U.S. Department of Transportation

Federal Railroad Administration

Evaluation of Concepts for Locomotive Crew Egress

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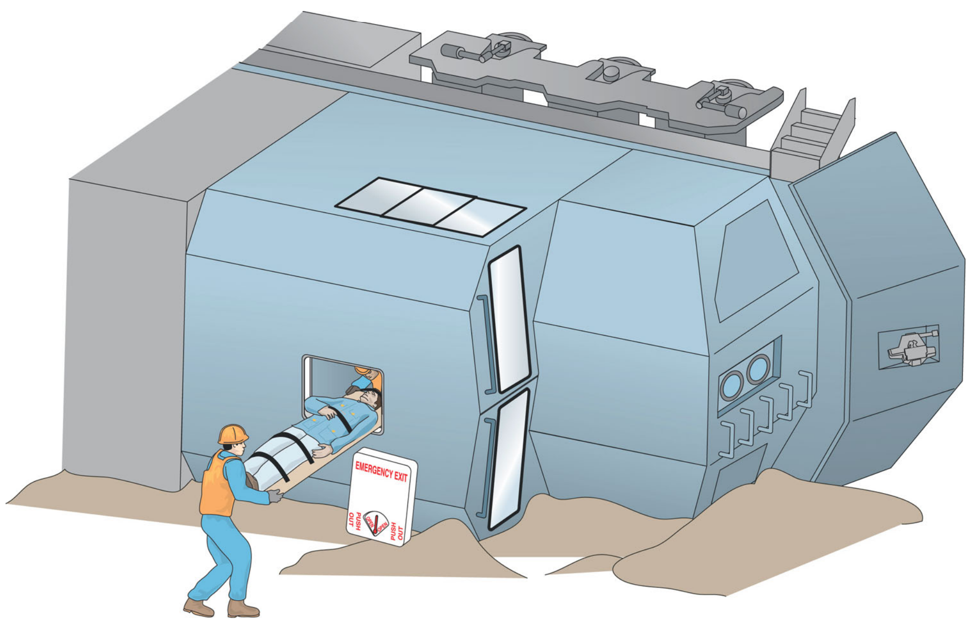

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16. Abstract

This report presents the results of the first phase of a program to develop innovative concepts for a locomotive crew egress system. The program targeted rollover derailment accidents, where the options for crew egress are most limited.

In Phase I of this program, Foster-Miller conceptualized an integrated roof mounted escape hatch system for use in a road locomotive cab. This system provides a centerline mounted escape hatch, along with a series of deployable hand/footholds to aid in climbing. The design approach was presented to railroad crews who provided feedback as a basis for design revisions. In general, the escape hatch concept was viewed as a significant improvement in locomotive egress equipment. Preliminary evaluation indicates that the hatch can be integrated into new locomotive designs with minimal cost impact.

The utility of the overall concept was evaluated using untrained personnel in a full-scale mockup of a toppled locomotive. With a minimum of instruction, test subjects were able to actuate the hatch and escape the cab in 30 s or less. Future research will involve refining the hatch design so that it is manufacturable. Secondary egress options identified in Phase I will also be given further attention in the subsequent research.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	kilometers squared	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	meters cubed	35.71	cubic feet	ft^3
m^3	meters cubed	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units

536-Conversion Factors

(Revised January 1992)

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Abbreviations

BLE	Brotherhood of Locomotive Engineers
CFR	Code of Federal Regulations
FMVSS	Federal Motor Vehicle Safety Standards
MBTA	Massachusetts Bay Transit Authority
OSHA	Occupational Safety and Health Administration
UTU	United Transportation Union

Acknowledgments

This report presents the results of the first phase of a program to develop innovative designs for a locomotive crew egress system. The Federal Railroad Administration (FRA) Office of Research and Development funded this work under Contract DTFR53-01-D-00029. Mr. John Punwani, the FRA COTR, provided guidance and encouragement to the study team.

In addition to Mr. Punwani, thanks are due to numerous individuals and organizations that provided information and feedback on our egress concepts. The locomotive window and door manufacturers, and the hatch manufacturers willingly provided information about their products. Assistance on manufacturing issues was rendered by a consultant to the program, Mr. Allen Bieber. Capt. Stephen Persson from the Cambridge, MA Fire Department gave the study team insights on the job of the emergency responder and provided feedback on candidate egress system designs. American Medical Response demonstrated their emergency rescue tools and allowed us to measure and photograph their rescue equipment. (AMR is responsible for municipal ambulance service in several communities in west suburban Boston.)

Thanks are extended to Mr. Ed Farr of CSX in Allston, MA and Mr. Paul Cottam of Amtrak's South Boston Repair Facility, who provided access to operational locomotives for close-up study.

The focus group research would not have been possible without the generous cooperation of numerous officers from the Brotherhood of Locomotive Engineers and the United Transportation Union. The authors wish to thank all of the focus group participants who provided valuable feedback on the candidate egress equipment designs. Their feedback was incorporated into the final designs described in this report.

Thanks are also extended to Mr. Fran Aho and Ms. Darlene Stokes for serving as test subjects for the initial usability evaluation. Finally, special thanks are due to Mr. John Flynn, Mr. Anthony DeMeo and Mr. Robert Clark of Foster-Miller for their time and effort in the construction of the locomotive cab mockup.

Executive Summary

This report presents the results of the first phase of a program to develop innovative concepts for a locomotive crew egress system. Current egress equipment, including cab doors and windows, is adequate for most accidents in which the locomotive remains upright. However, the equipment has serious limitations in rollover derailment accidents. In these scenarios, viable egress options for crewmembers are greatly reduced, particularly for injured persons. These limitations also hamper rescue workers who respond to these accidents by reducing the access to the cab and the injured crew members inside.

The Phase I effort defined and developed three concepts to improve the crew egress from a rollover accident. The initial set of concepts included hatches, removable doors, side access panels, and removable glazing systems. Ease of use, cost, manufacturing considerations, and other practical issues associated with integrating these concepts into new locomotives were weighed. From the overall concept list, three were chosen for further development:

1) *Hand/footholds to aid climbing inside a toppled locomotive.* Anecdotal evidence indicated that in several rollover accidents, uninjured crewmembers escaped from the cab by climbing up the consoles and seats to reach the side window on the high side of the locomotive. To aid crewmembers in climbing out of a toppled locomotive, a hand/foothold system on the cab ceiling was proposed. If the locomotive were toppled, the hand/foothold could be extended to provide climbing points to reach the high side of the locomotive. Notionally, the hand/footholds would be recessed into the cab ceiling in normal operation, and would be deployed by the crew in the event of an emergency.

2) *Roof-mounted escape hatch*. Many transportation vehicles, in particular transit and school buses, have a roof hatch as an emergency exit. A roof-mounted hatch could provide a means of crew egress and would be of particular value in the event of a toppled locomotive. The clear opening of the hatch must be of adequate size to allow easy egress by crewmembers. The hatch must also be sized such that rescue personnel in heavy gear could access the cab, as well as remove an injured crewmember on a body board. Opening the hatch must be accomplished by a single movement that requires little force, and be functional even if the cab is slightly deformed. With regard to exterior access, the hatch should provide easy operation for rescue personnel while not encouraging unauthorized use.

3) Externally removable windshield. To facilitate access for rescue workers, a removable windshield panel was proposed. The approach utilized a cutting cable to sever the windshield gasket, providing easier access from outside the cab. The commonality of windshield gasket design allows this concept to be adapted to various windshield configurations. The changes required to make the windshield removable by the crew from inside the cab, however, would be too costly to implement. This is driven by the structural requirements of the windshield, as it is designed to withstand the high loads associated with frontal impact.

Review of Concepts

As the potential users of the egress equipment, train crews and emergency rescue workers were interviewed to provide feedback on the design concepts. Focus group interviews with locomotive

engineers and conductors provided a forum to gather information about train crew perceptions of the three proposed locomotive egress designs.

Overall participants viewed the hatch concept as a significant improvement in cab egress. Several participants suggested that the design be such that the hatch falls out upon release, like an airplane's emergency exit. When asked which design provided the quickest escape for the crew, they unanimously agreed on the roof hatch. Similarly, participants unanimously agreed that the hatch would provide the quickest access for rescue workers.

Interviews with rescue personnel also provided insight to the basic problem of a locomotive rollover. Two major issues pertaining to rescue personnel facing a locomotive accident were identified: *ease of access* and *personnel safety*. Compared to current procedures, the hatch would make it much easier to get into the locomotive cab and rescue an injured person. The removable windshield was also viewed favorably by the rescue personnel. Safety issues related to the size of the opening, the ability of the personnel to access the cab in normal protective equipment, and the location of hazards in the cab such as electrical and air lines. In general, the rescue workers expressed a lack of specific knowledge of locomotive systems, and the need for training materials to improve preparation for accident response.

Revision and Evaluation of Concepts

The user feedback led to several changes to the basic concepts. The hatch was redesigned to fall away from the roof when opened. The hand/footholds became an accessory to the hatch, rather than a stand alone system. To be a viable egress option, the removable windshield would have to be usable from the cab interior.

Construction of a system mockup facilitated evaluating the overall concept. A full-sized locomotive cab, with an integrated hatch and hand/foothold system was constructed. The mockup is a wood-framed, plywood-sheathed structure representing a "generic" freight locomotive cab, using dimensions common to both GE and EMD road locomotives currently in service. The mockup was oriented to represent a toppled locomotive for egress evaluation.

The utility of the egress system was evaluated by two test subjects representing a likely range of personnel working as crew in locomotives. Neither of the subjects was familiar with locomotive equipment or operations. Both were able to exit the toppled cab utilizing the hatch in 30 s or less with little or no instruction. Two brief simulations of injured crewmembers were also attempted, with the test subject able to egress the cab without full mobility.

The present development of the hatch system design is not sufficiently detailed to allow for an in-depth analysis of its likely cost. However, a preliminary study identified the cost implications of several aspects of the design. These issues relate to the initial engineering rather than the recurring component costs in manufacturing. As such, it is believed that the overall cost for implementing the hatch in new locomotives will be low.

The results of this study suggest areas for future research relative to improved egress for locomotive crews. These include refining the design of the roof hatch into a manufactureable device, re-evaluation and development of the secondary egress options such as the internally removable windshield, and development of training aids for emergency personnel on locomotive accidents and rescue procedure.

1 Introduction

1.1 Background

Improving the survivability of a locomotive crew in the event of an accident has been a concern of the Federal Railroad Administration (FRA) in the past decade. The Rail Safety Enforcement and Review Act, passed by Congress in 1992, required the FRA to conduct an inquiry into locomotive crashworthiness and the safety effects of cab working conditions on productivity. In response to this mandate, the FRA undertook a comprehensive study of many aspects of locomotive crashworthiness (FRA, 1996). While the focus of this study was not specifically on emergency egress, the FRA's *Locomotive Crashworthiness and Cab Working Conditions Report to Congress* did note that, "Implementation of a crash survivability strategy should include consideration of an optional egress path in the roof of the cab to be used as an emergency exit." The FRA emphasized in this report that the acceptance of any improvements by locomotive crews should be considered in future research on proposed crashworthiness concepts.

Locomotive crashes can injure the crew as well as deform the locomotive cab. Exiting from a deformed cab can be difficult, particularly for injured crewmembers. If the locomotive is toppled, egress is even more challenging with current cab configurations. Fortunately this type of accident does not occur frequently, since its consequences can be significant. For example, a relatively recent accident in Carlisle, OH on 17 February 2001 caused the locomotive to topple. Figure 1 shows the position of the locomotive after this crash. Rescue workers could not readily enter the cab and one crewmember died as a result of the accident.

Figure 1. Aftermath of Accident in Carlisle, OH

In 2000, the FRA initiated a preliminary study of existing cab egress issues (Kokkins, 2002). The objectives of this study were to survey, identify and evaluate many aspects of current locomotive design and operation that affect crew egress or access by rescuers after an accident. This work included a broad survey of current egress and survivability issues and identified many opportunities for improvements. One area that the study identified as requiring improvement was equipment related to egress routes for crewmembers following an accident. This equipment could include doors, windows and other access points such as hatches, windshields and removable panels. The work described in this report builds on the preliminary study and focuses on the development of these types of egress systems.

1.2 Objectives

The purpose of the research described in this report was to evaluate locomotive cab egress/access equipment currently available in modern freight locomotives and to investigate modifications that will lead to improved survivability. The project had the following goals:

- Assemble data and information on currently available egress-related equipment.
- Identify and examine specific design improvements that will provide improved emergency egress.
- Determine required changes in locomotive cab structure to accommodate the candidate improvement concepts.
- Develop engineering designs for the innovative concept that provides the greatest enhancement to available egress routes.
- Demonstrate the selected concept via a full-size laboratory cab mockup.

1.3 Overall Approach

Figure 2 illustrates the overall approach to the design and development of an innovative egress concept. This project began with an assessment of current egress equipment, building on the information gathered in the initial study described above. The development of preliminary design concepts grew from an understanding of existing locomotives and their egress features. User acceptance will be key to future acceptance of any egress concept. Focus groups with train crews and interviews with emergency responders provided feedback on the designs, thus assuring that the design addresses all features and concerns of the likely users of the device or system. This feedback allowed the final design and mockup construction phases to focus on the concept most preferred by the users. The process of developing new concepts and reviewing them with train crews also identified additional areas where cab egress can be enhanced with further research.

1.4 Scope

The scope of this research was limited to road freight locomotives. While the egress concepts explored in this effort can potentially be incorporated into passenger and switching locomotives, the structural design considerations will differ for each type of locomotive. Since crew egress

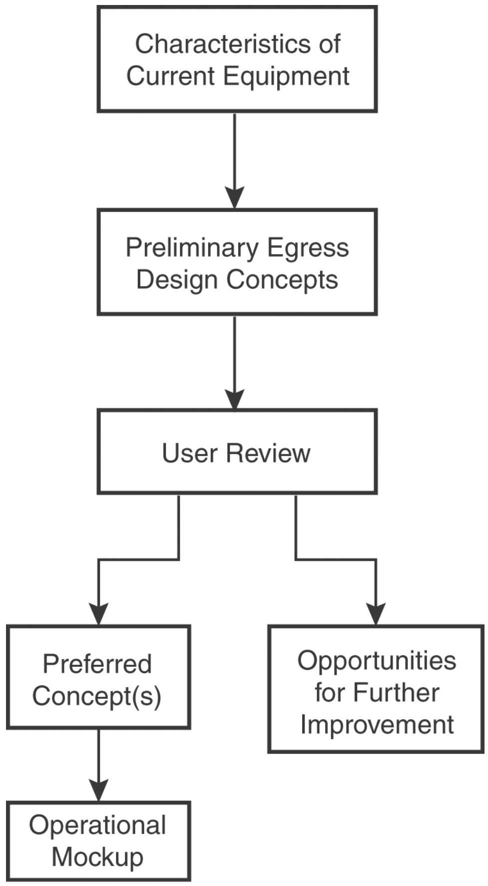

Figure 2. Overall Approach

from a toppled locomotive is the most challenging situation, the present study focused on this scenario. Egress options, in terms of door and windows, already exist when the locomotive is upright. The mockup, although operable, is intended to illustrate an egress concept. It is not intended as a working mechanical prototype.

