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Investigation of Freight Car Air Brake System Performance in Cold Temperatures

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Abstract

This paper presents results from controlled laboratory testing of the operational performance of 23 service worn and 21 refurbished freight car air brake systems at temperatures ranging from +50 °F to -40 °F (+10°C to -40°C). The 44 systems were tested using service and emergency brake applications from brake pipe pressures of 75 psi and 90 psi. Forces after 10 and 90 minutes are compared for emergency brake applications. Air flow demand is also compared. Findings are that service worn brake systems require up to 5 times more air at -40°F when compared to a new brake system at the same temperatures and that service worn brake systems demonstrate degraded performance at colder temperatures dependent on time since previous refurbishment.

Quantifying the performance of freight train air brakes under controlled and repeatable conditions requires the control of the external temperature of the air brake components as installed and operated on a freight car, and a controlled method of brake applications. To allow for such testing in controlled conditions, the National Research Council (NRC) Canada has built a Cold Weather Air Brake (CWAB) research facility to study freight car air brake systems under temperature-controlled conditions. The main goal of this research is to better understand the performance and operations of freight train air brakes under controlled and repeatable cold weather conditions.

Method

The CWAB lab is a facility built by NRC, shown in Figure 1, to allow for the testing of multiple freight car air brake systems in climate-controlled conditions in a compact, space saving arrangement. The lab is currently able to operate up to 14 complete working freight car air brake systems, representing approximately 600 feet of train length. The air brake systems are installed in a compact arrangement where each test rack has piping installed which equates to 40 feet of standard air brake line, with cars connected using standard end-of-car hoses and gladhands. The brake components which can be installed in the facility for testing are the car control valve (brake pipe bracket, emergency control valve, and service control valve); body-mounted (foundation) brake cylinder; empty/load valve; and retaining valve. Each brake system is instrumented to collect brake pipe pressure (BPP), auxiliary reservoir pressure (ARP), emergency reservoir pressure (ERP), brake cylinder pressure (BCP), brake force (BF), and brake piston displacement. The facility is able to perform standard braking operations as would occur in a train in service using an electronically controlled pneumatic air delivery system that allows for repeatable brake applications. The brake system supply air is filtered, dried and cooled to the ambient test temperature before entering the brake systems.

Air brake systems were tested in 6 separate testing rounds at the NRC facility between November 2021 and February 2023. The service and emergency portions and brake cylinders were provided by partner short line railways and from NRC's stock of air brake components. The ages of the air brake components were estimated from the dates of last service found on the service and emergency portions, and where these dates could not be found NRC estimated the ages based on discussion with the provider. The air brake components were installed in the brake system test modules and tested with an AAR approved automated single car test device (ASCTD).

The systems were tested in the NRC Climatic Facility, seen in Figure 2, for a minimum of 7 hours each day at 5 temperatures ranging from an above freezing reference of between 50°F (10°C) and 32°F (0°C), 14°F (-10°C), -4°F (-20°C), -22°F (-30°C) and -40°F (-40°C).

- The brake applications tested and discussed here include:
- Minimum service brake application of 6 psi from fully charged.
 - Full service brake application of 26 psi from fully charged.
 - Emergency brake application, held for 10 minutes.
 - Emergency brake application from fully charged state, held for 90 minutes.

An electronic air delivery system was used to make consistent and repeatable air brake applications at each test temperature. Test data was collected on a continuous basis for the duration of each test session at a sample rate of 100 Hz. At each tested temperature, brake applications were conducted at 2 brake pipe pressures (BPP). The BPP was 90 psi (representing a front of train brake pipe pressure) for one test day and 75 psi (representing a rear of train brake pipe pressure) for the second day of testing at each test temperature. After completing the testing the service worn brake systems were refurbished and tested under the same conditions.

Results

Results for tests on 44 brake systems are presented: 23 service worn systems and 21 refurbished systems. Each brake system was subjected to a minimum of 12 brake applications each day at 2 BPP (75 and 90 psi) and 5 test temperatures, resulting in data collected from over 5,280 controlled brake applications. The results are presented as the measured brake piston force, measured at the active end of the brake piston rod. Note that this force is not equal to the brake shoe force as would be seen on a freight car at the wheel as the applied brake shoe force is dependent on the type and condition of the brake rigging installed.

