in 2 psi
Car #	Sec.	Sec.	psi	Sec.	Sec.
1	0.8	20.5	15.3	11.5	18.2
50	6.7	30.9	14.7	31.2	328.3
100	9.1	19.3	16.6	72.3	720.0
150	13.0	22.0	15.5	112.9	913.6
200	15.2	21.6	14.0	108.4	926.8

The quick service exhaust and limiting features of the control valve initiate a controlled decrease of BP pressure during a brake application in each car. These local control features could assist in BC pressure development independent of the car location and could partly help explain the faster time for BC pressure development in the rear cars. Figure 6 shows a schematic of the quick service exhaust feature of the control valve.

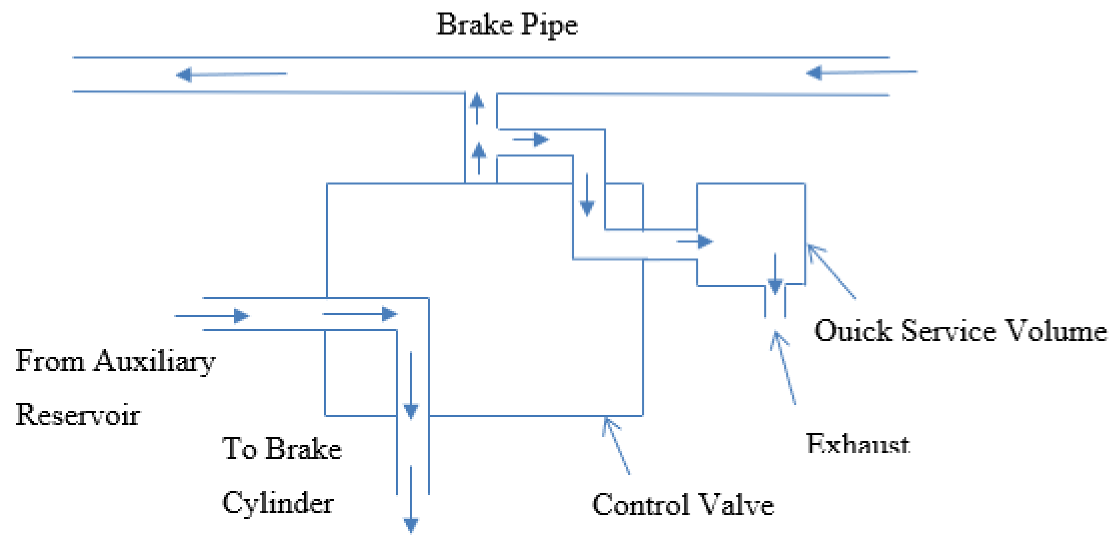

Figure 6. Quick Service Exhaust Feature

The average BC pressure as a function of time for a 15 psi brake application at minimum leakage condition is shown in Figure 7.

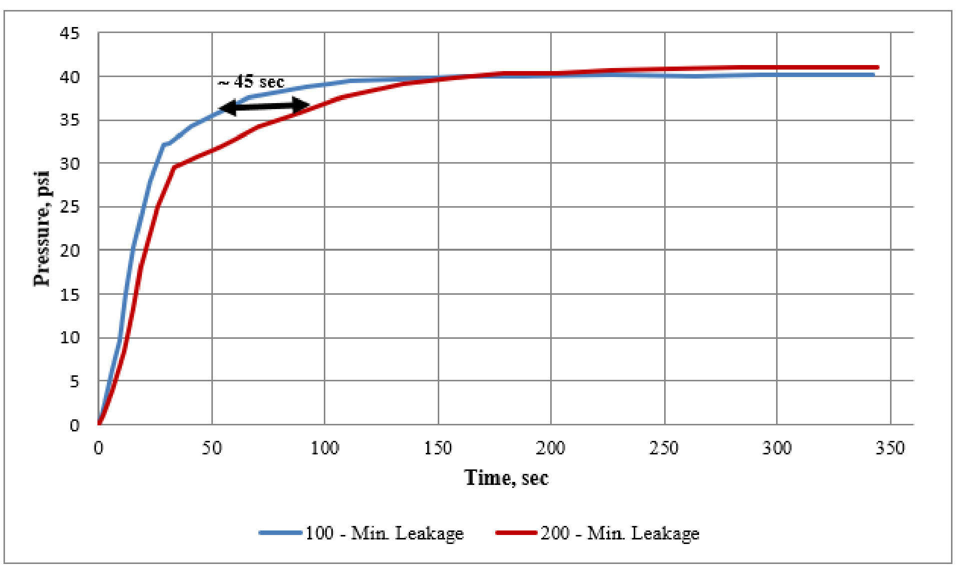

Figure 7. Average BC Pressure Development, 15-psi Application, Min. Leakage

The average BC pressure is 40 psi for both the 100-car and 200-car trains. As shown in the figure, the rate of the average BC pressure buildup for the 100-car train is faster. The loss in performance for the 200-car train is even more pronounced in the case of full service application at 60 CFM leakage (see Figure 8). As shown in the figure, the time to develop 55 psi BC pressure is approximately 31 seconds for the 100-car train, and the time to develop the same pressure in the 200-car train is 58 seconds. The loss of performance is both in terms of lower final average BC pressure and longer time taken to develop the pressure. In summary, based on the data on brake application propagation and BC pressure development, there appears to be minimal impact on train operation as long as the slower response and slightly reduced BC pressure in the VLTs are noted and planned for during train operation.