1.5 Organization of the Report

Section 2 provides an inventory of existing egress equipment and ergonomic standards that apply to any means of egress. Section 3 describes the development of three preliminary egress concepts and Section 4 presents user feedback on these concepts. Modification of the preliminary concepts, based on user feedback, is described in Section 5. Section 6 describes the construction of the locomotive cab mockup that incorporates the preferred egress system and presents the results of a preliminary functional evaluation. Recommendations for future cab egress research are in Section 7.

2 Inventory of Current Egress and Emergency Rescue Equipment

A previous study investigated the current configuration of locomotive cabs in terms of emergency egress (Kokkins, 2000). This investigation identified several areas including doors and windows as basic means of egress in the event of an accident or emergency. At the onset of the current program, this data was reviewed. Additional data was collected for not only current egress options but also emergency rescue equipment that is used to rescue locomotive crewmembers following a crash. This section provides a summary of the findings of this data collection effort as well as ergonomic design standards relevant to egress devices.

2.1 Side Windows

The basic side window configurations used in locomotives were reviewed from the previous egress study. In addition, some additional investigations were done to determine the status of any new systems being developed by window manufacturers. Finally, a series of windows were studied and measured at the CSX repair facility in Allston, MA. This provided a firsthand view of the various window configurations.

Side windows currently in use fall into two basic configurations – single slider and double slider. The single slider version is shown in Figure 3, as installed in a GE AC6000. The double slider is shown in Figure 4, as installed in an EMD SD60. Both configurations are available from the major window manufacturers. The clear opening of these windows varies from manufacturer to manufacturer, but measurements indicate that the maximum opening of both single and double sliding windows is large enough to provide an egress route for a 95th percentile male crewmember.

Figure 3. Single Sliding Side Window in GE AC6000 Locomotive

Figure 4. Double Sliding Side Window in EMD SD-60 Locomotive

Currently, there is only one side window designed specifically as an emergency egress device. This window is manufactured by R. E. Jackson for use in the F59-PHI Passenger Locomotive cab. An example of this window is shown in Figure 5. Although developed for passenger rail use, the design of this unit could be adapted for use in freight locomotives if required.

Figure 5. Removable Side Window for F59-PHI Locomotive by R. E. Jackson, Co.

2.2 Doors

Doorways in the locomotive cab are the common access routes for railroad personnel. As such, they are also the most obvious means of egress in the event of an accident. Door sizes range from 18 in to 23 in wide and 58 in to 72 in tall, depending on location. Given these dimensions, some of these doors are too small for a large segment of the train crewmembers to utilize comfortably even in normal operating situations. The viability of using these doors in an emergency is questionable, depending on the orientation of the cab and physical condition of the crew.

The crew doors in the nose of the locomotive hinge in opposite directions, with both doors opening outwards. Although there is adequate space between the doors so that both could be open at the same time, for a toppled locomotive, one would always tend to close due to gravity, which would limit access and egress. The inner door, shown in Figure 6, lies on the centerline of the cab. The outer-most door, shown in Figure 7, is off-center. For this reason, the path to the cab is not straight. In addition, the outer-most door is not rectangular. There is a corner cut above the hinge (right side as facing the locomotive), so that the full height varies from 64 in to 59 in. The door is only 23 in wide. The inner door is rectangular, 69 in tall and 22 in wide.

Figure 6. Inner Nose Door to Locomotive Cab (GE CW40-8)

Figure 7. Outer Nose Door to Locomotive Cab (GE CW40-8)

The rear door is a narrow, angled door, as shown in Figure 8. The configuration is similar to the outer-most door in the nose. The height varies from 68 in at the hinge side to 73 in towards the centerline of the cab. The door is only 18 in wide. For a toppled locomotive, this is not the best egress route. If the door were on the grounded side, the crew would have to crawl out under the locomotive to escape through this door. If the door were on the high side, the hinge orientation would tend to have this door fall closed.

2.3 Windshields

Typically, a freight locomotive windshield is constructed of two rectangular pieces of glazing fitted into the structural frame of the cab. In general, there is one piece of glazing on either side of the cab centerline, each measuring 51 in wide and 17 to 18 in tall. A typical windshield is shown in Figure 9. In locomotives manufactured by EMD, the windshield has a triangular extension along the lower outside edge to improve visibility along the track. A typical EMD windshield is shown in Figure 10. Impact requirements set in 49 C.F.R. § 233, Appendix A dictate that the glazing and frame must withstand the equivalent of a 24-lb concrete block traveling at 44 ft/s. For a typical road locomotive, the impact energy is on the order of 360 ft-lb. To meet this impact requirement, the glazing is typically 5/8 to 9/16 in thick laminated glass.

Figure 8. Rear Door of Locomotive Cab (GE AC6000)

Figure 9. Typical Locomotive Windshield (GE AC6000)

Figure 10. Typical EMD Windshield (EMD SD-60)

Structurally, the windshield is installed directly into the cab frame. In both GE and EMD cabs the windshield frame itself is a formed "J" channel of 0.09 in thick steel, welded into the cab body. A rubber gasket is used to hold the glazing into the frame. The inner edge of the J-channel extends approximately 1 in further into the opening than the outer edge. The extended inner channel edge provides structural support to the gasket and glazing against frontal impact loads as described above. The lowered outer channel edge provides clearance for inserting the glazing. A typical windshield frame is shown in Figure 11. The glazing and gasket are installed directly into the frame during assembly. A schematic of this assembly is shown in Figure 12. The gasket is pushed into the channel to provide a weather seal to the frame. Shims are installed to insure that the glazing is centered properly in the gasket. A locking rib in the gasket is then pushed into place to secure the glazing and provide a seal to the glass.

2.4 Hatches

Although there are no hatches currently in use in road locomotives, the inclusion of one in future designs is an option. As such, hatches used in other applications were investigated. Many transportation vehicles utilize roof hatches for different purposes. As part of this study, bus, plane and boat hatches were considered. An additional hatch, used as part of a subway escape system was also reviewed.

2.4.1 Passenger Rail Equipment

In searching current systems for a hatch being used in railroad operations, only one hatch was found. This hatch provides access to the roof pantographs on the Acela Regional and Acela Express power cars currently in Northeast Corridor service for Amtrak. The hatch is located at the rear of the power car. These hatches have an integrated locking system that holds down the pantographs prior to unlatching the hatch cover. An interior view of this hatch is shown in Figure 13.

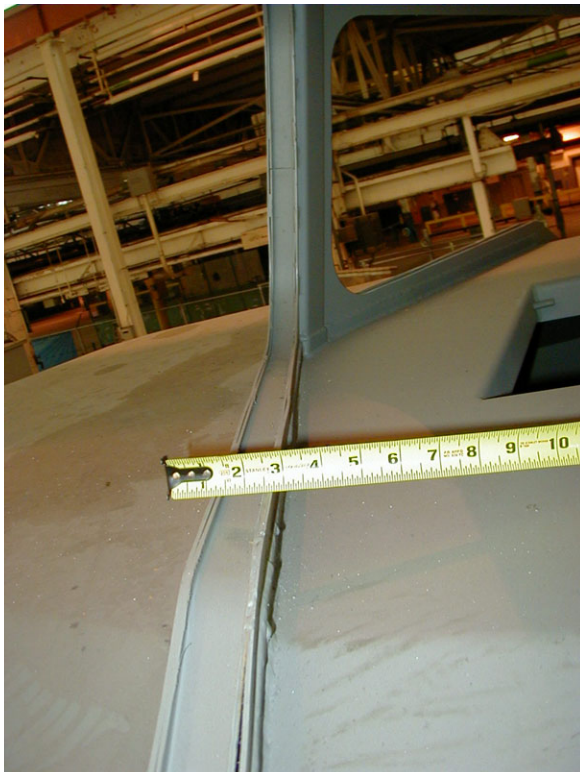

Figure 11. Windshield Framing "J" Channel (EMD SD-70)

The ladder shown in the photograph locks into the hatchway to provide access to the car roof. Given the level of effort associated with using this hatch/ladder system, it was not considered as a viable egress route in the event of an accident.

2.4.2 Buses

Typically, transit and school buses have roof hatches for use in emergencies. Most of these hatches are dual-use, allowing them to be used as vents in normal operation and fully opened for egress in emergency situations. Many hatches also provide exterior access to the latching mechanism for rescue personnel. Transit buses can only be opened from the inside. An example of a bus hatch is shown in Figure 14. The primary components are molded, high-impact plastic.

The venting mechanism seen in Figure 14 would be considered unnecessary for the locomotive cab, but the size seems applicable for railroad use. Other aspects of the design including materials, hinging, latching and sealing might also be adaptable, depending on the environmental assessment in the locomotive cab. The general size and shape of the opening does provide ample opening for egress.

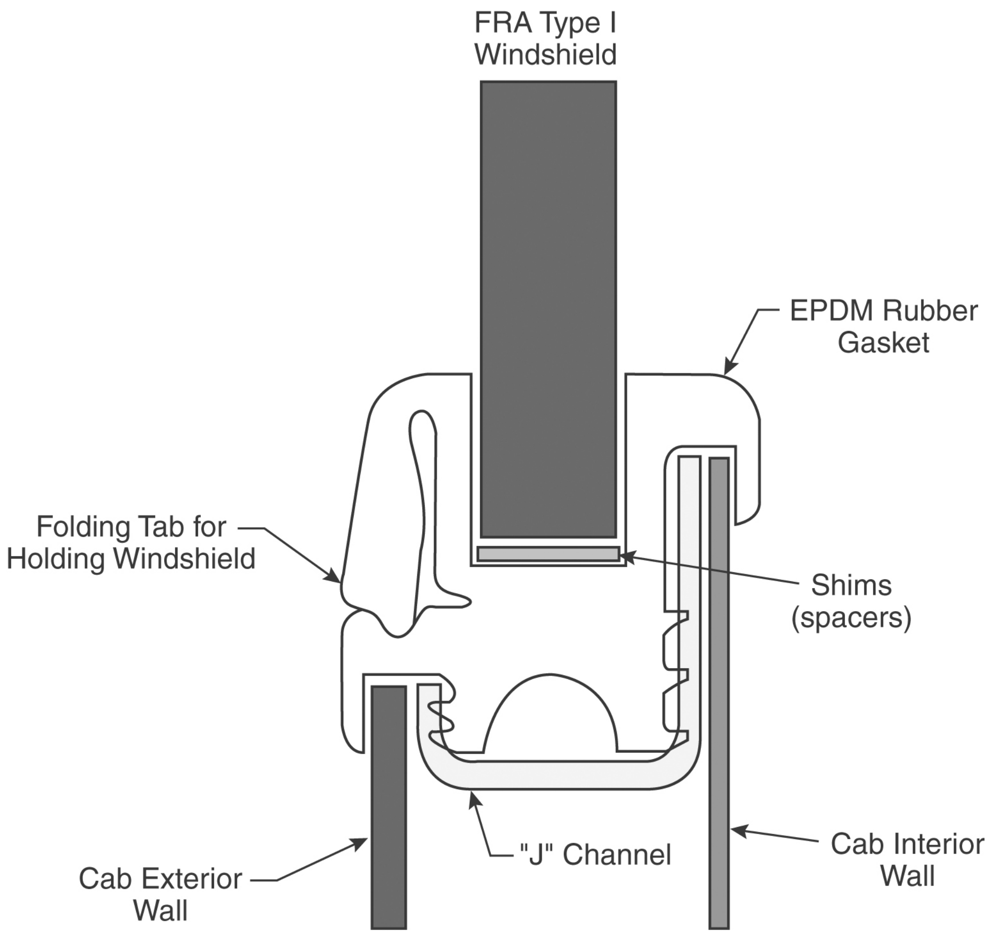

Figure 12. Typical Windshield Gasket Installation (EMD)

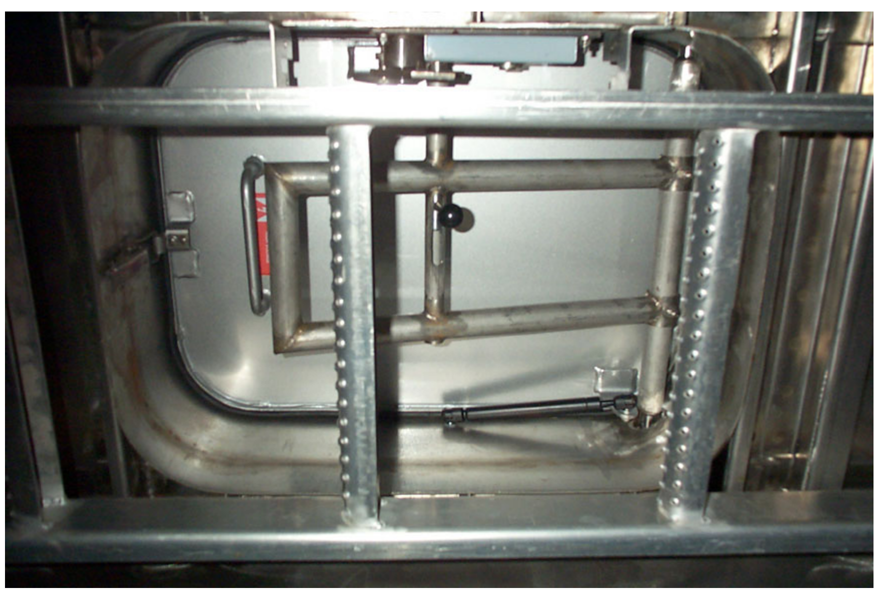

Figure 13. Pantograph Access Hatch in Amtrak Acela Express Power Car

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Figure 14. Transit Bus Hatch with Venting Hinge (Transpec)

2.4.3 Airplanes

Airplanes have utilized hatches for egress and access for more than 50 years. Typical access hatches are hinged openings providing space for crewmembers to enter and exit. Escape hatches are typically designed to fall away, providing a maximum opening. In the case of high-performance jet aircraft, these hatches are usually opened pyrotechnically. The explosive mechanism for ejecting these hatches is not suitable for railroad use.

2.4.4 Boats

In terms of retrofit and usability, boat hatches were considered impractical for railroad usage. Typically, the boat hatches were circular in shape and not considered conducive to the locomotive roof support structure. However, several designs of boat hatches were studied. Due to the harsh environment to which these hatches are exposed, they were considered for examples of latching and sealing mechanisms. Some aspects of these designs were applicable to the railroad application, but most would require extensive modifications to meet the desired structural requirements and cost targets.

2.4.5 Subway Tunnel Hatches

The Massachusetts Bay Transit Authority (MBTA) subway rail lines employ hatches as a part of their normal emergency equipment for the MBTA. They are located at the end of escape routes from the underground rail lines. Figure 15 shows an example of this hatch.