Service Braking: Minimum and Full Service Applications

Figure 3 shows the brake force after 10 minutes following a minimum (6 psi) service brake application from 90 psi brake pipe pressure (BPP), with the results for the service worn systems shown in the upper plot and the refurbished brake systems in the lower plot. The new and service worn systems both produce forces which diminish with lowered temperatures, but the service worn systems display a greater variance in the force. New systems perform consistently to temperatures of -4°F (-20°C) and lose approximately 20% average braking force at -40°F (-40°C). Service worn systems have lost on average approximately 30% average braking force, but are over 60% lower than the force of a new system at 32°F (0°C).

Figure 4 shows the brake force 10 minutes after a full service (26 psi) brake application was made from 90 psi BPP for the service worn (upper plot) and refurbished systems (lower plot). The larger brake application more clearly shows the difference in performance of the new systems compared to the service worn systems. New systems perform consistently to temperatures of -4°F (-20°C) and lose approximately 20% average braking force at -40°F (-40°C). At the same temperature service worn systems have lost on average approximately 30% braking force, but the force is 40% lower than the new system force at 32°F (0°C) and with considerably more scatter, with several service worn systems losing all braking force after the 10-minute holding time.



Figure 1: NRC air brake research mobile test facility



Figure 2: NRC Climatic Facility, Ottawa, Ontario, Canada
<https://nrc.canada.ca/en/research-development/nrc-facilities/climatic-testing-research-facility>

Emergency Braking: 10 minutes after application

During an emergency brake application, the train may take several minutes to completely stop. The available braking force in this time period is captured by the test data for the brake force 10 minutes following the initial emergency brake application.

Figure 5 shows the emergency brake force after 10 minutes from 90 psi BPP for both the service worn (upper plot) and refurbished systems (lower plot). New systems perform consistently to temperatures of -4°F (-20°C) and lose approximately 20% average braking force at -40°F (-40°C). Service worn systems have lost on average approximately 40% braking force, but are almost 50% lower than the new system force at 32°F (0°C) and with considerably more scatter, with several systems losing all braking force after the 10 minute holding time.

Emergency Braking: 90 minutes after application

Following an emergency brake application, the crew of the train must perform operations to secure the train [7] and may need to investigate the cause of the emergency brake event. They must also perform operations to recover the train from the emergency brake application, which may include the application of hand brakes to sufficient freight cars, and/or the application of the retainer valves to be set to "high pressure" (HP). These operations require time, and available braking force in this time period is captured by the test data for the emergency brake force 90 minutes following the initial emergency brake application.

Figure 6 shows the emergency brake force after 90 minutes from 90 psi brake pipe pressure (BPP) for both the service worn (upper plot) and refurbished systems (lower plot). The results show that service worn systems decline in brake holding force of over 60% at -40°F (-40°C) and are 70% lower than the new system force at 32°F (0°C). New or refurbished systems on average have lost approximately 25% of the braking force at -40°F (-40°C) after 90 minutes. Comparison with the results seen in Figures 7 and 8, which show the emergency brake force after 10 minutes of holding, shows that the service worn systems lose holding brake force more rapidly, and the loss in force begins following the brake application.

Air Flow

Figure 7 shows the average air flow requirements for service worn (SW) and refurbished (RF) brake systems at the fully charged state. The difference in flow requirement for 75 and 90 psi BPP is also shown. Flow data was averaged from 6 systems where the service worn valves were all of the ABD type, and the refurbished valves were 6 ABD emergency portions, 5 ABD and 1 ABDX type service portion. The air flow shown includes the loss of air through the gladhand gaskets, however as all tests are performed with new brake hoses and gladhand gaskets the differences in airflow shown can be attributed solely to increase in air leakage through the brake systems.

The implication of the increased air flow requirements is related to the ability of the locomotives to charge and maintain brake pipe pressure in a train. To pass the Number 1 brake test prior to leaving a yard the train must have its brake system charged to a state where the maximum permitted air flow at the locomotive is 60 standard cubic feet per minute (SCFM) or less. For the air flows shown in Figure 1, at -4°F (-20°C) this air flow limit will be reached with approximately 100 service worn cars, whereas at -40°F (-40°C) this air flow limit will be reached with approximately 30 service worn cars. An implication of this is that a train which passed the 60 SCFM air flow test at warmer temperatures will likely fail the test if it travels into a location with significantly colder environmental temperatures, such as high elevation or mountainous territories.

