

**IMPROVED BRAKING SYSTEM SIMULATION
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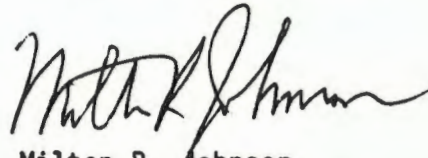
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PREFACE

The work described in this report was conducted by IIT Research Institute (IITRI) under authorization of Federal Railroad Administration (FRA) Contract No. DTFR53-82-C-00254, Task Order No. 4. The period of performance was from September 22, 1987 to October 24, 1988. The work was directed at the study of safety in the operation of freight trains where the air brake operating conditions were significantly different from current U.S. practices. The work was conducted by using the fluid mechanic air brake model, which IITRI has developed for the Research and Locomotive Evaluator/Simulator (RALES).

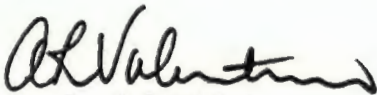
Dr. Milton R. Johnson was the IITRI Project Manager for this work. He was assisted by Mr. Graydon F. Booth. Messrs. M. Clifford Gannett and Garold R. Thomas were the FRA Contracting Officers Technical Representatives on this project. Their assistance throughout the course of the work is gratefully acknowledged.

Respectfully submitted,



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1. INTRODUCTION

1.1 OBJECTIVE AND SCOPE

This report presents results from an analytical study to examine certain questions relating to safety in freight train operation where the characteristics of the air brake system differ significantly from historic U.S. operating practices. Two conditions were considered. The first involved allowing train operation with greater leakages than permitted by current regulations through the use of the "air flow" method of conducting the terminal brake test. Most of the effort on the project was directed at examining the consequences of train operations under these conditions. The second area of investigation involved examining train operations and braking when air brake repeater relay units are used in trains.

The analysis of air brake performance was based on the use of a fluid mechanic air brake model. This model was developed for the Research and Locomotive Evaluator/Simulator (RALES) facility, which is located at IIT Research Institute (IITRI). The model was used to conduct parametric studies to evaluate the performance of train air brakes under a wide variety of conditions.

The use of fluid mechanic models to represent air brake operation is a relatively new development (Ref. 1). The RALES fluid mechanic model has been developed under a cooperative program with the Association of American Railroads (AAR) Technical Center and is also being used in the new AAR, TOES train operation simulation program. Details of the model are described in an Appendix to this report.

1.2 BACKGROUND

1.2.1 Air Brake Leakage Requirements

Federal regulation requires (49CFR232.12) that an air brake test be performed before a train departs from a terminal and during its operation if any cars are added. The purpose of the air brake test is to ensure that the train has an effective brake system. This is accomplished by:

- inspecting the train brake system and correcting any apparent leakage,

- assuring that the brake pipe gradient requirement is met (rear of train charged to within 15 psi of front of train),
- assuring that the train meets a 5 psi/min leakage requirement, and
- checking to see that the train brakes apply and release.

The conventional method for determining whether or not the leakage requirement is met is to first make a continuous 15 psi brake pipe pressure reduction. After cessation of the brake pipe exhaust the pressure maintaining feature of the locomotive brake valve is cut out and the brake pipe pressure is allowed to stabilize. A check is then made to determine that the brake pipe pressure does not reduce more than 5 psi per minute.

For a number of years there has been interest in using a different approach for satisfying the leakage requirement, namely, setting a limit to the air flow which is required to maintain the pressure in the brake pipe. Much work on this subject has been done in Canada where leakage presents quite a problem in cold weather. This has led to the development of an alternative procedure for determining whether or not there is excessive leakage. During the air brake test, after the air brake system has been charged to within 15 psi of the standard air pressure for the train, a determination is made through the use of the brake pipe flow indicator that the air flow required to maintain the pressure in the pipe does not exceed 60 SCFM*. A full service reduction is then made to insure that the brakes apply on every car in the train.

The major advantages that are claimed for air flow method are summarized as follows (Ref. 2):

- The test is made in the operating mode of the brake system rather than having the pressure maintaining feature cut out.
- The test is made at the full working brake pipe pressure for the train rather than at a 15 psi reduction.
- The brake branch pipe and emergency and auxiliary reservoirs are included in the tests.

*SCFM: Standard Cubic Feet per Minute (air at 60°F and 14.7 psi)

- The test is based on the flow of air into the entire system rather than by a pressure drop indicated by the locomotive gage.

The safety of utilizing this procedure has been verified by extensive operations in Canada.

1.2.2 Air Brake Repeater Relay Units

Repeater relay units have been developed which are intended to improve air brake operating characteristics on long trains (Ref. 3). A relay unit is normally inserted about the middle of the train and serves as the main operating device for the rear half of the train. Pressure signals, which are received from the front brake pipe, cause the main section of the repeater unit to relay service brake applications and releases to the rear section. The unit also contains directional by-pass check valves which allow passage of an emergency brake application from either end of the train through the repeater unit. The unit also contains its own air supply from an engine driven compressor.

A pneumatic repeater relay system includes two major parts:

- 1) an air compressor and storage reservoirs, and
- 2) the brake repeater systems assembly which includes safety valves, filter unit, reservoirs, feed valve and the pneumatic repeater relay unit. The latter component includes the devices which are connected to the brake pipes leading to each end of the car.

The pneumatic repeater unit is intended as the main operating device for the rear half of the train in which it is inserted. Pressure signals received from the front brake pipe will cause the main section of the repeater unit to relay service brake applications and releases to the rear brake pipe. To do this, the equipment contains a positioning valve, a repeater valve, a variable orifice valve, and a cut-off valve. There is also a small reservoir to provide a pressure level reference at the cut-off valve and two check valves for creating proper pressure differentials between the front and rear brake pipes. There are also two directional by-pass check valves which will pass an emergency brake application from either end of the train through the repeater unit.

The repeater valve is piloted by the state of the front brake pipe and connects the rear brake pipe to either an exhaust port or to the feed valve connection from the repeater unit air supply system. It also functions to supply air to maintain pressure in the rear brake pipe if the cut-off valve has not moved to its application position. It is at the repeater valve that the actual transfer of air to the rear brake pipe occurs.

The advantages of using a repeater relay unit are that it makes possible a reduction in the terminal time for charging the train air supply and testing the brakes. It also improves the train line pressure gradient, which is a particularly serious problem during cold weather on long trains. This makes possible the development of more uniform and effective braking forces throughout the train, which is especially important for the safe handling of long trains. It also provides for a decrease in the brake release and recharge time, another desirable feature for improved train handling. Although these systems have been developed and demonstrated they have not been widely used.

2. MEASURES OF AIR BRAKE SYSTEM PERFORMANCE

Past studies of the effects of leakage on air brake performance have used various measures to evaluate air brake system performance (Ref. 4). These have included:

- train gradient (brake pipe pressure difference between front and rear of train),
- brake cylinder application time (defined as the time to initiate the brake on the last car of the train),
- brake cylinder pressure build-up time (defined as the time for the pressure to reach a level within 5 psi of maximum pressure on the first car of the train),
- average train brake cylinder pressure,
- train stop distance,
- difference in brake cylinder pressure between first and last car of the train,
- brake release time, and
- brake system recharge time.

While these parameters serve to characterize the air brake system, with the exception of the stop distance parameter, they do not directly relate to the issue of safety.

Additional measures which are relevant to air brake performance as it relates to the safety of train operations include:

- tendency for the development of situations which would lead to undesired releases,
- failure of brakes to apply on all cars in the train when a brake pipe reduction is initiated at the locomotive,
- initiation of an undesired emergency brake application when a service reduction is made, and
- development of large transient (longitudinal) coupler forces due to slack action when a brake application is made.

3. ANALYSIS OF EFFECTS OF AIR FLOW AND LEAKAGE ON BRAKE SYSTEM PERFORMANCE

A large number of computer runs have been made to relate leakage, gradient and air flow to the performance of the train air brake system. These analyses have been made to determine if there are detrimental effects if one uses a terminal brake test criterion with constraints in the vicinity of a maximum 15 psi gradient and a maximum 60 SCFM air flow.

The analyses were conducted for 3 different trains with the following consists: 2 locomotives and 50 cars (total 52 vehicles), 3 locomotives and 100 cars (total 103 vehicles), and 4 locomotives and 150 cars (total 154 vehicles). An initial brake pipe pressure of 80 psi was assumed at the front of the train for each of the computer runs.

3.1 RELATIONSHIPS BETWEEN LEAKAGE, GRADIENT AND AIR FLOW

The implications of various criteria for a terminal test defining the acceptability of a train brake system (e.g., 5 psi/min leakage and 15 psi gradient, or 60 SCFM air flow and 15 psi gradient) can be shown on a series of figures where gradient is plotted as a function of leakage and air flow is shown by a series of lines on the figure. These plots are presented in Figures 1 to 6 for three different train lengths. Two figures are used for each train length. The first figure shows gradient as a function of leakage for a train with leakage concentrated at the rear of the train and a train with uniform leakage. The abscissa represents a third condition, namely, leakage concentrated at the front of the train. The curve representing leakage concentrated at the rear of the train is an extreme condition in the functional relationship between gradient and leakage. A plot representing a train with any other leakage condition would lie between the curve for concentrated leakage at the rear of the train and the abscissa. Lines representing constant values of air flow are also plotted on the figures to complete the depiction of the relationship between air flow, gradient and leakage. These lines show that air flow is roughly proportional to the leakage rate, but that the type of leakage in the train has some influence as shown by the slopes of these lines.

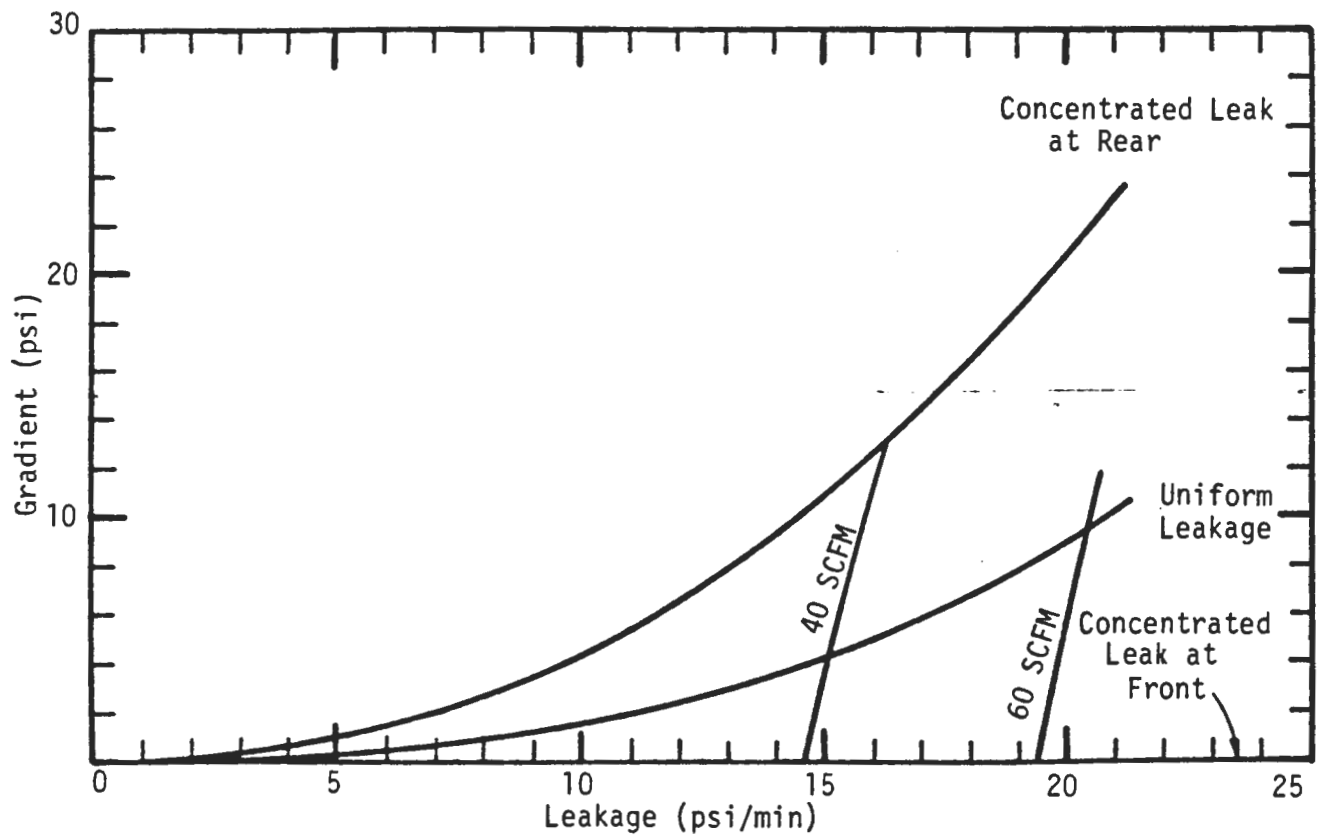


Figure 1. Gradient Versus Leakage for Various Leakage Conditions on Train with 2 Locomotives and 50 Cars

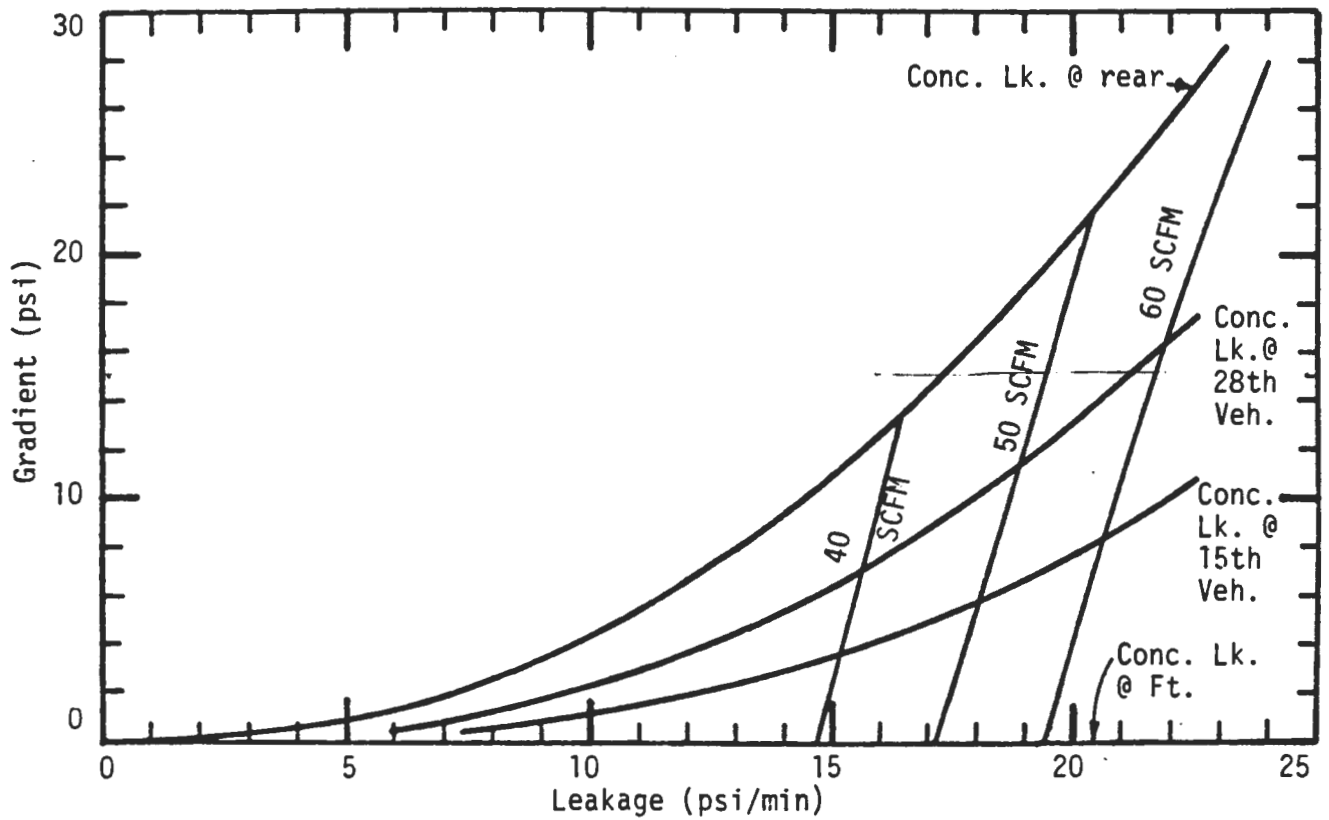


Figure 2. Gradient Versus Leakage for Concentrated Leakage Cases on Train with 2 Locomotives and 50 Cars

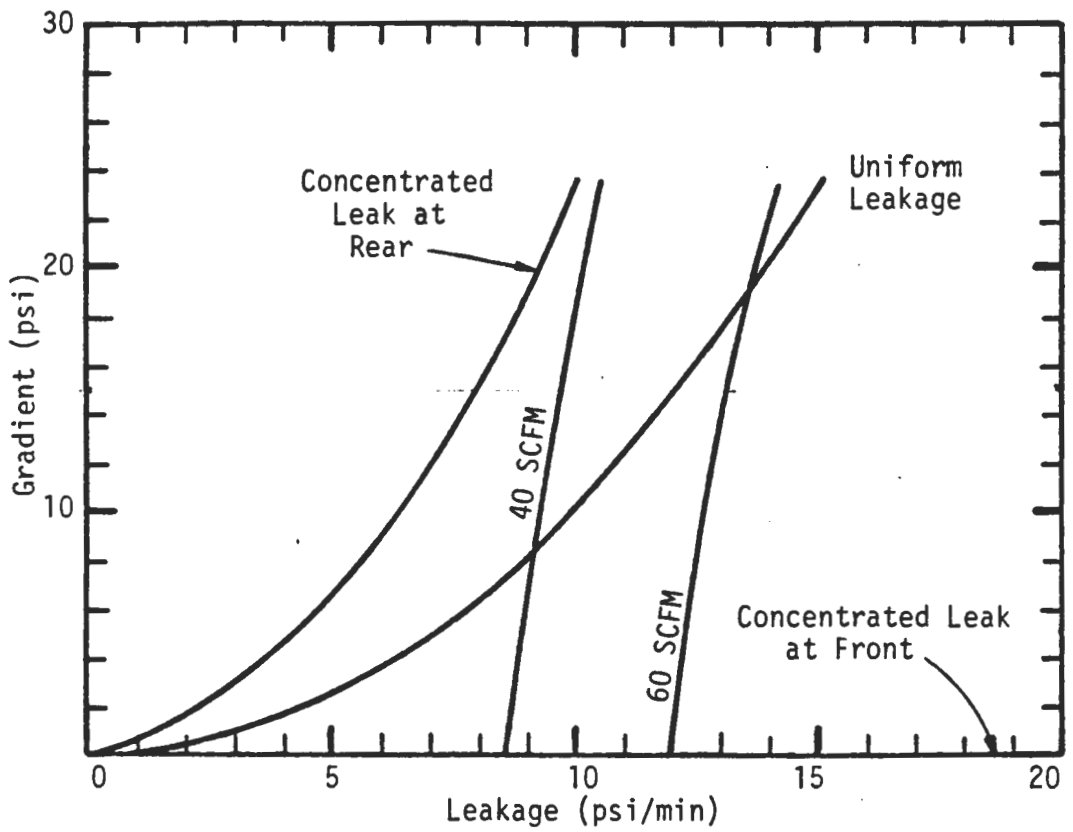


Figure 3. Gradient Versus Leakage for Various Leakage Conditions on Train with 3 Locomotives and 100 Cars

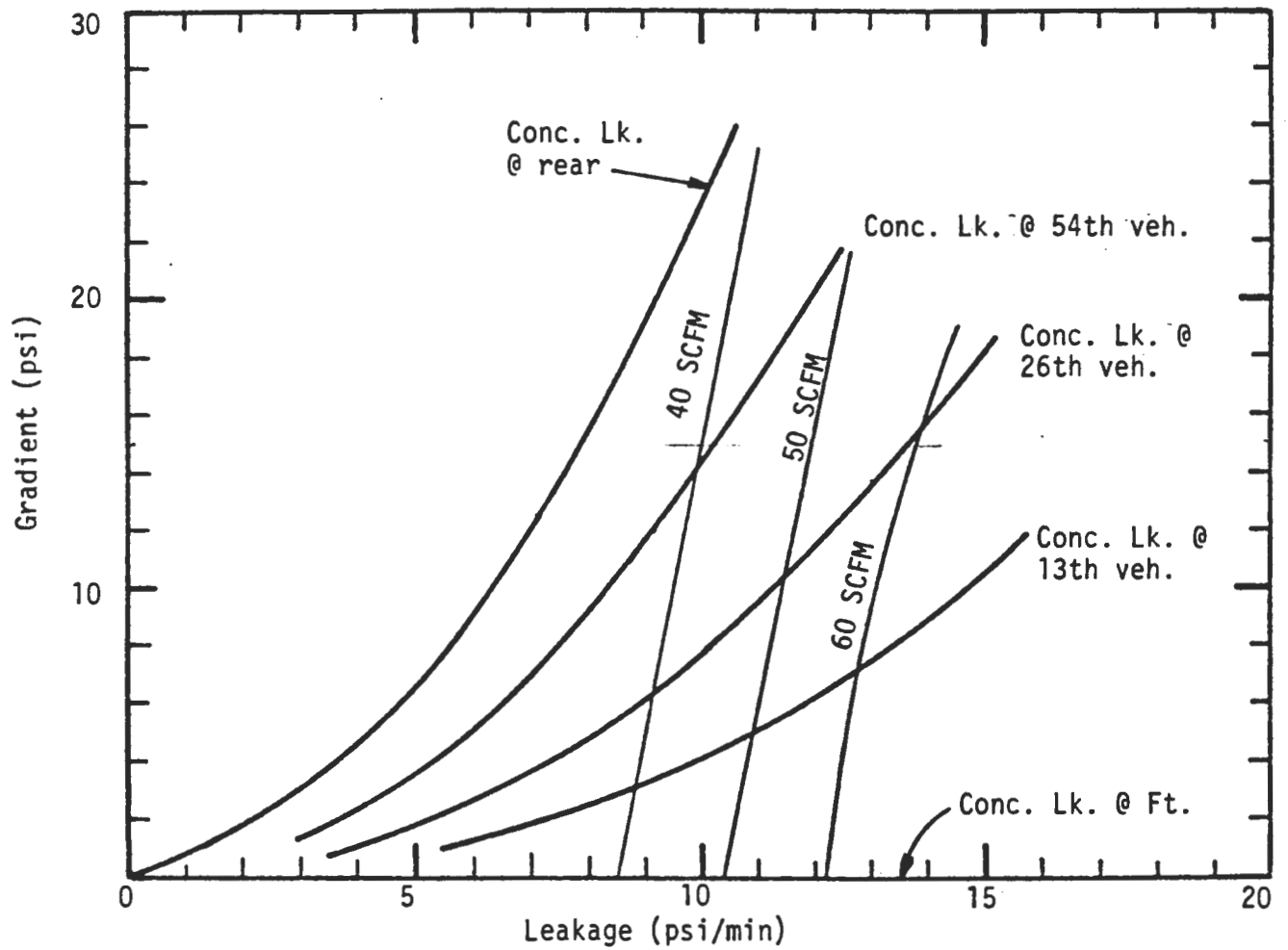


Figure 4. Gradient Versus Leakage for Concentrate Leakage Cases on Train with 3 Locomotives and 100 Cars

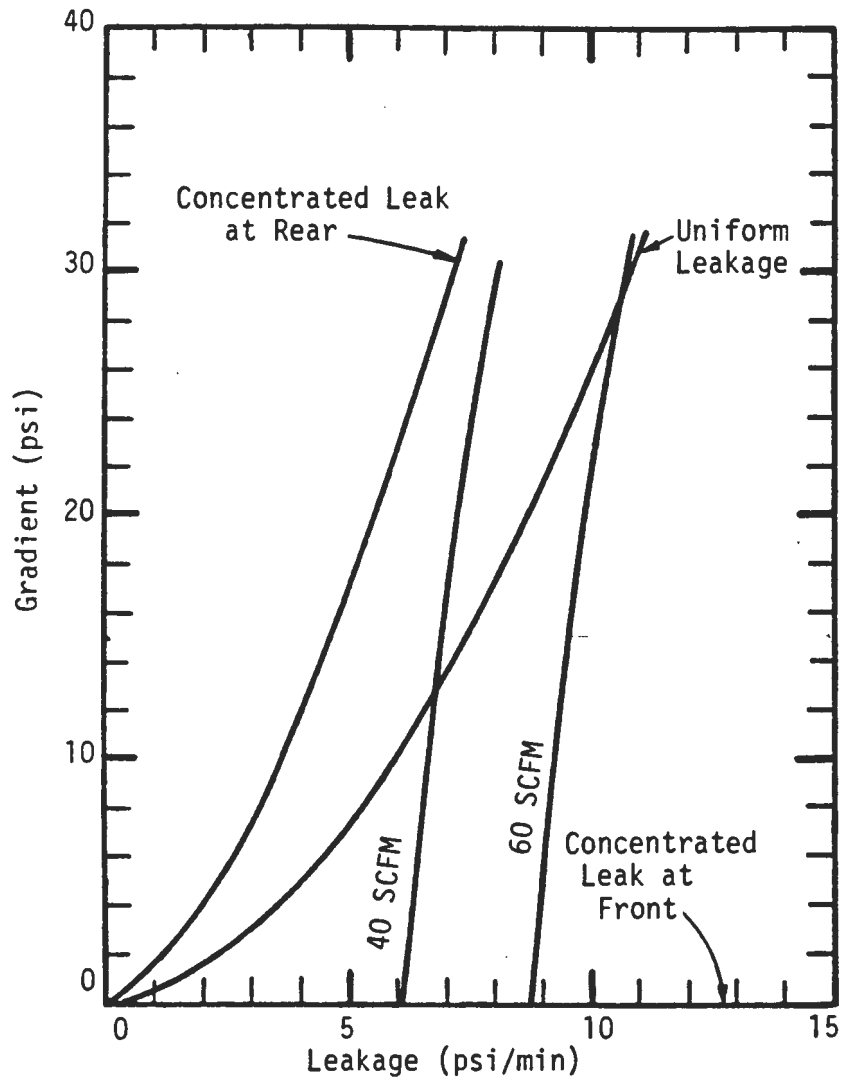


Figure 5. Gradient Versus Leakage for Various Leakage Conditions on Train with 4 Locomotives and 150 Cars

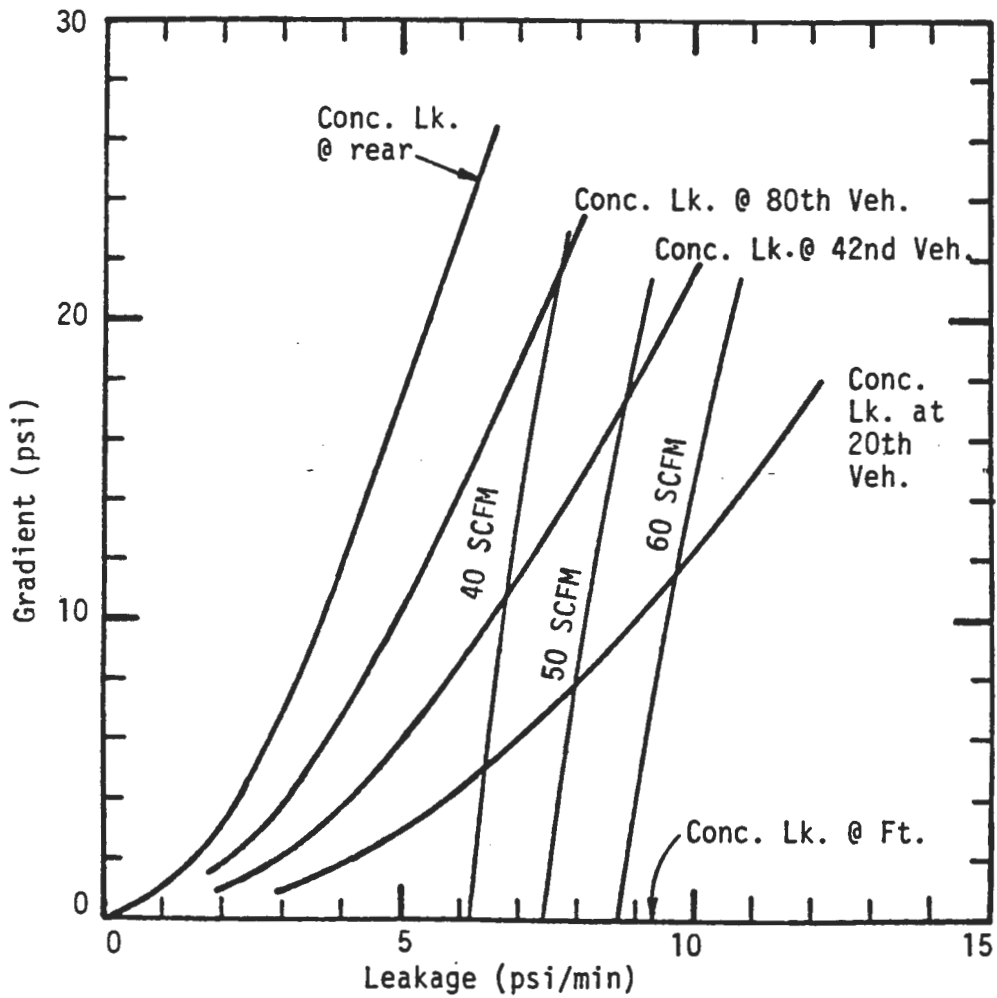


Figure 6. Gradient Versus Leakage for Concentrated Leakage Cases on Train with 4 Locomotives and 150 Cars

The second figure for each train consist shows similar information for concentrated leakage at various positions within the train. On the larger 103 and 154 vehicle trains three intermediate conditions of leakage are plotted. Two intermediate leakage conditions are shown for the 52 vehicle train. It is assumed that the temperature of the air brake system is at 70°F for the data shown in the figures.