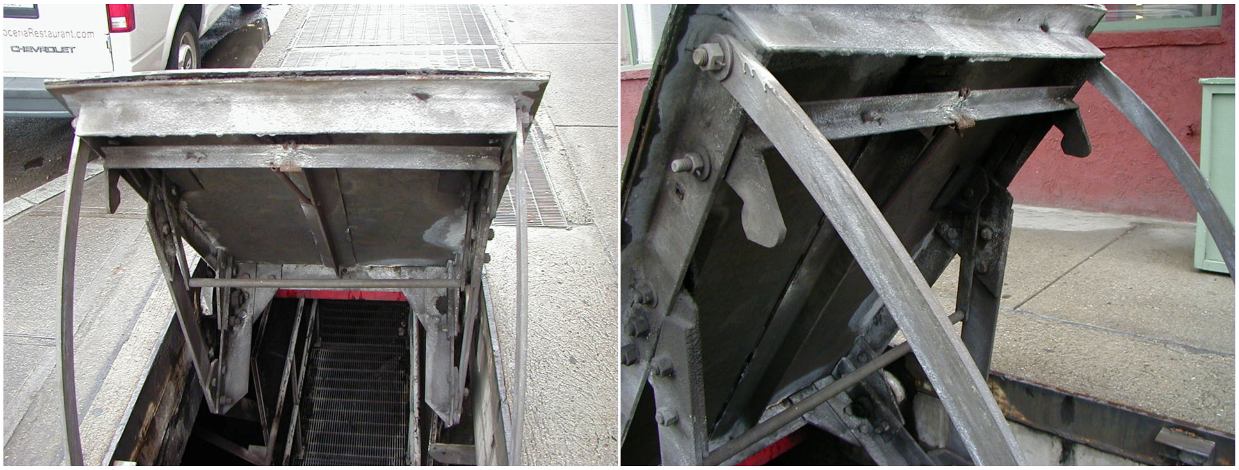


Figure 15. Sidewalk Hatch for Subway System, Boston, MA

The escape routes lead to stairways that provide passengers access to street level. The stairways terminate at an emergency hatch in the sidewalk. These hatches are 3 x 5-ft steel doors held flush to the sidewalk surface. The door is quite heavy, and is counter-balanced for operation by a single person. This device was designed to be very easy to operate in the dark by an injured person. It is also accessible from the street side by rescue personnel and provides a large access port when open. Although too large to be practical for use in the locomotive cab, the hatch arrangement did provide insight into methods of latching, releasing, and securing a hatch from vandalism while still providing easy access for both passengers and rescue personnel.

2.5 Assessment of Current Options

None of the existing egress options appears satisfactory in the event of a rollover. The windows may be an option when the locomotive remains upright, but an injured crewmember would have difficulty exiting via the window. Emergency rescue workers could fit a body board through existing windows but maneuvering the body board with an injured person would be difficult. In general, the size of most windows makes them not well suited for external rescue. The removable window does provide a larger opening but it must be actuated from the interior and as such it does not solve the problem of access from the exterior. If all crewmembers are injured and unable to release the window, it does not improve the egress situation.

Doors are not a viable egress route in the event of a rollover. The position of the two front doors limits access for rescuers with a body board. The rear door will only be accessible if the locomotive rolls to the opposite side. There is also the risk that the crash could deform the door frame, making the doors inoperable.

The windshield is the largest single opening accessible in a rollover. However, the windshield is virtually unbreakable by a crewmember and therefore does not offer an egress option to the crewmembers. Emergency rescue workers could likely break the windshield, but breaking the glass brings the risk of injuring the crew.

2.6 Ergonomic Design Criteria

To insure that any design implemented into railroad use would be both functional and practical, several references were consulted to determine the standards currently in use for hatches. The documents studied included U.S. military, U.S. civilian, and European transit standards. Where applicable, the basis for sizing was also noted, particularly for Mil-Spec requirements on clothing type and body size.

2.6.1 Size

The size of the opening is important when considering doors, windows, windshields, or hatches for emergency use. The most extensive information on hatch size standards is available from the U.S. Department of Defense. European and other transportation hatch standards were also reviewed. When applied to the proposed solution of a locomotive roof hatch, other factors were included. Most notably, the ability of rescue workers to access the cab in an emergency was considered as important. For that reason, clothing and gear typically worn by fire and rescue personnel, as well as typical rescue equipment were also taken into consideration when assessing size requirements. Table 1 shows the recommended size ranges for hatch openings.

Table 1. Applicable Hatch Standards

Standard	Size (in)	Additional information
49 C.F.R. § 238.441	18 x 24	High speed passenger rail
European Specs for safety	23 x 31	
Federal Motor Vehicle Safety Standard (FMVSS) 217	16 x 16	For school bus
MIL-STD-1427F	13 x 23	Top and bottom access, light clothing
	16 x 27	Top and bottom access, bulky clothing
	26 x 30	Side access, light clothing
	29 x 34	Side access, bulky clothing

2.6.2 Engagement/Deployment

Handle shape and operation were considered for the hatch design. Most of the basic standards available relate to U.S. military requirements for ease of use. However, these requirements assume an able-bodied user. In the case of the locomotive hatch, it is assumed that an accident in which the hatch would be needed for escape would likely cause injury to the crew to some degree. For that reason, the U.S. military specifications were taken as a guideline rather than a firm requirement. The basic criteria for opening the hatch were determined to be: ease of operation by an injured crewmember; impervious to jamming, even in the event of a wreck; and resistant to accidental opening.

2.6.3 Hand/Footholds

To assist the crew in reaching the hatch opening, it was determined that a set of hand/footholds should be set into the ceiling. These could be recessed in normal use, and deployed to aid in reaching the side window or roof hatch if the locomotive was toppled. A number of applicable standards for handholds, ladders, and other climbing aids were reviewed. For railroad specific information, the main reference was 49 C.F.R. § 238, which contains specifications for handholds on different types of rail cars. Additionally, U.S. military and Occupational Safety and Health Administration (OSHA) requirements for ladders were reviewed. For handholds, the minimum diameter was generally 5/8 in, with a minimum length of 16 in and 2.5 in of clearance (preferred). Table 2 is a summary of the 49 C.F.R. § 238 specifications for handholds and grab irons.

Table 2. Applicable Handhold Standards

Type of handhold	Minimum Diameter (in)	Minimum Clear Length (in)	Minimum Clearance (in)
Side - Box and other House cars	5/8	16 24 preferred 36 Caboose	2 2.5 preferred
Side – Passenger Cars	5/8	16 24 preferred	1.25 1.5 preferred
Horizontal End	5/8	18 24 preferred	2 2.5 preferred
End - Passenger car	5/8	16	2 2.5 preferred
Side – Steam Locomotives	5/8–horizontal 7/8-vertical	16	2 2.5 preferred

Ladder rung sizes vary based on the application and required standard. Rung diameter may vary from ¾ in to 1½ in in diameter, depending on the type and arrangement of the ladder. OSHA standards given in 29 C.F.R. § 1926.1053 provide a wide range of specifications for various ladder types. Typically, rungs may be spaced between 10 and 18 in apart with the width of the rungs being a minimum of 11½ in. Ladder specifications provided in MIL-STD-1472 are similar in sizing and spacing.

2.7 Emergency Responder Equipment

For accidents that might result in a rollover, it was assumed that firefighters or other rescue personnel would eventually respond to the scene. For this reason, the typical equipment used by emergency responders was reviewed. The equipment would affect the overall suitablity of the roof hatch as an access point, depending on the circumstances. The clear opening of the hatch and windows would need to be sized such that rescue personnel in heavy gear could access the cab. The typical tools available would also affect the ability of the rescue crews to open the hatch from the outside. Opening size and configuration would also determine the feasibility of using stretchers, body boards, or other equipment.

2.7.1 Gear

Clothing and breathing apparatus worn by rescue personnel, particularly firefighters, is intended to protect them from the hazards of their environment. Its bulk and weight, however, can limit their ability to perform certain functions. To better understand the implications of this equipment, typical fire fighting gear was reviewed and measured. In doing so, it would allow designers to determine the utility of hatch openings when approached by rescue personnel. An example of firefighters' clothing is shown in Figure 16.

Figure 16. Typical Firefighter's Gear

The jacket and trousers are fire resistant and very bulky. The boots are similar in size and construction to heavy-duty work boots. In general, the bulk of these items would have an impact on access through a window opening or hatch. However, since they are worn close to the body, the overall impact would be small.

The helmet shown in Figure 16 is made of hard leather and has a clear plastic face shield. It has a brim that extends approximately 2 in around the front and sides and about 4 in in the back. This style of helmet is still typical in certain parts of the country, but most fire departments are shifting to helmets constructed of Kevlar and high-impact plastic. The brim would likely have an impact when entering a confined space, but again, this impact may not be that great.

The breathing apparatus would likely provide the largest impediment to entry through a small opening. This is mainly due to the size of the oxygen tank. Typically, the tank supplies 30 min of oxygen. The high-pressure version of the tank is about 8 in in diameter and 20 in long. The low-pressure version is approximately 10 in in diameter and 22 in long. There is also a high-pressure 60-min tank that is the same basic dimensions as the low-pressure 30-min tank. The tanks are carried in a harness worn on the firefighter's back. This adds 8 to 10 in of depth to the body, creating an overall "thickness" of nearly 2 ft. A typical oxygen tank arrangement is shown in Figure 17.

Figure 17. Breathing Apparatus

2.7.2 Body Boards

Before moving an injured person, firefighters and Emergency Medical Technicians (EMTs) will immobilize the victim by strapping him/her to a body board. These boards are typically made of fiberglass and fitted with handholds and tie-down points. Typically, they are 16 in wide and 6 ft long. Shorter lengths are also available for use in automobile accidents where there is limited space and victims are in a seated position. Figure 18 contains an example of the longer board.

Figure 18. Body Board Utilized by Rescue Personnel

2.7.3 Tools

The rescue workers carry various tools that help them access victims in a variety of situations. One idea for the hatch locking mechanism was to design the lock so that it could be opened from the outside using a tool that was only common to emergency responders. This would limit the possible vandalism issue with the unlocked roof hatch. A similar concept is already in place with the subway tunnel hatches in Boston, MA. As described above, the subway tunnel can only be opened with a special wrench. The wrench, however, is not common throughout the United States.

Most fire and rescue crews in the United States utilize the Hurst Rescue Tool, commonly known as “The-Jaws-of-Life.” Although this tool has been shown to be effective in responding to railroad accidents, it is not well suited to the non-destructive opening of a roof hatch latch. However, there are a number of commonly used hand tools that might be used to turn a latching mechanism, allowing firefighters and rescue personnel to open a hatch while limiting access to vandals. Two types of pry-bars that would be suitable for this purpose are shown in Figure 19.

The common tool best suited to use with the latching mechanism is known as a Hallagan bar, shown in Figure 20. This tool was originally developed by a New York City firefighter as a multi-purpose prying tool. The double tyned end of the bar is well suited to use as a “key” for turning the exterior handle of the hatch.

Figure 19. Typical Pry-Bars Carried by Fire and Rescue Crews

Figure 20. Hallagan Bar

3 Development of Preliminary Design Concepts

Current egress equipment, including doors and windows, is adequate for most accidents in which the locomotive remains upright. However, these devices have serious limitations in a 90º rollover. In the event of a toppled locomotive, certain door openings would be blocked or unreachable and only one window would be accessible. For these reasons, rollover derailment accidents were the focus of the egress concept development.

Once the target accident case was determined, early concept development for new locomotive egress systems focussed on two key issues: ease of use and technical viability. Usage issues included ergonomic and structural aspects of the devices, where viability issues centered on cost and implementation. All were evaluated for practicality based on both rollover and non-rollover accidents, but the issues were weighted toward the 90º rollover. Initially, a large number of concepts were developed, including hatches, removable doors, side access panels, and removable glazing systems. Many of these concepts were rejected as either impractical or unreasonably expensive. Three basic concepts were chosen for further development: 1) hand/footholds for use as a climbing aid, 2) an escape hatch in the cab roof, and 3) a removable windshield. The following subsections describe each of these concepts.

3.1 Hand/Footholds

Anecdotal evidence indicated that in several rollover accidents, uninjured crewmembers had escaped from the cab by climbing up the consoles and seats to reach the side window on the high side of the locomotive. In most cases, an injured crewmember would be unable to accomplish this climb. To aid crewmembers in climbing out of a toppled locomotive, a hand/foothold system was proposed. These devices would be placed in the ceiling of the cab to be accessed in the event of an emergency. In normal operation, they would be flush with the ceiling. If the locomotive were toppled, the hand/foothold could be extended to provide climbing points to reach the high side of the locomotive.

The design concept provides for six hand/footholds, spaced approximately 16 in apart. A possible layout is shown in Figure 21. The hand/footholds would be recessed such that they are flush with the ceiling in normal operation. Once opened, the series of hand/footholds would act as a ladder, with each hand/foothold being a single rung. Each rung would be a minimum width of 12 in wide and would provide 4 in of toe depth. This provides a reasonably comfortable ladder step for climbing. To meet the basic 49CFR guideline, the rungs would be 1 in in diameter. Each rung would be designed to support the weight of a 300-lb crewmember, with overload reserve.

Three design approaches were investigated for deploying the rungs from their recessed position: swing-out, pull-out, and fold-out. In each case, it was determined that the rung must be usable regardless of the attitude of the locomotive. In addition, it should provide maximum access to the upper side of the cab to provide effective egress.

The swing-out rung approach is illustrated in Figure 22. In this approach, the rung is locked into a ceiling well during normal operation. When needed, the rung can be pivoted outward 90º. The rung will lock in place to provide climbing support. The well is designed to provide toe clearance for a boot. Once rotated into position, it would be usable from either direction.

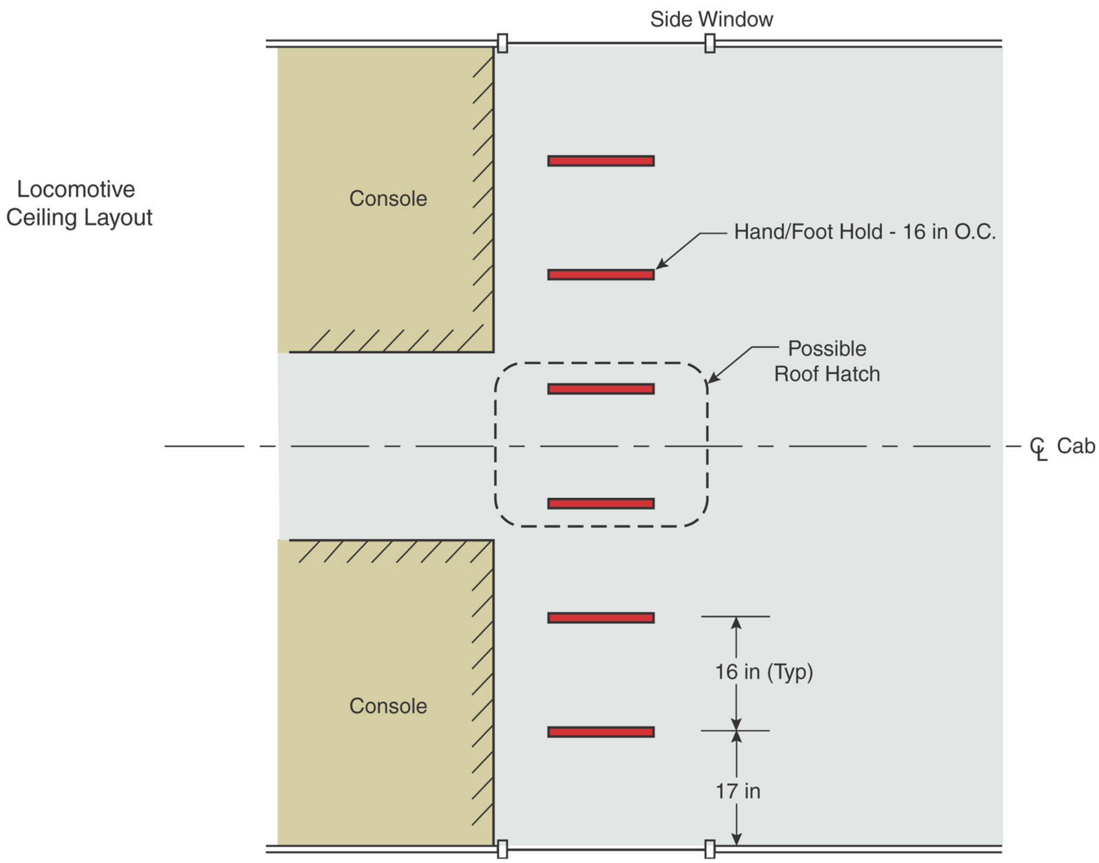


Figure 21. Cab Ceiling View of Hand/Foothold Layout

Conceptually, the swing-out rung is the simplest of the three approaches. However, it does require a large amount of ceiling area when folded. In addition, the locking device must be robust enough to support the entire weight capacity of the rung, since it would need to be usable from either direction.