Effect of Time Since Refurbishment on Performance

Figure 8 shows the emergency brake force after 90 minutes by time in years since refurbishment, where the time since refurbishment or manufacture of service worn systems was greater than 15 years or less than 15 years, and new/refurbished brake systems. Results for three temperatures are shown. The results show that new and refurbished systems provide as expected brake performance even at colder temperatures, and that brake system performance does progressively decline with age. The range of performance decline is evident at -4°F (-20°C), where systems up to 15 years old have lost on average 50% emergency braking force after 90 minutes at -40°F (-40°C), and systems older than 15 years have lost on average over 80% of brake force. Note that all systems shown in these results passed the single car air brake test at temperatures of approximately 50°F (10°C) or warmer.

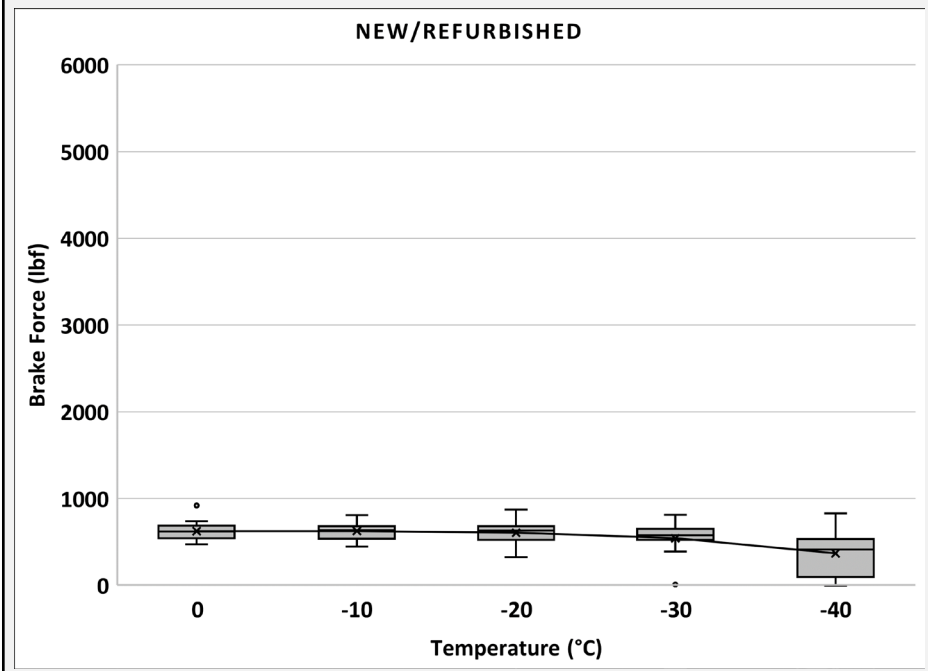
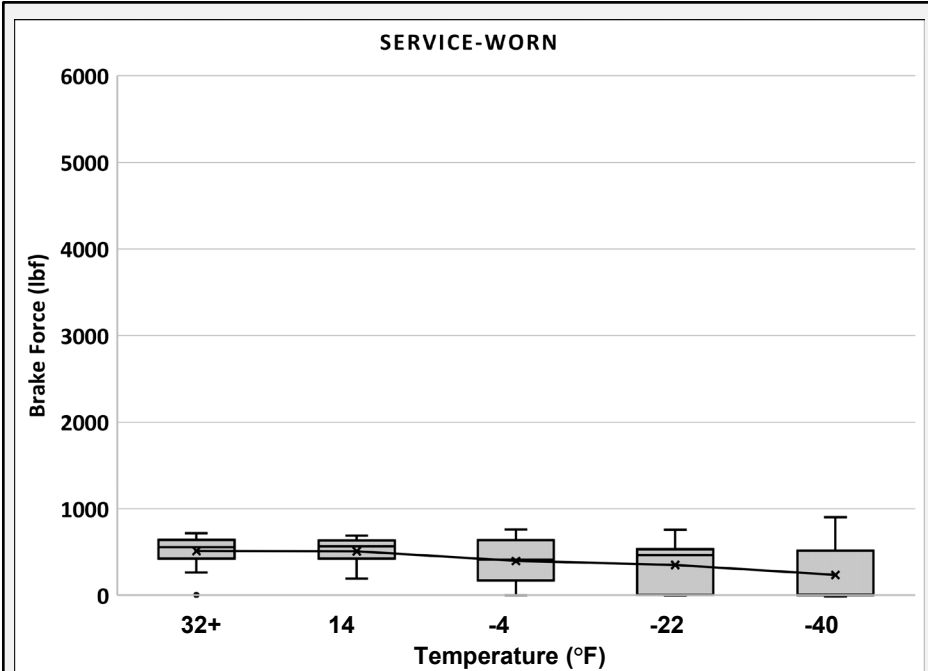