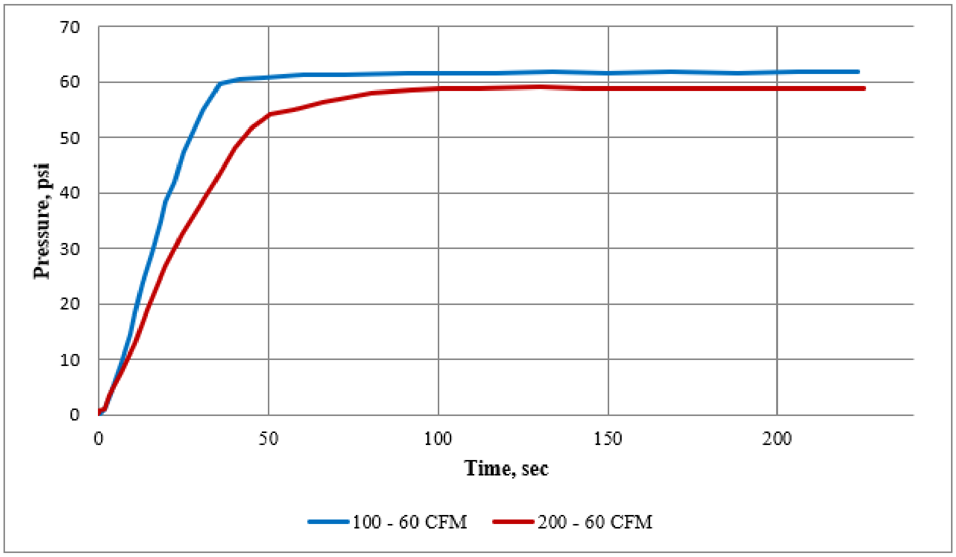

Figure 8. Average BC Pressure Development, Full Service, 60 CFM Leakage

3.3 Release Propagation Time

Brake release propagation time is the duration of the release propagation signal through the train (i.e., the time from when the locomotive handle is moved to release position to when the BC pressure starts to exhaust from the last car). In most cases, as shown in Figure 9, the release propagation time is approximately proportional to train length, including for emergency brake applications. As an example, in the case of a minimum brake application with 60 CFM leakage, the BC release propagation time is 46 seconds for a 100-car train and 100 seconds for a 200-car train.

However, in the case of a minimum brake application with minimum leakage, the release propagation time does not vary linearly with train length. For this case, the release propagation time is 13 seconds for a 100-car train, and 70 seconds for a 200-car train. The significantly shorter release propagation on the 100-car configuration is a result of the faster rate of BP pressure increase on the shorter train, which results in the Service Accelerated Release (SAR) feature propagating through the 100 cars, directing local emergency reservoir air to assist in replenishing the BP. Near the end of longer trains, the BP pressure increase is more gradual as the local SAR valves are not activated, increasing the time to release the application. A BP reduction that is not sufficient to reliably activate all the SAR valves upon brake release also contributes to the longer release propagation times from minimum applications compared to heavier service applications.

The increased brake release propagation time after a full-service application (compared to a 15 psi application) is driven by the over reduction of the BP pressure, 30 psi reduction rather than the 26 psi required for equalization pressure. Therefore, the BP pressure must increase to the equalized auxiliary pressure (nominally 65 psi) first and then another 1.5 psi to actuate the release.

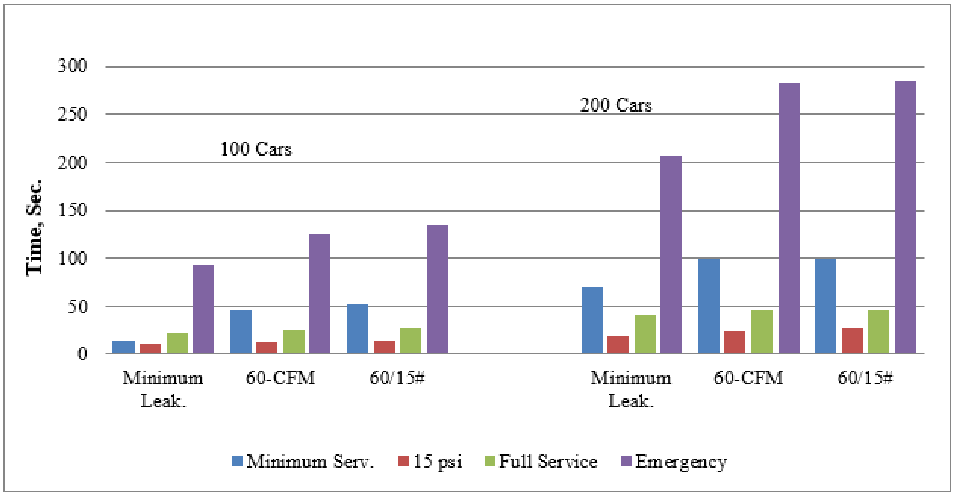

Figure 9. Brake Release Propagation Time

3.4 Last Car BC Release Time

The last car BC release time is the time between when the locomotive handle is moved to the release position and when the last car's BC pressure becomes less than 3 psi. The last car BC release times for 100-car and 200-car trains for various leakage and brake applications are shown in Figure 10. As expected, the release time for the last car BC is higher for the 200-car train in comparison to the 100-car configuration.