The region for permissible operation within the limitations of a maximum gradient of 15 psi and a maximum air flow of 60 SCFM is larger than if one used criterion of a maximum gradient of 15 psi and a maximum leakage of 5 psi/min. The air flow/gradient criterion allows higher leakages. The allowable leakage is larger on shorter trains than on longer trains. For example, the leakage which would be permitted on a 154 vehicle train with uniform leakage is 7.4 psi/min, only 2.4 psi/min greater than 5.0 psi/min because at the 7.4 psi/min leakage a gradient of over 15 psi is developed.

3.2 INCREASE IN STOP DISTANCE

The air flow/gradient criterion results in the operation of trains with larger gradients. This, in turn, can result in longer stop distances. Stop distances have been calculated for a range of leakage, air flow and gradient conditions. Two different braking procedures have been analyzed, emergency and service braking. It was assumed that the trains consisted of fully loaded 100 ton capacity cars for these analyses. An initial speed of 50 mph was also assumed.

The results for emergency braking are shown in Figures 7 to 9 where Figures 1 to 3 are repeated with the addition of lines representing increases in stop distance of 10 and 20 percent when compared to a train with no leakage. The increase in stop distance is more significant with longer trains. Figure 9, for example, shows that for a 154 vehicle train the 20 percent increase line begins to encroach on the area bounded by a 15 psi gradient line and the 60 SCFM line. The 20 percent increase line lies outside of these boundaries for the shorter trains.

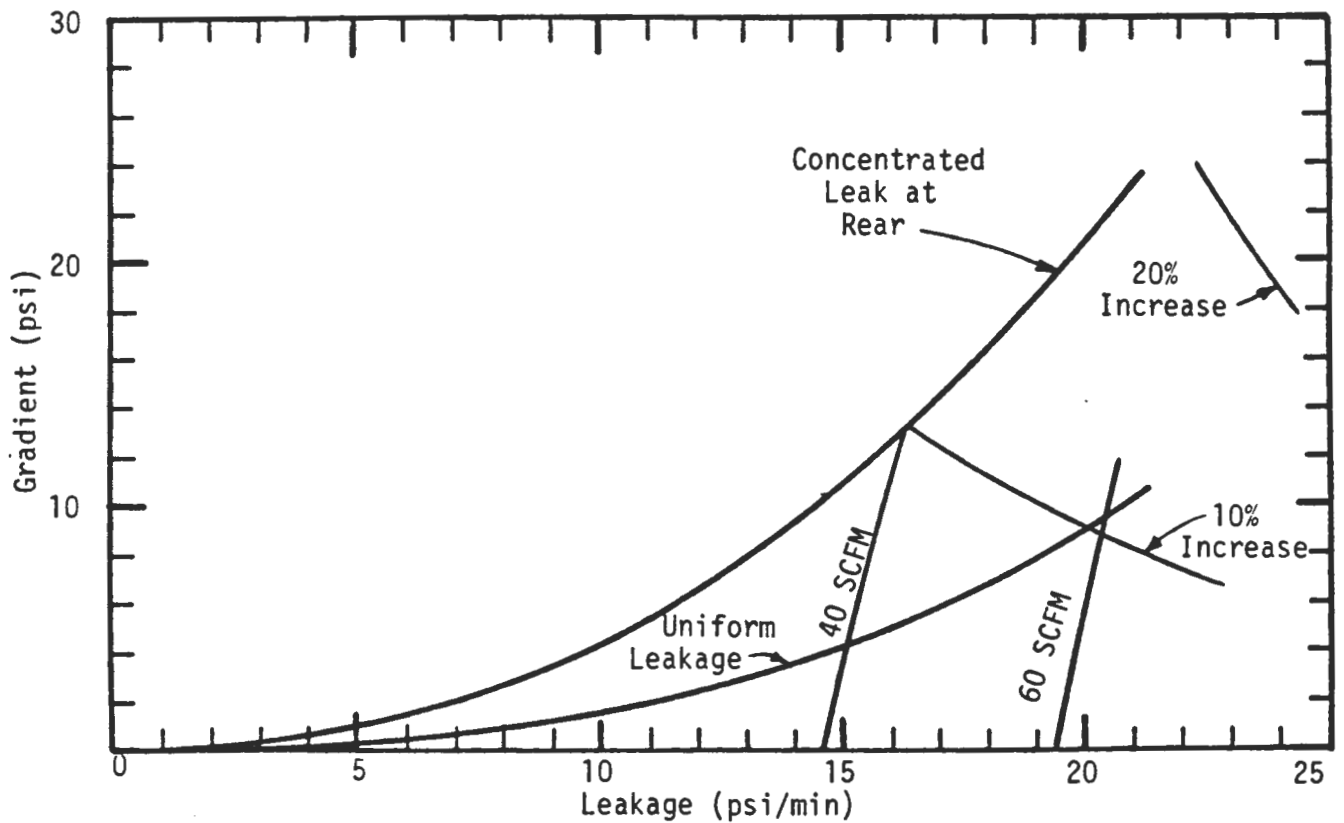


Figure 7. Gradient Versus Leakage for Train of 2 Locomotives and 50 Cars, with Lines Showing 10 and 20 Percent Increase in Emergency Braking Stop Distance

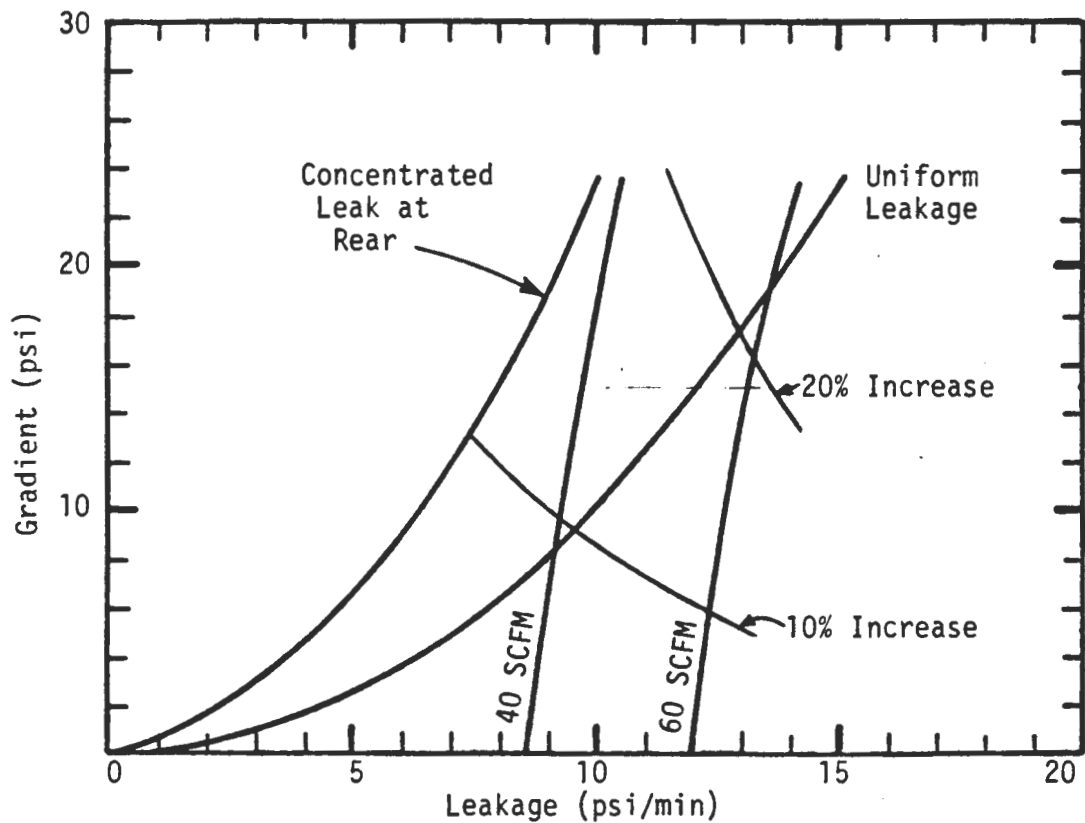


Figure 8. Gradient Versus Leakage for Train of 3 Locomotives and 100 Cars, with Lines Showing 10 and 20 Percent Increase in Emergency Braking Stop Distance

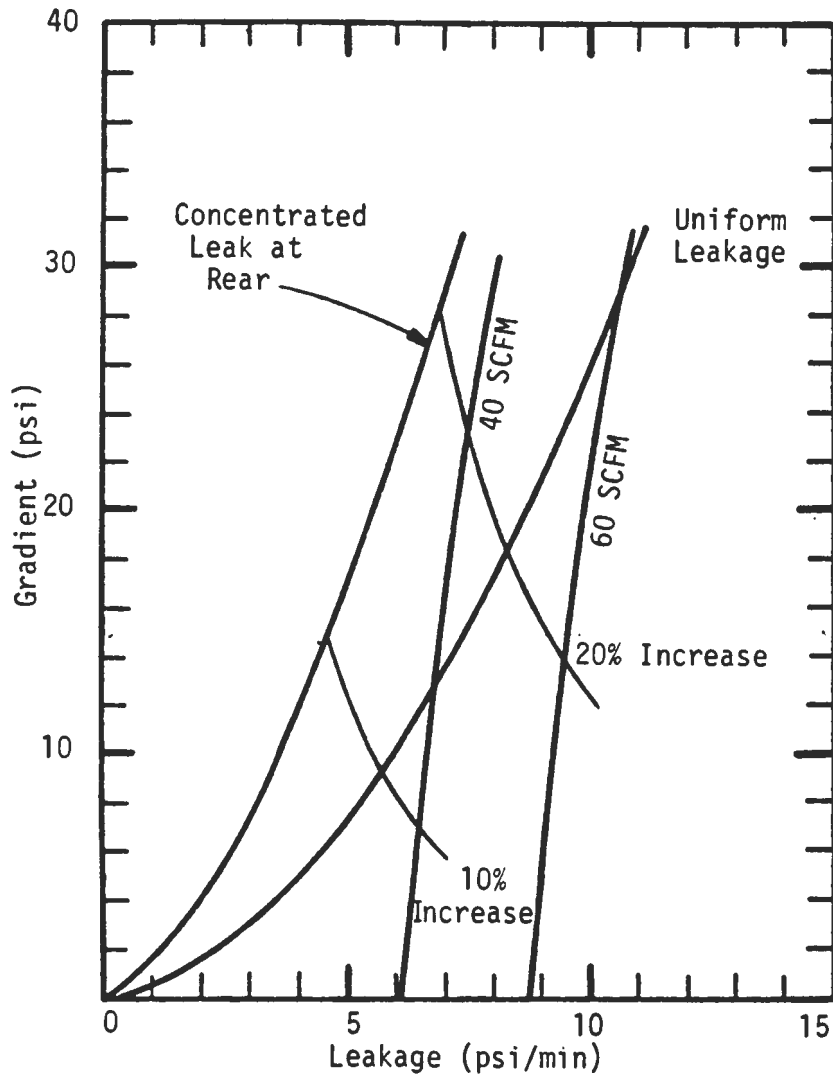


Figure 9. Gradient Versus Leakage for Train of 4 Locomotives and 150 Cars, with Lines Showing 10 and 20 Percent Increase in Emergency Braking Stop Distance

The results for service braking are shown in Figures 10 to 12 where stop distance is plotted as a function of leakage for the 3 trains of different length. On each plot a line is drawn to indicate the point beyond which either a gradient of 15 psi or an air flow of 60 SCFM would be exceeded. The service braking procedure assumed in these calculations was an initial 7 psi brake pipe reduction which was held for 30 seconds. It was then intensified to a full service reduction of 27 psi. The throttle was reduced from Position 6 to Position 1 at the initiation of braking. It was reduced to idle when the speed decreased to 2 mph.

Figure 10 shows that there are only small differences in stop distance with various leakage conditions on the 52 vehicle train. Results for the 103 and 154 vehicle trains (Figures 11 and 12) show in a more pronounced way that the minimum stop distance occurs when there is some leakage in the train. These figures also show a significant increase in stop distance both as the leakage increases and as its source moves back in the train.

The increase in stop distance associated with larger gradients apparently does not result in any significant increase in transient longitudinal train forces. Two simulations of emergency braking with the 154 vehicle train, one with 5 psi/min leakage and a gradient of 7.1 psi and the other with 7.5 psi/min leakage and a gradient of 15.6 psi, were made to compare transient longitudinal forces. The maximum transient run-in and run-out forces associated with the stop were -227,500 and 105,800 lbs for the 5.0 psi/min leakage train. The corresponding forces for the 7.5 psi/min leakage train were -227,700 and 113,400 lbs. The maximum run-in forces associated with service braking of the 154 vehicle train were in a similar range.

3.3 RELEASE OF A MINIMUM REDUCTION AT REAR OF TRAIN

One concern in the operation of a train with high leakage is that a brake application may not propagate through the entire train. Analyses have been conducted to consider the condition where leakage is concentrated at the rear of the train and a minimum reduction is made (7 psi). Results show that if the air flow is too high or the leakage is too large a minimum reduction cannot be sustained at the rear of the train. The brakes will come on for a

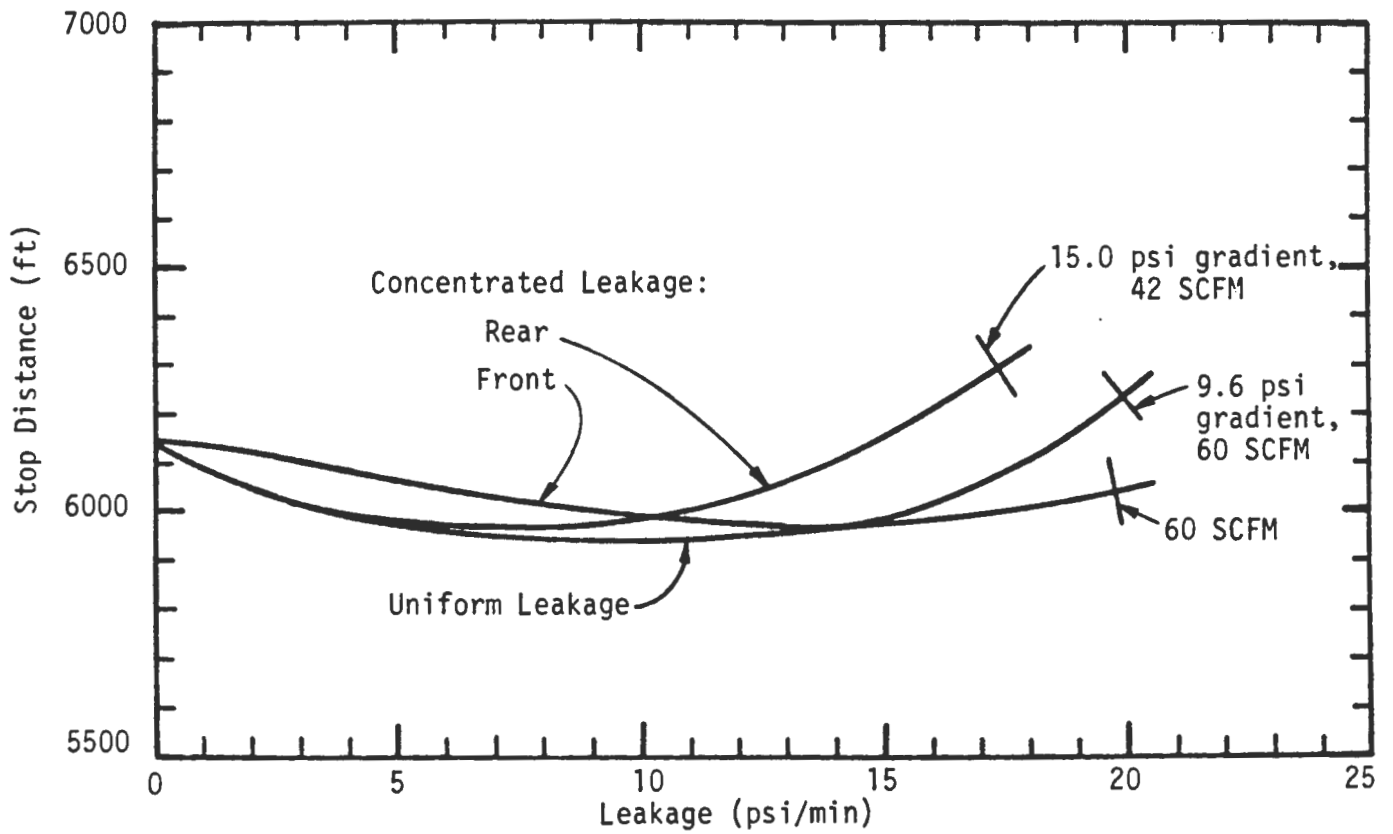


Figure 10. Stop Distance versus Leakage for Three Leakage Conditions with 52 Vehicle Train, Service Braking

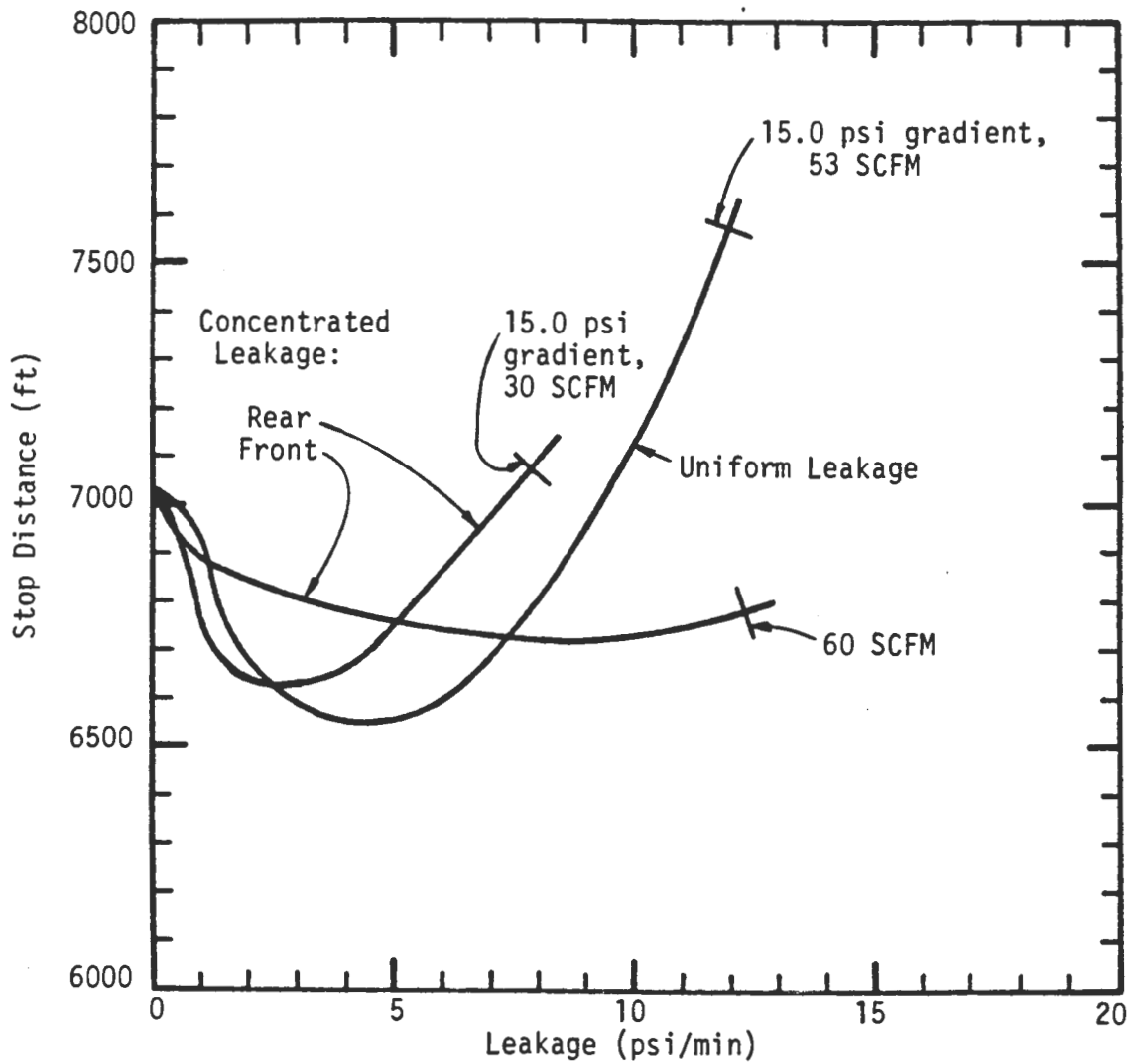


Figure 11. Stop Distance versus Leakage for Three Leakage Conditions with 103 Vehicle Train, Service Braking

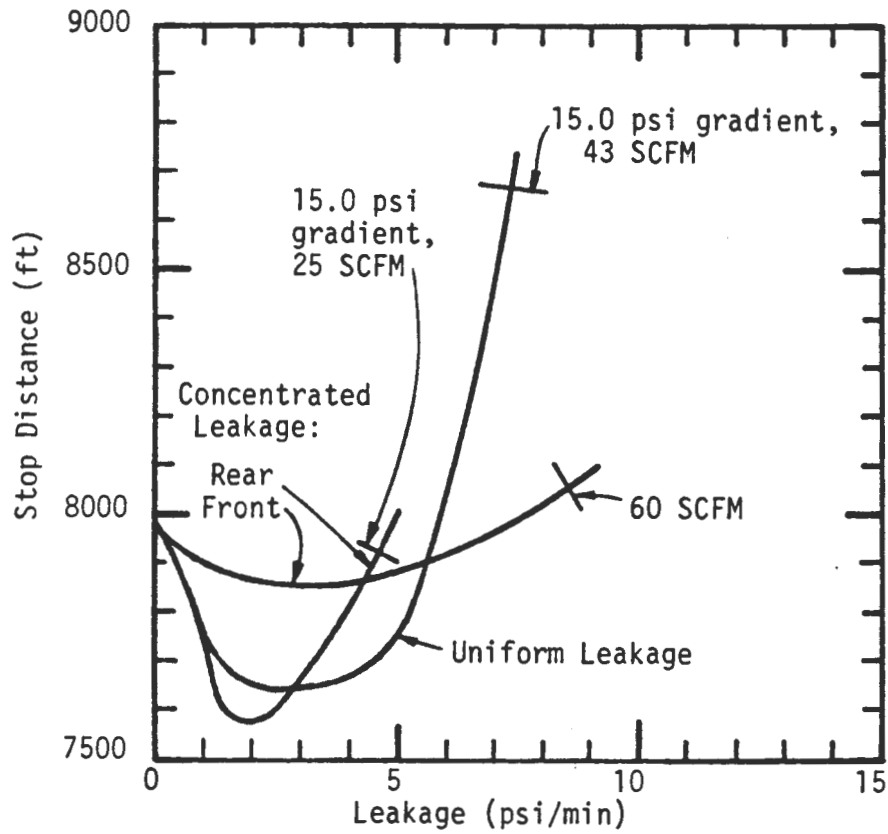


Figure 12. Stop Distance versus Leakage for Three Leakage Conditions with 154 Vehicle Train, Service Braking

short period of time, but then start to release. Results show the effect is limited to shorter trains, and that it falls outside of the region of operation with a 60 SCFM air flow 15 psi gradient criterion.

