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LOCOMOTIVE CAB DESIGN DEVELOPMENT
Volume III: Design Application Analysis

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16. Abstract

In Volume II of this series of reports on Locomotive Cab Design Development, changes were recommended in the layout and equipment content of locomotive cabs. This report studies the impact of these changes on the interface of the cab with the rest of the locomotive, the required structure, the reliability, the development costs, and the cost of introduction to the operating locomotive fleet. In addition, this report assesses the uses of various techniques of mockup use during the development phases of the design.

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PREFACE

The purpose of Contract DOT/TSC-913 is to develop a locomotive cab design based on the operator's functional requirements in train handling. A locomotive cab design has been developed through analysis of functional requirements based on human and other engineering disciplines. This document extends the design development process to include crew/ equipment/ locomotive interfaces, crashworthiness, reliability, cost, and mockup development. The author would like to acknowledge the assistance received from Dr. John P. Jankovich, the contract technical monitor, and Mr. Norman MacDonald of the Electro-Motive Division of the General Motors Corporation, the principal subcontractor.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

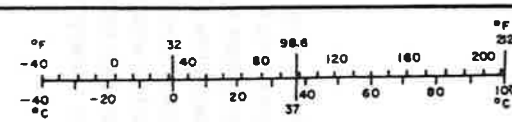


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This report was prepared under Contract DOT/TSC-913, Locomotive Cab Design Development. The new cab design is described in a previously issued document titled LOCOMOTIVE CAB DESIGN DEVELOPMENT, Volume II, ANALYSIS OF CAB ENVIRONMENT AND DEVELOPMENT OF DESIGN ALTERNATIVES (D339-10017-1). The human factors design recommended for further development includes changes to existing equipment in the standard locomotive cab. To assess the impact of these changes and further refine the cab configuration additional supporting analyses were done. These were:

a. Cab/locomotive Interface

b. Structure

c. Reliability

d. Cost

e. Mockup development

As expected, after reviewing the cab design some modifications of existing locomotives will be necessary to enable them to be used in a locomotive consist controlled by a locomotive with the new cab installed. Some problems were identified pertaining to mounting the new cab on existing underframes and mating it with the various locomotive assemblies and subassemblies that will require more detailed design analysis to resolve.

The design application analyses indicated, on a preliminary basis, that the new cab design was feasible and would serve the needs of the heavy rail freight jndustry that are likely to evolve during the next ten to fifteen years.

This report is presented in two parts: Design Application Studies in Part I and Mockup Development in Part II.

2. CAB 913/LOCOMOTIVE INTERFACES

An engineering analysis was conducted to examine the compatability of the new cab design with existing locomotives with emphasis on the propulsion and braking systems. The following items were examined:

a. Controls

b. Displays

c. Structure

d. Accessibility and equipment location.

2.1 CONTROLS

The design of the airbrake controls will require some modifications of locomotive airbrake systems. The independent braking system must be modified to incorporate the automatic release feature, not only to permit the installation of the new cab, but to enable the new cab to control the trailing locomotives in the locomotive consist.

The train brake system must be modified to permit service reductions of up to 35 psi depending upon initial brake pipe pressure. The 26 L braking valves do not presently accomplish this. They permit only a full service reduction of approximately 23 pounds, which is not sufficient to achieve equalization with todays higher brake pipe pressures.

The continuous function of the throttle controller should not present any new problems as all recent road locomotives, for example, employed on the Chessie System now have a similiar power control feature. In that application, however, the power reduction control requires the addition of a rheostat and is in effect an additional control device.

The emergency brake pushbutton must be designed to ensure operability under all conditions including a failure of the locomotive electrical system.

The reverse control panel functions should interface electronically with the locomotive subsystems regardless of how the controls on the main panel are implemented. There is a potential serious problem with this device if the design is not thought out carefully. For example, cables and wires may become twisted, frayed or broken as the unit is stowed and unstowed in the side wall. In addition the locking mechanism (90 degree position) must be constructed to withstand both normal daily use; i.e., should not move or jiggle under the engineman's hand, and contact with his body in the event of excessive train action such as a run in. Therefore, during manufacture precautions must be taken to ensure that the device's wire runs and locking mechanisms are able to withstand the rigors of use in the cab environment.

The overhead panel presents no serious problem. The braking system controls, such as the MU-2 valve and cutout valve, that are currently pneumatic on production cabs, have been engineered for electrical control on the 26 EL brake system.

The detailed engineering design of all the controls must be such as to ensure that they fit in their allocated panel space.

2.2 DISPLAYS

To implement the design of the power/drawbar force indicator, some type of integration must be accomplished to display the worst case in the locomotive consist for power and true drawbar force at the last coupler in the consist. This information will probably require trainlining the data and a signal conditioner to drive this display. There are in existence today, locomotive consists with power/force indicators installed. These consists are kept together as units because of the necessary modifications to the locomotives to accept the device. The present recommended design carries the concept a step further, rather than offering a radical alternative, with the requirement that the engineer not be made to make mental computations and data extrapolations because of the potential for error that has severe consequences.