Figure 3: Minimum (6 psi) Service Brake Force after 10 minutes (90 psi BPP):
Upper: Service Worn Systems
Lower: Refurbished Systems

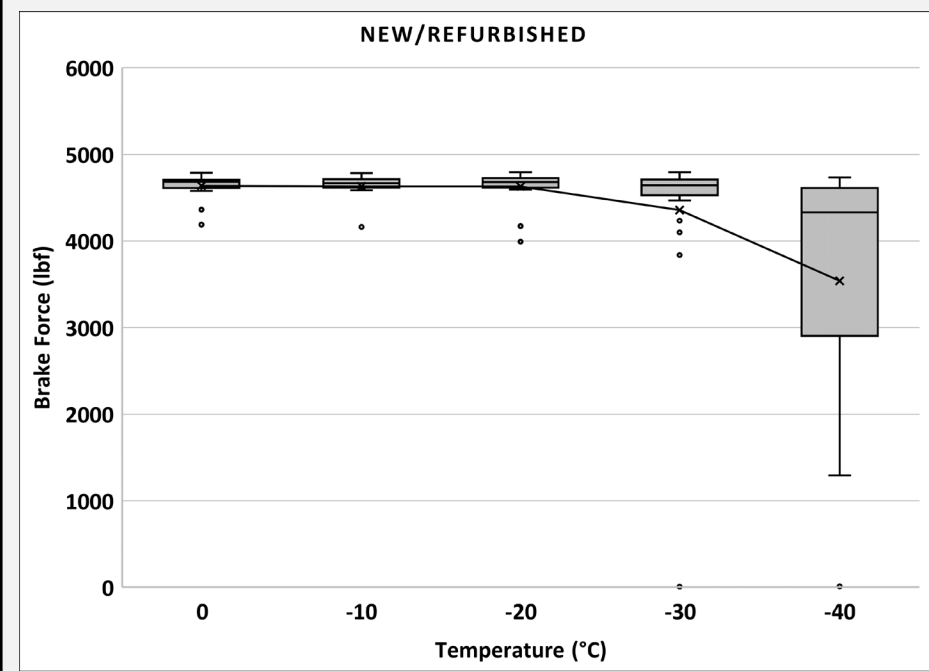
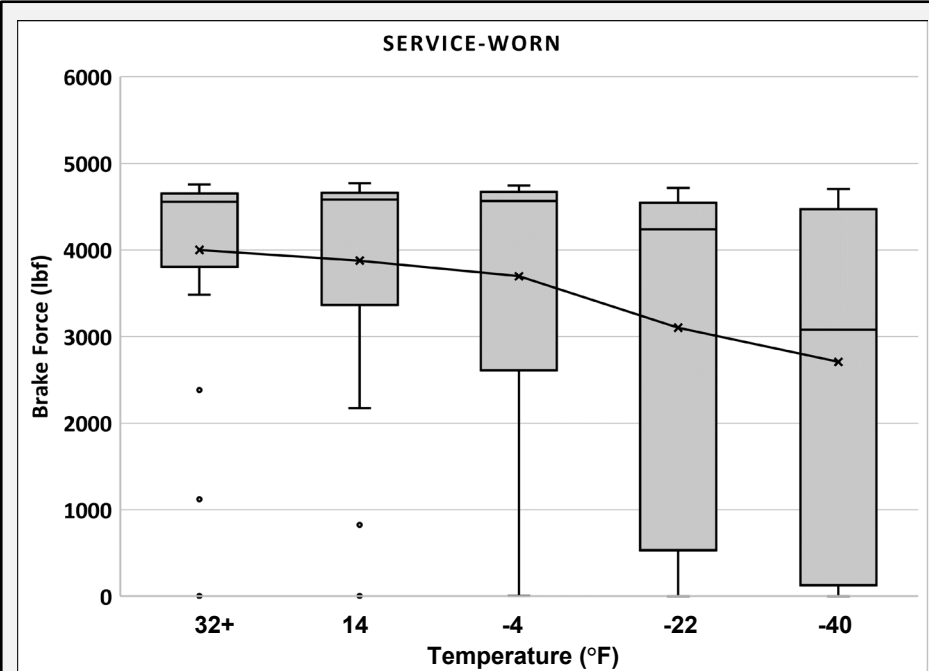