Specifically, analyses of the 52 vehicle train show that the threshold for this condition is a leakage of approximately 21 psi/min with a corresponding air flow of 52.1 SCFM and a gradient of 23.2 psi. This is illustrated in Figure 13. The results from this analysis show that the brakes will release on the last six cars of the train. For a leakage of 23 psi/min with a corresponding air flow of 55.4 SCFM and a gradient of 28.1 psi, the brakes release on the last 14 cars of the train. This effect is not predicted for the 100 car train up to a condition where the leakage is 10 psi/min, the air flow is 36.1 SCFM and the gradient is 22.9 psi.

The prediction of this effect is quite sensitive to the assumption of the differential pressure between the brake pipe and auxiliary reservoir which will trigger a release of the valve and the assumption of the rate at which the auxiliary reservoir is allowed to equalize with the brake pipe pressure. A slight change in either of these parameters will result in a different threshold for the onset of the release. However, since there will be valve-to-valve variations in these characteristics, the results of the calculation are indicative of a potential problem at large flow rates.

3.4 PROPAGATION OF MINIMUM REDUCTION IN TRAINS WITH CONCENTRATED LEAKAGE

Analyses have been conducted to determine the conditions where a minimum reduction fails to propagate through the train in a train with concentrated leakage. The effect was found to be significant in the trains with 103 and 154 vehicles. The results are shown in Figures 14 and 15.

Figure 14 shows results for the 103 vehicle train. The figure shows plots of gradient versus leakage where the concentrated leakage is at the front and rear of the train and at 3 intermediate locations. For the trains where the leakage occurs at the 26th and 54th vehicle, it was found that under high leakage and gradient conditions the propagation of a minimum reduction through the train is first slowed, and then under conditions of higher leakage, the minimum reduction fails to propagate past the leaking car. For example, when the concentrated leak is at the 54th vehicle the time to

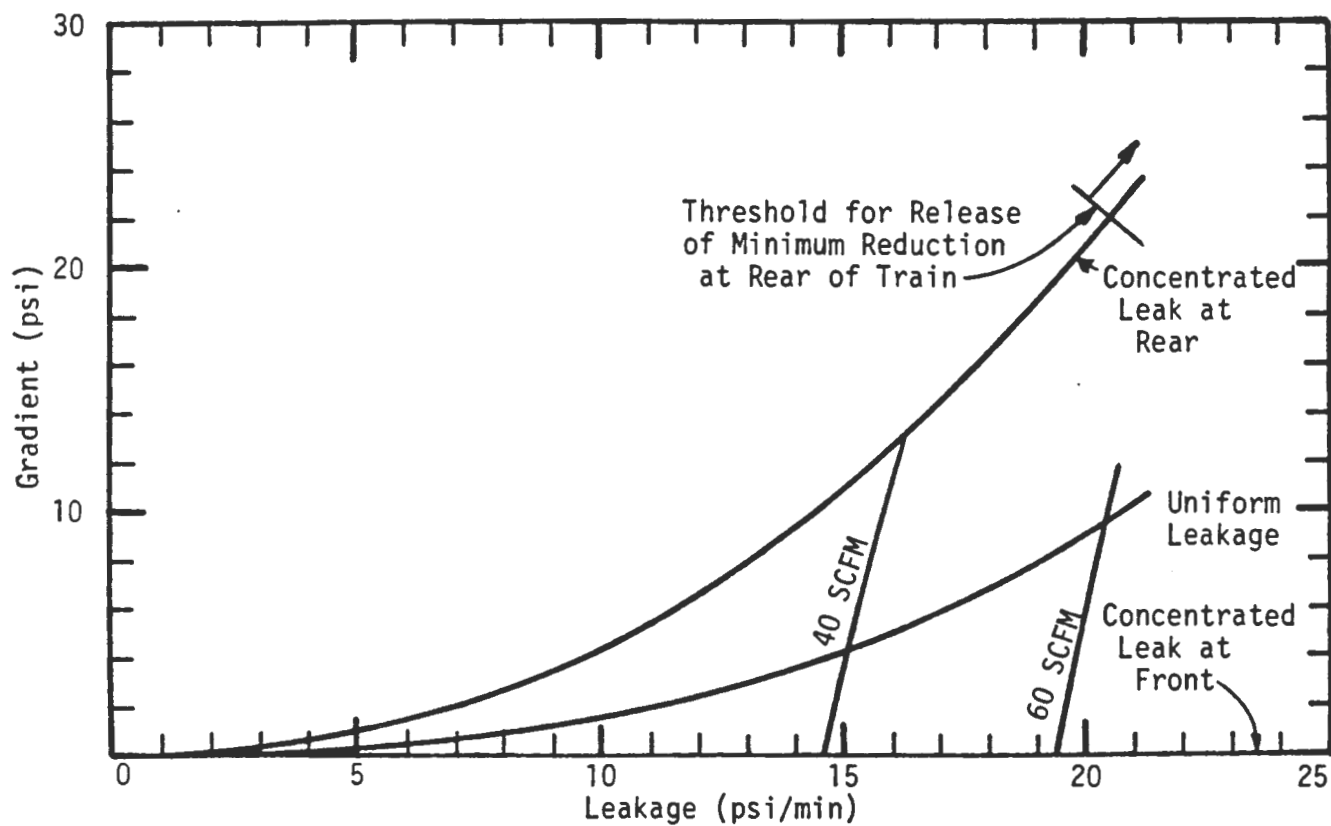


Figure 13. Gradient Versus Leakage for Various Leakage Conditions on Train with 2 Locomotives and 50 Cars, with Threshold for Release of Minimum Reduction Indicated

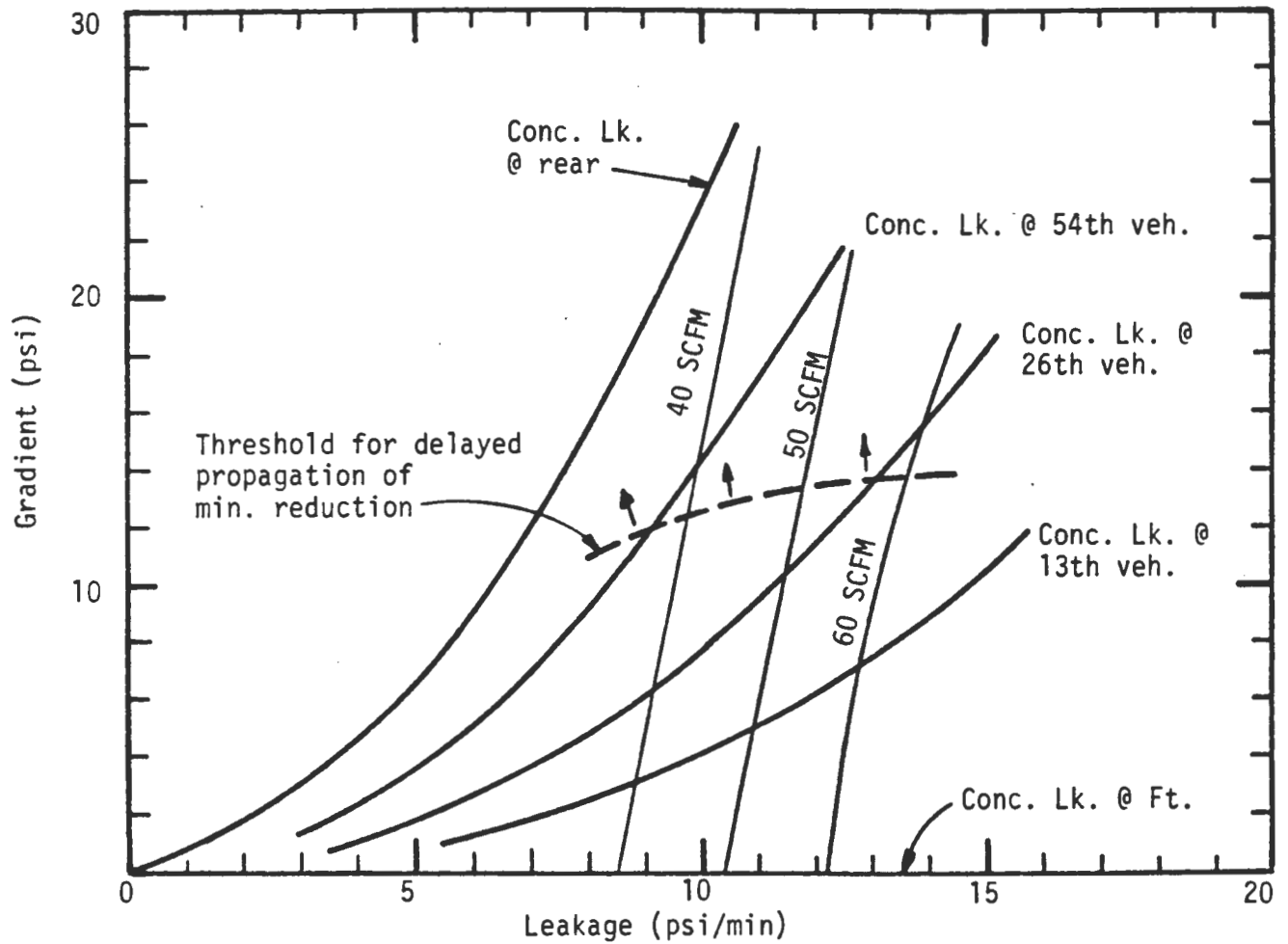


Figure 14. Gradient Versus Leakage for Concentrate Leakage Cases on Train with 3 Locomotives and 100 Cars, with Threshold for Delayed Propagation of Minimum Reduction Indicated

propagate a minimum reduction from the locomotive to the rear of the train increases from a normal time of approximately 9 seconds to 16 seconds for a leakage of 9 psi/min, an air flow of 36.8 SCFM and a gradient of 11.7 psi. The same increase in propagation time results when the leak is at the 26th vehicle for the condition of a leakage of 13 psi/min, an air flow of 56.8 SCFM, and a gradient of 13.6 psi. The threshold for this degraded brake performance is shown by a dashed line on the figure. It includes a portion of the region where the gradient is less than 15 psi and the air flow is less than 60 SCFM.

Further analysis shows that for the case of a concentrated leak at the 54th vehicle with a leakage rate of 12 psi/min, an air flow of 47.0 SCFM and a gradient of 20.1 psi the minimum reduction will not go past the leaking car. However, if a subsequent full service application is made it will propagate past the leaking car and apply brakes to all the cars on the train.

Figure 15 shows results for the 154 vehicle train. It was found that the propagation of a minimum reduction was significantly delayed when the leak was at the 80th vehicle for a leakage of 5.0 psi/min and when the concentrated leak was at the 42nd vehicle for a leakage of 6.0 psi/min. There was no significant effect in delaying the propagation of a minimum reduction when the concentrated leak was at the 28th vehicle up to a leakage condition of 21 psi/min with an air flow of 57 SCFM.

For the 50 car train it was found that there was no delay for the propagation of a minimum reduction when the concentrated leakage was at the 15th or 28th vehicle for air flows up to and exceeding 60 SCFM.

These analyses show that there are regions where degraded brake performance is indicated by the analytical model. Confirmation of these results by testing on a brake test rack may be warranted.

3.5 BRAKE PIPE REDUCTION FOLLOWING SPLIT SERVICE BRAKE APPLICATION

Analyses were conducted to determine the effect of a second application following a split service application and release. The question that was examined is how deep the second application must be in order for it to propagate through the train. Two different leakage conditions were analyzed in each of 3 trains. These conditions were, first, a limiting condition

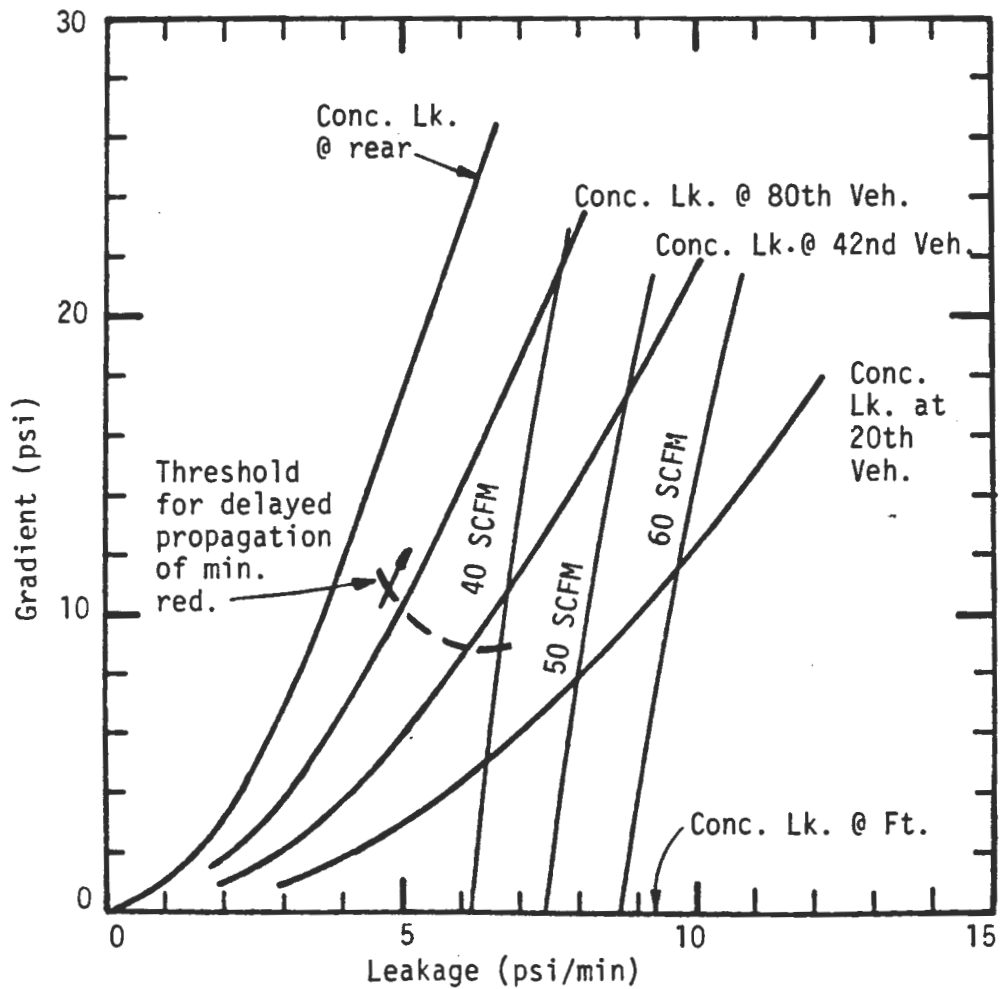


Figure 15. Gradient Versus Leakage for Concentrated Leakage Cases on Train with 4 Locomotives and 150 Cars, with Threshold for Delayed Propagation of Minimum Reduction Indicated

representative of current requirements, namely, a leakage of 5 psi/min and a gradient of 15 psi, and second, conditions representative of proposed criteria where the limiting condition is a 60 SCFM air flow or a 15 psi gradient.

The following sequence of events was assumed for these analyses. A minimum reduction (7 psi) was made and after 30 seconds it was increased to a 20 psi reduction. The 20 psi reduction was held for an additional 60 seconds and then released. Five minutes after the release was initiated a second application was made. The second application was made at a rate of 1 psi/sec pressure reduction in the brake pipe until the desired pressure was attained.

The results are summarized in Tables 1 to 3. The first part of each table shows the 4 cases that were considered for each of the trains. Two of the cases assume uniform leakage and two assume concentrated leakage at a car located near the middle of the train. The first and second cases represent the present criterion, namely, a 5 psi/min leakage and a 15 psi gradient. In all of the cases 5 psi/min leakage was the controlling factor. The third and fourth cases consider a revised criterion which would allow for up to a 60 SCFM air flow or up to a 15 psi gradient. In all of these cases the gradient was the limiting factor except for the short 52 vehicle train with uniform leakage where the air flow requirement governed.

The results of the analyses are summarized in the lower part of each table. The first analysis that was run for each case used a second application procedure where the brake pipe pressure was reduced to the point where air flow could be heard coming out of the brake pipe. This was assumed to be a 5 SCFM outflow. Then the reduction was intensified an additional 2 psi. This type of procedure is often used for making second applications where the brake pipe has not been fully recharged following an initial application. (See for example Ref. 5, pages 166 and 167 or Ref. 6, page 2-13). Another procedure used by at least one railroad is to make the second reduction to at least the brake pipe pressure being indicated at the rear of the train. In all of the analyses, where the second reduction was 2 psi below the point where there was a 5 SCFM outflow, the brakes were applied throughout the train and did not release because of a false gradient condition in the brake pipe.

Subsequent analyses were then made with lesser brake pipe reductions to determine the minimum brake pipe reduction pressure required to propagate and hold (no false gradient release) the application throughout the train.

The specific results for the various trains are now discussed. Table 1 presents results for the 52 vehicle train. Note that Cases 3 and 4 would allow much larger leakage rates than Cases 1 and 2. The results of the analyses for Cases 1 and 2 show that the second application procedure based on air outflow was close to the minimum reduction required to propagate and hold the second reduction. The results for Cases 3 and 4 show that a large second application reduction results if the procedure based on air flow out of the brake pipe is followed. This is because of the large air flow into the brake pipe at the time the second application is made. The reductions are much larger than required to propagate and hold the second application. The minimum reduction required to propagate and hold the second application is shown to be in the vicinity of 10 to 11 psi which is slightly larger than the reductions required under the Case 1 and 2 conditions.

Table 2 presents results for the 103 vehicle train. Note that Cases 3 and 4, where the allowable leakage rate is based on air flow and gradient, would allow leakage rates almost double Cases 1 and 2. The results for Cases 1 and 2 show that the magnitude of the brake pipe reduction required to apply and hold the brakes on the second application is slightly below the brake pipe reduction based on air outflow from the brake pipe. For Cases 3 and 4 the air outflow procedure results in much greater brake pipe reductions because of the large air flow into the pipe at the time of the second application. The analyses show that the depth of the second application required to apply and hold the brakes on all cars is about 15 psi for the case of the concentrated leakage, (Case 4), and 13 psi for the case of uniform leakage (Case 3).

Table 3 presents the results for the 154 vehicle train. For this train the air flow/gradient criterion (Cases 3 and 4) does not allow much greater leakage than the 5 psi/min leakage rate criterion (Cases 1 and 2) because the 15 psi gradient is developed at a much smaller leakage rate than in shorter trains. The results of the analyses for Cases 1 and 2 again show that the the magnitude of the second application required to apply and hold the brakes is slightly below the application procedure based on air flow from the brake pipe.

TABLE 1: RESULTS FROM 2ND APPLICATION ANALYSES OF 52 CAR TRAIN

Train Consist: 2 Locomotives and 50 Cars

Brake Application Sequence: 7 psi brake pipe reduction held for 30 seconds, then increased to 20 psi reduction which is held for 60 additional seconds and followed by a release. Second brake pipe reduction made 5 minutes after initiation of release.

Case	Leakage Condition and Vehicle	Leakage (psi/min)	Initial Conditions		Conditions at Second Application	
			Flow (SCFM)	Gradient (psi)	Flow (SCFM)	Gradient (psi)
1	Uniform	5.0	11.1	0.3	17.9	0.8
2	Concentrated at Veh. 28	5.0	11.0	0.5	18.2	1.3
3	Uniform	20.4	60.6	9.7	67.7	12.9
4	Concentrated at Veh. 28	21.1	57.8	15.5	63.2	18.4

Analysis No.	2nd Application Brake Pipe Reduction (psi)	Do All Brakes Come On	Application Time (sec)	Vehicles with Brakes on 4 minutes after 2nd Application
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Case 1 Results: Uniform 5.0 psi/min leakage

1	7.2*	Yes	8	A11
2	7.0	Yes	8	A11
3	6.5	Yes	8	1-20
4	6.0	Yes		None

Case 2 Results: Concentrated Leakage at Vehicle 28, 5.0 psi/min

1	7.7*	Yes	8	A11
2	7.0	Yes	8	A11
3	6.5	Yes	8	1-13
4	6.0	Yes	8	None
5	5.5	Yes	8	None

Case 3 Results: Uniform 20.4 psi/min leakage

1	28.9*	Yes	12	A11
2	14.0	Yes	12	A11
3	10.0	Yes	14	A11
4	9.0	Yes	14	1-5
5	8.0	Yes	14	1-5

Case 4 Results: Concentrated Leakage at Vehicle 28, 21.1 psi/min

1	33.6*	Yes	18	A11
2	18.0	Yes	18	A11
3	14.0	Yes	18	A11
4	12.0	Yes	18	A11
5	11.0	Yes	18	A11
6	10.0	Yes	20	1-18, 28-32

*Brake Pipe Reduction criteria is 2.0 psi below reduction pressure which gives outflow of 5 SCFM at locomotive automatic brake valve.

TABLE 2: RESULTS FROM 2ND APPLICATION ANALYSES OF 103 CAR TRAIN

Train Consist: 3 Locomotives and 100 Cars

Brake Application Sequence: 7 psi brake pipe reduction held for 30 seconds, then increased to 20 psi reduction which is held for 60 additional seconds and followed by a release. Second brake pipe reduction made 5 minutes after initiation of release.

Case	Leakage Condition and Vehicle	Leakage (psi/min)	Initial Conditions		Conditions at Second Application	
			Flow (SCFM)	Gradient (psi)	Flow (SCFM)	Gradient (psi)
1	Uniform	5.0	21.2	2.3	35.8	7.8
2	Concentrated at Veh. 54	5.0	20.8	3.6	33.8	8.9
3	Uniform	12.1	53.4	15.2	60.0	20.3
4	Concentrated at Veh. 54	10.3	41.5	15.3	48.3	20.0

Analysis No.	2nd Application Brake Pipe Reduction (psi)	Do All Brakes Come On	Application Time (sec)	Vehicles with Brakes on 4 minutes after 2nd Application
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Case 1 Results: Uniform 5.0 psi/min leakage

1	14.5*	Yes	16	A11
2	12.0	Yes	16	A11
3	11.0	Yes	16	1-56
4	10.0	Yes		1-8
5	8.0	Yes		1-7

Case 2 Results: Concentrated Leakage at Vehicle 54, 5.0 psi/min

1	15.0	Yes	20	A11
2	14.7*	Yes	20	A11
3	13.0	Yes	20	A11
4	12.0	Yes	20	A11
5	11.0	Yes	22	1-39
6	10.0	Yes		1-11

Case 3 Results: Uniform 12.1 psi/min leakage

1	27.9*	Yes	26	A11
2	21.0	Yes	26	A11
3	18.0	Yes	26	A11
4	15.0	Yes	28	A11
5	13.0	Yes	32	A11
6	12.0	Yes	40	1-59
7	11.0	No	--	1-73

Case 4 Results: Concentrated Leakage at Vehicle 54, 10.3 psi/min

1	23.2*	Yes	30	A11
2	15.0	Yes	42	A11
3	14.0	No	--	1-53
4	13.0	No	--	1-53
5	10.0	No	--	1-50

*Brake Pipe Reduction criteria is 2.0 psi below reduction pressure which gives outflow of 5 SCFM at locomotive automatic brake valve.

TABLE 3: RESULTS FROM 2ND APPLICATION ANALYSES OF 154 CAR TRAIN

Train Consist: 4 Locomotives and 150 Cars

Brake Application Sequence: 7 psi brake pipe reduction held for 30 seconds, then increased to 20 psi reduction which is held for 60 additional seconds and followed by a release. Second brake pipe reduction made 5 minutes after initiation of release.

Case	Leakage Condition and Vehicle	Leakage (psi/min)	Initial Conditions		Conditions at Second Application	
			Flow (SCFM)	Gradient (psi)	Flow (SCFM)	Gradient (psi)
1	Uniform	5.0	30.2	7.1	40.3	13.2
2	Concentrated at Veh. 80	5.0	28.5	10.3	37.0	15.6
3	Uniform	7.4	43.7	15.2	50.5	20.2
4	Concentrated at Veh. 80	6.2	34.1	15.2	41.6	20.0

Analysis No.	2nd Application Brake Pipe Reduction (psi)	Do All Brakes Come On	Application Time (sec)	Vehicles with Brakes on 4 minutes after 2nd Application
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Case 1 Results: Uniform 5.0 psi/min leakage

1	17.2*	Yes	22	A11
2	16.0	Yes	22	A11
3	14.0	Yes	22	A11
4	12.0	Yes	22	A11
5	11.0	Yes	22	1-14
6	10.0	Yes	22	1-12

Case 2 Results: Concentrated Leakage at Vehicle 80, 5.0 psi/min

1	16.5*	Yes	38	A11
2	15.0	Yes	48	A11
3	14.0	No	--	1-84
4	12.0	No	--	1-76
5	10.0	No	--	1-68
6	7.0	No	--	1-8

Case 3 Results: Uniform 7.4 psi/min leakage

1	23.1*	Yes	32	A11
2	20.0	Yes	32	A11
3	16.0	Yes	38	A11
4	14.5	Yes	40	A11
5	13.0	No	--	1-110
6	12.0	No	--	1-109

Case 4 Results: Concentrated Leakage at Vehicle 80, 6.2 psi/min

1	18.9*	Yes	42	A11
2	17.5	Yes	58	A11
3	17.0	No	--	1-104
4	15.0	No	--	1-78

*Brake Pipe Reduction criteria is 2.0 psi below reduction pressure which gives outflow of 5 SCFM at locomotive automatic brake valve.

The magnitudes of these reductions are slightly larger than for the 103 vehicle train. For Cases 3 and 4 a second application based on air flow out of the brake pipe again results in a larger reduction than necessary. The results are somewhat different for uniform leakage and for concentrated leakage in the middle of the train. In the case of uniform leakage a brake pipe reduction of 14.5 psi is sufficient to apply and hold the brakes whereas a reduction of 23 psi would result following the air outflow procedure. In the case of the concentrated leakage a brake pipe reduction of 17.5 psi is required to apply and hold the brakes, whereas a brake pipe reduction of 18.9 psi would result from the air outflow procedure.

The first conclusion from these results is that procedures for making second applications may need to be revised if the air flow/gradient criterion is adopted. For example, if the procedure for making a second reduction is based on listening for air flow out from the locomotive automatic brake valve, a much deeper second reduction results than is necessary. This is a result of the larger air flows which are associated with recharging the brake pipe and reservoirs on higher leakage rate trains. It would make train control more difficult. The analyses also show that the amount of reduction necessary to propagate and hold the brakes is greater than for first applications from fully charged trains, but not significantly so. The necessary reduction would range from 10 to 18 psi depending on the length of the train and the leakage conditions within the train (whether uniform or concentrated). The second conclusion is that the amount of pressure reduction needed to propagate and hold a second application is slightly greater for concentrated leakage than for uniform leakage. The increase required is more on longer trains than on shorter trains. For example, the results indicate that on the 154 vehicle train approximately 3 psi additional reduction is required. On the 52 vehicle train a 1 psi increase appears to be sufficient.