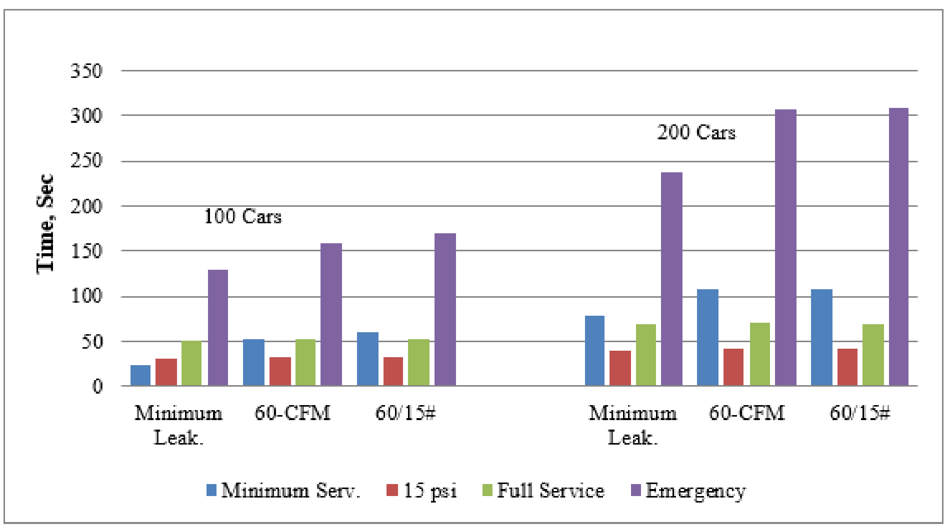

Figure 10. Last Car BC Release Time Including Propagation

When a running release of train brakes is to be made and operation conditions permit, train handling practices specify that BP reduction must be deeper than a minimum application (e.g., at least 10 psi) and sufficient time must be allowed for BP exhaust to stop before releasing brakes.

Applying throttle before waiting for complete release of the brakes at the rear of the train could lead to high draft forces.

For a particular leakage condition and for a given brake application, the difference between the last car BC release time in Figure 10 and release propagation time in Figure 9 is the time needed to empty a BC. Figure 11 shows the time to release the BC pressure excluding the propagation time.

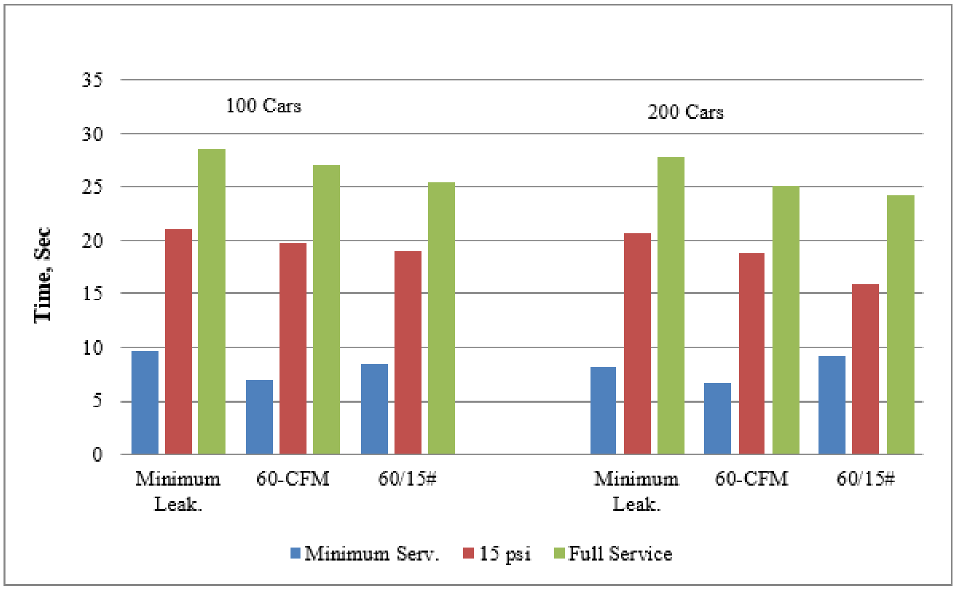

Figure 11. Last Car BC Release Time Excluding Propagation

For example, the time between the release start time and release finish time in the last car of a 100-car train for a minimum brake application is 9.6 seconds at minimum leakage condition. As the brake application increases to 15 psi and then full service, the time to fully release the last car cylinder increases to 21.1 seconds (delta between 31.3 seconds in Figure 10 & 10.2 seconds in Figure 9) and 28.6 seconds (delta between 50.1 seconds in Figure 10 and 21.5 seconds in Figure 9), respectively. For a 200-car train with minimum leakage, the time to release after a minimum 15 psi and service brake applications are 8.2 seconds, 20.7 seconds, and 27.8 seconds, respectively. Once the signal is received, the time to empty the BC in the last car is independent of the train length.

3.5 Recharge Time

Recharge time is the time between the locomotive handle being moved to the release position and last car reservoir pressure reaching within 2 psi of the original pressure (i.e., the time to recharge the train's brakes). As shown in Figure 12, the time to recharge a 200-car train increases approximately by a factor of 3 in comparison to a 100-car train for the same brake application and leakage condition. For example, as seen in the figure, the time for recharging a 200-car train with 60 CFM leakage condition is 32 minutes after release from a 15 psi brake application. The corresponding time for a 100-car train is 10 minutes.