Figure 4: Full-Service Brake Force after 10 minutes (90 psi BPP):
Upper: Service Worn Systems
Lower: Refurbished Systems

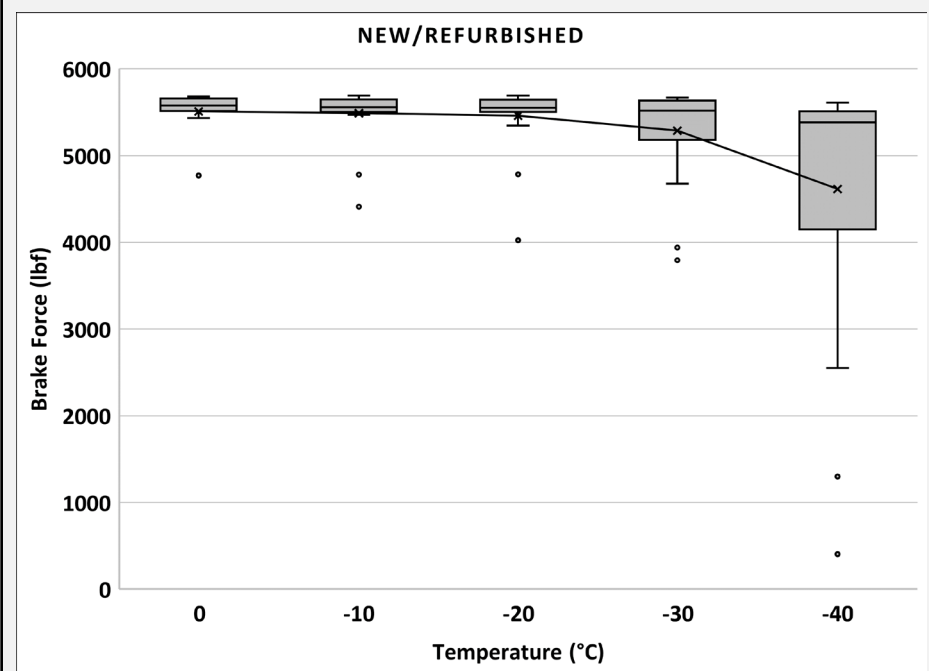
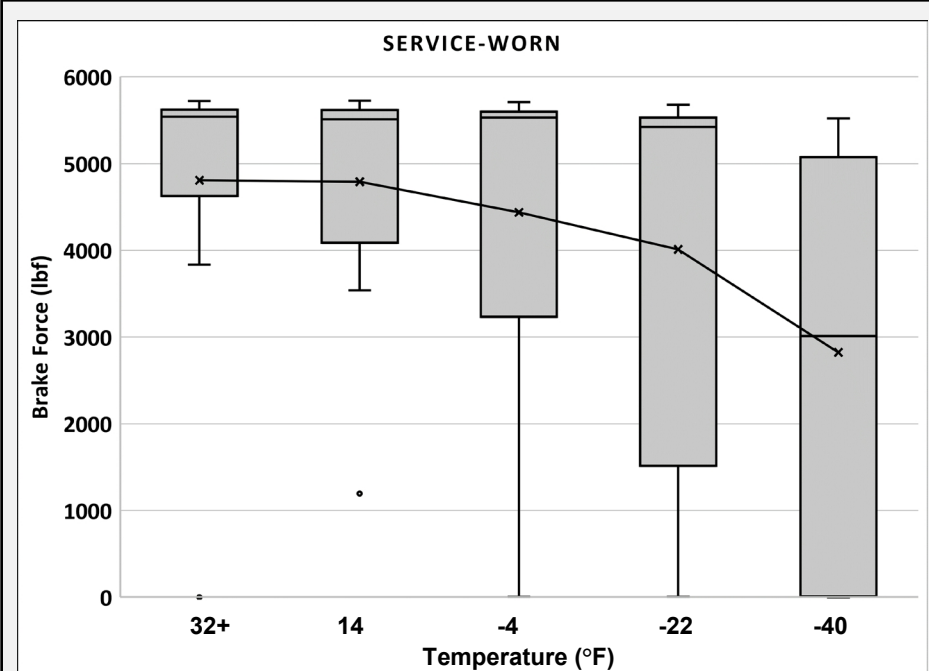