3.6 TEMPERATURE EFFECTS IN THE CALIBRATION OF AIR FLOW METERS

The use of measurements of air flow into the brake pipe and train gradient as a means of qualifying the acceptance of the train brake system requires assurance that these parameters are being measured accurately. Concerns have been raised over the accuracy of the air flow measurement because of the effects of temperature. Figure 16 shows the relationship

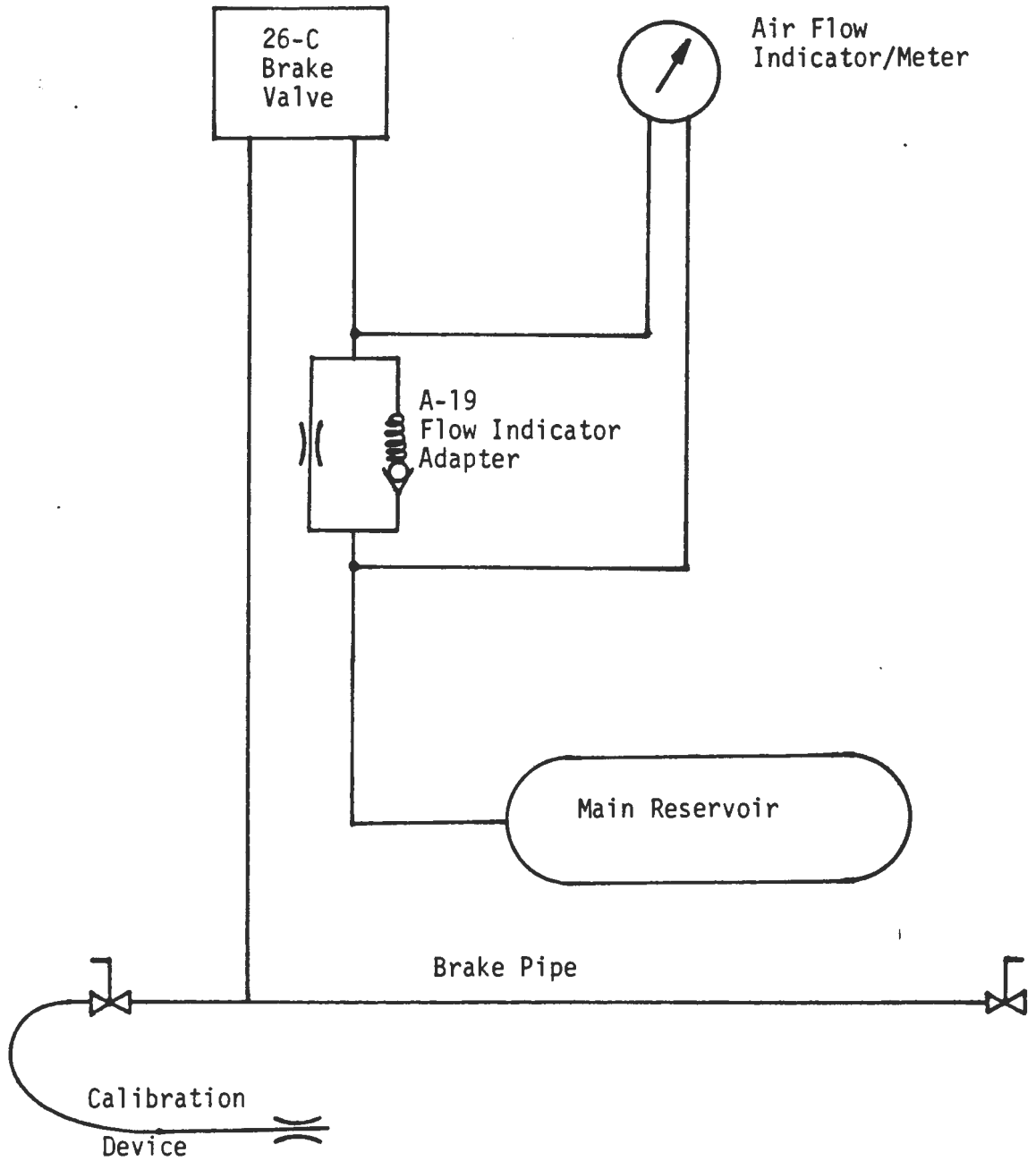


Figure 16. Air Flow Indicator Calibration Schematic

between the air flow indicator and other major components of the air brake system. The air flow meter operates by sensing the pressure difference across a choke in the A-19 adapter which is inserted in the pipe between the main reservoir and the locomotive automatic brake valve. The choke contains an orifice which is typically 19/64 inches in diameter. The air flow meter is calibrated by connecting a short length of hose to the coupling on the brake pipe air hose at the end of the locomotive. This short length of hose has a hose coupling at one end and an orifice at the other end. The diameter of the orifice is chosen to allow a given flow rate (e.g., 60 SCFM) at a given ambient temperature, main reservoir pressure, and locomotive brake feed valve setting. With the calibration orifice connected to the brake pipe the air flow meter is set to indicate the critical position on the meter (e.g., 60 SCFM). A typical set of operating conditions for this calibration would be a main reservoir pressure of 130 psi, a feed valve setting of 75 psi and a temperature of 0°F.

Once a flow indicator dial on a particular locomotive has been set or marked for 60 SCFM under one set of conditions, it is desirable to know the actual flow when the indicator needle points to this calibration mark under some other set of conditions. The following discussion will evaluate the effects of temperature and pressure changes on flow indicator calibration, and identify those conditions which could cause the meter to indicate a lower flow rate than actually exists. The two principal areas of concern are 1) when the locomotive air flow meter is calibrated in the field to set the 60 SCFM indicator point under conditions which are not the same as the laboratory conditions used to establish the accuracy of the calibration device, and 2) when operating conditions in the locomotive are different from those during the field calibration.

Flow through the orifice at the end of the brake hose used in the field calibrations from brake pipe to atmosphere is described by the following relation for sonic flow:

$$\dot{m} \propto AP / \sqrt{T} \quad (1)$$

where: \dot{m} is the mass flow rate (such as SCFM or slugs/sec),
 A is the area of orifice,
 P is the absolute pressure upstream (in brake pipe), and
 T is the absolute temperature upstream (in brake pipe).

Flow through the A-19 orifice choke from the main reservoir to the inlet of the 26-C brake valve is subsonic and described by the following relation:

$$\dot{m} \propto A \sqrt{P \Delta P / T} \quad (2)$$

where: \dot{m} is the mass flow rate,
 A is the area of A-19 orifice,
 P is the absolute upstream pressure (main reservoir),
 ΔP is the pressure drop across A-19 as measured and indicated on flow indicator/meter, and
 T is the absolute temperature upstream (main reservoir).

During the field calibration of a locomotive, the brake pipe pressure, as controlled by the feed valve setting, must be held at the same pressure which was used to establish the accuracy of the field calibration orifice. If a higher brake pipe pressure is used (assuming the rated temperature of 0°F is maintained), then the actual flow will be greater than the rated flow of 60 SCFM and consequently the indicator will give false low readings. Similarly, if the air temperature during calibration is lower than the rated 0°F (and the brake pipe pressure is maintained at the rated pressure), then the actual flow will again be greater than 60 SCFM and the meter will indicate flow less than actual.

The effect of the main reservoir pressure on the calibration is now considered. Assume that the temperature and pressure in the brake pipe are maintained at their rated values so the actual flow is the rated flow of 60 SCFM. As the main reservoir pressure fluctuates with demand and compressor cycling, the flow is maintained constant by the action of the relay valve in the 26-C brake valve. Referring to the subsonic relation for flow, it can be seen that for constant flow and temperature, as the main reservoir pressure

(P) increases, the flow indicator reading (ΔP) must decrease. For a compressor cycling between 130 and 140 psig this can produce a 7 percent difference in the indicated reading for a given actual flow. In order to avoid false low readings, the indicator should be marked or set when the main reservoir is at its maximum pressure (compressor cut-out setting).

Once the flow indicator on a locomotive has been calibrated and is operating, the actual flow that exists for a given meter indication (say the "60 SCFM" calibration mark) depends on the main reservoir air temperature and pressure. As can be seen from the subsonic relation, Equation 2, if the main reservoir pressure is higher than the pressure used to establish the mark, and the indicated (ΔP) is the same (i.e., the current indication is at the calibration mark), then the actual flow will be greater than the indicated 60 SCFM. As mentioned previously, this condition can be avoided by making the calibration mark when the main reservoir pressure is at its maximum.

To illustrate the evaluation of temperature effects, assume that the main reservoir pressure (P) is held constant at the value used for calibration. It can be seen that for a given flow indication (ΔP), the actual flow (\dot{m}) increases as the temperature (T) decreases. It must be remembered, however, that if the indicator were calibrated at a temperature above the rated temperature of the calibration device (usually 0°F), then the indicator was calibrated to false high reading (i.e., the calibration mark corresponds to an actual flow of less than 60 SCFM). As the temperature falls toward 0°F, the meter becomes more accurate. Only when the operating temperature falls below the rated temperature of the calibration device, regardless of the temperature during the field calibration of the indicator, will the actual flow be greater than the indicated flow rate.

3.7 TEMPERATURE EFFECTS ON RELATIONSHIPS BETWEEN LEAKAGE, GRADIENT AND AIR FLOW

A change in temperature will affect the relationship between leakage, gradient and air flow. This is shown in Figures 17 to 19 where the data shown in Figures 1, 3 and 5 are plotted for a -10°F temperature and compared with the 70°F data. These figures show that larger air flows are associated with lower leakage rates at lower temperatures.

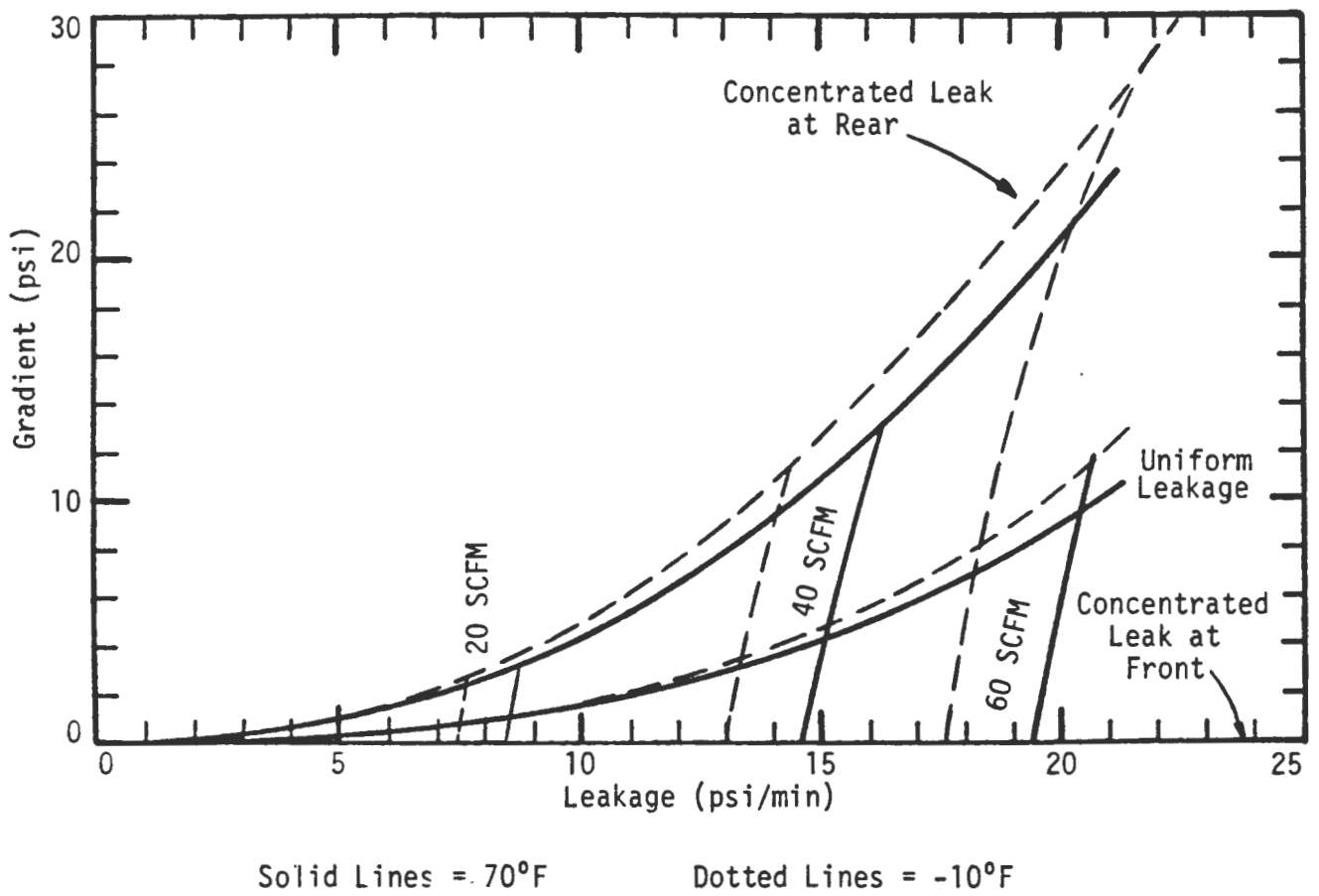


Figure 17. Gradient Versus Leakage for Different Temperatures, Train of 2 Locomotives and 50 Cars, 80 PSI Brake Pipe Pressure

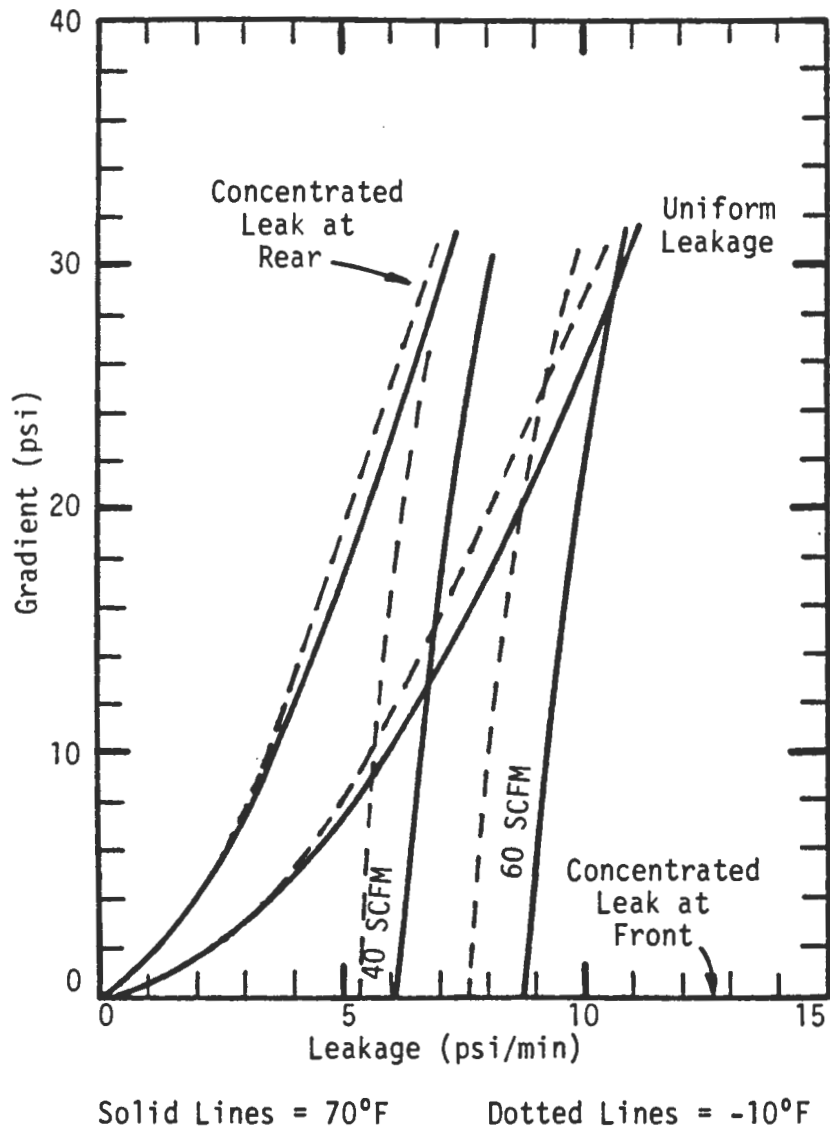


Figure 19. Gradient Versus Leakage for Different Temperatures, Train of 4 Locomotives and 150 Cars, 80 psi Brake Pipe Pressure

4. REPEATER RELAY UNITS

Repeater relay units are usually placed at the middle of trains so that they can supply air to the rear half of the train. At the present time they are most often used on trains approximately 100 cars long. The units are usually set to boost the brake pipe pressure by 20 percent. Thus, if the brake pipe pressure at the car in front of the relay unit were 70 psi the unit would charge the brake pipe in the rear section of the train to 84 psi. With this setting it is possible that the brake pipe in the rear half of the train would be charged to a higher pressure than the front half, especially if there is a low leakage rate in the front half of the train.

The major safety concerns with repeater relay use are the consequences of the failure of the unit to transmit a brake application, procedures used in conducting a terminal brake test, and the potential for the development of large transient longitudinal train forces during emergency braking because of the unequal charging of the emergency and auxiliary reservoirs in the two sections of the train.

Presumably the relay units would be constructed with a high reliability so that there would be a very remote chance of failure of the unit. If the unit were to fail all of the braking would be done in the front half of the train which would mean that the stop distances would be approximately doubled. If the relay unit were to fail during the use of air brakes to control speed on a grade, there is the possibility of the development of a run-away condition if adequate braking could not be developed on the front half of the train. Also, if speed could be controlled by braking the front section of the train it would mean that much greater braking energy would have to be absorbed on these cars resulting in high wheel temperatures. Presumably an engineer would be able to detect whether or not the relay unit would have failed by noting that the brake pipe pressure did not change at the end of the train and would be able to take corrective action before a dangerous situation develops.

Conducting a terminal test with a relay unit poses the problem of how to assure a satisfactory condition in both sections of the train since one is only able to check the leakage rate (or air flow) and gradient in the front half of the train. The gradient in the rear section of the train can be estimated from the brake pipe pressure at the rear of the front section, the

increase in brake pipe pressure provided by the relay unit and the brake pipe pressure at the end of the train. Knowledge of the gradient at the rear of the train does not, however, give any indication of the air flow from the repeater relay unit into the rear section of the train. For example, if the leakage were concentrated near the front of the rear section a large air flow would produce a negligible gradient. On the other hand, if the leakage were concentrated near the rear of the second section, a gradient of 15 psi could be developed with an air flow less than 60 SCFM. Simulations with 50 car trains, which would be representative of the rear section on a 100 car train with a relay unit, have shown that if the leakage is near the front of the train (front of rear section) a minimum reduction (7 psi) will not propagate back through the train if the air flow exceeds approximately 75 SCFM.

One possibility for a terminal brake test on a train with a repeater relay unit would be to incorporate a minimum reduction brake application into the test procedure. First, air flow and gradient would be checked on the front section and the gradient estimated on the rear section. Then a minimum reduction would be made and its propagation to the rear of the train could be determined from the brake pipe reading at the end of the train. Propagation of the minimum reduction to the rear of the train would insure that the flow in the second section of the train was not large enough to interfere with the functioning of the brake system.

The chance for the development of dangerously high levels of transient longitudinal forces during emergency braking appears to be remote. Simulations have been run on 100 car trains with fully loaded 100 ton capacity cars to determine maximum transient longitudinal forces with and without the presence of a relay unit. In the train with the relay unit the conditions were set to give a maximum flow rate of 60 SCFM in the front and rear halves of the train. In the train without the relay unit the conditions were set to give a maximum gradient of 15 psi which resulted in an air flow at the locomotive of 54 SCFM. The results of these analyses show that the maximum transient longitudinal forces are about the same order of magnitude in both cases. In the case of the train with the repeater relay unit the maximum draft and buff forces were 174,700 lbs and 111,500 lbs respectively. In the case of the train without the relay unit the maximum transient draft and buff forces were 73,300 lbs and 170,100 lbs respectively.

5. CONCLUSIONS

The principal results of this study are that there appears to be no significant safety problem that results by allowing trains to operate within the constraints of an air flow into the brake pipe of up to 60 SCFM and train gradients of up to 15 psi. It must be recognized that changing the criterion for passing the terminal brake test from a maximum leakage rate of 5 psi/min and a maximum gradient of 15 psi to a maximum air flow of 60 SCFM and a maximum gradient of 15 psi will allow trains to run with leakage rates greater than 5 psi/min. The associated permissible leakage rates are larger on shorter trains. For example, on a 52 vehicle train (2 locomotives and 50 cars) the permissible leakage rate would run between 17 to 21 psi/min, the range covering various positions and distributions of leakage within the train. The corresponding permissible leakage rate ranges for 103 and 154 vehicle trains are, respectively, 8 to 14 and 5 to 10 psi/min.

The relationship between leakage, gradient and air flow will depend on the length of the train and the condition of leakage within the train (i.e., uniform or concentrated and if concentrated the location of the concentrated leakage). In most cases the train gradient will become the controlling factor, that is, with increasing leakage the gradient will reach 15 psi before the air flow gets to 60 SCFM. By allowing trains to operate with larger gradients one must recognize that as gradients become larger they can increase rapidly with small increases in the leakage rate. This effect becomes more pronounced with longer trains and when the leakage is concentrated toward the rear of the train. Therefore, it will be important to monitor the pressure of the rear of the train during train operations to insure that an excessive gradient does not develop.

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APPENDIX

FLUID MODEL FOR SIMULATION OF TRAIN AIR BRAKE OPERATIONS

The analyses conducted on the project made use of a mathematical model (Ref. 1) which has been developed for the Research and Locomotive Evaluator/Simulator (RALES) facility to conduct a parametric analysis of brake system performance. The RALES facility uses a number of mathematical models to simulate all aspects of train operation. One of the models describes the operation of the air brake system. The initial configuration of RALES included an air brake model which was based on a series of parametric relationships. These relationships define the state of the air brakes on each car of the train based on the positions of the controls in the locomotive and on the time that has elapsed from the movement of these controls. While this model provided sufficient simulation of the air brake system to represent most situations that occur during train operations, it was not sufficiently flexible to represent all of the characteristics of the braking systems which could be encountered particularly when the brake system is not being operated in the normally prescribed method.

In order to be able to consider all aspects of braking system operation with the RALES facility, IITRI embarked on the development of an air brake model which was based on the actual fluid mechanic properties of the air brake system. By actually predicting the flow of air in the brake pipe, and into and out of the various reservoirs and cylinders in the system it is possible to simulate all of the characteristics of the air brake system. It is also possible to simulate its performance under all possible operating conditions and to introduce other features into the system such as air brake repeater relay units to determine their effect on train operations.

There are two main parts or modules to the complete model:

- the brake pipe, and
- the components on each car including the control valves and reservoirs on each car.

The major elements which are considered include the locomotive control valve(s), the brake pipe, and on each car, one or more control valves, auxiliary reservoir, emergency reservoir and brake cylinder. The type of control valve (either AB, ABD, or ABDW) may be individually specified for each car, thus allowing a heterogeneous mixture of valve types in a single train. In addition, A-1 reduction relay valves may be included on long cars.

A.1 BRAKE PIPE MODEL

For computational purposes the pipe is divided into sections (not necessarily of uniform length) such that each section is centered on a control valve. Sections correspond roughly to vehicles, but if, for example, a long vehicle has a A-1 reduction relay valve in addition to an ABD control valve, then the brake pipe of that vehicle would be divided into two sections. Air flow into and out of the brake pipe is calculated at each section considering the effects of both the control valve and leakage. The leakage rate at each section is a function of the local brake pipe pressure and a constant coefficient which may be specified for each section. This provides the ability to simulate leakage throughout the entire length of the brake pipe using either a uniform distribution or some user-specified non-uniform distribution.

The representation of air flow in the brake pipe is based on the solution of the partial differential equations describing one-dimensional flow. Isothermal flow is assumed because the mass of air in the system is small compared to the mass of the reservoirs, cylinders and the brake pipe itself. The most important consideration is the development of a stable solution scheme which can proceed with a relatively large time step. The equations of flow are nonlinear so that they must be linearized and an iterative solution considered. A solution scheme has been formulated which gives stable solutions at integration times up to at least 0.2 seconds.

A.2 CONTROL VALVE MODULE

Control of the brake pipe is accomplished through the 26-C automatic brake control valve model. This portion of the model considers the main reservoir, equalizing reservoir, control handle setting, regulating feed valve and position of the brake pipe cut-off valve. Air flow into and out of the brake pipe is calculated based on the pressure of the pipe and the handle position (the emergency position allows more flow than the service position).

The comparison of equalizing reservoir pressure to brake pipe pressure allows for the modeling of the self-lapping and pressure maintaining features of the 26-C control valve.

The modular structure of the brake pipe model allows for placement of a 26-C control valve anywhere within the train. Thus, the braking of a multiple consist operation can be simulated with one or more remote 26-C control valves operated from a common control stand, each with the ability to initiate an emergency application.

Modeling on each car considers the control valve, the A-1 reduction relay valve (where appropriate), the auxiliary reservoir, the emergency reservoir and the brake cylinder. Flow between these reservoirs (and to atmosphere) is governed by the control valve which is able to assume different positions. The position, or state, of each control valve is determined by the rate of change in brake pipe pressure and the relationship between pressure in the brake pipe, auxiliary reservoir, emergency reservoir and brake cylinder.

A generalized model for numerically calculating flows between reservoirs has been developed which considers interconnection of up to three reservoirs through small passages represented by orifices which control the flow rate. The passages within a control valve and through connecting piping are generally quite complex, but the flow is often controlled by a single choke (precision drilled orifice). The reservoir flow model, therefore, simulates the connection between reservoirs as a simple sharp edged orifice. The ratio of downstream to upstream absolute pressure is calculated to determine whether the flow is sonic or subsonic. A conductance factor (similar to a "coefficient of discharge") is used in the flow equation to account for different orifice sizes and minor effects such as entrance losses. Changes in the reservoir pressures are determined (from the ideal gas law) based on the calculated flow rate (assumed constant over the integration interval) and adjusted, if necessary, for equalization between the reservoirs.

The significant control valve characteristics which are included in the model are summarized below:

1. preliminary quick service activity: limited venting of the brake pipe to atmosphere through the quick service volume,

2. quick service limiting feature: flow from the brake pipe to brake cylinder (in service or lap position) until the brake cylinder pressure is greater than 10 psig,
3. brake cylinder pressure build-up reflecting the use of a simplified return spring model to account for the effect of piston displacement,
4. ABDW accelerated application: partial venting of brake pipe to atmosphere to increase the rate of brake pipe pressure reduction,
5. accelerated service release: flow of air from emergency reservoir to brake pipe,
6. activation of the emergency functions at any particular valve based on the local rate of brake pipe pressure reduction,
7. emergency brake application functions at each valve: brake pipe pressure rapidly vented to atmosphere, vent valve remains open for 60 seconds after activation, emergency and auxiliary reservoirs connected to brake cylinder, two stage pressure build up resulting from closing of the inshot valve after brake cylinder pressure increases by 15 psi,
8. accelerated emergency release: air from the brake cylinder and auxiliary reservoir flows into the brake pipe,
9. brake cylinder release controlled by retainer setting: direct release, slow release, retain 10 psi, or retain 20 psi,
10. normal or retarded recharge of the auxiliary and emergency reservoirs based on the difference between the brake pipe pressure and the auxiliary reservoir pressure, and
11. charging port close off: activated by small decrease in brake pipe pressure prior to application.