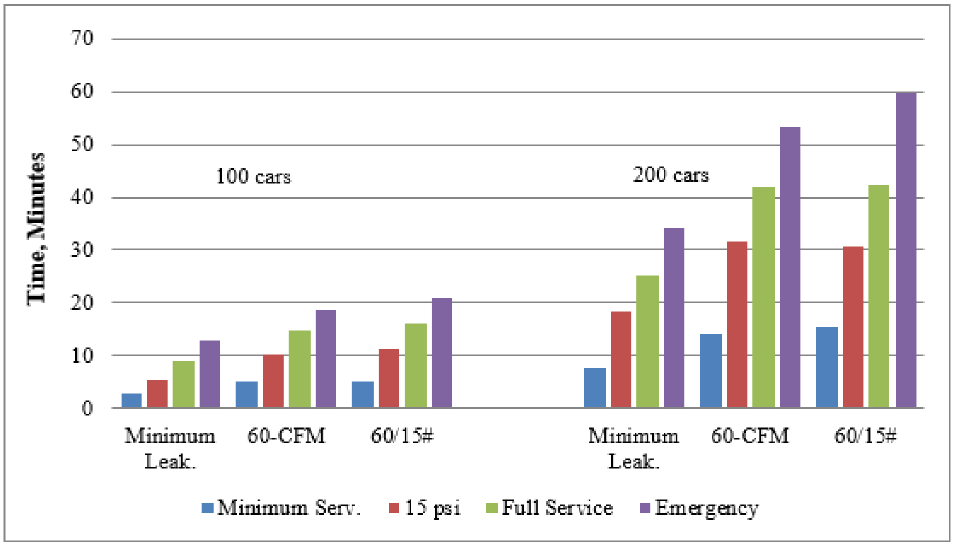

Figure 12. Recharge Time (Last Car Reservoir w/in 2-psi)

As seen in the graph, the recharge time is not proportional to the train length for all the cases tested. The non-linearity is probably due to the pipe friction increasing the recharge time for longer trains for a given leakage and brake application condition. In a VLT, adequate time must be allowed for the brake system to completely charge and stabilize after a release before applying brakes again. The longer recharge times require a longer wait in cycle braking situations to avoid potential unintended brake release situations.

As seen from the chart, the time to recharge after emergency brake application is 21 minutes in a 100-car train, and increases to an hour for a 200-car train with 60 CFM/15# leakage condition.

3.6 Stepped Reduction

3.6.1 Six to 10 psi Stepped Reduction

The effects of stepped reduction in BP pressure (i.e., graduated brake application) were evaluated on the 100-car and 200-car train configurations by applying the brakes with 6 psi application and allowing the entire train to set up, after which an additional application of 4 psi was made. The results from the tests are provided in Table 6 to Table 11 for the three leakage conditions and for both 100-car and 200-car trains.

Table 6. Test 4-100, 6 to 10 psi Stepped Reduction, Min. Leakage

	BC Development (6 psi Application)			**BC Development** (Step to 10 psi Application)		
	Initial	**8 psi**	**Final**	**Initial**	**90%**	**Final**
Car #	**Sec.**	**Sec.**	**psi**	**Sec.**	**Sec.**	**psi**
1	1.0	8.4	10.7	0.2	50.9	25.3
25	2.7	8.7	11.0	1.7	64.1	25.7
50	4.6	10.0	10.2	7.2	61.0	22.8
75	6.0	10.8	10.5	9.7	63.0	23.1
100	6.9	10.7	10.3	8.8	60.8	22.8

Table 7. Test 4-200, 6 to 10 psi Stepped Reduction, Min. Leakage

	BC Development (6 psi Application)			BC Development (Step to 10 psi Application)		
	Initial	**8 psi**	**Final**	**Initial**	**90%**	**Final**
Car #	**Sec.**	**Sec.**	**psi**	**Sec.**	**Sec.**	**psi**
1	1.1	8.4	10.6	0.7	114.9	24.4
50	5.1	11.8	10.4	7.0	127.6	21.9
100	7.9	13.3	12.6	25.5	122.7	22.8
150	12.5	17.3	12.2	38.9	125.5	21.1
200	15.1	18.6	11.7	41.8	126.0	20.9

Table 8. Test 16-100, 6 to 10 psi Stepped Reduction, 60 CFM

	BC Development (6 psi Application)			BC Development (Step to 10 psi Application)		
	Initial	**8 psi**	**Final**	**Initial**	**90%**	**Final**
Car #	**Sec.**	**Sec.**	**psi**	**Sec.**	**Sec.**	**psi**
1	0.7	7.6	11.4	0.3	26.2	24.9
25	3.0	9.2	12.3	2.8	99.5	24.0
50	5.4	11.4	11.6	20.9	113.4	20.8
75	6.4	11.8	11.3	29.3	125.5	20.4
100	7.4	11.7	12.2	31.8	116.4	20.5

Table 9. Test 16-200, 6 to 10 psi Stepped Reduction, 60 CFM

	BC Development (6 psi Application)			BC Development (Step to 10 psi Application)		
	Initial	**8 psi**	**Final**	**Initial**	**90%**	**Final**
Car #	**Sec.**	**Sec.**	**psi**	**Sec.**	**Sec.**	**psi**
1	0.9	7.2	11.7	0.4	7.8	23.7
50	6.5	13.1	11.3	24.0	219.4	17.9
100	8.8	15.0	14.5	125.3	307.4	19.8
150	13.3	18.5	12.9	187.1	315.6	17.0
200	15.4	19.2	12.5	180.0	381.2	17.8