Figure 5: Emergency Brake Force after 10 minutes (90 psi BPP):
Upper: Service Worn Systems
Lower: Refurbished Systems

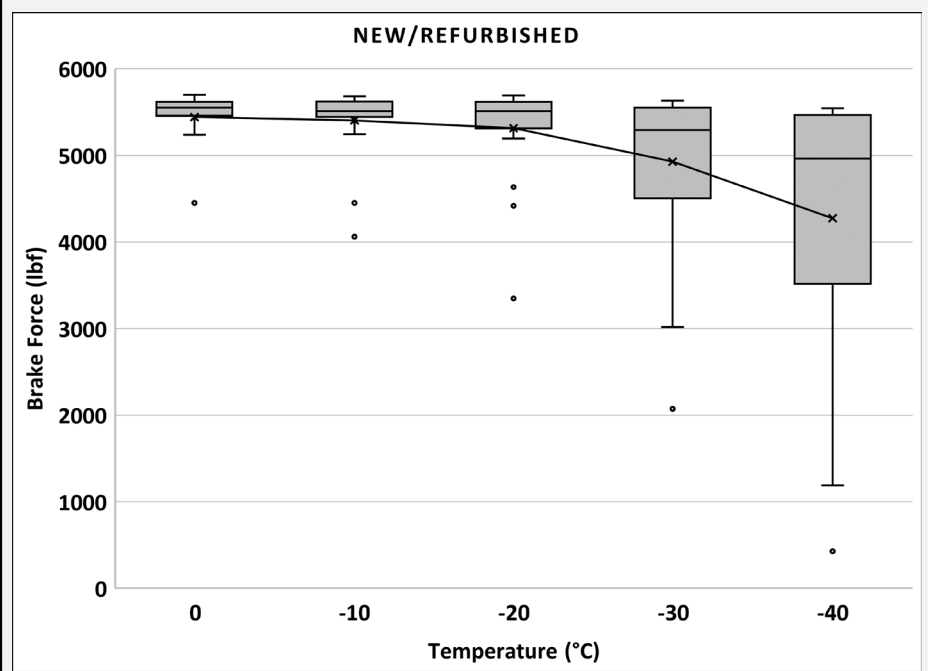
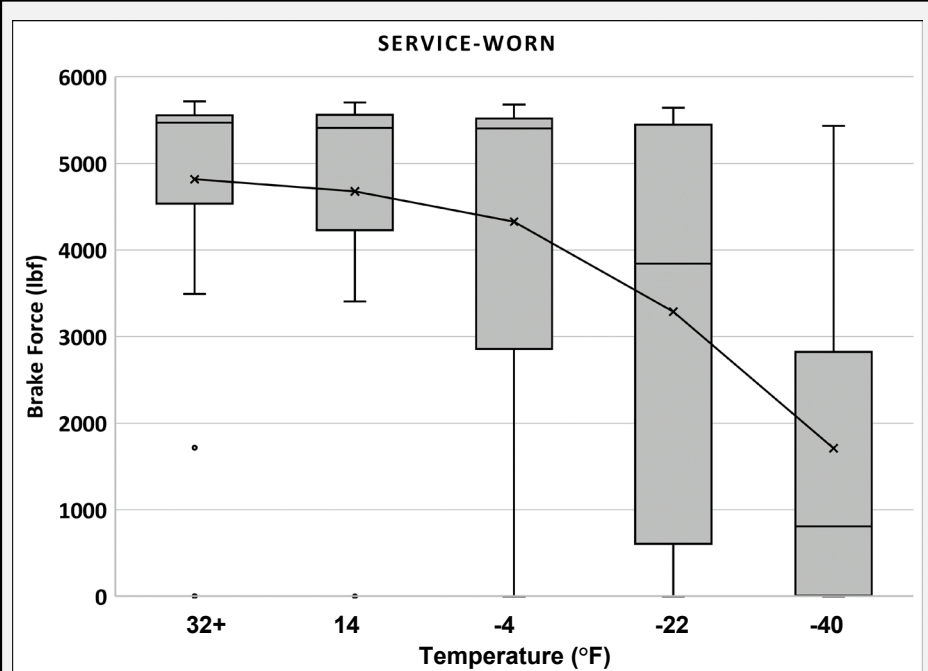