A.3 VALIDATION OF MODEL

Predictions from the model compare favorably with air brake test rack data. A large number of cases have been used to check and adjust the model.



IIT Research Institute
10 West 35 Street, Chicago, Illinois 60610
312/567-4000

April 13, 1988

Mr. Garold Thomas, RRS-32
Federal Railroad Administration
Office of Research and Development
400 Seventh Street, SW, Room 8305
Washington, DC 20590

Subject: Sixth Monthly Progress Report, February 27 to March 25, 1988
Contract DTFR53-82-C-00254, Task Order No. 4, "Improved Braking
System, Simulation", IITRI Project E06593

Dear Mr. Thomas:

During the reporting period work was conducted on Subtasks 1A, 1B, 2A and 2B of the subject task order. Over 50 computer runs have been made using the off-line RALES train operations model to relate leakage, gradient and air flow parameters to train operation performance variables.

The results of the work that have been conducted thus far can be summarized in a clear and concise manner on a series of figures where gradient is plotted as a function of leakage. One figure is used for each train consist. Each figure presents plots of gradient as a function of leakage for two conditions of leakage: leakage concentrated at the rear of the train and uniform leakage. As indicated on the figures the abscissa represents a third condition, namely, leakage concentrated at the front of the train. The curve representing leakage concentrated at the rear of the train is an extreme condition in the functional relationship between gradient and leakage so that a plot representing any other leakage condition would lie between the curve for concentrated leakage at the rear of the train and the abscissa. Lines representing constant values of air flow are also plotted on the figures to complete the depiction of the relationship between air flow, gradient and leakage.

The region for permissible operation within the limitations of a 15 psi maximum gradient and a maximum air flow of 60 SCFM are outlined by a yellow marking pencil on each of the figures. Note that this region is much larger than if one used criterion of a maximum gradient of 15 psi and a leakage of 5 psi. With this criterion the maximum rate of 5 psi leakage is the controlling factor for all cases except the 150 car train with the leakage concentrated at the rear of the train.

Figures 1 to 3 are repeated in Figures 4 to 6, respectively, where additional information indicative of degradation in braking performance has been plotted. These figures show lines representing increases in stop distance of 10 and 20 percent for an emergency brake application.

Mr. Garold R. Thomas
April 13, 1988
Page Two

Work is currently under way to determine what other characteristics of braking system performance may be significantly degraded within the operating limits shown in the figures. The conditions being examined include failure to propagate the brake application to the rear of the train, unintended releases, etc.

Project costs and labor hour expenditures are summarized in the attached table and figure.

Sincerely yours,



Milton R. Johnson
Senior Engineering Advisor
Railroad Technology Center

Approved:



A. R. Valentino
Director
Electromagnetics and Electronics

cc: M. Clifford Gannett, FRA
S. A. Bolling, FRA
W. Bolin, IITRI

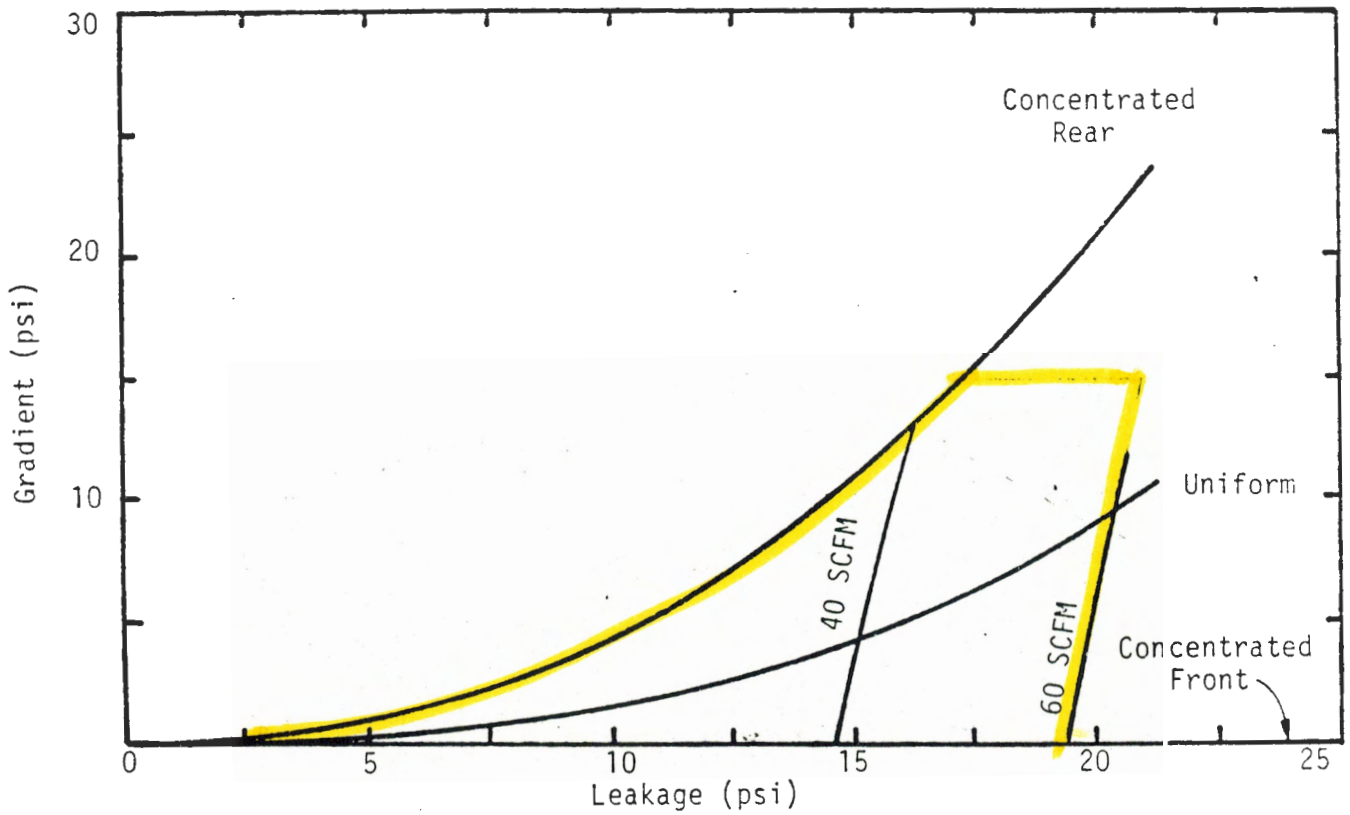


FIGURE 1. GRADIENT VERSUS LEAKAGE FOR VARIOUS LEAKAGE CONDITIONS ON TRAIN WITH 2 LOCOMOTIVES AND 50 CARS (80 PSI BRAKE PIPE PRESSURE); LINES OF CONSTANT AIR FLOW ALSO INDICATED (SCFM)

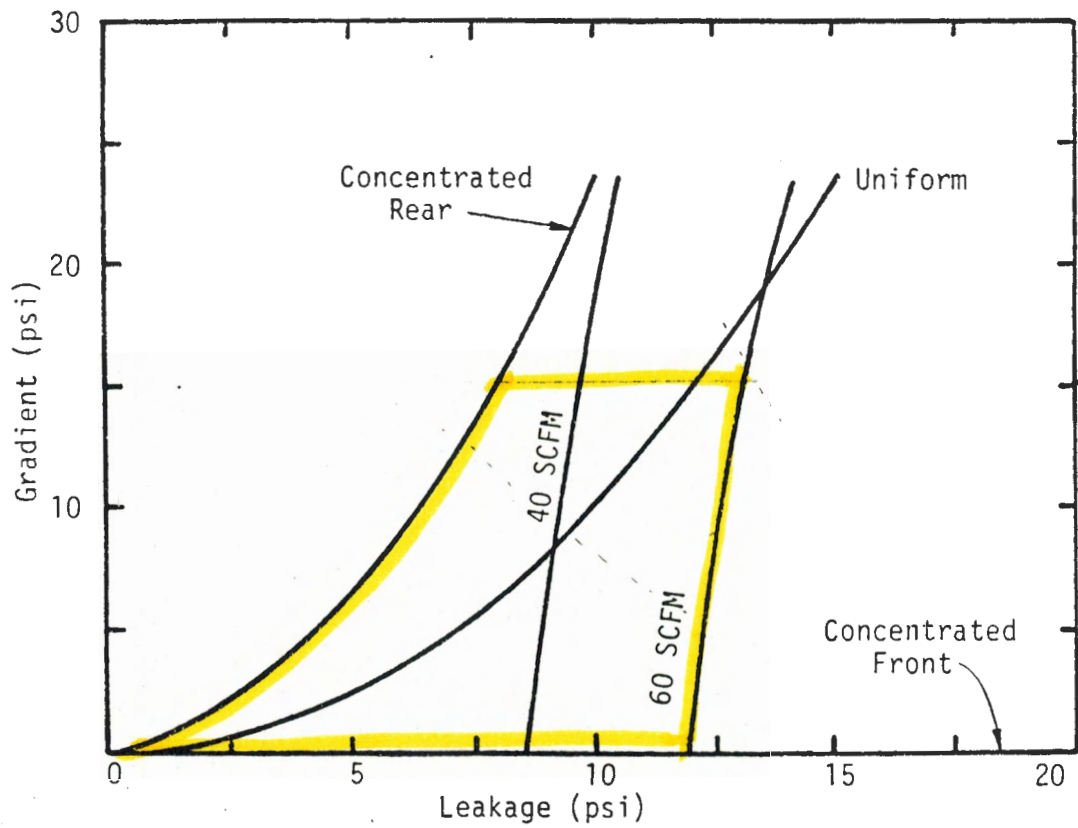


FIGURE 2. GRADIENT VERSUS LEAKAGE FOR VARIOUS LEAKAGE CONDITIONS ON TRAIN WITH 3 LOCOMOTIVES AND 100 CARS (80 PSI BRAKE PIPE PRESSURE); LINES OF CONSTANT AIR FLOW ALSO INDICATED (SCFM)

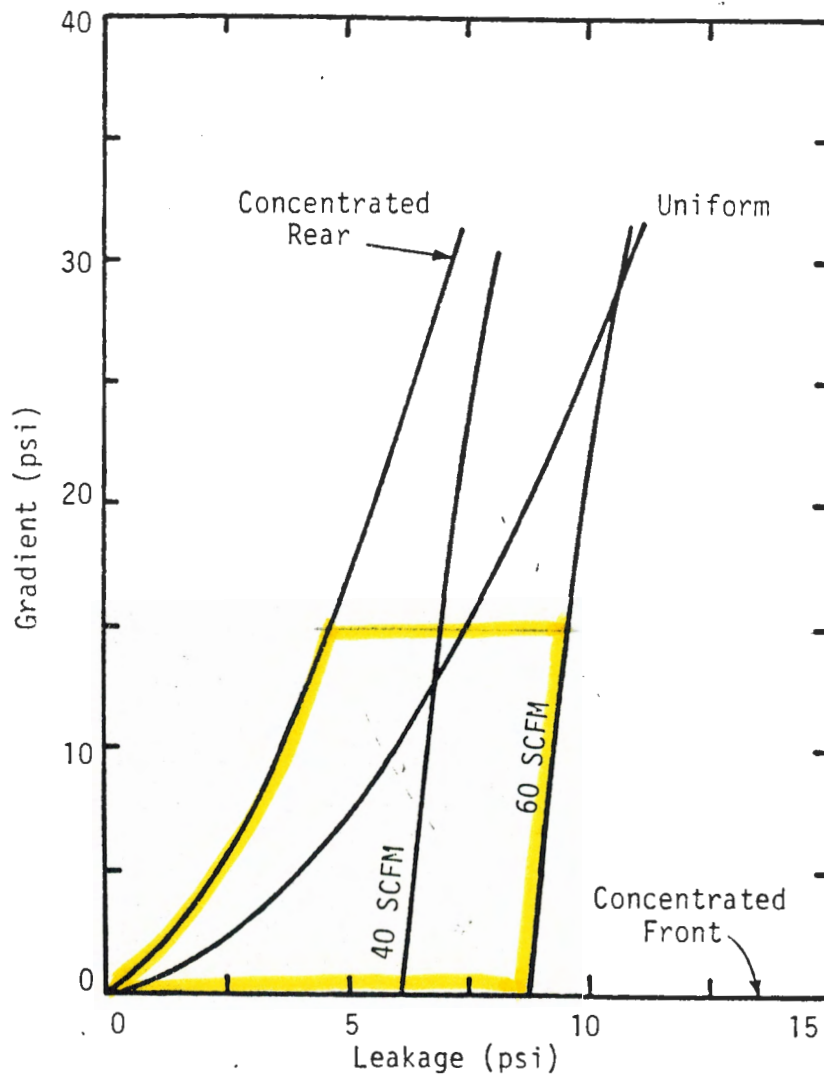


FIGURE 3. GRADIENT VERSUS LEAKAGE FOR VARIOUS LEAKAGE CONDITIONS ON TRAIN WITH 4 LOCOMOTIVES AND 150 CARS (80 PSI BRAKE PIPE PRESSURE); LINES OF CONSTANT AIR FLOW ALSO INDICATED (SCFM)

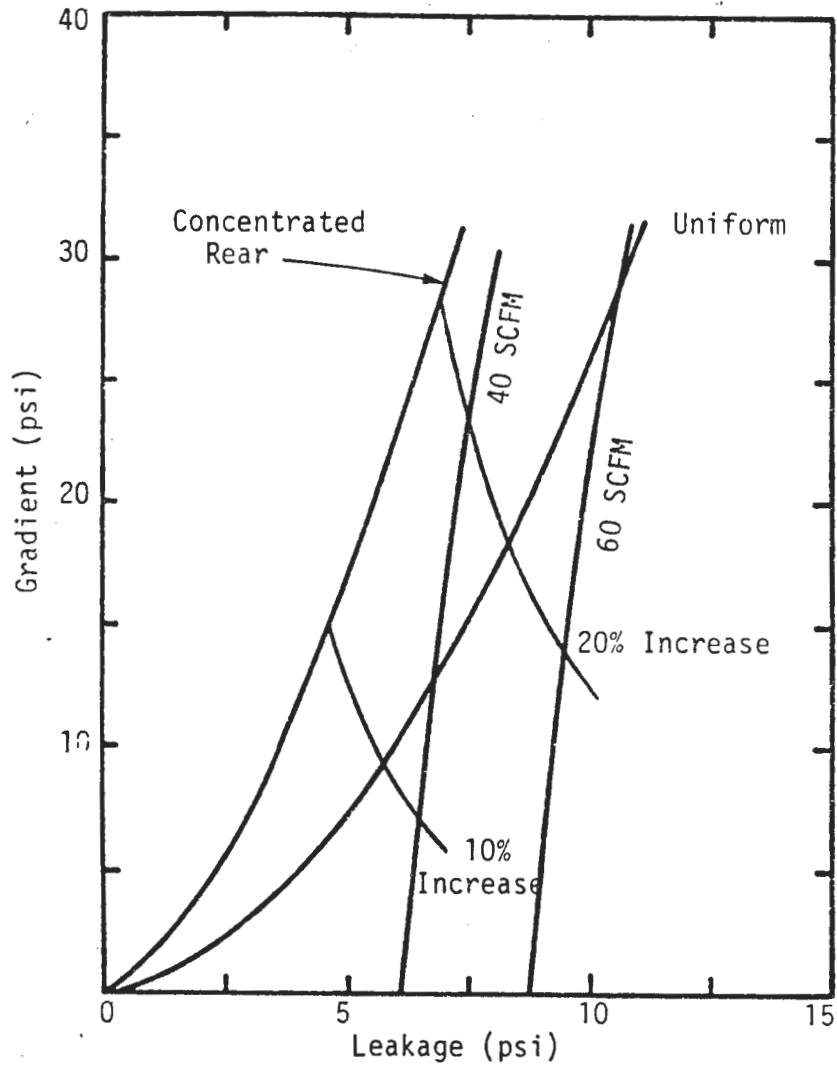


FIGURE 6. GRADIENT, LEAKAGE AND AIR FLOW, TRAIN OF 4 LOCOMOTIVES AND 50 CARS, WITH LINES SHOWING 10 AND 20 PERCENT INCREASE IN EMERGENCY BRAKING STOP DISTANCE

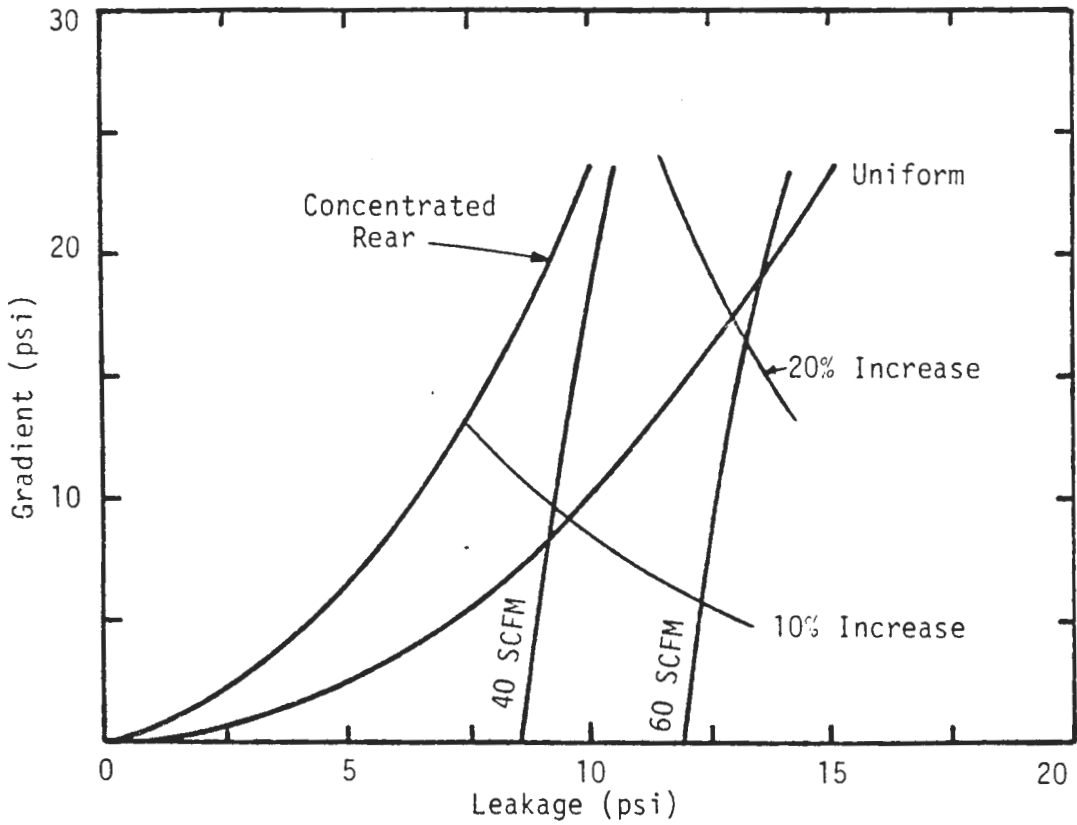


FIGURE 5. GRADIENT, LEAKAGE AND AIR FLOW, TRAIN OF 3 LOCOMOTIVES AND 100 CARS, WITH LINES SHOWING 10 AND 20 PERCENT INCREASE IN EMERGENCY BRAKING STOP DISTANCE

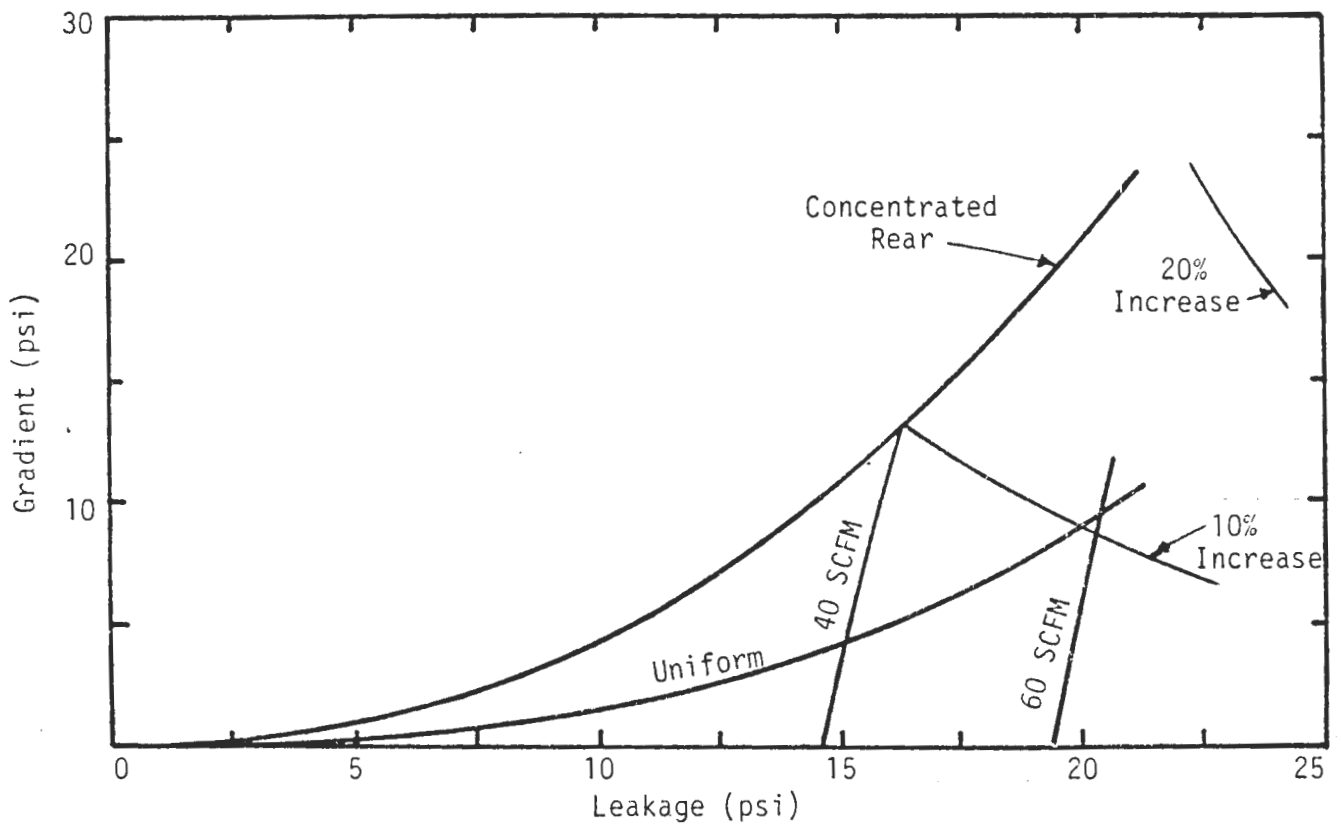


FIGURE 4. GRADIENT, LEAKAGE AND AIR FLOW, TRAIN OF 2 LOCOMOTIVES AND 50 CARS, WITH LINES SHOWING 10 AND 20 PERCENT INCREASE IN EMERGENCY BRAKING STOP DISTANCE



U.S. Department
of Transportation
**Federal Railroad
Administration**

Memorandum

Date: September 22, 1987

Reply to Attn. of: 366-0466

Subject: INFORMATION: AAR Specifications for Calibration
and Test of AFM Air Flow Indicator

From: M. Clifford Gannett *M.C.G.*
Chief, Equipment and Operating Practices
Safety Research Division, RRS-32

To: Edward R. English
Chief, Maintenance Programs Division
Office of Safety Enforcement, RRS-13

The calibration procedure described in RP 402 for AFM-type air flow indicators appears to be satisfactory.

One consideration is whether the A-19 brake pipe flow indicator adaptor, shown on the attachment, is in a location where it will not be subject to ambient temperature. If the AFM indicator is calibrated at standard temperature and the orifice in the adapter becomes subject to much lower temperature, the flow could be greater than indicated on the indicator.

The environmental test described in Section 4.0 is apparently for the AFM indicator alone and does not include the adapter with orifice. I suggest tests also be made including the adaptor to determine the effects of air temperature changes at the orifice. Section 4.1 indicates that the pressure differentials for various upstream-to-downstream pressures, with 60 c.f.m. air flow, will not vary more than 1/2 p.s.i. It would be of interest to know the pressure change that will be brought about by flow through the orifice in the A-19 adaptor.

Missing is information concerning the calibration device. It is very unlikely calibration can always be completed under ideal conditions of 68° F. and one atmosphere pressure. Under other than ideal conditions, some adjustment must be made to the calibration of the AFM indicator.

Section 6.1 refers to Vibration and Shock tests. The mill specification for 2 g. input vibration refers to a shock-mounted device. If not shock-mounted, the input should be increased to 5 g. The vertical and lateral shock should be increased from 2 g. to 15 g. in 0.11 seconds for this type of application.

Attached are comments furnished by Battelle. I suggest, at some time, we have a meeting to discuss the questions raised concerning the specifications.