The pull-out rung approach is shown schematically in Figure 23. In this concept, the rung is locked into a ceiling well such that it is flush in normal operation. When needed, the rung can be pulled out and locked into position. Again, the well is designed to provide toe clearance.

To provide adequate strength, the actual mechanism would need to telescope in a much more robust fashion than shown. As with the swing-out rung, the locking device may have to carry the full weight capacity of the rung. Conceptually, however, this approach does have some advantage over the swing-out rung. The rung is actuated by a pulling action, which implies that it could be deployed by the weight of a climbing crewmember. It would also provide some level of utility even if not actuated. Actuation would be necessary to provide comfortable toe clearance, since the well depth would be limited to the framing in the cab roof. The added area on both sides of the rung also impacts the amount of ceiling area required.

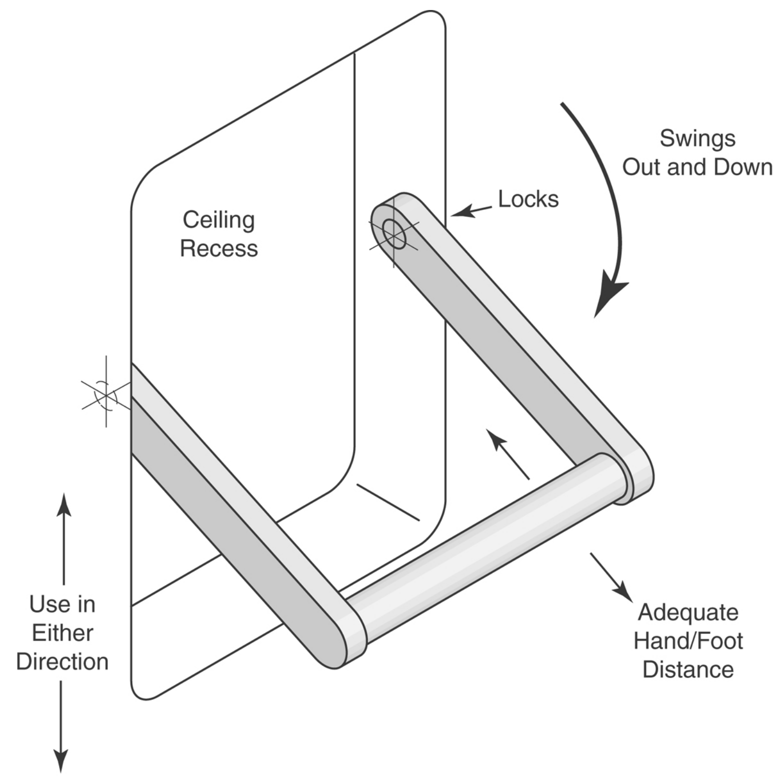


Figure 22. Swing-Out Rung Concept

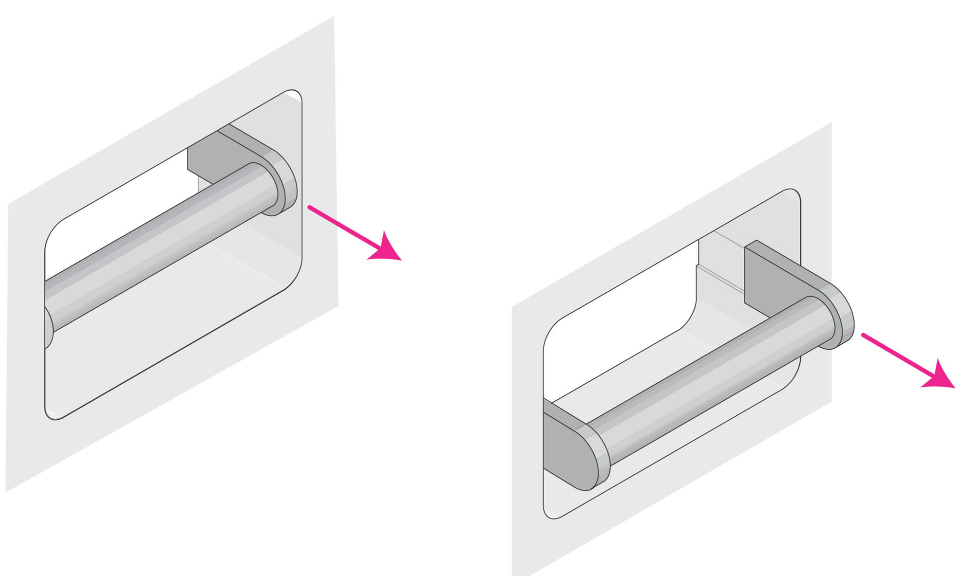


Figure 23. Pull-Out Rung Concept

The fold-out rung concept is illustrated in Figure 24. In this concept, the rung is folded latterally to be flush with the ceiling. When needed, the rung is unfolded so that it provides 4 in of clearance from the ceiling. It will lock in place when actuated to provide climbing support.

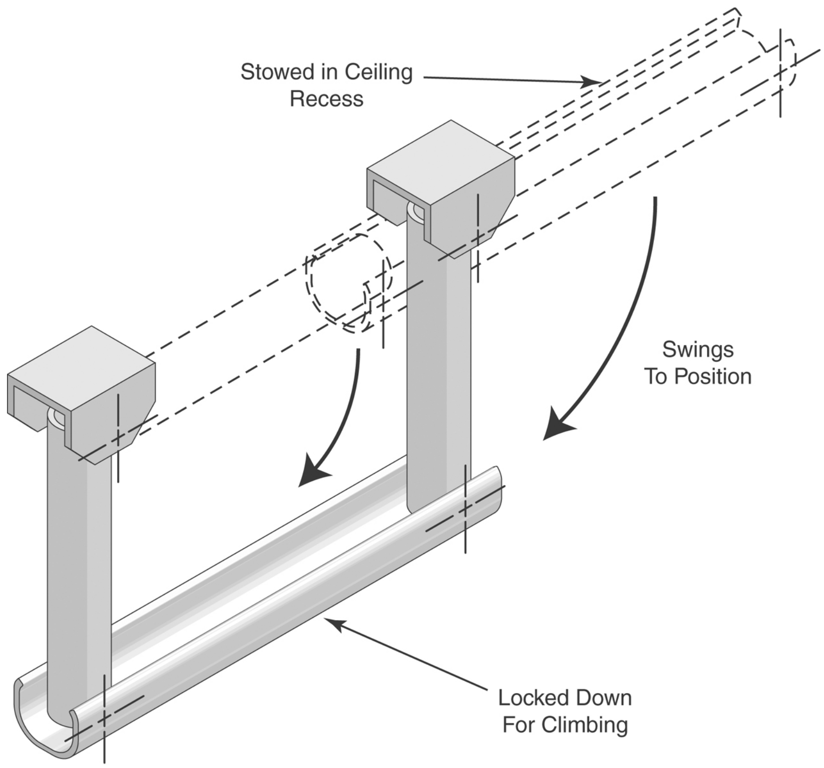


Figure 24. Fold-Out Rung Concept

The fold-out approach would use the minimum amount of ceiling area since there is no toe well. The main advantage of this approach is that the locking device would not be required to carry the entire weight capacity, since the pivot arms act as the main structural member. However, it is the most mechanically complex concept, and potentially the most expensive option.

Given the merit in each of the approaches, all three concepts would be provided for review by the users. In this way, crews familiar with the operational environment of the locomotive could assess the overall utility of each approach based on experience. From a cost assessment, each concept was considered to be roughly equal, with the fold-out rung being slightly more expensive. However, there was not a sufficient difference from the other two concepts to eliminate the fold-out rung based on cost alone.

3.2 Hatch

Design of the hatch system began with consideration of the bus hatch in the hope that it might be possible to adapt an existing hatch for use in a locomotive roof. Typically, the bus hatches are constructed of high impact plastics, are 22 x 22 in , and can function as vents, as shown previously (Figure 14). Conceptually, the operation of the hatches would adapt well to locomotive design, but some of the aforementioned attributes are not suitable for a locomotive. Structurally, it is desirable that the hatch be constructed of steel. Dimensionally, the hatch should be larger than a standard bus hatch. Given the proximity of the hatch to the diesel exhaust, a vented hatch would not be practical.

From the standpoint of external conditions, the hatch should seal completely against weather. This would include moisture driven by movement of the locomotive. In addition, the seal should prevent internal air from escaping under normal conditions. It should also prevent permeation of exhaust gases from the outside. Due to the proximity of the hatch to the diesel exhaust in a locomotive, both the structural material and the seals would need to withstand temperatures approaching 300ºF for periods of 20 to 30 min.

Operationally, the hatch should provide a full open area for egress. Hinges, latches, seals, or other mechanical aspects of the hatch should not occlude the available opening. Ideally, the hatch would open flush to the roof of the cab. For egress, opening the hatch must be accomplished by a single movement that requires little force, and be functional even if the cab is slightly deformed. For access, the hatch should provide easy operation for rescue personnel while deterring vandalism.

Based on these attributes, some basic conceptual drawings of the hatch were developed. Dimensionally, the hatch would be 22 in wide and 30 in long. This is a larger opening than a standard bus hatch. It would, however, provide maximum clearance for egress by the crew and permit rescuers to utilize body boards. Initial investigation with some current hatch manufacturers indicated that the high impact plastic construction of some bus hatches would meet the structural requirement for the locomotive cab. Hatch manufacturers indicated that it would be possible to construct the hatch frame or panel out of steel if necessary.

Operationally, the proposed unit would look similar to that shown in Figure 25. The latch would be to the far left, actuated by a handle that turns 45º in either direction. The hatch would be hinged on the far right, allowing the hatch to fully open in the event of an emergency. The crewmember would then be able to climb out through the hatch utilizing the hand/footholds as shown in Figure 26.

Making the hatch weather tight is an engineering challenge when highspeed operation, long term durability and snow/ice accumulation are considered. Based on the assumption that a bus hatch could be adapted to use in the locomotive, a double sealing approach was devised. The overall concept, illustrated in Figure 27, includes a molded composite hatch cover similar to those currently manufactured for buses. The dual seal would provide an outer wiper seal to prevent penetration of moisture driven by wind and motion, and an internal compression seal that blocks air and moisture flow into the cab. The entire unit could be bolted to the cab roof as a final operation during construction. A butyl rubber or similar material would provide a seal between the cab roof and the hatch frame.

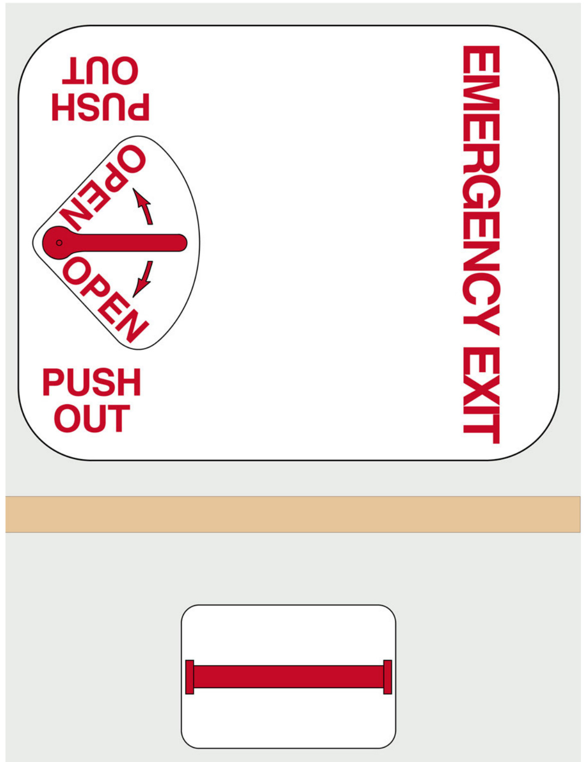


Figure 25. Initial Design for Roof-Mounted Escape Hatch

The oversized hatch also provides maximum access for rescue personnel. Unlike the exterior doors and windows, the hatch was sized to accommodate the use of a body board as illustrated in Figure 28. In addition, the exterior latch would be actuated by a tool commonly carried by rescue personnel, such as the Hallagan bar shown in Figure 20. This increases the overall effectiveness of the hatch, making it usable for the crew and rescuers while making it secure from vandals.

3.3 Windshield Removal

The final area targeted as a potential egress route was the windshield. As described in subsection 2.3, the windshield represents a significant opening in the cab, providing there is a means of removing the glass. In the discussions with firefighters, paramedics, and police officials, the rescue workers immediately viewed the windshield as a possible means of access to the cab. Several types of windshield construction are used, depending on the model and manufacturer, so a “universal” method for opening the windshield is required. In all cases, a rubber gasket is used as a weather seal between the glazing and a fixed frame. This commonality of design does allow concepts to be adapted to various windshield design. Every approach, however, must be capable of meeting the impact requirements for the windshield. In older model locomotives, particularly EMD cabs, the gasket is the principal structural retainer for the glass, and methods that compromise this structure were avoided.

Figure 26. Emergency Roof Hatch in Operation to Allow Crewmember Egress

One design scheme developed for a removable windshield is shown in Figure 29. In this approach, a cutting wire would be imbedded in the gasket. Inside the cab, a handle allows the crewmember to pull the cable, severing the outer portion of the gasket. To facilitate this action, the gasket would be extruded with voids near the glass face to allow an easy path for the cable. The cable would be looped on itself like a lariat, so that as the handle is pulled, the cable constricts around the perimeter. Once the gasket begins to tear, the force required to fully separate the gasket is reduced. An access plug would be provided on the exterior of the cab so that rescuers could reach the cable to sever the gasket from the outside.