Table 10. Test 28-100, 6 to 10 psi Stepped Reduction, 60 CFM/15#

	BC Development (6 psi Application)			BC Development (Step to 10 psi Application)		
	Initial	**8 psi**	**Final**	**Initial**	**90%**	**Final**
Car #	**Sec.**	**Sec.**	**psi**	**Sec.**	**Sec.**	**psi**
1	0.7	7.4	11.1	0.3	13.2	23.1
25	3.3	9.3	11.9	4.0	95.9	22.2
50	6.8	13.0	11.4	32.7	128.6	17.9
75	9.3	14.8	11.4	60.3	144.8	17.2
100	9.6	14.7	12.7	66.5	149.3	18.0

Table 11. Test 28-200, 6 to 10 psi Stepped Reduction,60 CFM/15#

	BC Development (6 psi Application)			BC Development (Step to 10 psi Application)		
	Initial	**8 psi**	**Final**	**Initial**	**90%**	**Final**
Car #	**Sec.**	**Sec.**	**psi**	**Sec.**	**Sec.**	**psi**
1	0.8	7.7	11.9	0.4	12.1	23.3
50	6.7	13.4	11.1	26.1	139.9	16.5
100	9.3	15.9	15.2	176.1	186.6	17.5
150	13.1	18.8	14.3	311.5	-[1]	15.3
200	15.3	19.4	13.2	331.3	-[2]	14.2

The tables provide times for initial propagation (i.e., from time of air brake handle movement to start of BC pressure reaching 0.5 psi), BC pressure reaching 8 psi or 90 percent of final BC pressure after the initial propagation, and final BC pressures for all the cases.

The times for the 100th car BC pressure development are shown in Figure 13. The time for BC pressure development for the 200th car in the 200-car train is also shown in the figure.

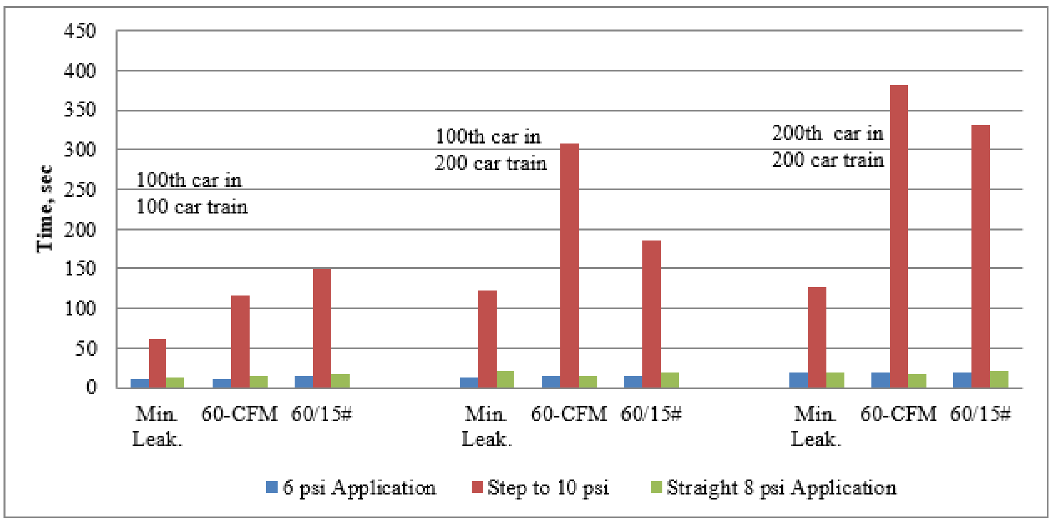

Figure 13. Time for BC Pressure Development, 6 to 10 psi Stepped Reduction

The time to develop 8 psi BC pressure from a 6 psi BP reduction for the 100-car configuration with 60 CFM leakage condition is 11.7 seconds, which increases to 15 seconds in the 100th car of the 200-car train. For an additional reduction of 2 psi in the BP pressure, time to develop 90 percent of the BC pressure is 116 seconds in the 100-car configuration and 307 seconds in the 200-car configuration. There is a large increase in time for the stepped BP reduction for both configurations as compared to the 6 psi straight reduction. The faster build up time for initial 6 psi reduction is due to the quick service volume feature that is activated for the initial reduction only and not for any subsequent reductions.

The percent time delta for the 6 psi reduction at the 100th car in the 200-car configuration for the minimum 60 CFM and 60 CFM/15# psi leakages are 24, 28 and 8 percent, respectively, in

[1] 90% of final cylinder pressures at cars 150 and 200 developed during the initial BP reduction

comparison to the 100th car in a 100-car configuration. There is a significant increase in time to build up to 90 percent of final BC pressure for the 200-car configuration in comparison to the 100-car configuration. The percent time delta for the minimum 60 CFM and 60 CFM/15# psi leakages are 102, 164, and 25 percent, respectively, at the 100th car of the 200-car train configuration in comparison to the 100th car of the 100-car train configuration in the case of 10 psi stepped BP pressure reduction.

The time for the 100th car BC pressure development from straight 8 psi minimum brake application tests are shown for comparison. These data points for the straight minimum brake applications are from test numbers 1-100, 13-100, and 25-100 for the 100-car configurations and 2-100, 13-200, and 25-200 for the 200-car configurations in the Wabtec air rack test. These are very similar to the results from 6 psi application tests.

There is no significant difference in the time for building up to 8 psi of BC pressure between the 100-car and 200-car train configurations. Comparing the results for straight reduction of 8 psi to the stepped reduction case, the time for BC pressure development for the stepped reduction from 6 to 10 psi is much longer than would have been the case for straight reduction to 10 psi.