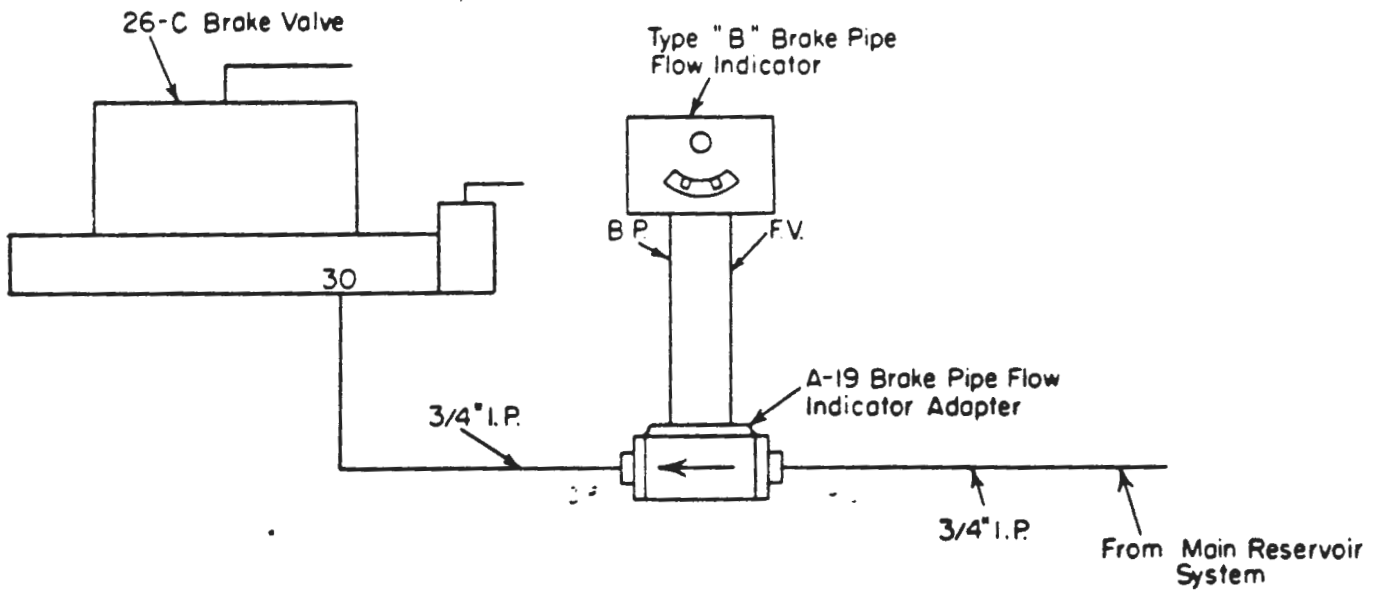


PLATE 10
Piping Arrangement Of Equipment For Addition
Of Type "B" Brake Pipe Flow Indicator.

Comments on
PROPOSED RP-402
CALIBRATION PROCEDURE FOR AFM TYPE
AIR FLOW INDICATORS

2.0 CALIBRATION DEVICE

The flow control calibration device has a certain "black box" flavor to it. If the device is the same as described in CN Maintenance Regulations No. 3420 (Rev. Aug. 1980), consisting of a brake hose (WABCO P.C. 587101) and a choke (WABCO P.C. 302447), each device will itself have to be certified (calibrated) for 60 scfm at the desired brake pipe pressure (75 psig). The device will itself have an uncertainty band due to brake pipe air temperature (+/- 6 percent from 0 to 130 deg. F). The term "exactly" is therefore somewhat a nonsequitur. One must measure the barometric pressure, the brake pipe pressure and the brake pipe temperature, plus achieving steady-state conditions, to be assured an accurate air flow.

There is also some confusion over "scfm": "standard" (Mark's Handbook) is one atmosphere (14.7 psia) at 60 deg F. "Normal" is one atmosphere, 68 deg F and 36 percent humidity. About one percent difference in air density.

Sept. 17, 1987

Comments on
PROPOSED SPECIFICATION M-950
AIR FLOW INDICATORS

3.0 REQUIREMENTS

- 3.3 "Should" implies an optional accuracy, change to "must".
- 3.4 Again, "should" implies optional, change to "must".
- 3.5 Suggest changing to "The device sensitivity must be capable of indicating a +/-2 scfm change in flow at the 60 scfm level...etc."
- 3.8 Suggest changing to "The device must indicate flow in units of scfm,...etc.". We're not so sure "scfm" is the right notation. If the gauge face displays markings in 10 scfm increments, isn't it a square-root-of-pressure spacing? This has implications in the calibration process, moving the pointer to coincide with 60 scfm (how accurate then does the rest of the dial read?). Scale length and readability might be mentioned here.

The last sentence, the 57-63 scfm band: does this refer to normal variations in ambient temperature and pressure during the calibration process? At the indicator itself, variations in scfm readings are at the mercy of main reservoir pressure and air temperature at the indicator. A true 60 scfm flow could read from 53 to 70 at the indicator, using the pressure and temperature extremes of 4.1.

- 3.12 Suggest "dust free environment" be changed to "dirt free interior".

4.0 ENVIRONMENTAL TEST

- 4.1 "...where the upstream pressure and temperature, and downstream pressure can be independently controlled...".

"These pressures will also be recorded with a temperature of +150 F, +70 F, 0 F." Not explicit that these are source air temperatures, rather than ambient temperatures.

Last sentence: if you vary both temperature and pressure extremes at once, pressure differential may deviate up to 4 psid.

AFM device should be calibrated prior to beginning of 4.1 activities.

5.0 ENDURANCE TEST

5.1 The type and duration of flow or pressure pulses should be specified here, otherwise one could use a 10 msec pulse duration, for example, which could have an entirely different service life effect than a 6 second pulse duration. Pulse rise time is also important in its dynamic effects. Should define whether this is accelerated normal use or abuse.

5.2 Device should be calibrated prior to beginning 5.1 activities.

5.3 Define "leakage"...is this bubbles (soap and water), or is it by leak detector, and if so, what levels?

After 5.3, device should be retested for performance to see if it is out of spec or out of calibration.

5.4 Tolerances of wear should be specified somehow, which may be difficult while allowing a wide range of devices.

6.0 VIBRATION AND SHOCK TESTS

6.1 MIL-STD-810C (10 March 1975) shows a typical vibration spec for aircraft (helicopters) of 2 g peak from 14-500 Hz when mounted on racks and panels with vibration isolation. Without isolation, they recommend the following:

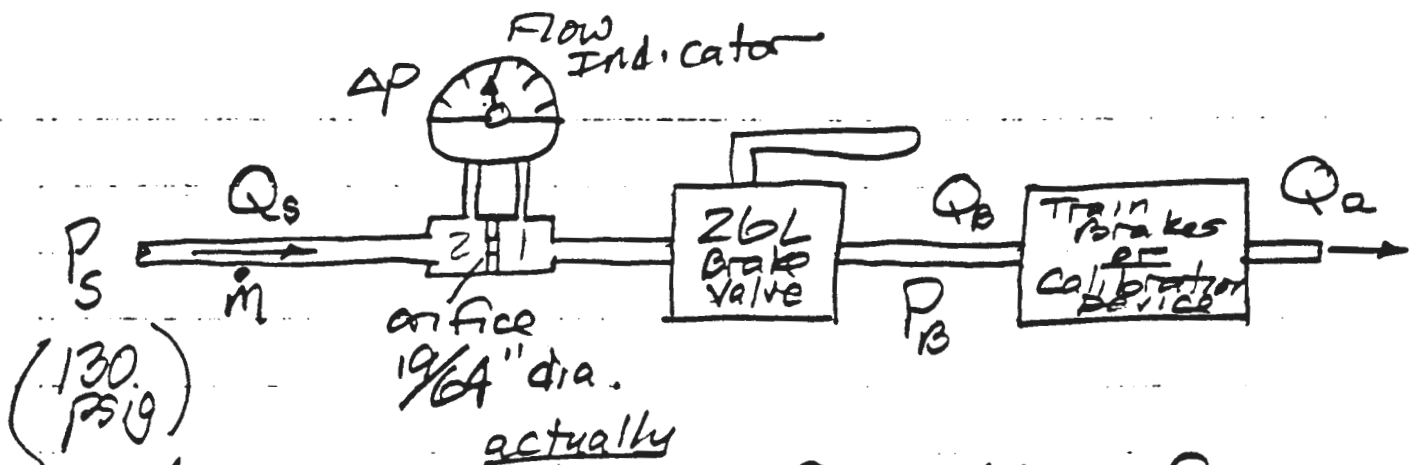
2 g peak	14-33 Hz
0.036 in. p-p	33-52 Hz
5 g peak	52-2000 Hz

Typical shock tests are a 15 g peak half-sine acceleration pulse with an 11 msec duration. Don't coddle the device!

6.2 Must calibrate prior to 6.1 activities.

Air Flow Method —

9-16-87₆



Assume we have $Q = 60$ scfm

$$\dot{m} = C_D \gamma A_0 \sqrt{2 \rho \Delta P}$$

$$\dot{W} = \dot{m} g = C_D \gamma A_0 \sqrt{2 w, g \Delta P}$$

$$= 60 \frac{\text{ft}^3}{\text{min}} (.0764 \frac{\text{lb}}{\text{ft}^3}) / (60) \frac{\text{sec}}{\text{min}}$$

$$= .0764 \text{ lb/sec @ } 60^\circ\text{F}$$

$$\Delta P = \frac{\dot{W}^2}{2 w, g (C_D \gamma A_0)^2}$$

Assume $C_D = 0.60$, $\gamma = 0.95$

$$A_0 = \left(\frac{\pi}{4}\right) \left(\frac{1}{64}\right)^2 = .06922 \text{ in}^2$$

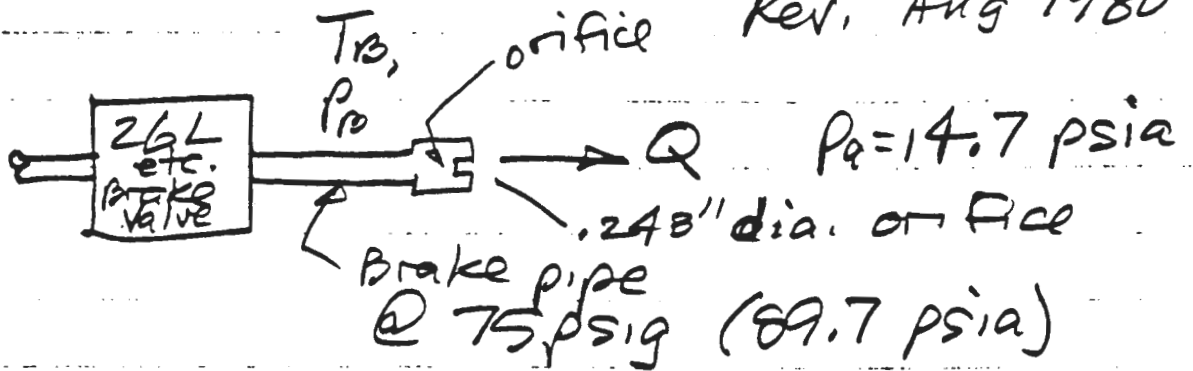
$$w, = 4.350 (10)^{-4} \text{ lb/in}^3 \text{ @ } 130 \text{ psig } 60^\circ\text{F}$$

$$\Delta P = \frac{(.0764)^2}{2 (4.350 \times 10^{-4}) g [0.60 (0.95) (.06922)]^2}$$

$$= 11.17 \text{ psid across flow ind.}$$

$$= 10.52 \text{ @ } 30^\circ\text{F to } 11.80 \text{ @ } 90^\circ\text{F}$$

CN Test — Maint. Reg. No 3420
Rev. Aug 1980



Since $\frac{P_a}{P_B} = \frac{14.7}{89.7} = .164 \ll 0.53$,
we're at sonic ~~choke~~ flow.

$$\begin{aligned}\dot{W} &= 0.53 G P_B A_o \sqrt{T_B} \quad \text{lb/sec} \\ &= 0.53 (0.60) (89.7) \left(\frac{\pi}{4}\right) (.243)^2 \sqrt{520} \\ &= .0580 \text{ lb/sec @ } 60^\circ\text{F}\end{aligned}$$

$$Q = (.0580)(60) / (.0764) = 45.6 \text{ scfm}$$

If we used the wrong equation (for subsonic flow):

$$\begin{aligned}\dot{W} &= \frac{1.06}{\sqrt{T}} A \sqrt{P_D (P_S - P_D)} \\ &= \frac{1.06}{\sqrt{520}} (.04638) \sqrt{14.7 (75)} = .0716\end{aligned}$$

$$Q = .0716 (60) / (.0764) = 56.2 \text{ scfm}$$

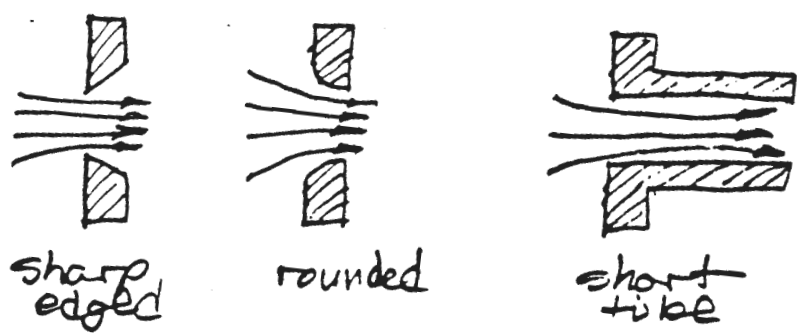
To get 60 scfm with CN's gadget, C_D must be ...

$$\dot{W} = 60(.0764)/60 = .0764 \frac{\text{lb}}{\text{sec}} \text{ reading}$$

$$C_D = \frac{\dot{W} \sqrt{T_0}}{0.53 P_0 A_0} \quad \begin{matrix} \text{b/sec} \\ \text{in}^3 \\ \text{instant} \end{matrix}$$

$$= (.0764) \sqrt{520} / (0.53)(89.7)(.04638)$$

= 0.79 ... can this be?



$C_D = 0.61$ 0.98 0.80

CN's gizmo \rightarrow

Okay, then. It's still sonic and depends on temperature: n)

T_0	Q	% change
0	63.8	+6.3
30	61.8	+3.0
60	60	0

10psi

Air Flow Indicator

$$\Delta P = C \frac{\dot{W}^2}{w_a} \quad \text{lb/in}^2, \text{ the reading}$$

where \dot{W} = weight flow rate, lb/sec
 w_a = weight density, lb/in³
 C = 0.832 sec²/in⁵ (a "constant")

since $w_a \sim \frac{P_2 T_1}{P_1 T_2}$

$$\Delta P = C \frac{\dot{W}^2}{w_0} \left[\frac{P_0 T_2}{P_2 T_0} \right]$$

where w_0 , P_0 and T_0 are the "standard" values.

Now, assume "standard" at 60 scfm (60°F) air:

$$\dot{W} = .0764 \text{ lb/sec (60 scfm)}$$

$$w_0 = 4.350 (10)^{-4} \text{ lb/in}^3$$

$$P_0 = 130 \text{ psig (144.7 psia)}$$

$$T_0 = 60^\circ \text{F (520}^\circ \text{R)}$$

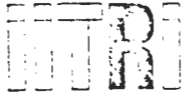
$$\Delta P = 11.16 \text{ psid nominal}$$

$$= 15.20 \text{ psid } (T_2 = 150^\circ \text{F}, P_2 = 110 \text{ psig})$$

$$= 8.68 \text{ psid } (T_2 = 0^\circ \text{F}, P_2 = 150 \text{ psig})$$

<u>ΔP</u>	<u>Indicated scfm</u>
8.68	52.9
11.16	60
15.20	70.0

<u>%</u>	<u>ΔP</u>	<u>P_2</u>	<u>T_2</u>	<u>Indicated scfm</u>	<u>Change in ΔP</u>
-	11.16	130 psig	60°F	60	-
-11.5	9.87	130	0	56.4	-1.3
+17.3	13.09	130	150	65.0	+1.9
+16.0	12.95	110	60	64.6	+1.8
-12.2	9.80	150	60	56.2	-1.4



IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

April 13, 1988

Mr. Garold Thomas, RRS-32
Federal Railroad Administration
Office of Research and Development
400 Seventh Street, SW, Room 8305
Washington, DC 20590

Subject: Sixth Monthly Progress Report, February 27 to March 25, 1988
Contract DTFR53-82-C-00254, Task Order No. 4, "Improved Braking
System, Simulation", IITRI Project E06593

Dear Mr. Thomas:

During the reporting period work was conducted on Subtasks 1A, 1B, 2A and 2B of the subject task order. Over 50 computer runs have been made using the off-line RALES train operations model to relate leakage, gradient and air flow parameters to train operation performance variables.

The results of the work that have been conducted thus far can be summarized in a clear and concise manner on a series of figures where gradient is plotted as a function of leakage. One figure is used for each train consist. Each figure presents plots of gradient as a function of leakage for two conditions of leakage: leakage concentrated at the rear of the train and uniform leakage. As indicated on the figures the abscissa represents a third condition, namely, leakage concentrated at the front of the train. The curve representing leakage concentrated at the rear of the train is an extreme condition in the functional relationship between gradient and leakage so that a plot representing any other leakage condition would lie between the curve for concentrated leakage at the rear of the train and the abscissa. Lines representing constant values of air flow are also plotted on the figures to complete the depiction of the relationship between air flow, gradient and leakage.

The region for permissible operation within the limitations of a 15 psi maximum gradient and a maximum air flow of 60 SCFM are outlined by a yellow marking pencil on each of the figures. Note that this region is much larger than if one used criterion of a maximum gradient of 15 psi and a leakage of 5 psi. With this criterion the maximum rate of 5 psi leakage is the controlling factor for all cases except the 150 car train with the leakage concentrated at the rear of the train.

Figures 1 to 3 are repeated in Figures 4 to 6, respectively, where additional information indicative of degradation in braking performance has been plotted. These figures show lines representing increases in stop distance of 10 and 20 percent for an emergency brake application.

Mr. Garold R. Thomas
April 13, 1988
Page Two

Work is currently under way to determine what other characteristics of braking system performance may be significantly degraded within the operating limits shown in the figures. The conditions being examined include failure to propagate the brake application to the rear of the train, unintended releases, etc.

Project costs and labor hour expenditures are summarized in the attached table and figure.

Sincerely yours,



Milton R. Johnson
Senior Engineering Advisor
Railroad Technology Center

Approved:



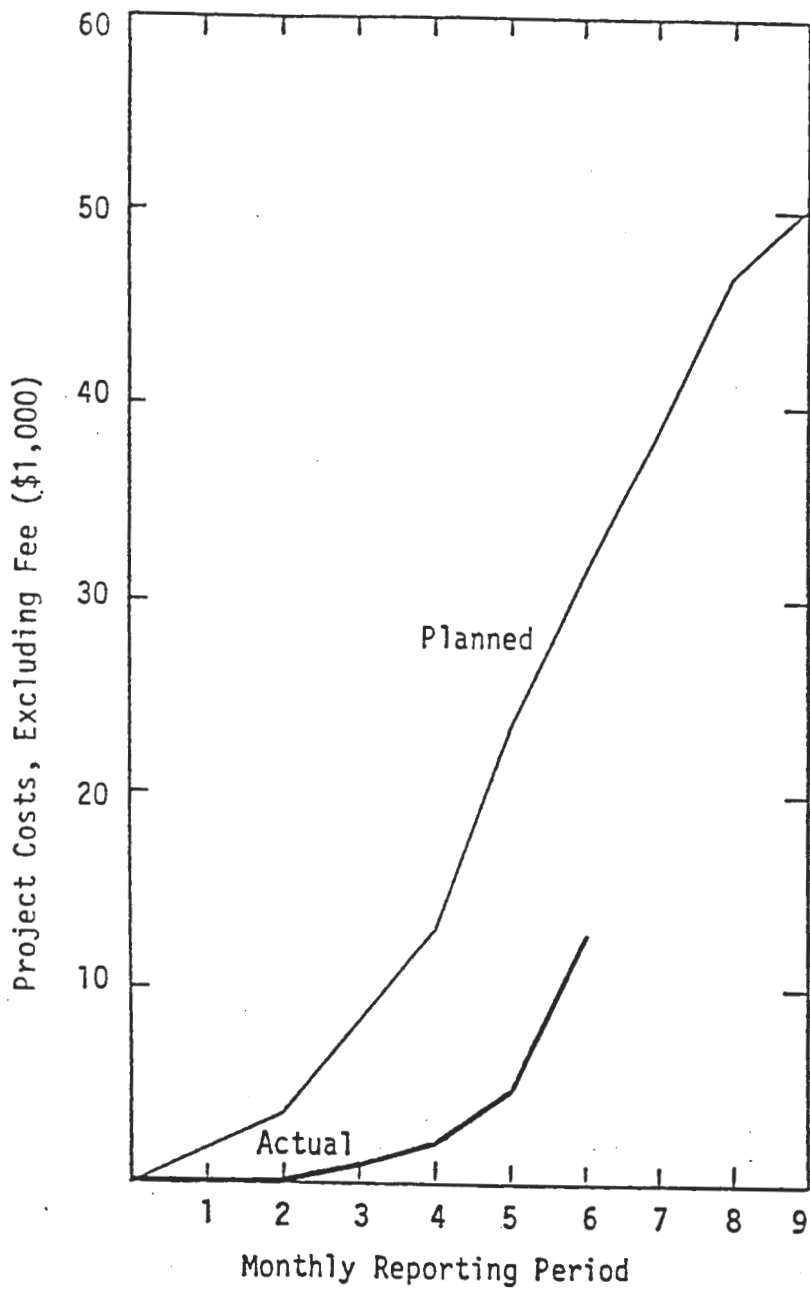
A. R. Valentino
Director
Electromagnetics and Electronics

cc: M. Clifford Gannett, FRA
S. A. Bolling, FRA
W. Bolin, IITRI

MONTHLY AND CUMULATIVE LABOR HOURS AND COSTS
(LABOR AND OTHER, EXCLUDING FEE)
FOR CONTRACT DTFR53-82-C-00254, TASK ORDER NO. 4

<u>Current Period*</u>		<u>Cumulative</u>		<u>Percent of Present Funds Expended</u>
<u>Labor Hours</u>	<u>Costs</u>	<u>Labor Hours</u>	<u>Costs</u>	
86	8,610	123	12,260	24

*Current Period Covered February 27 to March 25, 1988



CUMULATIVE PLANNED AND ACTUAL PROJECT EXPENDITURES,
CONTRACT. DTFR53-82-C-00254, TASK ORDER NO. 4

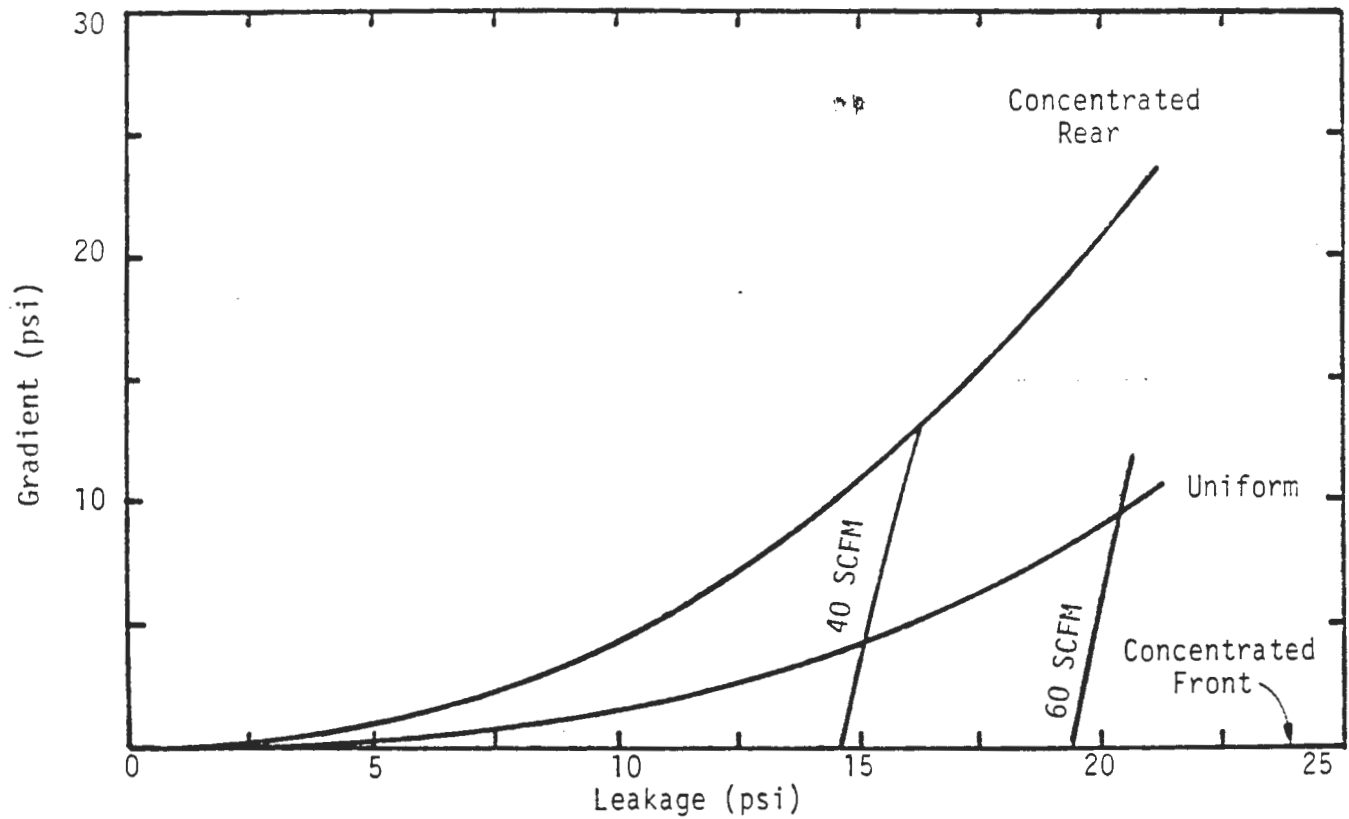


FIGURE 1. GRADIENT VERSUS LEAKAGE FOR VARIOUS LEAKAGE CONDITIONS ON TRAIN WITH 2 LOCOMOTIVES AND 50 CARS (80 PSI BRAKE PIPE PRESSURE); LINES OF CONSTANT AIR FLOW ALSO INDICATED (SCFM)