Early investigation into using the windshield as an egress route indicated that implementation of this approach would prove to be costly. The primary difficulty is circumventing the strong backup flange of the cab windshield frame. As such, the overall approach to windshield use was changed to removal by rescue workers rather than as a means of egress. To facilitate access for rescue workers, the cable cutting windshield gasket was redesigned to provide easier access to the cable from outside the cab, and coupling the glass and cutting cable. This approach, shown

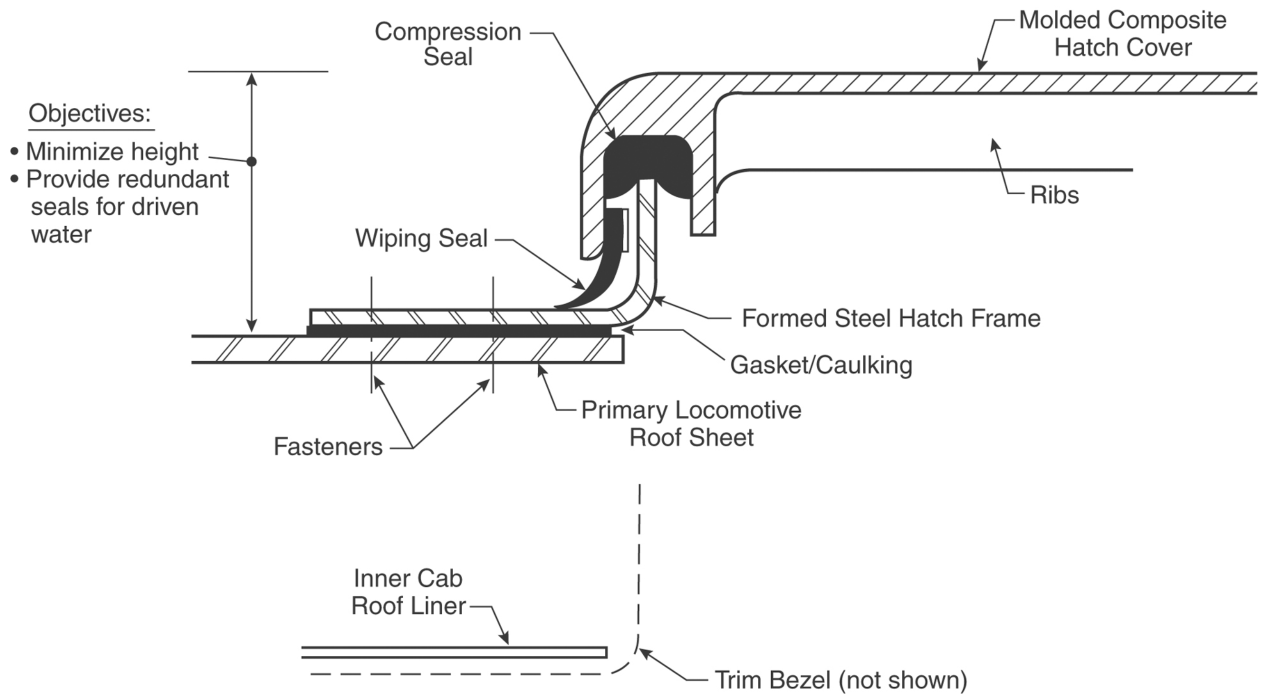


Figure 27. Roof Hatch Seal and Mounting Concept

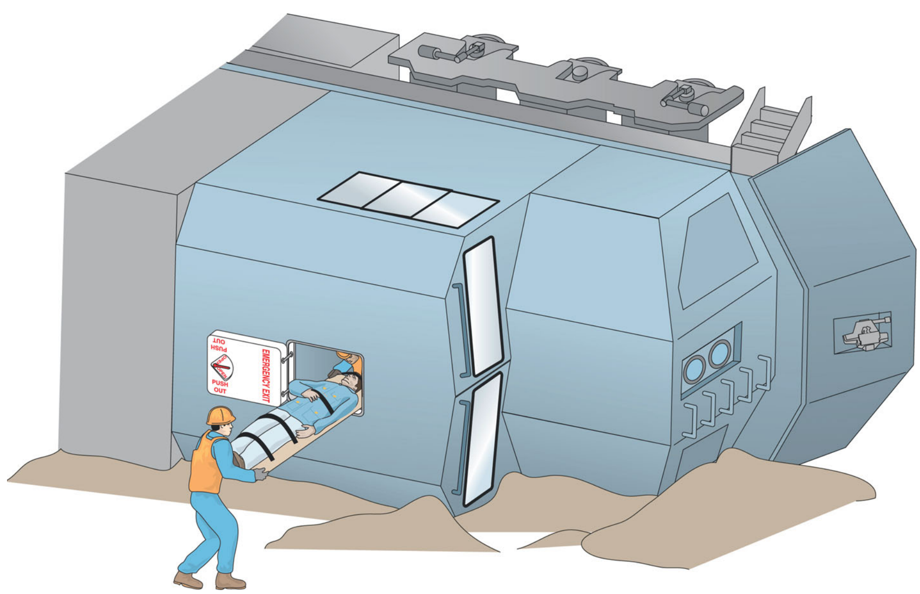


Figure 28. Roof Hatch Provides Easy Access for Rescue Personnel

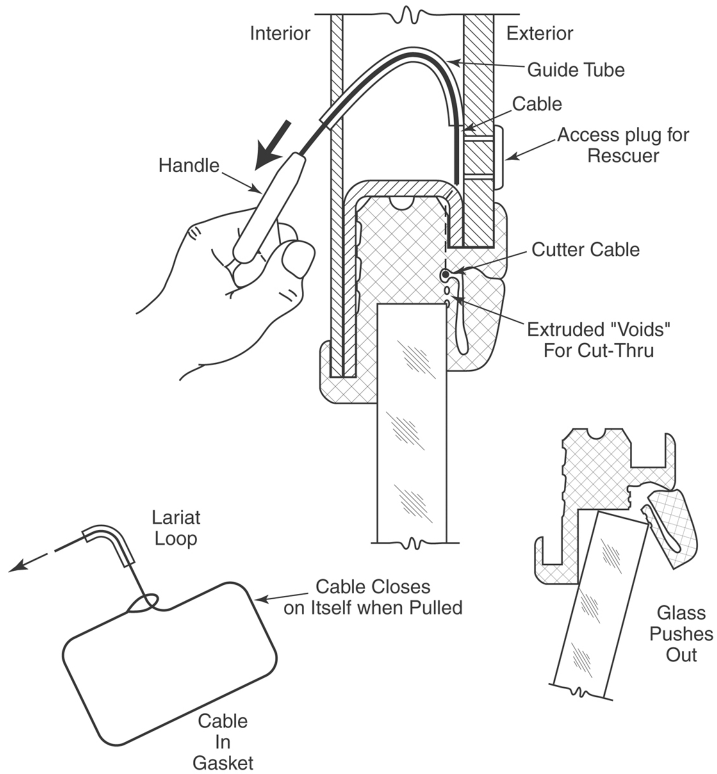


Figure 29. Removable Windshield Gasket Concept

in Figure 30, allows the glazing to be removed by a rescue worker at the end of the gasket cutting. To limit the possibility of vandalism, the gasket would be close fitted to the frame and there would be no external handle to remove the gasket. Rather, an access point will be provided at several places around the window perimeter, which would allow a screwdriver or small prying tool to be used to pull up the gasket. Once the gasket is pulled free, the glazing could be removed or allowed to fall out of the opening as shown in Figure 31. The strength of the gasket would not be compromised, as the primary direction of impact load would be toward the cab frame.

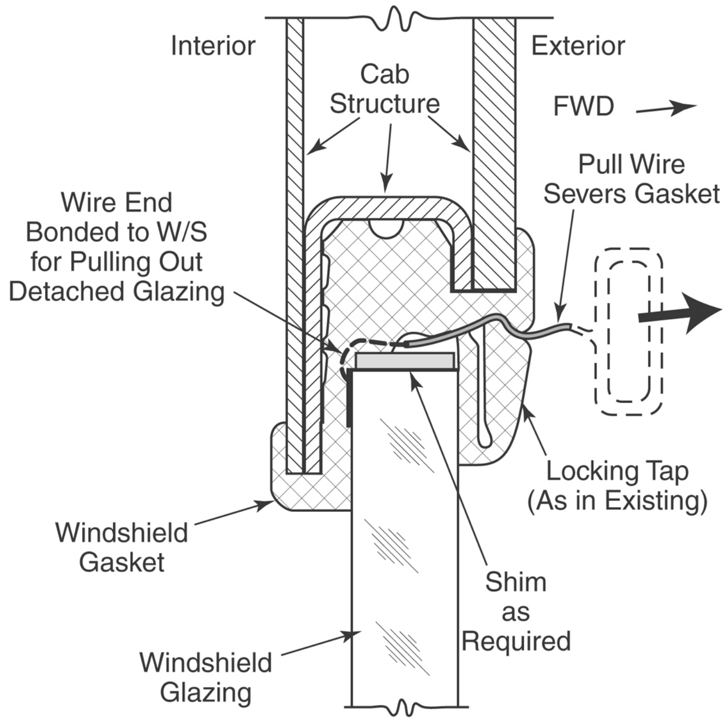


Figure 30. Externally Removable Windshield Concept

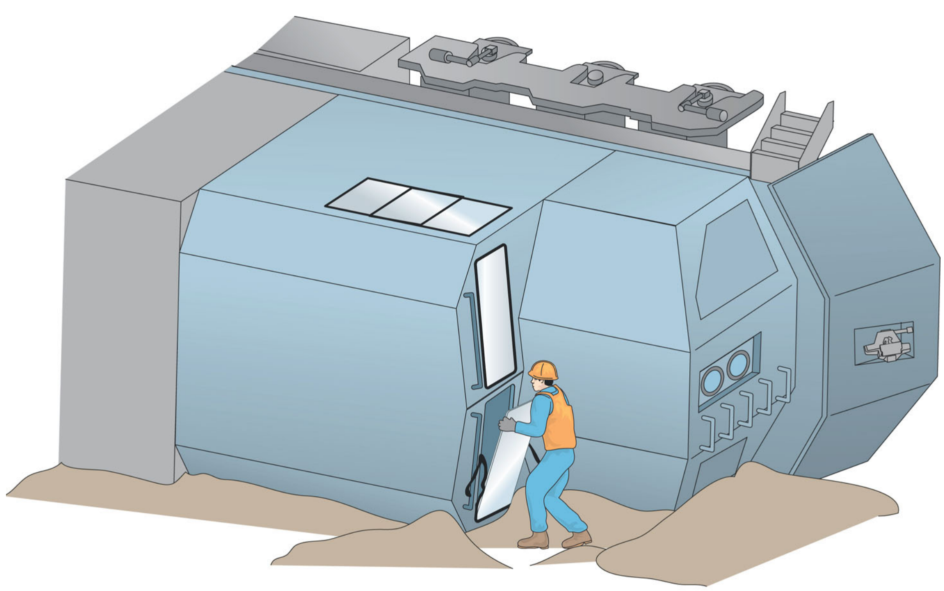


Figure 31. Removable Windshield Provides Easy Access for Rescuers

4 User Review of Preliminary Concepts

Train crews and emergency rescue workers will be the potential users of egress equipment. Before proceeding with further design work, the study team sought feedback from these two stakeholder groups. Since train crews are of primary concern, input from locomotive engineers and conductors was obtained through focus group interviews. An interview with a fire department specialist in emergency rescue and contacts with an ambulance company provided a critical review of the concepts from the second group of potential users.

4.1 Focus Group Interviews with Railroad Labor

Focus group interviews with railroad engineers and conductors provided a forum to gather information about train crew perceptions of the three proposed locomotive egress designs. This forum allowed the railroad workers to review the three concepts, provide feedback on the validity of the designs, and suggest other emergency improvements. The group interview also gave the workers an opportunity to express their concerns about safety and personal security in the locomotive.

The following sections summarize the information gathered from the three focus groups. The information is organized and presented by topic. Appendix A contains the original set of focus group questions. The responses from the sessions are reported as a whole as the questions were the same for each group.

4.1.1 Procedures

Chicago, IL was selected as the focus group interview site because of the large number of railroad road freight workers available. Chicago is the country's most active rail hub and has many railroad workers living in the area.

Participants were recruited from the two crafts that make up the road freight train crew: engineers and conductors. An attempt was made to have both crafts represented in each focus group. The unions representing these crafts, the United Transportation Union (UTU) and the Brotherhood of Locomotive Engineers (BLE), assisted in identifying candidate participants.

The following criteria were used to identify candidate participants:

- The candidate must be a current engineer or conductor and preferably have been in a road freight wreck.
- The candidate must have at least five years experience on a road freight crew.
- The candidate must be interested in sharing his or her perceptions and opinions regarding innovative concepts for emergency locomotive egress.

A total of three focus groups were conducted. The same concepts were presented to each group in the same order, using the same props and pictures to convey the design's purpose and properties. Each focus group interview lasted approximately 1½ h and participants were compensated for their participation.

Each session began with an explanation of the purpose of the meeting. The participants introduce themselves, giving their craft and years of railroad experience. After the introductions, the facilitator asked the participants to describe a significant locomotive wreck in which they were involved. The purpose of sharing wreck experiences was to have situations to which the group could relate when discussing the proposed locomotive egress concepts.

The facilitator also asked the participants to identify any safety risks they perceive when riding in the locomotive cab. Responses to this question provided an indication of crewmember concerns with regard to personal safety in the cab. The facilitator also asked about personal security concerns on the job. This issue was of interest with regard to the need to lock or secure any egress device to protect against intruders. The majority of the focus group discussion focused on review of the three novel egress concepts: hand/footholds, ceiling hatch with hand/footholds and removable windshield. At the end of the session the participants completed a brief anonymous profile form.

4.1.2 Participant Profile

A total of 18 people participated in the 3 focus groups interviews. Each group included both engineers and conductors and drew from the membership of both the UTU and the BLE. Nearly two-thirds of the participants were BLE and one-third were from the UTU. Years of experience ranged from 2 to 42 years, with the median being 29.5 years.[1] Twelve of the 18 participants had been in a wreck of some kind. Table 3 presents a profile of the participants across all three focus group interviews.

Table 3. Profile of Focus Group Participants

Craft	Engineers	15
	Conductors	3
Union Affiliation	BLE	10.5*
	UTU	7.5*
Years on a road crew (median)		29.5
Experienced a wreck?	Yes	12
	No	6

* One participant reported membership in both labor organizations.

4.1.3 Cab Safety Environment

This section summarizes the information from focus group participants with regard to safety in the locomotive cab. There is information dealing with wreck experiences, perceived cab safety risks and personal security issues.

[1] Although the criterion for participation in the focus groups was five years of experience, one individual reported two years of road freight experience on his participant profile form.

Representative Wrecks

Group participants reported a variety of wreck experiences. The ones with the most relevance to the egress concepts under considerations were the following:

- A conductor reported that his train proceeded at slow speed through a Wye and was hit by another train entering from a siding. The engine toppled to a 45° angle and two small fires resulted on either side of the locomotive. The impact of the crash caused both the engineer and the conductor to be thrown around the cab. The crew was able to exit via the cab's front door.
- An engineer reported that his train hit a school bus at a grade crossing. The crash took out the engineer's side of the cab, but the locomotive remained upright. The crew exited through the door on the fireman's side of the cab.
- An engineer reported that his locomotive hit a large truck at a grade crossing. The locomotive derailed and rolled over on its side. The front door was unusable as a result of the accident. The crew got out of the locomotive through the side door, which was now on top.
- An engineer reported that after moving past a stop signal his locomotive hit a derail causing the engine to overturn and slide down a 40-ft embankment. This accident occurred at 11 p.m. so it was completely dark inside the cab. The engineer was thrown on top of the control stand and the conductor was on the floor. Some 15 to 20 min after the impact, the crew exited via the engineer's side window using the engineer's control stand as a platform to reach the window.