Figure 6: Emergency Brake Force after 90 minutes (90 psi BPP):
Upper: Service Worn Systems
Lower: Refurbished Systems

Observed Failure Modes

Although loss of brake force was the primary focus of this study in colder temperatures, the observed failures of the service worn brake systems at colder temperatures did not always occur in this manner. Other failure modes observed during testing include:

1. No response to brake pipe pressure changes; failure to pressurize the brake cylinder.
2. Initial pressurization of brake cylinder followed by immediate depressurization (release).
3. Proper brake cylinder pressurization soon followed by premature release.
4. Proper brake cylinder pressurization, followed by slow loss of brake cylinder pressure.
5. Proper brake cylinder pressurization, followed by continued pressurization of the brake cylinder (over braking).
6. Loss of emergency reservoir pressure during service brake applications.
7. Complete loss of system response to brake pipe pressure commands, with air from the brake pipe pressurizing the reservoirs and brake cylinder at all times.

These observed failure modes were typically not consistent in their occurrence. An exception was mode 6 listed above – once a system reached a temperature where the emergency reservoir pressure was dropping with the auxiliary reservoir pressure during service brake applications, the system continued to do so at colder temperatures. This is a flaw in that the emergency reservoir air pressure is to be reserved for when an emergency brake application is demanded, and a loss of emergency reservoir air pressure during service brake applications is not standard.

For all the systems observed to fail in the modes listed above, these failure modes no longer occurred when the systems were operated again at warmer temperatures, proving that these are low temperature induced failures and not permanent failures of the systems which occurred during testing. New systems did not display any of these failure modes during testing.

Discussion

The air brake systems tested and reported on in this paper were removed from working in-service freight cars owned by 2 short line railways in Canada. The complete systems were installed into the NRC's CWAB facility. Prior to testing at a range of temperatures, the brake systems were tested with an AAR approved ASCTD and found to pass. Therefore, all the results presented here at a range of temperatures are from freight car air brake systems that would be considered to be typical of in-service systems and would not be considered out of specification for operation. The service worn systems varied in time from refurbishment of 3 years to greater than 20.

The results show that service worn brake systems showed a consistent loss of brake force at colder temperatures, and for the emergency brake forces where data was collected for considerable lengths of time, showed a decrease in holding force with time. These lower brake forces have several relevant consequences for freight train operations:

1. Stopping distances in colder temperatures will be longer, as brake force will be lower than it would be under comparable warm-weather conditions.
2. Lower available brake force when using the automatic (train) air brake system may require increased use of the locomotive dynamic brake to control train speeds.
3. An emergency brake event will take longer for the train to stop compared to the same stop in warmer conditions.
4. Once stopped the crew will have less time compared to similar conditions at higher temperatures to set hand brakes to recover the train from the emergency brake situation before braking force is diminished.

With the data collected by the NRC to date with 23 service worn systems a difference in performance with system age is seen, with systems older than 15 years showing an 80% reduction in emergency brake holding time at -40°F (-40°C) after 90 minutes compared to new brake systems at the same temperature. As stated above, the time window to secure a train following an emergency brake application in winter compared with summer is shortened considerably with brake systems of greater age. The loss of brake force may also have implications regarding the effective use of positive train control (PTC) systems, where estimated or modelled stopping distances are used as part of the PTC system [8].

Conclusions

From the over 5000 brake applications recorded, the following are conclusions which can be made based on the results of testing at NRC concerning freight car air brake systems operating at cold temperatures:

- New and refurbished systems do not lose performance to the same extent as service worn systems.
- System performance at low temperatures appears to degrade with age since refurbishment.
- The time that sufficient emergency brake force is held to secure a train decreases with decreasing temperatures – consideration should be made for the time required to apply sufficient hand brakes on grades following emergency brake applications.
- Reduced brake forces at lower temperatures will affect stopping times during service braking, as well as holding times following an emergency brake application.