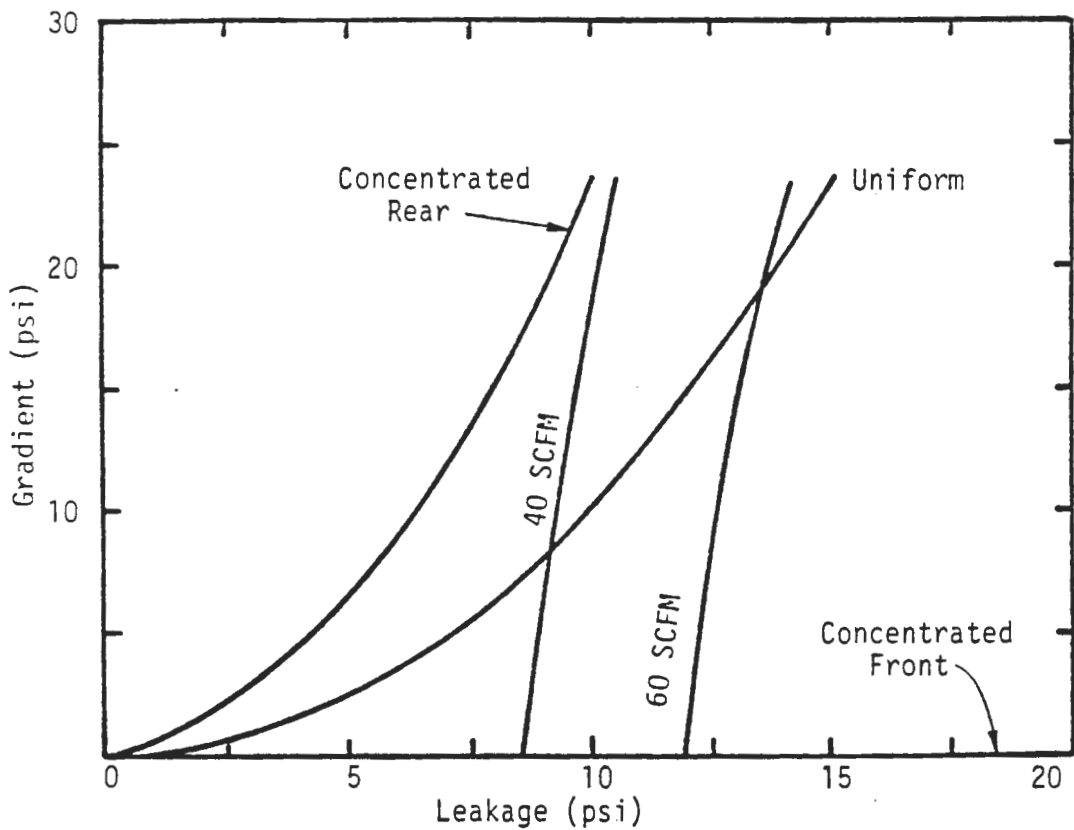


FIGURE 2. GRADIENT VERSUS LEAKAGE FOR VARIOUS LEAKAGE CONDITIONS ON TRAIN WITH 3 LOCOMOTIVES AND 100 CARS (80 PSI BRAKE PIPE PRESSURE); LINES OF CONSTANT AIR FLOW ALSO INDICATED (SCFM)

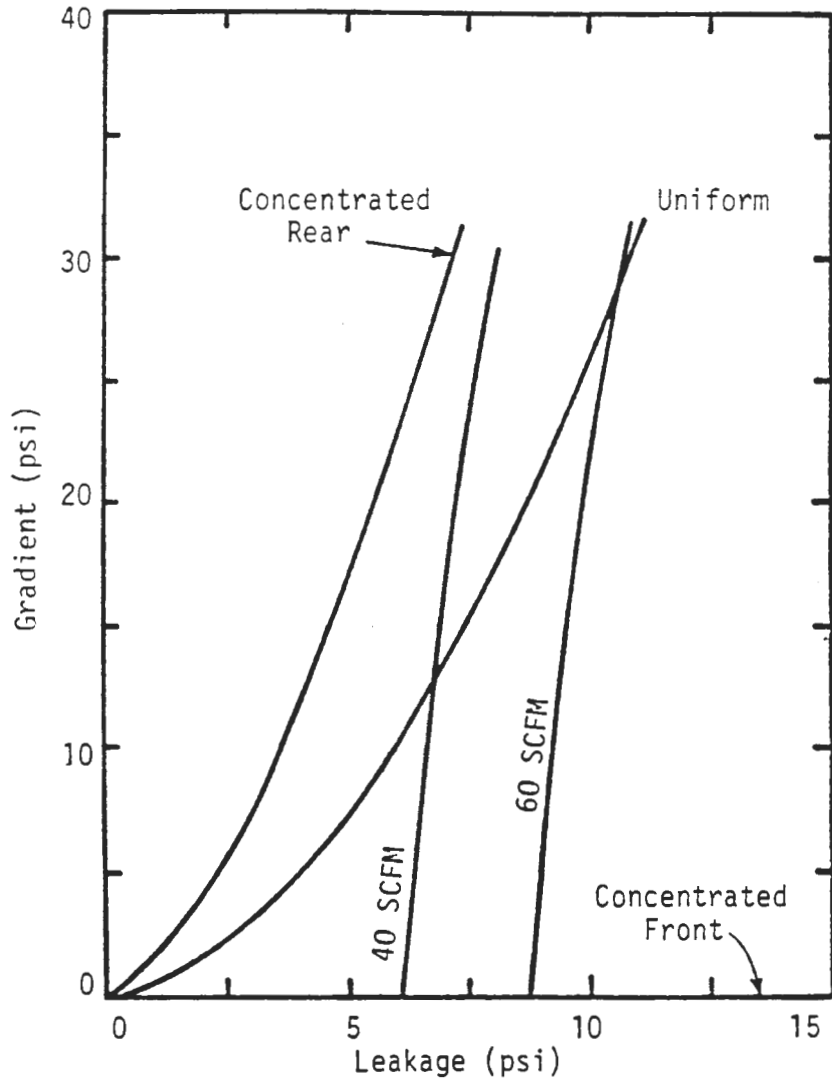


FIGURE 3. GRADIENT VERSUS LEAKAGE FOR VARIOUS LEAKAGE CONDITIONS ON TRAIN WITH 4 LOCOMOTIVES AND 150 CARS (80 PSI BRAKE PIPE PRESSURE); LINES OF CONSTANT AIR FLOW ALSO INDICATED (SCFM)

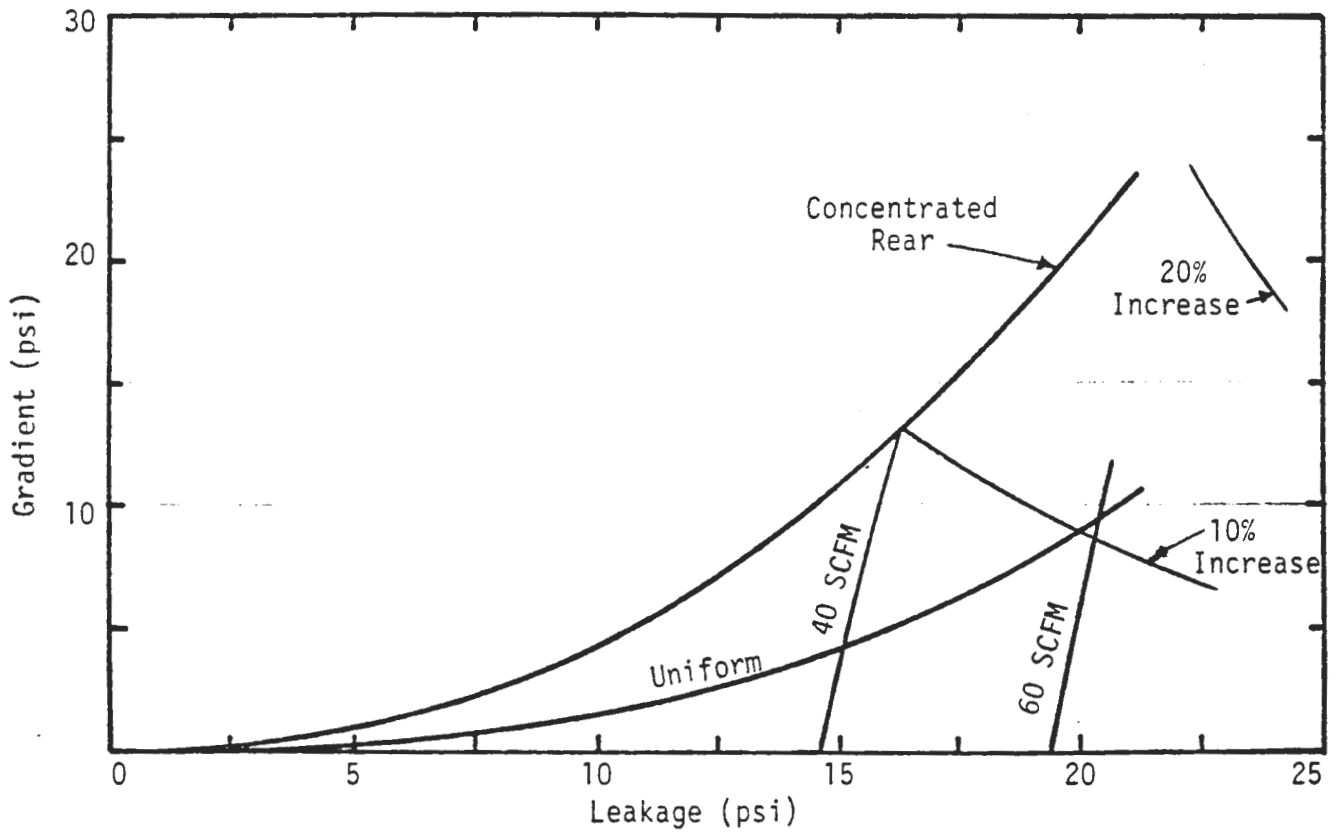


FIGURE 4. GRADIENT, LEAKAGE AND AIR FLOW, TRAIN OF 2 LOCOMOTIVES AND 50 CARS, WITH LINES SHOWING 10 AND 20 PERCENT INCREASE IN EMERGENCY BRAKING STOP DISTANCE

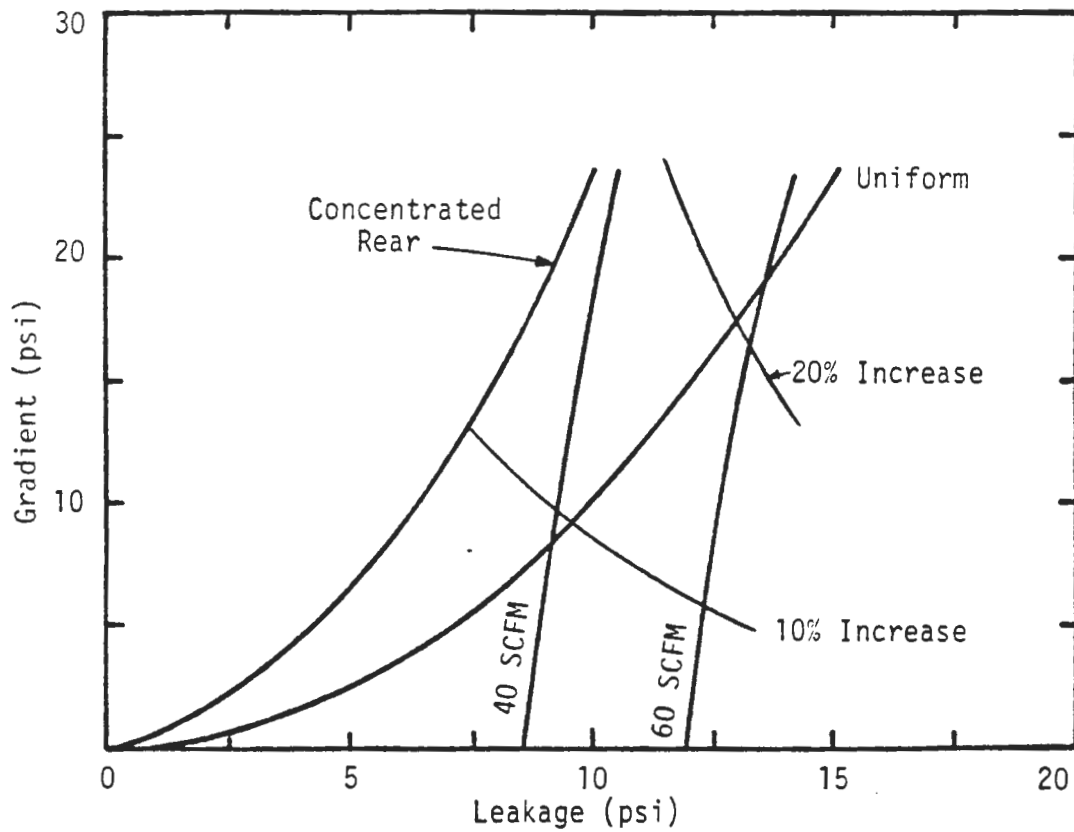


FIGURE 5. GRADIENT, LEAKAGE AND AIR FLOW, TRAIN OF 3 LOCOMOTIVES AND 100 CARS, WITH LINES SHOWING 10 AND 20 PERCENT INCREASE IN EMERGENCY BRAKING STOP DISTANCE

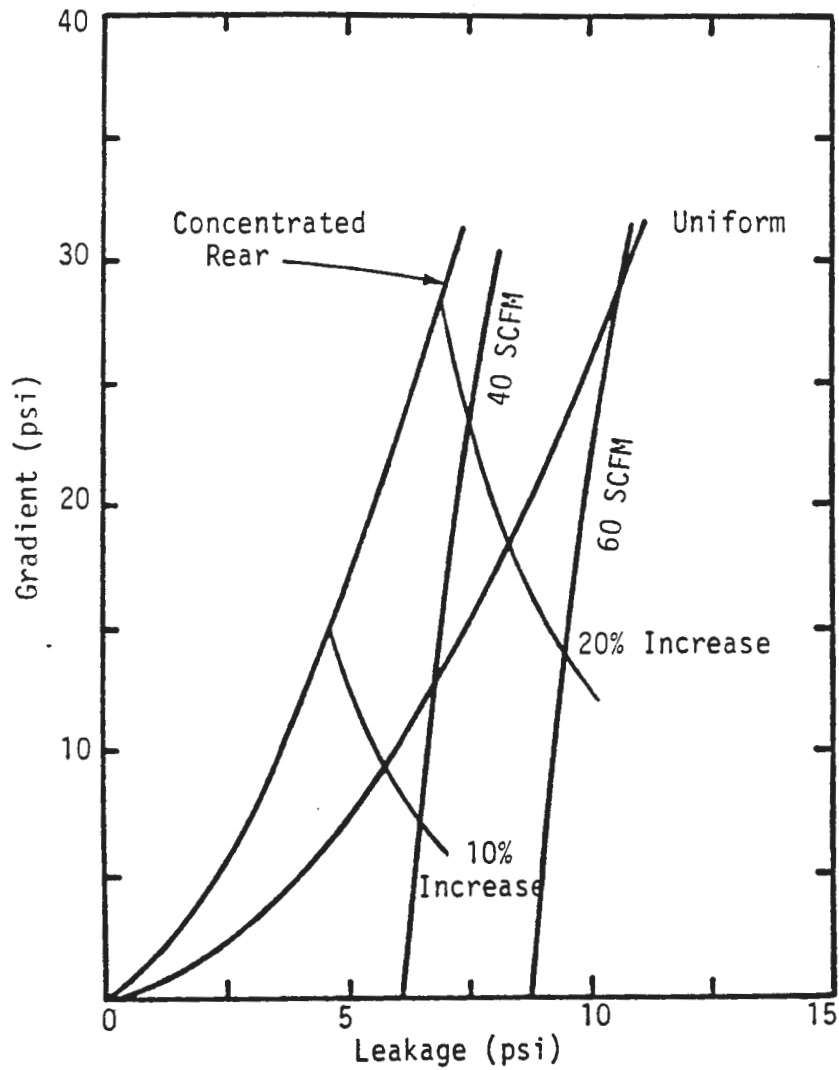


FIGURE 6. GRADIENT, LEAKAGE AND AIR FLOW, TRAIN OF 4 LOCOMOTIVES AND 50 CARS, WITH LINES SHOWING 10 AND 20 PERCENT INCREASE IN EMERGENCY BRAKING STOP DISTANCE



IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

May 17, 1988

Mr. Garold Thomas, RRS-32
Federal Railroad Administration
Office of Research and Development
400 Seventh Street, SW, Room 8305
Washington, DC 20590

Subject: Seventh Monthly Progress Report, March 26 to April 22, 1988,
Contract DTFR53-82-C-00254, Task Order No. 4, "Improved
Braking System, Simulation", IITRI Project E06593

Dear Mr. Thomas:

During the reporting period work was conducted on Subtasks 1A, 1B, 2A and 2B of the subject task order. A large number of computer runs have been made using the off-line RALES train operations model to relate leakage, gradient and air flow parameters to train operation performance variables.

Results published in last month's progress report showed that under large leakage and air flow conditions emergency braking stop distances are significantly increased. Additional analyses have now been made to determine if there are other deleterious effects on braking performance if one were to consider a terminal brake test criterion with constraints in the vicinity of a maximum 15 psi gradient and 60 SCFM air flow.

One set of analyses have been conducted to consider the condition where leakage is concentrated at the rear of the train and a minimum reduction is made (7 psi). Results from the use of the analytical brake model show that if air flow is too high or leakage is too large that a minimum reduction cannot be sustained at the rear of the train. The brakes will come on for a short period of time, but then start to release. The effect appears to be limited to shorter trains. For example, analyses of the 50 car train show that the threshold for this condition is a leakage of approximately 21 psi/min with a corresponding air flow of 52.1 SCFM and a gradient of 23.2 psi. The results from this analysis show that the brakes will release on the last six cars of the train. For leakage of 23 psi/min with a corresponding air flow of 55.4 SCFM and a gradient of 28.1 psi, the brakes release on the last 14 cars of the train. This effect is not predicted for the 100 car train up to a condition where the leakage is 10 psi/min, the air flow is 36.1 SCFM and the gradient is 22.9 psi.

The prediction of this effect is quite sensitive to the assumption of the differential pressure between the brake pipe and auxiliary reservoir which will trigger a release of the valve and the rate at which the auxiliary reservoir is allowed to equalize with the brake pipe pressure. A slight change in either of these parameters will result in a different threshold for the onset of these conditions. However, since there will be valve to valve variations in these characteristics, the results of the calculation are indicative of a potential problem at these flow rates. An experimental examination of the phenomena on a brake test rack may be warranted.

Another set of analyses have been conducted to determine the effects of concentrated leakage at various locations in the train. These analyses have been made using the 100 car train. The attached figure shows plots of gradient versus leakage for trains where the concentrated leakage is at the front and rear of the train, and at 3 intermediate locations. For the trains where the leakage occurs at the 26th and 54th car, it has been found that under high leakage and gradient conditions the propagation of a minimum reduction through the train is first slowed, and then under conditions of higher leakage, the minimum reduction fails to propagate past the leaking car. For example, the time to propagate a minimum reduction from the locomotive to the rear of the train increases from a normal time of approximately 9 seconds to 16 seconds for a leakage of 9 psi/min, air flow of 36.8 SCFM and a gradient of 11.7 psi where the concentrated leak is at the 54th car. The same increase in propagation time results for the condition of a leakage of 13 psi/min, an air flow of 56.8 SCFM, and a gradient of 13.6 psi where the concentrated leak is at the 26th car. The threshold for this degraded brake performance is shown by a dashed line on the figure. It includes a portion of the region where the gradient is less than 15 psi and the air flow is less than 60 SCFM.

Further analysis of this condition shows that for the case where the leakage is at the 54th car with a leakage of 12 psi/min, air flow of 47.0 SCFM and a gradient of 20.1 psi the minimum reduction will not go past the leaking car. However, if a subsequent full service application is made it will propagate past the leaking car and apply brakes to all the cars on the train. Again, these analyses show that there are regions where degraded brake performance is indicated by the analytical model. Confirmation of these results by testing on a brake test rack may be warranted.

Work will continue to determine what other characteristics of braking system performance may be significantly degraded when operating at large air flows and gradients.

Some delays have been encountered in the program because of difficulties encountered in running the brake model at conditions which are outside the normal operating range. One of the major difficulties was in the proper initialization of the model. These difficulties have been cleared up, but the progress of the work has been delayed. The need for requesting a no-cost time extension is being evaluated.

Mr. Garold Thomas
May 17, 1988
Page 3

Project costs and labor hour expenditures are summarized in the attached table and figure.

Sincerely yours,



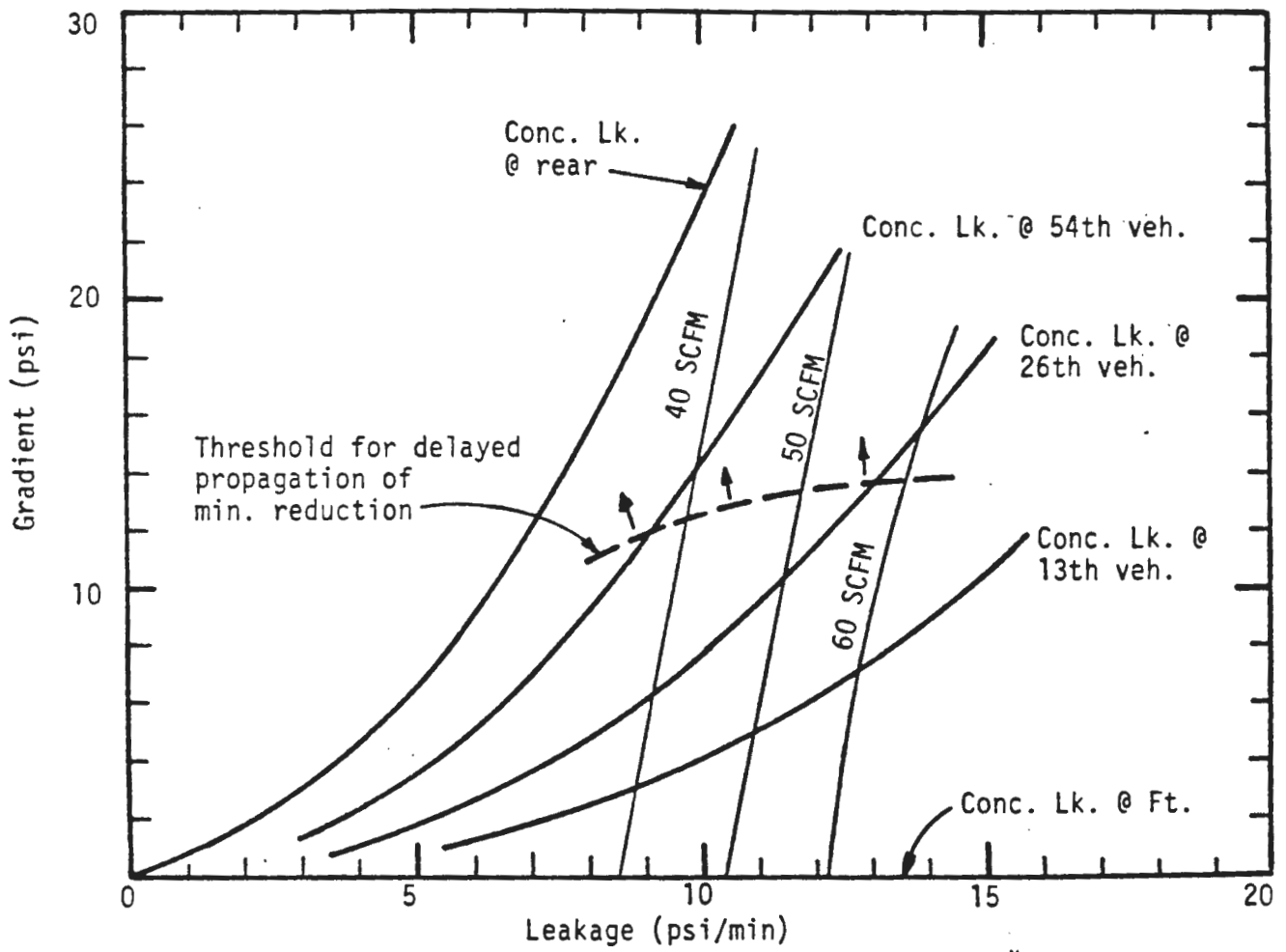
Milton R. Johnson
Senior Engineering Advisor
Railroad Technology Center

Approved:



A. R. Valentino
Director
Electromagnetics and Electronics

cc: M. Clifford Gannett, FRA
S. A. Bolling, FRA
W. Bolin, IITRI

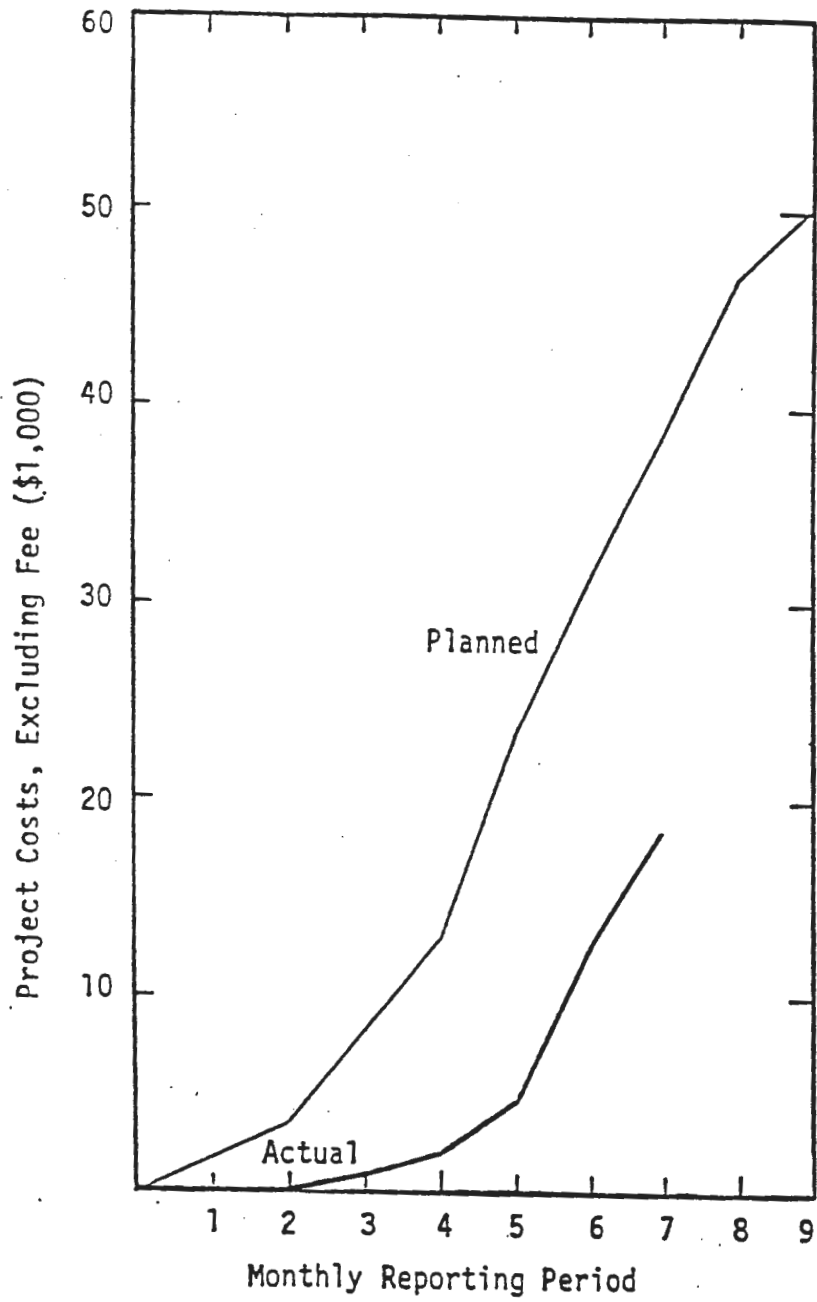


Gradient Versus Leakage for Concentrate Leakage Cases
on Train with 3 Locomotives and 100 Cars

MONTHLY AND CUMULATIVE LABOR HOURS AND COSTS
(LABOR AND OTHER, EXCLUDING FEE)
FOR CONTRACT DTFR53-82-C-00254, TASK ORDER NO. 4

<u>Current Period*</u>		<u>Cumulative</u>		<u>Percent of Present Funds Expended</u>
<u>Labor Hours</u>	<u>Costs</u>	<u>Labor Hours</u>	<u>Costs</u>	
70	6,374	193	18,634	37

*Current Period Covered March 26 to April 22, 1988



CUMULATIVE PLANNED AND ACTUAL PROJECT EXPENDITURES,
CONTRACT. DTFR53-82-C-00254, TASK ORDER NO. 4

7884



IIT Research Institute
10 West 35 Street, Chicago Illinois 60616
312/567-4000

June 28, 1988

Mr. Garold Thomas, RRS-32
Federal Railroad Administration
Office of Research and Development
400 Seventh Street, SW, Room 8305
Washington, DC 20590

Subject: Eighth Monthly Progress Report, April 23 to May 20, 1988,
Contract DTFR53-82-C-00254, Task Order No. 4, "Improved
Braking System, Simulation", IITRI Project E06593

Dear Mr. Thomas:

During the reporting period work was conducted on Subtasks 1A, 1B, 2A and 2B of the subject task order. A large number of computer runs have been made using the off-line RALES train operations model to relate leakage, gradient and air flow parameters to train operation performance variables. These analyses have been made to determine deleterious effects on braking performance if one were to consider a terminal brake test criterion with constraints in the vicinity of a maximum 15 psi gradient and 60 SCFM air flow.