Typical comments were:

- "When I got hit I wasn't thinking straight."
- "Your mind clears maybe after 30 s."
- "I didn't know where I was initially."

Safety Risks

Participants voiced a number of safety concerns. Their comments fell into two broad categories: dealing with a wreck and structure of the cab. They were concerned with finding a way out of the cab in the event of a wreck. This concern also involved the absence of emergency lighting to help find a way out quickly and safely. The speed of rescue was also a concern. Many locomotive wrecks happen in rural areas, hours away from towns and rescue personnel. There was also a concern about the lack of tools in the cab that could aid in an escape from the cab or could be used to signal for help.

In terms of the structure of the cab, participants pointed out that interior surfaces of many cabs do not have rounded edges. The radio housing in particular could cause injury in an accident. Participants were concerned about possibly hitting the edges in an accident and sustaining life-threatening injuries. Several participants also voiced concern that currently there is no "safety cage construction" in locomotives to make the cab crashworthy. They also pointed out that there is no automatic fire suppression equipment in the cab.

Personal Security

Participants voiced one primary security issue – protection from transients. There were numerous stories of transients climbing up onto the locomotive to ask for money, attempt to damage the locomotive or physically threaten the crew. The discussion in all three sessions centered on the need for locks on the cab doors to protect the crew from these intruders. The participants were unanimous in their feeling that their personal security concerns would be eliminated if all locomotive doors had locks that could be locked by the crew from inside the cab.

Typical comments were:

- "Transients come up on the train and startle you."
- "I think it's more important that we have the [door] locks. When a wreck comes I don't think there's going to be a problem getting in or out. [The loco] is not going to be intact."
- "If you had an escape route other than doors, I think I'd rather have a locked door while sitting at a signal."

4.1.4 Design Concepts

This section presents the focus group findings with regard to each of the three design concepts.

Hand/Footholds

Overall Assessment

The three groups were presented with diagrams of a locomotive roof with hand/footholds located every 16 to 17 in (see Figure 21). The facilitator explained that this concept is intended for installation in new cabs but a retrofit into existing cabs is also possible. The purpose of the hand/footholds is to assist the crew in reaching the side window that would be above their heads in a rollover.

The general consensus was that the hand/foothold concept would be of limited utility unless the locomotive has toppled to nearly a 90° angle. If this were the case, then probably the crew could use the hand/footholds to exit out the side doors, or reach the side windows with little difficulty. Participants in each group agreed that the concept would have been helpful in the rollover wrecks that they described.

Participants saw some potential problems with the hand/foothold concept. They felt that the hand/foothold mechanisms might jam preventing them from engaging the hand/foothold. They suggested that the simpler the construction of the engagement mechanism, the less likely it would be to jam. They also pointed out that the normal locomotive vibration might cause hand/footholds to release and protrude from the ceiling. The participants voiced concern that if the hand/footholds engage on their own, they become a protruding obstacle that can injure a crew member. Several participants commented that the width of the hand/foothold might not be adequate and suggested that the design team examine OSHA standards for ladders.

Another concern raised by participants had to do with lighting. Without adequate lighting, the hand/footholds may be difficult to find in the dark. They suggested that this problem could be solved with track lighting or lights placed within the recessed area of the hand/foothold.

The groups also mentioned that the crew might have a tendency to "play" with the hand/footholds. This was seen in a positive light in one group because playing with the device would make crewmembers familiar with its operation. One participant commented that everyone would likely know how it worked because every new device on the train gets "played" with. In a different session, this was seen in a negative light because if someone is engaging the mechanism for fun, they might leave it in its operational mode and the next person to enter the cab might hit his/her head on the hand/foothold.

Comparison of the Alternative Hand/foothold Concepts

Table 4 summarizes the overall assessments of the three hand/foothold concepts.

The *pull-out design* (Figure 23) was shown first. Participants noted that this design was probably not useful if it jams and it is likely to be a safety hazard if not locked in position. The majority of participants said this design appeared easy to use and a minority favored it over the other two designs.

Participants pointed out that the *swing-out design* (Figure 22) might pin a crewmember's fingers when trying to engage it. There was also the problem of using this design if the cab did not roll in a position that allowed engagement of the device by pulling down. Participants felt it would be hard to lock the hand/foothold into position if it had to be pushed up instead of swung down. Overall, participants found this design more foolproof and more accessible than the pull-out design. They felt that it would be useful even if jammed because the opening alone would allow for foot or hand placement. Overall, the majority favored this design.

Table 4. Assessment of Hand/Foothold Concepts

Concept	Assessment
Pull-Out	• Not useful if it jams • Safety hazard if not locked in position • Easy to use • Favored by minority
Swing-Out	• Risk of pinching fingers when opening • Direction problem-hard to lock if in swing-up position • More foolproof than pull-out • More accessible than pull-out • Useful even if jammed • Favored by majority
Fold-out	• Risk of pinching fingers when opening • Risk of it refolding if not locked properly • Less expensive • Easier to retrofit into existing locomotives

The *fold-out design* (Figure 24) was the last one shown to the groups. Participants felt this design had the highest risk of pinning fingers when opening and also a risk of it folding in if not properly locked in position. However, participants felt that it was the least expensive to install and easier to retrofit into existing locomotives than the other two designs.

Participants suggested two improvements to the swing-out design. First, the swing-out design could be made easier to use by making the release area bowl-shaped. This design would provide adequate space so that the hand/foothold could be used as a step whether or not the swing-out mechanism was engaged. The second suggestion was to provide lighting to the hand/footholds so that they could be located in the dark.

Some typical comments were:

- With regard to knowing how to use the hand/footholds "You're either gonna be out of it or with it. If you're out of it, it doesn't matter."
- "If you are that banged up, would you be smart enough to pull something out when you don't use it every day?"

Hatch with Hand/Footholds

The facilitator explained the roof hatch concept using three drawings: 1) a life size sketch of a roof hatch, 2) an artist's rendering of people climbing out through the hatch, and 3) an artist's rendering of rescue workers using a roof hatch to extricate an injured crew member. The facilitator demonstrated the operation of the Transpec bus hatch to illustrate how the locomotive hatch might operate. The hatch was presented in conjunction with the hand/footholds as steps to help reach and then exit via the hatch.

Overall participants viewed the hatch concept as an improvement in cab egress. They offered a number of possible improvements to the proposed design. The first improvement concerned the hinge. The hatch would be useless if there were something obstructing the hatch door from opening out. To eliminate the problem facing a hinged hatch, several participants suggested that the design be such that the hatch falls out upon release, like an airplane's emergency exit. The second suggestion concerned the need for emergency lighting. If there were no lighting, then it would be difficult to find and engage the hatch in nighttime accidents.

Other concerns were that the hatch be rugged enough to withstand the crash and also weatherproof. They also wanted the hatch to be easy to engage. All three groups felt that additional grab irons or handholds should be placed on the roof around the exterior edge of the hatch to provide an assist when exiting.

With regard to an exterior locking device, the overwhelming majority of participants said that there was no need to lock the roof hatch. They felt that the security issues come from the doors to the cab not having locks. They did not see a roof hatch as a security risk in terms of transients entering the cab. One individual was concerned with terrorists entering via the hatch. The facilitator suggested that a lock that would only open with a rescue tool was a possible solution.

All three groups favored the idea of a roof hatch that could be utilized if the locomotive were to topple over. Participants recognized that the hatch would not help in every situation, but would like to have it there in the roof as an option if the cab did roll on its side.

Typical comments included:

- "All my prayers are answered with this. If someone is injured, he could probably get out."

Removable Windshield

The facilitator described the removable windshield concept using artistic renderings of the concept. The picture showed a rescue worker removing a windshield from an overturned freight locomotive. The rescue worker was depicted standing outside the wreck, removing the gasket from around the windshield and then lifting it up out of the frame.

Participants saw one major limitation to the removable windshield – it can only be accessed from the outside and the crew cannot remove the windshield themselves. The participants wanted the windshield to be made in such a way that the crew could either kick it out or remove the gasket from the inside. They indicated that the wreck might occur in a remote area. If not seriously hurt, the crew should have a way to egress quickly and not have to wait for the rescue teams to come.

Another concern was that of the windshield popping out of the frame on impact. If this were to happen, some of the crew may be thrown from the train. In making the windshield removable, it must be rugged enough to withstand impact.

The issue of vandalism or terrorism was an initial concern with one group. However, someone commented that, "The element of safety that it provides far overrides the security risk." This sentiment seemed to be the consensus of the group.

The groups were not against the removable windshield concept, provided that it was designed to stay in place during a wreck. Participants liked the idea of an easy way for rescue workers to reach them if they were incapacitated. They would prefer if the windshield could be designed in a way that allows the crew as well as rescue workers to remove it. They also wanted it to be easy to engage so that other train crews and "Good Samaritans" who might reach the wreck before the rescue team could remove the windshield.

Some typical comments were:

- "If you're incapacitated, you'll need some way to get you out."
- With regard to ease of use, "Make it idiot proof."

Comparison of Concepts

After discussing the three design concepts, the facilitator asked the participants to compare the designs. When asked which design provided the quickest escape for the crew, they unanimously agreed on the roof hatch. Similarly, participants unanimously agreed that the hatch would provide the quickest access for rescue workers.

4.1.5 Other Egress Concepts

Participants offered suggestions for additional improvements to egress options in the locomotive cab. The most frequently voiced idea was standardization of door locks. Wider doors and a second back door were also mentioned. One participant suggested doors that provide an exit through the car body, as in Amtrak locomotives. When speaking of the removable windshield, several participants wanted all the windows in the cab to be removable. Grab irons next to the side windows were also suggested to facilitate egress through the windows.

4.2 Interviews with Rescue Personnel

Interviews with firefighters and Emergency Medical Technicians (EMTs) provided insight as to how emergency egress equipment might be utilized by rescue personnel responding to a railroad accident. This information allowed the designers to tailor certain aspects of the design to better suit rescue personnel while maintaining maximum utility to the locomotive crews. The following sections summarize the information gathered from an interview with Capt. Steven Perrson of the Cambridge, MA Fire Department.

4.2.1 Fire Department Rescue Personnel

To obtain feedback from fire personnel on the egress concepts, two study team members met with Capt. Steven Perrson, Training Officer for the Cambridge Fire Department. Capt. Perrson is a 20-year veteran of the department, and has had experience with passenger train and subway rescue procedures. In addition to being a Battalion Commander for the East Cambridge district, Capt. Perrson is responsible for all training conducted in the Boston area related to rescue procedure. Due to the high concentration of rail traffic within the city limits, including freight, passenger rail, and subway, Capt. Perrson has become familiar with rail systems in general and possible responses to an accident. Photographs and drawings of the egress concepts facilitated the discussion.

To begin the session, Capt. Perrson was shown two photographs of the toppled locomotive from an actual rollover derailment. While reviewing the photos, it was mentioned that generally two crewmembers are in the cab, and occasionally three. He was then asked how he would apply the current rescue procedures and equipment if responding to this accident. Capt. Perrson began by assessing the apparent situation, and the general condition of the locomotive.

The first issue addressed was gaining access to the inside of the cab. Capt. Perrson determined that the locomotive could not be accessed from underneath the cab due to the structure and thickness of steel. He noted that he was not familiar with freight locomotives and would assume that the door on the nose led to the engine. He stated that the most likely point of entry would be from the side, which was now in an upward position. This would require using a ladder to climb up onto the side of the locomotive. The firefighters would then try to open the window to access the cab. Generally, they would use their normal "forcible entry tools." These would be hand tools followed by power tools if needed.

Capt. Perrson noted that a major concern would be the size of the openings, either windows or holes made by the firefighters. In Cambridge, procedure dictates that all the firefighters be in "full protective gear," which includes helmets and breathing apparatus. He stated that the Cambridge department has done rescue training on Massachusetts Bay Transit Authority (MBTA) trains, both commuter rail passenger cars and F40 locomotives. He has never encountered a toppled train, but felt that such an incident could happen in certain areas of the city. When doing the MBTA drills the firefighters' immediate concern was shutting down fuel lines and high voltage electrical service on the car.

4.2.2 Design Concepts

Hatch

Capt. Perrson was provided with the artist's depiction of the egress roof hatch on a toppled locomotive. In this picture, a body board is used to remove an injured person through a roof hatch. Capt. Perrson's immediate response was favorable, followed by questions concerning the height and size of the hatch. He was told the size of the hatch and its location in the roof of the locomotive. Based on this, the position of the hatch was described in relation to the ground for the accident in the photo. Capt. Perrson commented that the angle of the locomotive would determine how viable the hatch would be as an access route. He commented his approval of the concept again, pointing out that there should be no "rough spots" around the opening that might snag or cut. He also asked about the location of the high voltage and fuel lines on the locomotive.

Capt. Perrson stated that from a rescuer's perspective, it is much easier to extricate a victim through a side opening than lifting him or her up and overhead. Compared to current procedures, the hatch would make it much easier to get into the locomotive and rescue an injured person. Capt. Perrson could not think of any potential problems or disadvantages to the design except for the concern of vandalism. For this reason, he suggested that the hatch should be flush to the cab roof and secure.

Regardless of the direction of access to the locomotive, the size of the opening is an issue. A firefighter's gear is bulky and heavy. Capt. Perrson said that most rescue personnel would be wearing breathing apparatus. This is the standard procedure in Cambridge and for most other departments in Massachusetts. Capt. Perrson believed that it is the common practice nationwide. The breathing apparatus does add another 10 in to a person's thickness, as discussed in Section 2 (Figure 17). If entering from the top, a ladder would have to be inserted so that the rescuer could climb down into the cab. This further decreases the usable opening space. The ladder combined with the gear and breathing apparatus might make it impossible for the rescue worker to gain access through the current window openings.

Capt. Perrson was then asked for his thoughts regarding the exterior design of the hatch. The question was asked with the constraints of locking for vandalism and designing the hatch with a tool that most rescue personnel across the United States would possess. Capt. Perrson said that a specific tool for operating the latch would facilitate access. He also commented that firefighter would get in eventually. In his opinion, designing a lock to be used with a common tool would decrease rescuer entry time significantly. He suggested that the opening device be flush to the hatch. Exterior access should require a tool that is not easily accessible to the general public. He suggested the six-sided spanner wrench used for the MBTA subway hatches in Cambridge, but he noted that it might not be universal. He commented that there had never been a problem with someone getting into a subway hatch by opening it from the outside.

Capt. Perrson saw the need for two types of instruction. First, if the hatch were implemented, there would have to be some external labeling for on-scene use. In addition, Capt. Perrson feels there is a need for a short training video showing how to safely access a locomotive after a wreck. The video could have a short segment on opening the hatch and other egress options. This video could be sent to the National Fire Academy and the National Fire Prevention

Association. He thought it would be fairly easy to distribute the tapes nationwide. He knows of no current nationwide training on railroad safety or rescue.

Removable Windshield

Capt. Perrson was provided with the artist's depiction of a rescue worker gaining access through the windshield via a pullout gasket. His immediate reaction was that this design was preferable to dropping down from the top. The windshield in a toppled locomotive would be close to the ground and provide crawling or possible crouched access if it were easily removable. He has removed a gasket from a MBTA train passenger window and an automobile windshield for access, so he is familiar with the concept. The 50-lb weight of the windshield did not appear to be an issue. Capt. Perrson said that when removing a car windshield, they generally use two people because of the awkwardness of the shape.