3.6.2 Fifteen to 17 psi Stepped Reduction

Similar tests were conducted for stepped reductions from 15 to 17 psi for 100-car and 200-car train configurations and the three leakage conditions. The results are shown in Table 12 to Table 17. The results are similar to the stepped reduction 6 to 10 psi cases.

Table 12. Test 5-100, 15 to 17 psi Stepped Reduction, Min. Leakage

	BC Development (15 psi Application)			BC Development (Step to 17 psi Application)		
	Initial	90%	Final	Initial	90%	Final
Car #	Sec.	Sec.	psi	Sec.	Sec.	psi
1	1.0	46.2	36.1	1.8	15.7	42.7
25	2.7	52.8	39.9	3.2	19.2	47.6
50	4.8	51.8	39.4	4.1	19.5	46.6
75	6.3	52.4	39.4	5.4	25.2	47.4
100	7.4	56.0	40.1	6.6	22.3	47.7

Table 13. Test 5-200, 15 to 17 psi Stepped Reduction, Min. Leakage

	BC Development (15 psi Application)			BC Development (Step to 17 psi Application)		
	Initial	90%	Final	Initial	90%	Final
Car #	Sec.	Sec.	psi	Sec.	Sec.	psi
1	1.3	76.8	36.7	1.4	5.1	42.2
50	5.0	85.7	39.8	8.4	16.8	45.4
100	7.7	91.2	42.2	8.1	29.0	48.6
150	12.0	95.8	41.6	18.2	34.1	47.6
200	14.3	99.9	39.8	25.8	39.9	46.6

Table 14. Test 17-100, 15 to 17 psi Stepped Reduction, 60CFM

	BC Development (15 psi Application)			BC Development (Step to 17 psi Application)		
	Initial	90%	Final	Initial	90%	Final
Car #	Sec.	Sec.	psi	Sec.	Sec.	psi
1	0.6	37.2	34.9	0.3	0.6	41.4
25	2.7	57.7	37.4	2.7	14.2	44.2
50	4.7	60.9	36.6	15.7	25.6	42.5
75	6.2	64.8	36.1	20.6	40.9	42.8
100	7.2	64.0	36.7	21.0	35.0	42.9

Table 15. Test 17-200, 15 to 17 psi Stepped Reduction, 60 CFM

	BC Development (15 psi Application)			BC Development (Step to 17 psi Application)		
	Initial	90%	Final	Initial	90%	Final
Car #	Sec.	Sec.	psi	Sec.	Sec.	psi
1	0.7	40.5	33.8	0.4	0.7	39.8
50	5.3	44.6	33.6	5.3	28.3	39.8
100	8.0	117.3	35.4	26.0	85.3	41.6
150	11.8	119.3	32.8	53.8	102.1	38.2
200	14.0	155.9	32.9	31.2	115.8	38.6

Table 16. Test 29-100, 15 to 17 psi Stepped Reduction, 60 CFM/15#

	BC Development (15 psi Application)			BC Development (Step to 17 psi Application)		
	Initial	90%	Final	Initial	90%	Final
Car #	Sec.	Sec.	psi	Sec.	Sec.	psi
1	0.7	46.8	34.6	0.4	0.7	39.7
25	3.0	68.8	36.4	3.9	5.2	41.9
50	6.0	75.0	34.4	18.2	15.5	39.0
75	8.5	89.0	33.3	26.0	43.2	38.2
100	8.8	86.9	34.2	28.5	30.0	38.9

Table 17. Test 29-200, 15 to 17 psi Stepped Reduction, 60 CFM/15#

	BC Development (15 psi Application)			BC Development (Step to 17 psi Application)		
	Initial	90%	Final	Initial	90%	Final
Car #	Sec.	Sec.	psi	Sec.	Sec.	psi
1	0.8	39.4	33.1	0.5	0.7	38.9
50	5.7	76.1	32.4	10.3	20.0	37.7
100	8.6	95.3	33.5	42.5	82.9	39.4
150	12.5	114.0	30.6	60.3	89.9	35.5
200	14.6	131.8	30.1	80.3	111.8	35.7

The times for BC pressure development for the 100th and 200th car for 100-car and 200-car trains are shown in Figure 14. For brake intensification, the effect of increased leakage in a longer train is more significant than in a 100-car train.

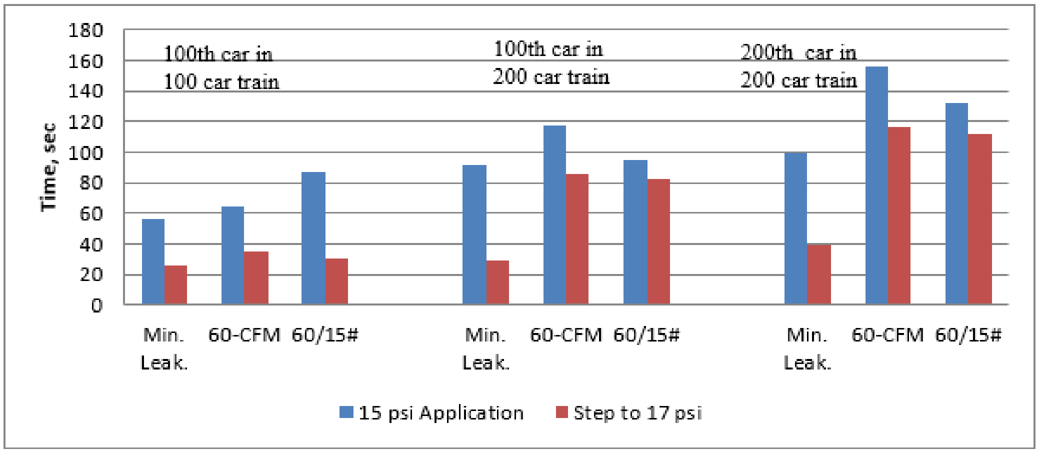

Figure 14. Fifteen to 17 psi Stepped Reduction, Time for BC Pressure Development

In summary, the time for stepped reduction in a VLT is much longer, up to 164 percent in some cases, than in a conventional 100-car train. An engineer on a VLT with leakage may not see the benefit of a second application for some time.