The remote control panel has a power/drawbar force indicator. Its function is to provide information from a remotely controlled locomotive loacted in the center or at the end of the train. Therefore, the data from the remote locomotive must be passed to the controlling unit either via hardware or radio frequency transmission.

The annunciator panel may have to be expanded to include information on which locomotive in the consist is afflicted with a particular fault and the nature of the fault. This information would have to be trainlined.

The train handling display will require a significant interface with the hardware and software that would require development to make this device perform to specification. For example, the system must be capable of receiving train data in real time, processing it and providing the information to the engineer. In addition the system must provide the capability to store information prior to beginning a run, such as grade, curvature, and train tonnage distribution. The system must be provided with a means to update it either directly by the engineer (mile post position,for example, or from the wayside, (hot box detection), or both (train makeup).

A significant addition in the hardware and software capability to transmit real time train information to the engineman will be required to implement the cab features described above. Implementation would take place on both the locomotive and rolling stock. For example, if additional train data is trainlined either the conventional 27 pin connectors must be modified or digital multiplexing techniques considered. It is reasonable to assume that locomotives of the future will probably contain a microprocessor with the necessary peripherals to handle the potential array of data available. The man/software/hardware interfaces will have to be carefully defined to implement an optimum selection and presentation of information to the engineman.

As shown in the Table 2–1 and discussed previously, the video display requires the most extensive development. The none category in the above table indicates that hardware items exist off the shelf and that no further development is required to establish a proper interface with the locomotive. The minor category indicates that some relatively small modifications are required to the locomotive to accommodate the device. The major category indicates that although the hardware and technology exist further engineering analysis is required for development in the present application. The new category was defined to indicate that in depth engineering analysis would be required in the areas of sensing, transmitting, data integration display techniques, and hardware for providing additional information concerning the train and right of way to the engineman.

2.3 STRUCTURES

The additional weight of the added crashworthy structure presents a problem with respect to balancing the mass of the locomotive. Major components may have to be shifted to maintain equal weights on each axle. Various strategies for balancing the locomotive with the new cab added should be examined along with considerations of new lightweight materials, advanced construction techniques, and use of composite materials. It should be noted that EMD now adds ballast to the short hood of production locomotives because present cabs are very lightweight. Installation of the new cab on the underframe may present a problem because production underframes have only a single center sill while the new design has two side sills. Design studies should be done to determine the best way to transfer loads in the event of a collision to these side sills. Finally, it is recommended that for anticlimbers to be effective all locomotives should be equipped with them.

2.4 EQUIPMENT ACCESSIBILITY AND LOCATION

There is a high voltage electrical cabinet located behind the locomotive cab. In today's production locomotives access to this cabinet is through covers located on the rear wall of the cab. In the new cab design this mode of access is prohibited because of the location of the lavatory, refrigerator and storage area against the rear wall. There are no control features necessary for operating the locomotive are located in this cabinet. Most of the controls that were formerly located on the rear wall have been moved to the engineman's control console. Fuses and circuit breakers are located in a separate compartment in the lavatory area. The electrical cabinet, however does contain electrical equipment, such as, printed circuit boards, relays, contactors, resistors, capacitors, etc., that require inspection, test, repair, and replacement by maintenance crews. This means access should be provided for maintenance purposes. The access should be designed to permit maintenance personnel to troubleshoot the locomotive electrical systems while the locomotive is moving.

Access to air brake equipment and batteries located under the cab floor is presently accomplished via a floor hatch in the rear of the cab. Air brake equipment installation may have to be modified to permit access from the side. There appears to be sufficient space under the cab to do this.

The short hood on production locomotives may typically contain the following items:

Table 2-1. Design Development Required for Compatibility

Item	None	Minor	Major	New
Direction Lever		X		
Throttle/Dynamic Brake Thumb Wheel		X		
Train Brake Lever		X		
Independent Brake Lever		X		
Horn Foot Pedal		X		
Bell Knob	X			
Sand Pushbutton	X			
Emergency Brake Pushbutton		X		
Engine Stop Pushbutton	X			
Lock and Key		X		
Brake Pipe and Equalizer Reservoir Pressure Indicator			X	
Main Reservoir Pressure Gage		X		
Brake Cylinder Pressure Gage		X		
Power/Force Indicator Gage			X	
Speedometer Gage			X	
Brake Pipe Vent Annunciator and Auditory Signal			X	
Air Flow Gage		X		
Instrument Lighting	X			
Video Display				X
Reverse Control Panel			X	

a. Toilet

b. Sand box

c. Speed recorder

d. Air brake cut out corks and associated piping

e. Radio chasis

f. Automatic train control (ATC) electronics

g. Spare knuckles

h. Spare air hoses

i. Large wrenches

j. Tool box

The new design should include provisions for relocating these items as it has no short hood. As noted previously, the toilet has been relocated to the rear wall of the cab. The tool box, for example, could be relocated to the engineroom. ATC devices, speed recorder and radio chasis should be relocated to the electrical cabinet. Air brake cocks should be relocated to provide access by the engineman and piping rerouted. The air cocks must be accessible to the engineman because they must be adjusted in the event of a penalty air brake application on tracks where ATC is implemented. They should also be accessible under the worst possible condition, namely, a penalty air brake application on a single track bridge.