One potential problem Capt. Perrson saw with the removable windshield design was vandalism. Another potential problem might be the layout of the cab behind the windshield. He was shown photographs of the console layout, windshield, and cab interior. His impression was that maneuvering through the windshield and past the console looked fairly easy. To extricate a victim from a cramped space such as the cab, the firefighters would probably orient a body board to match the victim's position prior to passing it through the opening. Having to turn a body board on its side to extract a victim through the windshield opening was still preferred over lifting the person up through the top.

Comparison of Concepts

Overall, Capt. Perrson prefers an access method that does not require a rescuer to drop down or to lift a victim vertically. Both the hatch and the windshield offer access closer to the ground but Capt. Perrson preferred the hatch to the removable windshield.

4.2.3 Discussion

Capt. Perrson identified two major issues pertaining to rescue personnel facing a locomotive accident: *ease of access* and *personnel safety*. The access issue surfaced in several forms. First was the addition of normal equipment to the physical size of the firefighter. On several occasions, Capt. Perrson noted that the firefighters would be wearing "full protective gear" when responding to an accident. Helmets and bulky clothing certainly will inhibit access though any opening, but the breathing apparatus appears to be the biggest issue. Capt. Perrson did not appear concerned about entering through the windshield opening even though he was told that it was only 17-18 in high. It would be best if no entry dimension was smaller than this.

The second access issue was one of geometry. Capt. Perrson noted several times that a horizontal entry is preferable to a vertical one. Having to drop into the toppled cab from the high side would be difficult without a ladder. Adding a ladder to the opening would greatly limit access for a rescuer in protective clothing and wearing breathing apparatus. A vertical access would also require lifting a victim to extricate him/her from the cab. Based on Capt. Perrson's comments, this would require two firefighters inside the cab, and two or more outside the cab. Given the cramped nature of the cab itself, the addition of several persons would make rescue work very difficult.

Personnel safety was the second major issue. When discussing procedures in and around trains and subway cars, Capt. Perrson always mentioned high voltage electricity and fuel shutoffs. Typically, rescue workers will cut their way into a vehicle by whatever means necessary. Hitting a high voltage line with a hand tool or power saw is likely to occur. Since he felt that most rescue personnel are not familiar with locomotives, Capt. Perrson suggested that some type of training aid be developed showing the likely paths of electrical wiring. He also mentioned pressurized pneumatic and hydraulic lines as possible hazards.

Fuel shut off is another safety issue. Leaking fuel or the possibility of leaks greatly increases the hazard to the rescue personnel, regardless of fire. Clearly, the ability to quickly neutralize this threat would be of interest to the firefighters. Due to the variety of configurations of locomotives, it may not be possible to describe the position of a fuel shutoff in every make and model. However, a generalized description would be valuable.

Another significant comment made several times by Capt. Perrson related to the determination of the rescuers. When discussing tools, methods, or procedures for gaining access, the comment invariably ended with "we'll find a way in." Based on this, it is clear that the rescuers will continue to escalate their efforts to gain access. He did note on several occasions that any device or scheme that would ease access would be of benefit to the rescue personnel, as this would reduce the time spent extricating victims.

4.3 Recommended Design Changes

The information gathered through the focus group interviews and the meeting with the Cambridge Fire Department clearly indicates that the hatch concept appears most promising and should be the one that is developed in the mockup. The engineers and conductors clearly preferred the hatch concept. The preference of emergency rescue personnel, as indicated through Captain Persson, was the removable windshield, however, he also clearly saw the benefit of the hatch. The immediate preference by rescue personnel for the removeable windshield is a reaction to training. Typically, when responding to automobile accidents, rescue personnel are trained to break out windshields to gain access to trapped victims. When informed of the basic construction of a locomotive windshield, all of the emergency personnel asked about other means of access. As indicated by Captain Perrson, most firefighters are unfamiliar with freight locomotives and would probably benefit from some specific training. Ultimately, the crewmembers are the primary stakeholders so the hatch system became the focus of the mockup.

Based on the feedback from the focus group participants one major design change is necessary. *The hatch should have a "fall away" rather than hinged design*. Other design issues that merit further consideration are the following:

- Noise insulation.
- Vibration effects.
- Weather sealing.
- Structural considerations.
- Exterior profile.
- Exterior grab irons.

With regard to the hand/foothold design that is used with the hatch, the swing-out design is preferable. Further design work on this concept should focus on the following:

- Shape of the opening.
- Surface and length of rung.
- Locking mechanism.
- Direction of actuation.

5 Revised Design Concepts

The feedback from both the train crews and emergency rescue personnel led to modification of the design concepts described in Section 3. This section describes each of the three revised concepts. Potential users of egress equipment clearly favored the hatch in conjunction with hand/footholds. Cost considerations for this concept are also considered in this section.

5.1 Hatch

Based on the feedback from the focus groups, the hatch was clearly the most desirable egress option for the crew. Each group had concerns as they relate to the design, some of which overlap, others of which are unique to one or the other group.

The railroad crews would clearly prefer a non-hinged, fall away hatch. The rescue workers had no particular preference to hinging, provided the opening would provide clearance for entry and extraction of victims. The overall design should be free from sharp corners or edges. According to the railroad crews, the exterior latching arrangements did not need to be secure. In fact, they would prefer a simple handle arrangement that could be operated by a passerby in the event of an accident.

Based on these attributes, a revised hatch design was developed. The basic size of the hatch was left unchanged from the conceptual design presented to the focus groups. Functionally, the hinge was eliminated and the latching arrangement altered. These changes allow the hatch to fall free after opening, and the handle to be moved to a more central location. Conceptually, the weather sealing arrangement would remain unchanged. External locking or tamper proofing of the latching mechanism is not part of the revised design. It is likely, however, that the locking issue will be raised again in the future. A schematic of the design is shown in Figure 32.

5.2 Hand/Footholds

The train crews favored the use of hand/footholds as part of a hatch egress system. However, as a standalone device, they considered the concept marginal. This was mainly due to their view that climbing out of a wreck would always be possible for an uninjured crewmember. They did feel that the use of hand/footholds would provide aid for an injured crewmember, and as such should be pursued. In practice, the crewmembers' chief concerns were the size of the rungs, the ease of use, and the approach to locking. In general, the groups felt that the device should still provide some basic utility when jammed.

Of the three possible solutions provided (swing-out, pull-out, fold-out) the railroad crews preferred the swing-out. Pull-out was considered second best, and fold-out was a distant third. This was mainly due to the simplicity of the Swing-out design and the perception that it would be the easiest to operate in the event of an accident.

Given that the hand/foothold concept would be adopted as part of the hatch system, several design changes were introduced. First among these is the alteration of the design as a "one-way" device. The rung could be centered in a relatively compact opening, providing toe clearance both above and below the bar. This would provide utility even if the rung jammed in place. The

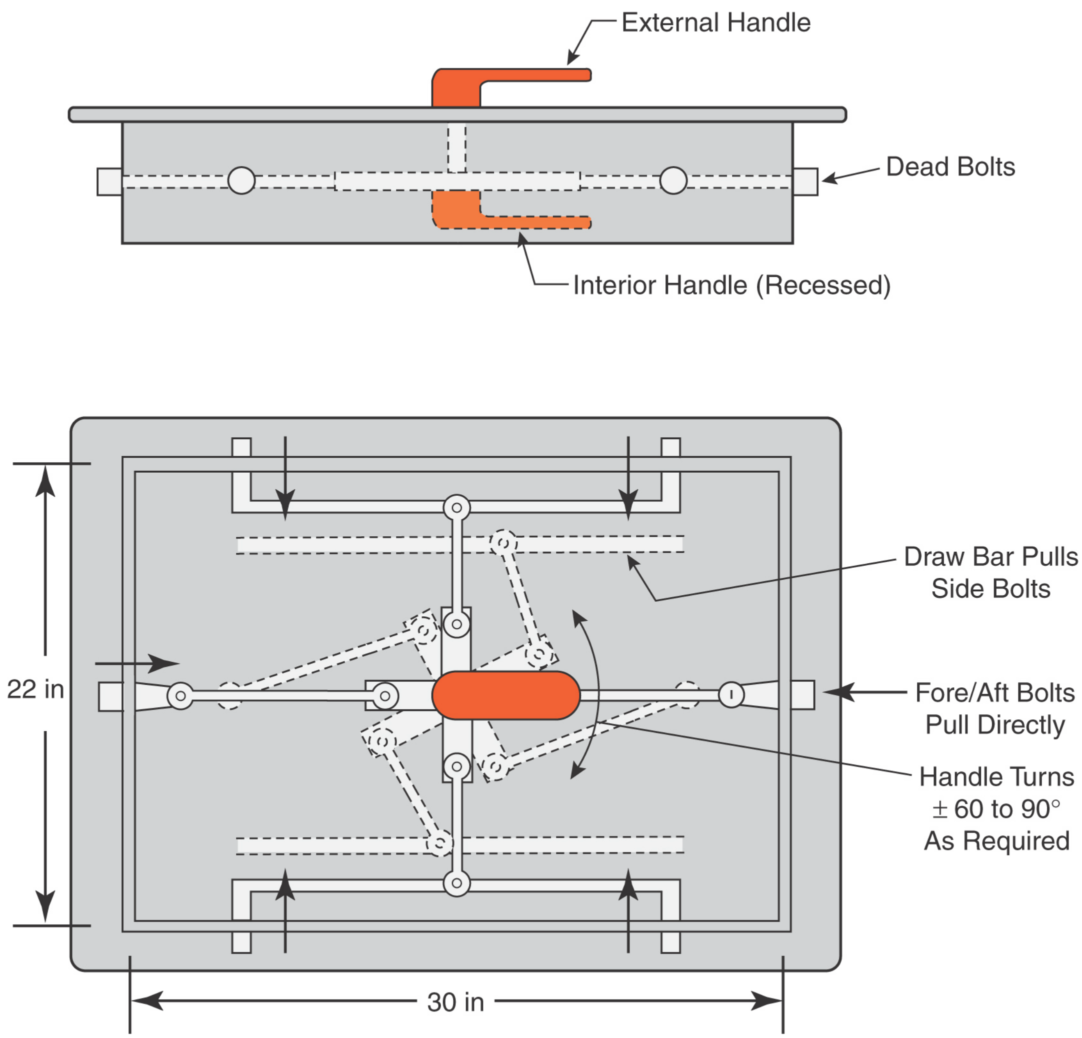


Figure 32. Revised Hatch Design

major design challenge in this case is providing toe clearance for a jammed rung while still providing noise abatement from the cab roof.

Design approaches for the locking device could be greatly simplified. In the stowed condition, a simple detent pin could be used to hold the rung in place. In an emergency, the pin would deploy over the rung to prevent it from refolding under load. A block below the hinge could be used as a support for the rung, providing ample strength for climbing.

Rung dimensions were altered slightly from the original design. To minimize any framing alterations required to install the hand/footholds, the rung width was reduced to 11 in. Based on the hand and foot width of a 99th percentile male, this leaves ample room to either grab a rung with both hands or stand on a rung with both feet. To make the rung more comfortable to use, the rung diameter was increased to 1¼ in. The rung surface could be roughened to provide a non-skid foot surface, but the level of roughness would need to be limited so it would still be useful as a handhold.

5.3 Windshield

As a means of access for rescue workers, the windshield is considered to be the next best option to the hatch. Feedback from the rescue personnel indicates that the windshield would be immediately targeted as a means of entry to a toppled locomotive. The firefighters main concern was for easy access while wearing equipment. This might, in certain situations, preclude access via the doors or "up-side" windows. From the view of the railroad crews, external windshield removal was considered a distant second to the hatch concept, since it was not useable from inside the cab. If implemented, their concern would be ease of use by non-trained "Good Samaritans" who would likely be on scene before professional rescue workers.

Utilizing this information, a removable windshield gasket is still considered the best option for outside access. The glazing itself would be removable from the outside with very simple tools, making it possible for passers by to remove. Design impact on the locomotive frame would be minimal.

5.4 Cost/Design Considerations

The present state of development of the design for the hatch system is not sufficiently detailed to allow for an in-depth analysis of its likely cost. However, it is possible to identify the cost implications of several aspects of the design. This preliminary study suggests the following cost implications:

- Modification of current locomotive designs to accommodate a hatch will likely require relocation of a few structural roof members and rerouting of wiring and air lines for wipers. This appears feasible and not likely to be a costly change.
- The current hatch design has internal rounded corners. From a structural perspective, the rounded corners will make it easier to incorporate a gasket and minimize seams and potential leaks. However, rounded corners require special dies and fixtures to produce and additional manufacturing operations, thus making them more costly to manufacture than square corners. The limited production runs of the locomotive manufacturers may not justify the added expense.
- Design of the combined seal and latching mechanism proposes challenges that may result in a costly solution. The proposed hatch is 22 in x 30 in. The length required to seal the perimeter of the hatch would be 104 in. The forces required to compress a seal of this length can become very high, placing considerable strain on the latching mechanism. The seal must secure the opening from air and water leaks while still allowing for quick release with one hand by a crewmember. Installation of the hatch cover may require more than one person, but this is not a major concern because this will not be a time-critical activity.
- If the hatch frame is distorted in a crash, the hatch cover may become jammed in the opening. Sloped edges on the hatch cover may help the release under these circumstances but a sloped-edge design will have a corresponding increase in the cost to

manufacture the hatch system. Another option is to allow extra space between the frame and the cover but this may compromise the effectiveness of the seal.

- The hatch cover must be designed so that it can support the weight of a railroad worker walking on it. This requirement may lead to the use of a high strength material that is more costly than the steel used for the roof. Alternately, the structural design of the hatch may become more complex, which would also affect the overall cost of manufacture.

6 Mockup

Construction of a mockup of a locomotive cab with the hatch system provided a means to conduct a preliminary assessment of its function. This section describes the mockup along with the results of initial testing.

6.1 Locomotive Cab Mockup

To evaluate the overall utility of the egress concepts developed under this program, a full-size mockup of a locomotive cab was constructed. As Figure 33 illustrates, the mockup is a wood-framed, plywood-sheathed structure representing a "composite" locomotive cab. The cab dimensions reflect sizes common to both GE and EMD locomotives currently in service. The cab interior is 9.5 ft wide, 6.5 ft from floor to ceiling, and 7.5 ft from the operator's console to the rear wall. In its current configuration, the rear wall has been removed to provide better viewing and access for testing. The mockup was constructed with openings for a roof hatch and hand/footholds in place. Currently, the mockup is built to represent the basic configuration of the operator's station, roof, windshield, and hood, and does not include the front doors, electrical switching panels, or seating. The design of the structure is such that refinement and expansion of the mockup is possible.