Last month's progress report discussed the effects of concentrated leakage at various locations in a train of 3 locomotives and 100 cars. It was shown that the propagation of a minimum reduction through the train was significantly delayed under conditions of high gradients and leakages at certain locations in the train.

The effects of concentrated leakage have now been examined for trains of 4 locomotives and 150 cars and 2 locomotives and 50 cars. Plots relating gradient to leakage with air flow plotted as a parameter are shown in Figures 1 and 2. The effect of a delayed propagation of a minimum reduction was examined for these 2 trains. For the 50 car train it was found that there is no delay in a propagation of the minimum reduction when the concentrated leakage was at the 15th or 28th vehicle for air flows up to and exceeding 60 SCFM. For the 150 car train it was found that the propagation of a minimum reduction was significantly delayed for a leakage of 5.0 psi/minute when the leak was at the 80th vehicle and for a leakage of 6.0 psi/minute when the concentrated leak was at the 42nd vehicle. This is shown in Figure 1. There was no significant effect in delaying the propagation of a minimum reduction when the concentrated leak was at the 28th vehicle up to a leakage condition of 21 psi/minute with an air flow of 57 SCFM.

Mr. Garold Thomas
June 28, 1988
Page 2

Additional analyses are now being conducted to determine the effect of a second application following an application and release. The question being addressed is how deep the second application must be in order for it to propagate through the train if the second application is made 5 minutes after the release. This question is being examined for 2 different leakage conditions in each of the 3 trains which have been previously studied. These conditions are, first, a condition representative of current requirements, namely, a maximum leakage of 5 psi/minute and a gradient of 15 psi, and second, conditions representative of proposed criteria where the limiting condition is 60 SCFM air flow or 15 psi gradient. The results from these analyses will be presented in next month's progress report.

Some delays have been encountered in the program as outlined in last month's progress report. As a result a 60 day no cost time extension has been requested.

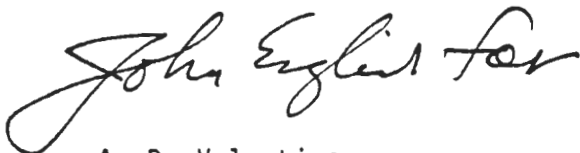
Project costs and labor hour expenditures are summarized in the attached table and figure.

Sincerely yours,



Milton R. Johnson
Senior Engineering Advisor
Railroad Technology Center

Approved:



A. R. Valentino
Director
Electromagnetics and Electronics

cc: M. Clifford Gannett, FRA
S. A. Bolling, FRA
W. Bolin, IITRI

MONTHLY AND CUMULATIVE LABOR HOURS AND COSTS
(LABOR AND OTHER, EXCLUDING FEE)
FOR CONTRACT DTFR53-82-C-00254, TASK ORDER NO. 4

<u>Current Period*</u>		<u>Cumulative</u>		<u>Percent of Present Funds Expended</u>
<u>Labor Hours</u>	<u>Costs</u>	<u>Labor Hours</u>	<u>Costs</u>	
57	\$5,331	250	\$23,965	47

*Current Period Covered April 23 to May 20, 1988

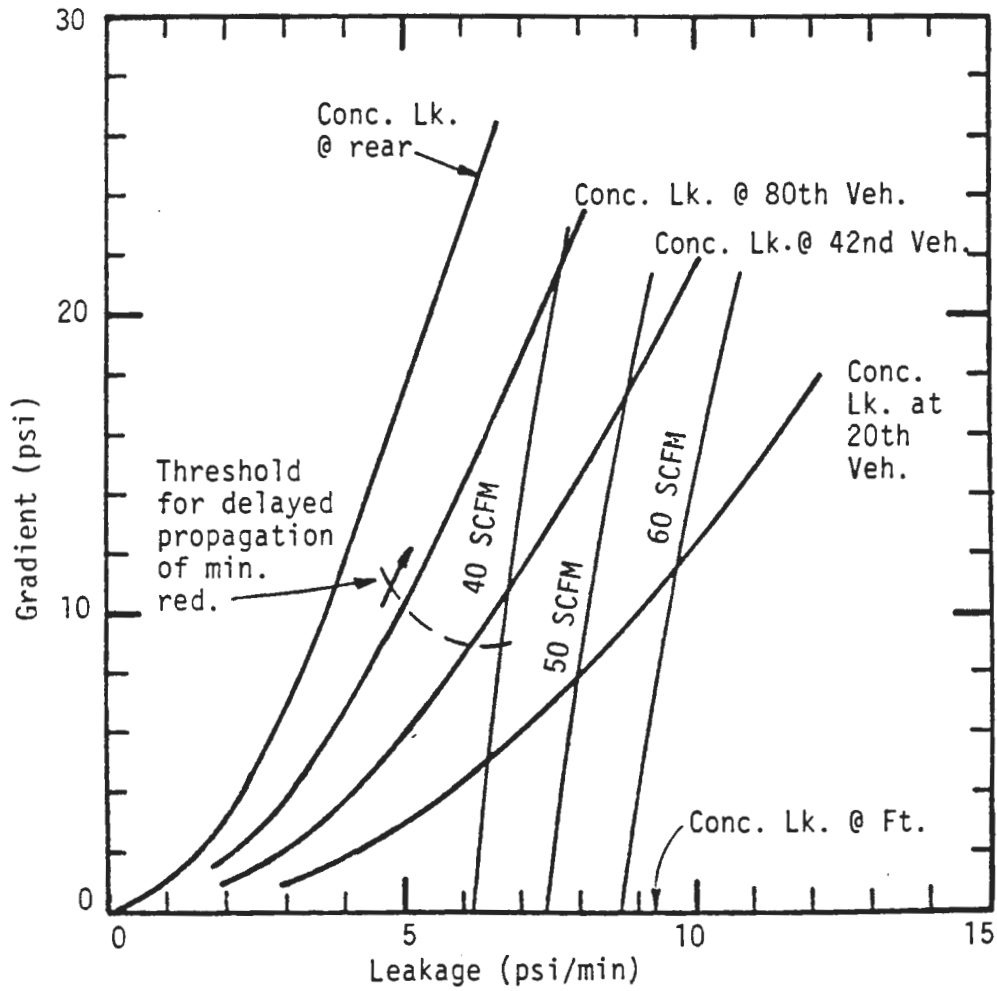


Fig. 1 Gradient Versus Leakage for Concentrated Leakage Cases on Train with 4 Locomotives and 150 Cars

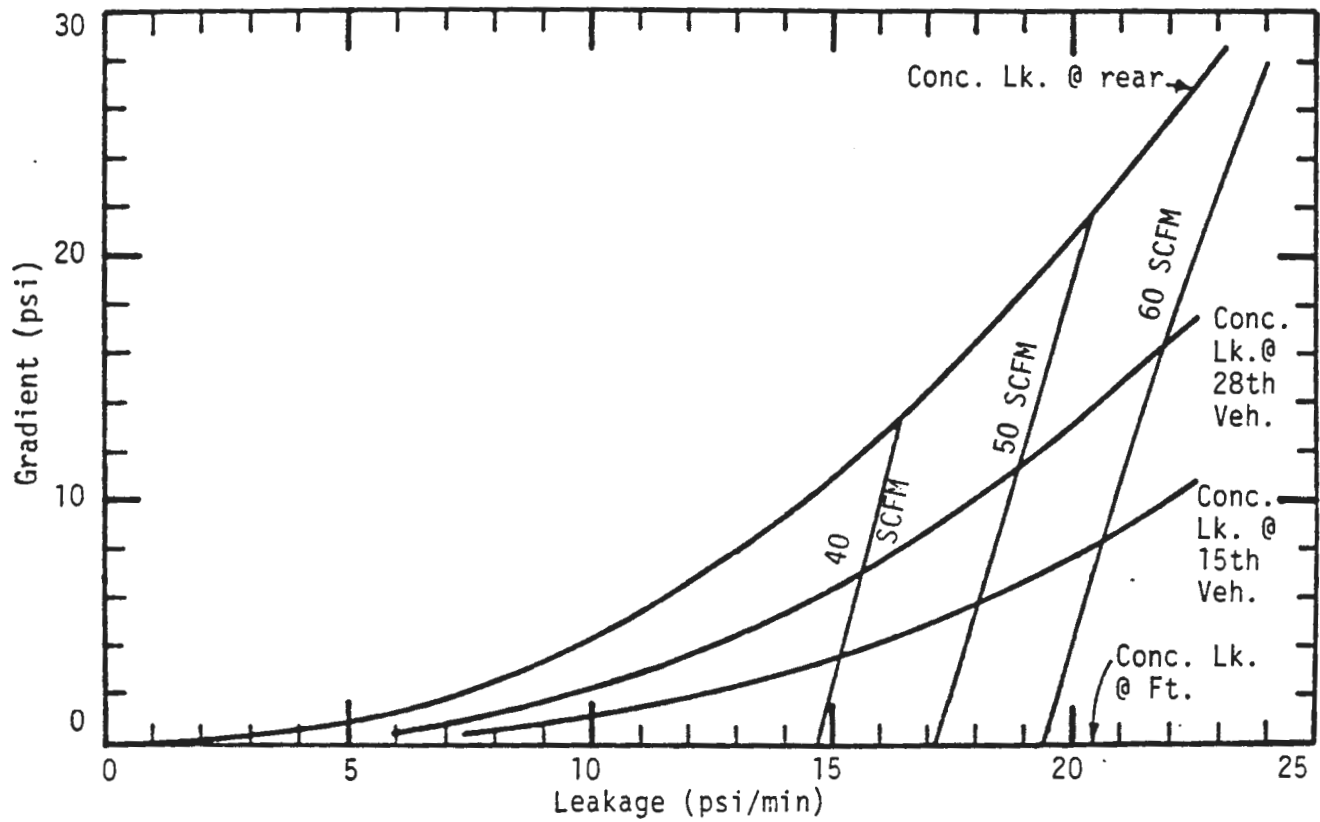
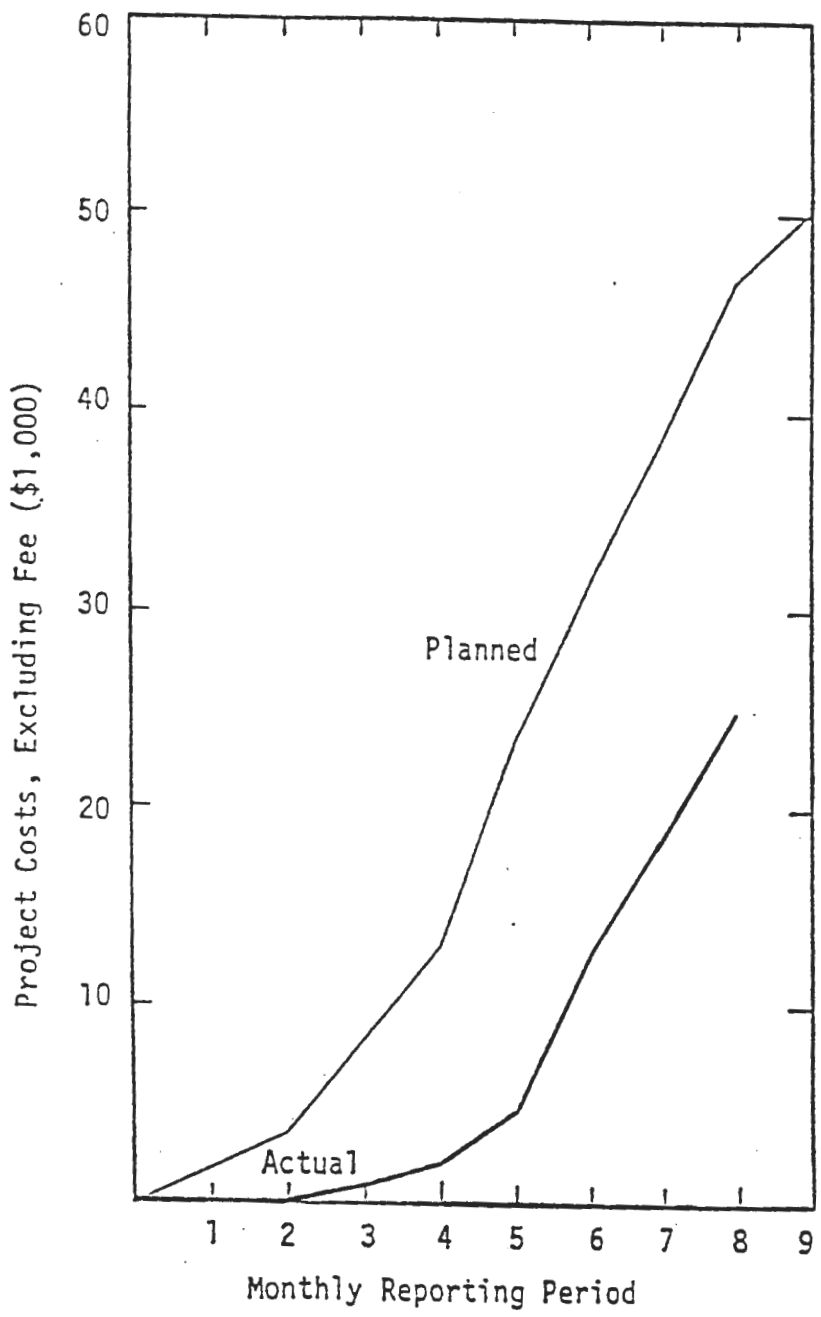


Fig. 2 Gradient Versus Leakage for Concentrated Leakage Cases on Train with 2 Locomotives and 50 Cars



CUMULATIVE PLANNED AND ACTUAL PROJECT EXPENDITURES,
 CONTRACT. DTFR53-82-C-00254, TASK ORDER NO. 4



IIT Research Institute
101 West 35 Street, Chicago, Illinois 60616
312/567-4000

August 1, 1988

Mr. Garold Thomas, RRS-32
Federal Railroad Administration
Office of Research and Development
400 Seventh Street, SW, Room 8305
Washington, DC 20590

Subject: Ninth Monthly Progress Report, May 21 to June 17, 1988,
Contract DTFR53-82-C-00254, Task Order No. 4, "Improved
Braking System, Simulation", IITRI Project E06593

Dear Mr. Thomas:

During the reporting period work was conducted on Sub-Tasks 1B, 1C, and 2B, of the subject task order. This report presents results of 65 analyses which were made to examine braking performance when a second application is made five minutes following a release from a prior service application. These analyses have been made to determine the effects on braking performance if one were to consider a terminal brake test criterion with constraints in the vicinity of a maximum 15 psi gradient and 60 SCFM air flow, instead of the present 5 psi/min leakage, 15 psi gradient criterion.

The analyses were conducted for 3 different trains with the following consists: 2 locomotives and 50 cars (total 52 vehicles), 3 locomotives and 100 cars (total 103 vehicles), and 4 locomotives and 150 cars (total 154 vehicles). The second application was made at a rate of 1 psi/sec pressure reduction in the brake pipe until the desired pressure was attained.

The results are summarized in Tables 1-3. The first part of each table shows the 4 cases that were considered for each of the trains. Two of the cases assume uniform leakage and two assume concentrated leakage at a car located near the middle of the train. The first and second cases represent the present criterion, namely, 5 psi/min leakage and 15 psi gradient. In all of the cases 5 psi/min leakage was the controlling factor. The third and fourth cases consider a revised criterion which would allow for up to 60 SCFM flow or up to a 15 psi gradient. In all of these cases the gradient was the limiting factor except for the short 52 vehicle train with uniform leakage where the air flow requirement governed.

The results of the analyses for the different trains are summarized in the lower part of each of the tables. The first analysis that was run for each case used a second application procedure where a brake pipe pressure reduction was first made to the point where air flow could be heard coming out of the brake pipe. This was assumed to be a 5 SCFM outflow. Then the reduction was intensified an additional 2 psi. This type of procedure is often used for making second applications where the brake pipe has not been fully recharged following an initial application. (See for example Ref 1, pages 166 and 167). Another procedure used by at least one railroad is to make the second reduction to at least the brake pipe pressure being indicated at the rear of the train. In all of the analyses, where the second reduction was 2 psi below the point where there was a 5 SCFM outflow, the brakes were applied throughout the train and did not bail off because of a false gradient condition in the brake pipe. Subsequent analyses were then made with lesser brake pipe reductions to determine the minimum brake pipe reduction pressure required to propagate and hold (no false gradient bail-off) the application throughout the train.

The specific results for the various trains are now discussed. Table 1 presents results for the 52 vehicle train. Note that Cases 3 and 4 would allow much larger leakages than Cases 1 and 2. The results of the analyses for Cases 1 and 2 show that the second application procedure based on air outflow was close to the minimum reduction required to propagate and hold the second reduction. The results for Cases 3 and 4 show that a large second application reduction results if the procedure based on air flow out of the brake pipe is followed. This is because of the large air flow into the brake pipe at the time the second application is made. The reductions are much larger than required to propagate and hold the brakes on the second application. The minimum reduction required to propagate and hold the brakes is in the vicinity of 10 to 11 psi which is slightly larger than the reductions required under the Case 1 and 2 conditions.

Table 2 presents results for the 103 vehicle train. Note that Cases 3 and 4, where the allowable leakage is based on air flow and gradient, would allow leakages almost double Cases 1 and 2. The results for Cases 1 and 2 show that the magnitude of the brake pipe reduction required to apply and hold the brakes is just slightly below the brake pipe reduction based on air outflow from the brake pipe. For Cases 3 and 4 the air outflow procedure results in much greater brake pipe reductions because of the large air flow into the pipe at the time of the second application. The analyses show that the depth of the second application required to apply and hold the brakes on all cars is about 15 psi for the case of the concentrated leakage, (Case 4), and 13 psi for the case of uniform leakage (Case 3).

Table 3 presents the results for the 154 vehicle train. For this train the air flow/gradient criterion (Cases 3 and 4) does not allow much greater leakage than the 5 psi/min leakage criterion (Cases 1 and 2) because the 15 psi gradient is developed at a much smaller leakage than in shorter trains. The results of the analyses for Cases 1 and 2 again show that the magnitude of the second application required to apply and hold the brakes is slightly below the application procedure based on air flow from the brake pipe. The magnitude of this reduction is slightly larger than for the 103 vehicle train. For Cases 3 and 4 a second application based on air flow out of the brake pipe again results in a larger reduction than necessary. The results are somewhat different for uniform leakage and concentrated leakage in the middle of the train. In the case of uniform leakage a brake pipe reduction of 14.5 psi is sufficient to apply and hold the brakes whereas a reduction of 23 psi would result following the air outflow procedure. In the case of the concentrated leakage a brake pipe reduction of 17.5 psi is required to apply and hold the brakes, whereas a brake pipe reduction of 18.9 psi would result from the air outflow procedure.

There are several conclusions that can be drawn from the results of these analyses. First, it is obvious that the air flow/gradient criterion allows higher leakages than the present criteria of a maximum 5.0 psi/min leakage. The allowable leakage is much larger on shorter trains than on longer trains. For example, the leakage which would be permitted on 154 vehicle trains is only 2.4 psi/min greater than 5.0 psi/min before a gradient of over 15 psi is developed. The second conclusion is that procedures for making second applications may need to be revised if the air flow/gradient criterion is adopted. For example, if the procedure for making a second reduction is based on listening for air flow out from the locomotive automatic brake valve, a much deeper second reduction results than is necessary. This is a result of the larger air flows which are associated with recharging the brake pipe and reservoirs on higher leakage trains. It would make train control more difficult. The analyses also show that the amount of reduction necessary to propagate and hold the brakes is greater than for first applications from fully charged trains, but not significantly so. The necessary reduction would range from 10-18 psi depending on the length of the train and the leakage conditions within the train (whether uniform or concentrated). The third conclusion is that the amount of pressure reduction needed to propagate and hold a second application is slightly greater for concentrated leakage than for uniform leakage. The increase required is more on longer trains than on shorter trains. For example, the results indicate that on the 154 vehicle train approximately 3 psi additional reduction is required. On the 52 vehicle train a 1 psi increase appears to be sufficient.

Other Project Information

The brake simulation program has been modified to allow for the simulation of an air brake repeater unit at any position in the train.

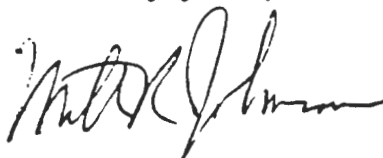
Mr. Garold Thomas
August 1, 1988
Page 4

The question of how ambient temperature affects the performance of the brake system will be the next major area of investigation.

Some delays have been encountered in the program as outlined in previous progress reports. As a result a 60 day no cost time extension has been requested.

Project costs and labor hour expenditures are summarized in the attached table and figure.

Sincerely yours,



Milton R. Johnson
Senior Engineering Advisor
Railroad Technology Center

Approved:



A. R. Valentino
Director
Electromagnetics and Electronics

cc: M. Clifford Gannett, FRA
S. A. Bolling, FRA
W. Bolin, IITRI

TABLE 1: RESULTS FROM 2ND APPLICATION ANALYSES OF 52 CAR TRAIN

Train Consist: 2 Locomotives and 50 Cars

Brake Application Sequence: 7 psi brake pipe reduction held for 30 seconds, then increased to 20 psi reduction which is held for 60 additional seconds and followed by a release. Second brake pipe reduction made 5 minutes after initiation of release.

Case	Leakage Condition and Vehicle	Leakage (psi/min)	Initial Conditions		Conditions at Second Application	
			Flow (SCFM)	Gradient (psi)	Flow (SCFM)	Gradient (psi)
1	Uniform	5.0	11.1	0.3	17.9	0.8
2	Concentrated at Veh. 28	5.0	11.0	0.5	18.2	1.3
3	Uniform	20.4	60.6	9.7	67.7	12.9
4	Concentrated at Veh. 28	21.1	57.8	15.5	63.2	18.4

Analysis No.	2nd Application Brake Pipe Reduction (psi)	Do All Brakes Come On	Application Time (sec)	Vehicles with Brakes on 4 minutes after 2nd Application
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Case 1 Results: Uniform 5.0 psi/min leakage

1	7.2*	Yes	8	All
2	7.0	Yes	8	All
3	6.5	Yes	8	1-20
4	6.0	Yes		None

Case 2 Results: Concentrated Leakage at Vehicle 28, 5.0 psi/min

1	7.7*	Yes	8	All
2	7.0	Yes	8	All
3	6.5	Yes	8	1-13
4	6.0	Yes	8	None
5	5.5	Yes	8	None

Case 3 Results: Uniform 20.4 psi/min leakage

1	28.9*	Yes	12	All
2	14.0	Yes	12	All
3	10.0	Yes	14	All
4	9.0	Yes	14	1-5
5	8.0	Yes	14	1-5

Case 4 Results: Concentrated Leakage at Vehicle 28, 21.1 psi/min

1	33.6*	All	18	All
2	18.0	All	18	All
3	14.0	All	18	All
4	12.0	All	18	All
5	11.0	All	18	All
6	10.0	All	20	1-18, 28-32

* Brake Pipe Reduction criteria is 2.0 psi below reduction pressure which gives outflow of 5 SCFM at locomotive automatic brake valve.

TABLE 3: RESULTS FROM 2ND APPLICATION ANALYSES OF 154 CAR TRAIN

Train Consist: 4 Locomotives and 150 Cars

Brake Application Sequence: 7 psi brake pipe reduction held for 30 seconds, then increased to 20 psi reduction which is held for 60 additional seconds and followed by a release. Second brake pipe reduction made 5 minutes after initiation of release.

Case	Leakage Condition and Vehicle	Leakage (psi/min)	Initial Conditions		Conditions at Second Application	
			Flow (SCFM)	Gradient (psi)	Flow (SCFM)	Gradient (psi)
1	Uniform	5.0	30.2	7.1	40.3	13.2
2	Concentrated at Veh. 80	5.0	28.5	10.3	37.0	15.6
3	Uniform	7.4	43.7	15.2	50.5	20.2
4	Concentrated at Veh. 80	6.2	34.1	15.2	41.6	20.0

Analysis No.	2nd Application Brake Pipe Reduction (psi)	Do All Brakes Come On	Application Time (sec)	Vehicles with Brakes on 4 minutes after 2nd Application
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Case 1 Results: Uniform 5.0 psi/min leakage

1	17.2*	Yes	22	All
2	16.0	Yes	22	All
3	14.0	Yes	22	All
4	12.0	Yes	22	All
5	11.0	Yes	22	1-14
6	10.0	Yes	22	1-12

Case 2 Results: Concentrated Leakage at Vehicle 80, 5.0 psi/min

1	16.5*	Yes	38	All
2	15.0	Yes	48	All
3	14.0	No	--	1-84
4	12.0	No	--	1-76
5	10.0	No	--	1-68
6	7.0	No	--	1-8

Case 3 Results: Uniform 7.4 psi/min leakage

1	23.1*	Yes	32	All
2	20.0	Yes	32	All
3	16.0	Yes	38	All
4	14.5	Yes	40	All
5	13.0	No	--	1-110
6	12.0	No	--	1-109

Case 4 Results: Concentrated Leakage at Vehicle 80, 6.2 psi/min

1	18.9*	Yes	42	All
2	17.5	Yes	58	All
3	17.0	No	--	1-104
4	15.0	No	--	1-78

*Brake Pipe Reduction criteria is 2.0 psi below reduction pressure which gives outflow of 5 SCFM at locomotive automatic brake valve.