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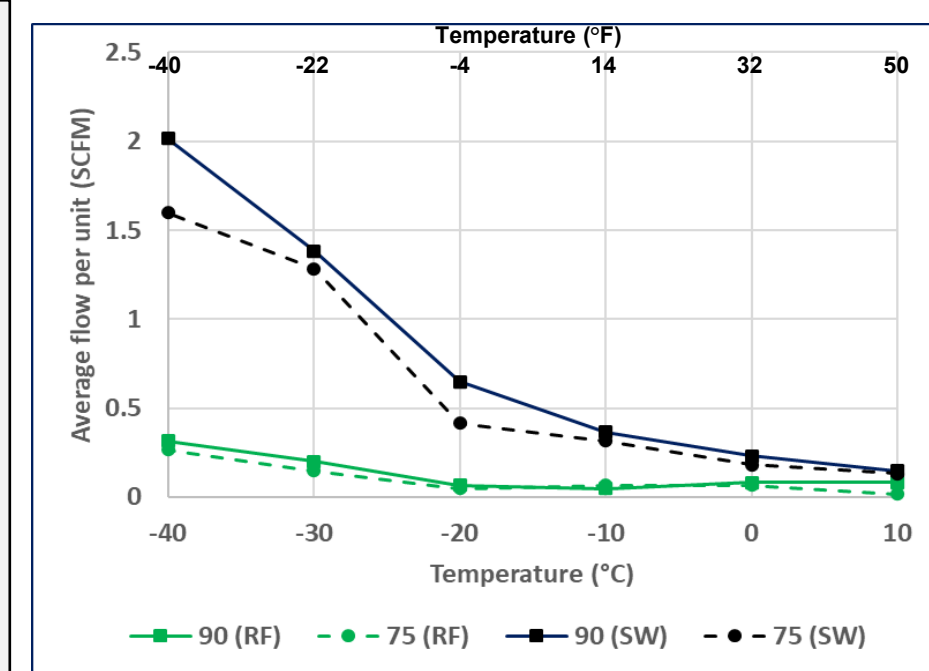


Figure 7: Airflow requirements for Service Worn (SW) and refurbished (RF) brake systems

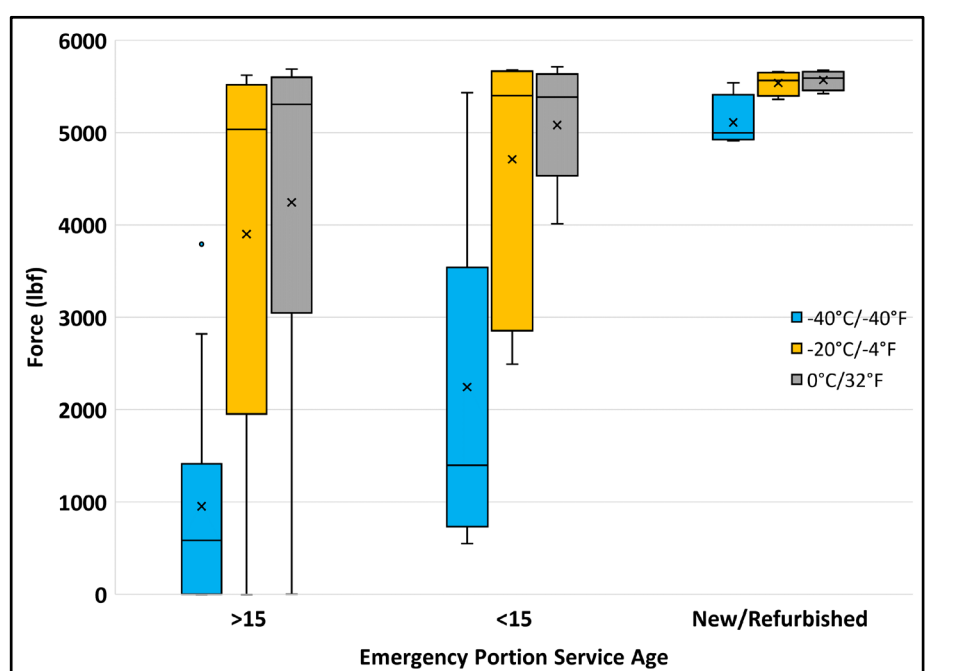


Figure 8: Emergency Brake Force after 90 minutes for emergency control portion service age

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