3.7 False Gradients

If a locomotive engineer makes a brake application and a running release of the brake and then follows it with another reduction before the ARs have had time to recharge, there is a good possibility that some of the brakes will not apply from the second reduction, unless the second reduction is greater than the first.

A false gradient is the difference between the actual BP pressure and the targeted BP pressure. An unintended release of brakes occurs when the BP pressure at the rear of the train increases (as pressure maintaining feature recovers the lower BP pressure) above the AR due to insufficient recharge of the system.

In tests to simulate false gradient scenarios, a release was made after a 20 psi brake application. The release was followed by an 8 psi minimum application with a partial recharge. In Table 18, test results from a 20 psi brake application are provided for various test configurations of train lengths and leakage levels and for false gradients from -4 psi to 0. As seen from the table, minimum brake application did not cause unintended brake release on cars with a partial recharge to within 2 psi of the full charge.

Table 18. Effect of False Gradients

	Time from brake release (min) / Number of cars released			
False Gradient (psi) →	**-4**	**-3**	**-2**	**0**
100 Cars – Min. Leakage	4.3/**50**	6.5	7.9	10.5
100 Cars - 60-CFM	6.5/**63**	8.3/**49**	11.5	20.1
100 Cars - 60-CFM / 15-psi Gradient	7.8/**50**	10.8/**48**	14.0	23.8
200 Cars – Min. Leakage	13.7/**105**	16.0/**60**	20.7	29.7
200 Cars - 60-CFM	21.5/**151**	28.5/**143**	37.5	64.8
200 Cars - 60-CFM / 15-psi Gradient	21.5/**151**	28.8/**148**	37.7	71.5

In the table, cells with unintended brake releases are highlighted in red. On a 200-car train with minimum leakage, if a brake application was made after 16 minutes after release, a false gradient of 3 psi results in the release of brakes on 60 cars. Figure 15 plots the BP pressures for the locomotive and the last car for this case.

The results of the false gradient tests are shown in Table 19 for the 100-car and Table 20 for the 200-car trains. The unintended release situations can be avoided if the false gradient is less than 2 psi for all conditions. The unintentional brake releases do not occur during a 13 psi brake application (instead of an 8 psi minimum application).

Based on the test cases discussed, the team found that a VLT takes more time for recharge after a running release in comparison to the 100-car train. This slower response in handling the VLTs should be noted and planned for during train operation. During unintended release, a larger proportion of cars release the brakes in a VLT.

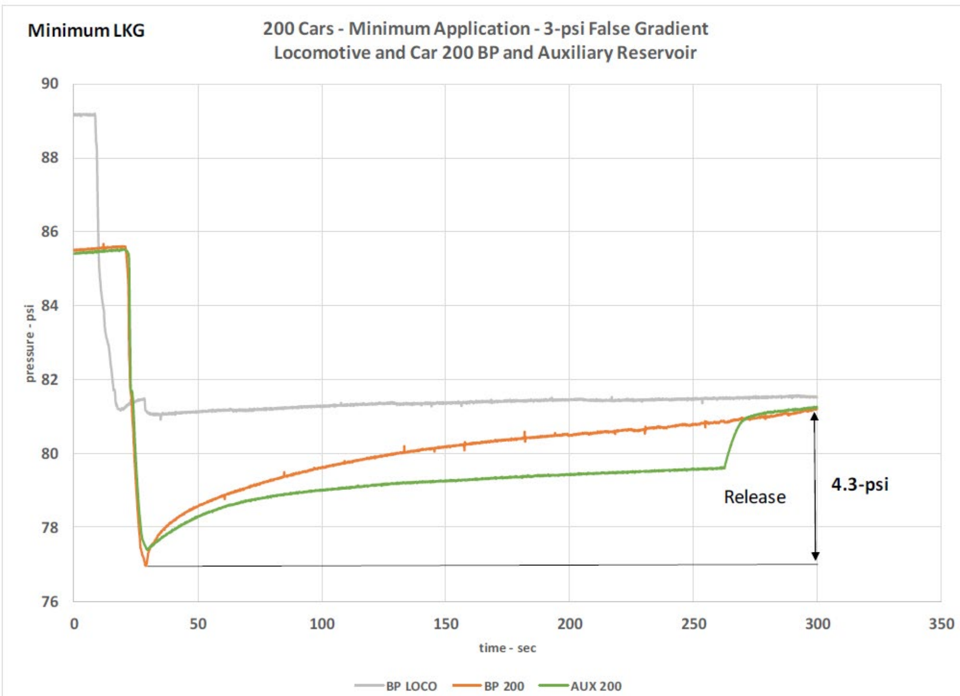

Figure 15. False Gradient on 200-car Train

Table 19. Effect of False Gradient, 100 Cars – Minimum Leakage

Test Number	False Gradient	Application	Time from Release of 20-psi Reduction	Flow	Number of Cars Released	Last Car Time to Release
	psi	psi	min:sec	CFM		sec
1-100	0	8	10:26	9.7	0	----
9-100	-2	8	7:52	22.4	0	----
10-100	-3	8	6:32	28.6	0	----
11-100	-4	8	4:21	34.6	50	50.2
12-100	-4	13	4:33	31.3	0	----