Top View Rear View

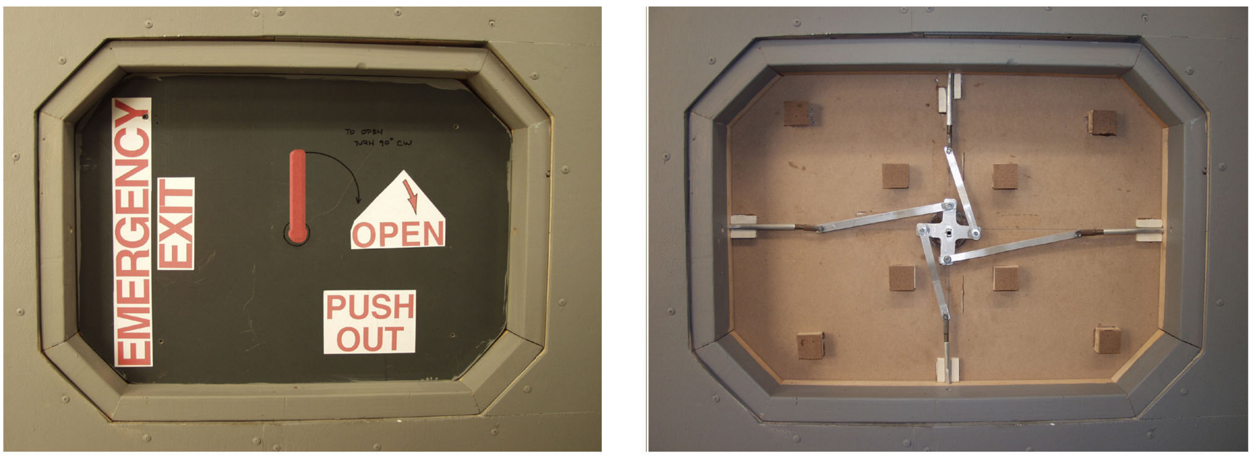
Figure 33. Locomotive Cab Mockup

Originally, the structure was assembled at Foster-Miller's Corporate Headquarters in Waltham. During the initial assembly, the mockup was oriented in the normal operational configuration. This allowed various aspects of the geometry to be compared to actual locomotive dimensions. Following this initial fit-up, the structure was disassembled and moved to Foster-Miller's

Locomotive Structural Test Facility in Fitchburg, where it was reassembled on its side. In this configuration, the mockup is in the orientation of a 90º rollover derailment, allowing evaluation of the conceptual egress equipment.

6.2 Roof Egress Hatch Mockup

A functioning mockup of a roof hatch, shown in Figure 34, was constructed for use in the toppled cab. As with the mockup itself, this hatch is wood-framed and plywood sheathed. A latching mechanism consisting of aluminum dead-bolts and a central cam allows all four sides of the latch to operate simultaneously. The cam can be actuated from inside and outside the cab by use of a handle.



Interior View

Latching Mechanism

Figure 34. Hatch Mockup

Prior to testing, a cover was fitted over the mechanism and appropriate placards for its use applied to the surface. The signage was designed to be informative to persons unfamiliar with its use, so they could readily identify the device, operate the hatch, and clear the opening for egress.

6.3 Hand/Foothold Mockup

Hand/footholds on the interior of the cab provide a means of reaching and utilizing the hatch. The hand/footholds are constructed of 1¼ in diameter wooden dowels, held in place by aluminum hinge brackets. The rungs are 11 in wide, and re-enforced with a full length of ¼ in diameter steel rod. The rungs are hinged so they can be folded flush to the ceiling when not in use, and folded down to allow access to the roof hatch as shown in Figure 35. An additional wood block is included in the mockup framing to provide positive locking of the rungs for climbing.

There are two hand/footholds below the hatch, and one above the hatch in the rolled-over orientation. The spacing between the hand/footholds is approximately 16 in. The single rung above the hatch was included for use as a climbing aid. In the fully outfitted cab, there would be

Folded   Actuated

Figure 35. Hand/Foothold Mockup

two rungs on either side of the hatch. As a visibility aid, the rungs were coated with reflective black and yellow tape.

6.4 Initial Concept Evaluation

To provide insight into the utility and effectiveness of the hatch and hand/foothold concepts, a limited sequence of testing was performed. These tests utilized a 50th percentile female subject and a 95th percentile male subject. Neither subject had railroad industry experience and both had limited prior knowledge of the egress program. Each subject was tested independently. In each case, the subject was given a brief orientation in an actual locomotive cab frame. The frame is an unfinished EMD locomotive currently under test at the same facility. The orientation of the test subjects consisted of a basic description of the cab layout, generally utilized egress routes, and the areas where egress would not be possible in a working locomotive. Following this, they were given a description of the roof hatch concept and the mockup orientation of the 90º rollover. They were *not* given any instruction on the use of either the hatch or the hand/footholds. Once the orientation was complete, the subject was placed in the mockup cab and instructed to escape.

6.4.1 Egress Test 1 - 50th Percentile Female Subject

The female subject unlatched the hatch without difficulty while standing on the side wall of the mockup. She did have some difficulty pushing the hatch out, due to lack of leverage. Once the hatch was pushed free of the opening, she climbed up the wall using the hand/footholds. She went out through the opening head first, grabbed an external framing member to pull herself up, and sat in the opening. She then brought her legs through, and climbed backwards down the roof of the cab. On the outside, it was necessary for her to grasp and step on the exposed framing to maintain balance and safety indicating a need for exterior grab irons. The escape sequence is shown from the inside in Figure 36, and from the outside in Figure 37. A total of 30 s elapsed between actuating the latch handle and clearing the opening after egress.

Figure 36. Egress of 50th Percentile Female Subject, Interior View

Figure 37. Egress of 50th Percentile Female Subject, Exterior View

6.4.2 Egress Test 2 - 95th Percentile Male Subject

The male subject unlatched and opened the hatch in less than 4 s. He folded down the hand/footholds below the hatch, climbed up to grasp the hand/foothold above the hatch, and pulled himself up to the opening. He then dropped his legs out through the hatchway, and lowered himself to the ground. The escape sequence is shown from the inside in Figure 38, and from the outside in Figure 39. A total of 15 s elapsed between actuating the latch handle and clearing the opening after egress.

6.4.3 Egress Test 3 - Simulation of Injured Crewmember

With the hatch removed, two brief simulations of injured crewmembers were attempted. These simulations were performed to establish the level of difficulty an injured crewmember might have in utilizing the hatch. The subject in this case was a 25th percentile male. It is important to note that in both cases, the subject was able-bodied, and simply limiting the use of his arms and legs. This subject was very knowledgeable in the design and usage of the hand/footholds.

Figure 38. Egress of 95th Percentile Male Subject, Interior View

Figure 39. Egress of 95th Percentile Male Subject, Exterior View

In the first simulation, the subject utilized the hand/footholds to egress the cab using one hand. In the second, the subject egressed the cab using only one leg. In both cases, the subject was able to maneuver through the opening and drop to the ground. The one-handed egress is shown in Figure 40, the one legged egress is shown in Figure 41. The one handed egress was relatively easy, but did require a degree of arm strength to accomplish. Pain caused by the injury would likely have made this egress much more uncomfortable. The one legged egress was much more difficult, and did require grasping of the exposed exterior framing to accomplish safely. In practice, this might not be possible without assistance.

6.5 Observations/Conclusions

Testing of the hatch and hand/footholds did show that with minimal knowledge and training, the devices were easy to use. None of the subjects had complaints about the location of either the hatch or hand/footholds. It should be reiterated that for this preliminary test, the subjects were not experienced railroad workers and were performing in an incomplete cab. Future testing will

Figure 40. Simulation of Injured Crewmember – One Handed Egress

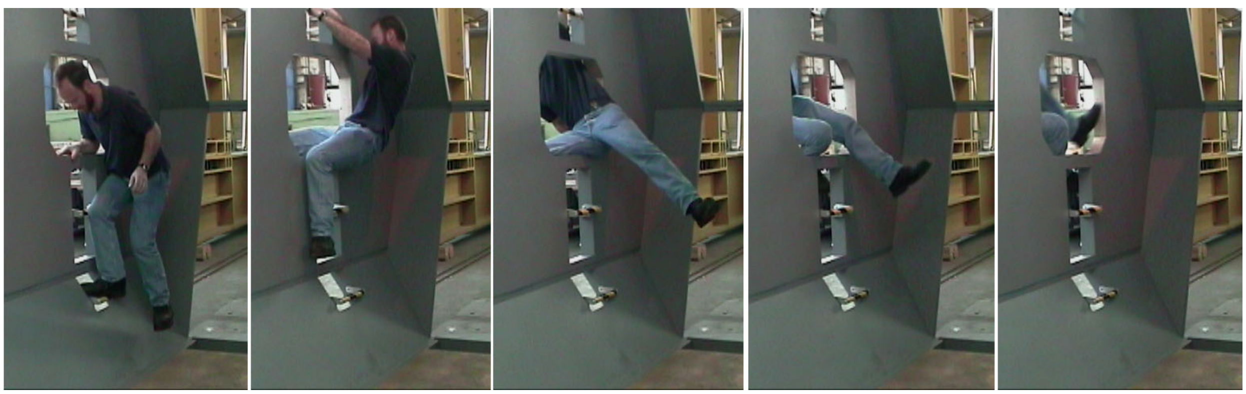


Figure 41. Simulation of Injured Crewmember – One Legged Egress

require actual train crews and a more fully fitted cab. The testing does indicate, however, that in their current form, the hatch and hand/footholds are practical and useful as a means of locomotive egress.

From the case of the female subject and the injured crewmember, it is clear that exterior grab irons would be a necessary addition to the egress system. In both cases, the subjects needed some means of exterior support to egress the cab and safely reach the ground.

7 Recommendations for Future Research

The results of this study suggest areas for future research relative to improved egress for locomotive crews. These are discussed below.

- *Prototype hatch system.*

  The mockup described in this report demonstrated the feasibility of the proposed roof hatch with a hand/foothold system to facilitate access to the hatch. The next step in the development of this concept is construction of a working prototype that can be used for operational testing. Progressing from the current mockup to a working hatch prototype will require detailed latch and seal designs, an overall framing structure for the hatch, enclosures, insulation and actuators. Design of the prototype hand/footholds will require consideration of rung sizing, hinging, mounting arrangements and locking devices. The goal should be to design the prototype hatch system as close as possible to the units that would ultimately be installed in new locomotives.

- *Roof strength verification.*

  In designing the mockup, the issue arose as to whether or not the hatch opening will diminish the cab roof strength. This issue must be a part of the overall design process for the prototype. One method for assuring equivalent strength will be to compare the structural performance of a typical cab roof with and without such a hatch opening. A finite element analysis of the roof, subjected to a series of simplified static overall roof loads such as shear, axial compression and panel bending, can be the basis of this analysis.

- *Usability testing.*

  The hatch system must be easy for crewmembers and emergency rescue personnel to use. Of specific concern are 1) access to the hatch from inside the cab in a rollover or partial rollover accident, 2) ease of operation of the release mechanism for uninjured and injured crewmembers, and 3) ease of egress through the hatch opening. Once the prototype is complete, a well-structured usability test can assure that the design meets specific operational criteria.

- *Improved emergency egress lighting.*

  Focus group participants emphasized that crew egress from locomotive cabs in an emergency or accident situation can be critically dependent on availability of adequate interior lighting. Consideration of the lighting issue was beyond the scope of the present study but it should be addressed in future emergency studies. Once a lighting design is identified, it can become a part of the working prototype hatch system described above.

- *Improved secondary egress equipment.*

  The program described in this report identified several areas where additional aids could enhance crew survivability in the event of an accident. In addition to the primary recommendation of a roof hatch and associated hand/footholds, proposed improvements include removable windshield glazing, and removable door hinge pins to enable the crew to cope with a jammed or distorted door.

Focus group participants felt that a removable windshield would be most useful if inside actuation by the crew were possible. Future research should explore the feasibility and design that would allow inside release of the windshield glazing. In a typical locomotive, release of the windshield would provide an opening of 17 in x 55 in.

Another secondary egress aid is a removable door hinge pin. Existing cab doors, including the side-facing doors on passenger locomotives, rear doors on freight locomotives and front cab doors on narrow-nose freight locomotives, all use side hinges attached to the cab structure. Some designs use a "refrigerator" style configuration in which the door overlaps the body. The refrigerator design resists jamming but distortion of the cab in an accident can freeze the door due to its fixed hinges and latch. If either a crewmember or a rescuer could remove the hinge pins, then a jammed door could be released and the crew could escape. Further research should examine the feasibility of hinge pins that can be removed from the cab interior. While outside removal of hinge pins is desirable for emergency rescue workers, there is a concern that vandals or intruders could have cab access with this feature. Removal from the cab interior is clearly the priority.

- *Training video for rescue workers.*

Contact with emergency rescue personnel revealed that there is a lack of training materials regarding emergency rescue from a locomotive. It is not a situation that emergency workers encounter frequently, but nevertheless they must be adequately prepared to deal with this type of situation. Moreover, in the future, emergency rescue personnel must be aware of the hatch system and the access that it will provide for accessing the cab. Given this situation, there is a need to develop a videotape to train emergency workers on rescue from the cab of a locomotive. The users of this training video will be primarily the Fire Academies in each state. Fire departments in areas where there is heavy train traffic, such as the Chicago area, might also have an interest in the video.

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Appendix A - Focus Group Questions

This appendix contains the list of questions used to guide the focus group discussions held with railroad labor.

Personal Experiences

- Tell us about a train accident that you were involved in. Describe the events leading up to the accident. Describe the situation immediately after the accident.
- What safety concerns do you have in the event of an accident while inside the locomotive?
- What concerns do you have about your personal security in the loco cab?

Hand/Footholds

Overall Concept

- How would this have helped you in the wreck you were involved in?
- What do you like about the design?
- What do you not like about the design?
- What potential problems do you see with this design?
- What are particular situations you think this design will be advantageous? Disadvantageous?
- Do you have any suggestions for improving the design?

For Each of the Three Designs

- How easy would this be to engage?

1	2	3
Difficult	Neither difficult nor easy	Easy

- What do you like about this design?
- What do you not like about this design?
- What potential problems do you see with this design?
- Do you have any suggestions for improving this design?
- What potential problems do you see with this design?

Overall Comparison

- Which of the three hand/footholds would you prefer to have in your locomotive?

Pullout	
Swing out	
Foldout	

- How would the handhold/foothold have helped you in the wreck you were involved in?

Roof Hatch with Hand/Footholds

- How easy would this be to engage?

1	2	3
Difficult	Neither difficult nor easy	Easy

- What do you like about the design?
- What do you not like about the design?
- What potential problems do you see with this design?
- What are particular situations you think this design will be advantageous? Disadvantageous?
- Do you have any suggestions for improving the design?
- How would this have helped you in the wreck you were involved in?
- How would you exit via the hatch?
- In what situation would you need an assistive device such as a rope or ladder to safely exit via the hatch in a rollover accident?
- *If anyone expressed concern about personal security*, Do you feel that an exterior lock should be a part of the hatch?

Removable Windshield

- What do you like about the design?
- What do you not like about the design?
- What potential problems do you see with this design?

- What are particular situations you think this design will be advantageous? Disadvantageous?
- Do you have any suggestions for improving the design?
- How useful would this have been in your accident?

Rank the Designs

- Which design do you think would give you the quickest escape?

Handhold/footholds	
Hatch with handhold/footholds	
Removable windshield	

- Which design do you think would allow for the quickest access for emergency responders?

Handhold/footholds	
Hatch with handhold/footholds	
Removable windshield	

Concluding

- Can you suggest any other methods of egress?
- Is there anything else that you would like to add to what we have discussed tonight/today?