Table 20. Effect of False Gradient, 200 Cars – Minimum Leakage

Test Number	False Gradient	Application	Time from Release of 20-psi Reduction	Flow	Number of Cars Released	Last Car Time to Release
	psi	psi	min:sec	CFM		sec
1-200	0	8	29:38	10.5	0	----
9-200	-2	8	20:40	20	0	----
10-200	-3	8	16:04	22.1	60	254.4
11-200	-4	8	13:42	25.6	105	124.3
12-200	-3	13	16:28	22.9	0	----

4. Conclusion

Air brake rack tests were conducted to simulate air brake performance of a VLT in a variety of real-life operating scenarios, including leakage and pressure gradients. The air brake performance of a 200-car train configuration was compared with a 150-car and 100-car train configuration.

Brake Application and BC Pressure Buildup

As expected, during brake application, signal propagation time was approximately proportional to the train length, and was almost double for the 200-car train compared to the 100-car train. This observation is valid across all leakage conditions and brake application conditions.

The BC pressure in the last car was almost equal and the train average BC pressure was slightly lower in the VLT (i.e., 37 psi for 100-car train vs 34 psi after a 15 psi brake application for the 200-car train at the 60 CFM leakage condition).

The BC pressure build up time was high during brake applications in the 200-car train in comparison to the 100-car train for the various leakage conditions.

The team found that there were slightly slower response times and slightly reduced BC pressures as train length increased, with leakage levels further contributing to the differences.

Brake Release

The time to release the brake in the last car, after various brake application levels and at three leakage conditions, was compared between the conventional 100-car train and the VLT.

During brake release, signal propagation was approximately proportional to the train length, except for the case of release after a minimum brake application with the minimum leakage condition[2].

Applying throttle before waiting for complete release of the brakes at the rear of the train could lead to high draft forces.

Recharge

Time for the brake system to completely recharge and stabilize after a release for the 200-car train was approximately three times longer than the recharge time for the 100-car train. For example, the recharge time a 100-car train with 60 CFM leakage condition was 10 minutes after release from a 15 psi brake application. The corresponding time for a 200-car train was 32 minutes.

Longer recharge times required longer wait times in cycle braking situations to avoid potential unintended brake release situations

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[2] In this case, the release time is more than triple for the 200-car configuration in comparison to the 100-car configuration.

Stepped Reduction

In the case of an initial 6 psi application, the 100th car in a 200-car configuration took 28 percent more time for BC pressure development than the 100th car in a 100-car train with 60 CFM leakage.

For the stepped reduction from 6 to 10 psi under 60 CFM leakage condition, the increase in time was 164 percent to achieve the final BC pressure in the 100th car in a 200-car train in comparison to the 100-car configuration.

Straight BP reductions rather than a stepped reduction was advantageous in terms of time for BC pressure build up during service brake applications in both a conventional 100-car train and VLTs.

False Gradient

In the case of brake application with a partial recharge (e.g., after a running release from a 20 psi application), there is a possibility for unintended release of brakes in some cars during a subsequent minimum BP reduction. When subsequent brake applications were made without waiting for the BP pressure at the rear of the train to fully recover, the likelihood of unintended brake releases were higher with longer trains. Such situations can be avoided by making the second brake application appropriately deeper than the first application.

To avoid an unintended release for a 200-car configuration, the required charging time was approximately 16.5 minutes under a 3 psi false gradient. For a 100-car configuration, a recharge time of approximately 4.5 minutes was sufficient to avoid unintended release.

Unintended release situations could be avoided if the false gradient was less than 2 psi for all conditions. The amount of brake application should be appropriately deeper than a minimum application to avoid the possibility of unintended brake releases in both the 100-car and 200-car configurations.

The team found that a VLT takes up to 2.5 times more time to recharge after a running release compared to a 100-car train. This slower response in handling VLTs should be accounted for during train operation. When the brakes released unintentionally, a larger proportion of cars released the brakes in a VLT.

5. References

1. New York Air Brake Instruction Manual MU-21, "DB-60 Control Valve, Instruction Manual MU-21," IP-185 Rev. 3, March 2013.
2. Federal Railroad Administration, Department of Transportation. 49 CFR § 232 – BRAKE SYSTEM SAFETY STANDARDS FOR FREIGHT AND OTHER NON-PASSENGER TRAINS AND EQUIPMENT; END-OF-TRAIN DEVICES.

Abbreviations and Acronyms

ACRONYM	DEFINITION
AAR	Association of American Railroads
AR	Auxiliary Reservoir
BC	Brake Cylinder
BP	Brake Pipe
CAD	Computer Aided Design
CFR	Code of Federal Regulations
CFM	Cubic Feet per Minute
DOT	Department of Transportation
ER	Emergency Reservoir
FEA	Finite Element Analysis
FRA	Federal Railroad Administration
kips	kilo pounds
Ksi	kilo pound per square inch
SCFM	Standard Cubic Feet per Minute
VLT	Very Long Train