To summarize the control and display interfaces in terms degree of development required to make them compatable with present locomotives Table 2-1 was prepared.

2.5 LOCOMOTIVE

Assuming that the new cab design is implemented, it is reasonable to present an assessment of the changes required to a production locomotive to enable them to be compatable. The following tasks would have to be accomplished to achieve this. These tasks were supplied by EMD based on drawings and sketches of the new design that were submitted to them and their inspection of the cab mockup.

Cabless Locomotive

1. Delete complete cab

2. Delete complete short hood

3. Delete toilet

4. Delete cab heater piping
5. Delete battery boxes but retain batteries. Provide tray bases.
6. Delete handrails, but retain 27 point receptacle at front end.
7. Delete pilot and front steps. Replace with end sheet and ladders as per rear of SDP-72 locomotives.
8. Delete cable harnesses to cab, class lights, ground lights, etc. on front end.
9. Retain complete high voltage cabinet including doors.
10. Retain complete sub base air equipment. Cap off lines to cab. Provide bracket for components normally hung from the floor.
11. Retain cable harness to 27 point receptacle on front end.
12. Retain front sanding lines and sand traps, but not sand boxes. Provide sanding magnet and valves.
13. Move hand brake (wheel type) to end of long hood operating No. 2 truck.
14. Move filter behind fireman's side of cab to provide clear walkway back along left running board of locomotive.
15. Provide temporary shipping cover over sub base, batteries, front deck and front surface of high voltage cabinet.

The slant of the collision posts from a structural and diversion of energy standpoint is probably not optimum. A more shallow sloping post would be better for crashworthiness. However, the effect on visibility and cab layout would have to assessed.

The anticlimber as it now is shown in the layout should extend further forward to be more effective in catching climbing vehicles. The anticlimber with its interlocking plate concept is good, however other locomotives, freight car and cabooses do not have compatible type anticlimbers. The interlocking plate concept would require all vehicles to have this type anticlimber. The question then arises what happens to the vehicle that is trapped by the anticlimber? Are more fatalities caused by this new anticlimber?

The amount of structure added to the locomotive approaches 14,000 pounds for this cab concept. The effect on the operation and design of the locomotive must also be evaluated. Adding this much weight to one end of the locomotive requires additional weight to be distributed elsewhere on the locomotive. What effect does this have on the axle loading? The present GP-40 axle loading is approximately 75,000 pounds per axle.

The entire concept must be evaluated during detail engineering design for its impact on the human factors design with respect to visibility, cab controls and crew location. The impact of costs for new locomotives and for retrofitting old locomotives could be quite large. The effects on the proven efficient underframe design must also be looked at. Cost benefit studies for installing the crashworthy cab on all locomotives are shown in Section 5 of this report.

3. STRUCTURE

Early in the design development process it was recognized that providing the engineman with improved visibility might compromise the structural integrity of the new cab design. Therefore, both concepts were studied very early in the design development program with the objective of providing acceptable visibility from the cab while maintaining a crashworthy environment. Conceptual studies and preliminary structural analyses were developed based in part on Contract DOT/TSC-856, Structural Survey of Classes of Rail Vehicles for Crashworthiness. Because the cab design is conceptual, no detailed engineering drawings were made of the structure or analysis attempted. However, structural concepts were considered as shown in Figure 3-1, based on some preliminary assumptions concerning improvement of the cab from a structural crashworthiness standpoint. The object of the cab structure is to protect the crewmen by maintaining a survivable volume primarily in a collision environment where a climbing vehicle is impacting the locomotive. As illustrated in the figure, ways of achieving this objective include, deflector type designs that would keep the climbing vehicle from impinging on the cab structure; an anticlimbing system that would not allow climbing but would trap the vehicle before it could rise from the tracks; designing the structure to deform under load while not intruding into the occupied area.

From analyses and data reviews, certain areas that could be improved were identified.

1. All cab superstructure members should be provided with a load path to the underframe. This includes the roof, sides and collision posts.

2. Stronger collision posts are required in addition to better attachments to the roof and underframe. They should be slanted at some optimum angle.

3. A more effective anticlimbing system should be utilized. Compatibility between anticlimbers of freight car and cabooses with locomotives is non-existent.

4. Sides and roof should be provided with rollover protection.

5. Antitelescoping plates in the roof of cab.

6. Welds and joints should allow maximum load development of attaching members.

7. Underframe must have a controlled collapse design.

8. Hard nose plate and horizontal members between collision posts that would prevent penetration.

Of all the items listed above, the controlled collapse of the underframe would require the most extensive redesign when compared to the present GP-40 or SD-45 locomotives. For the sides to have direct load paths to the underframe, it would require the addition of side sills and

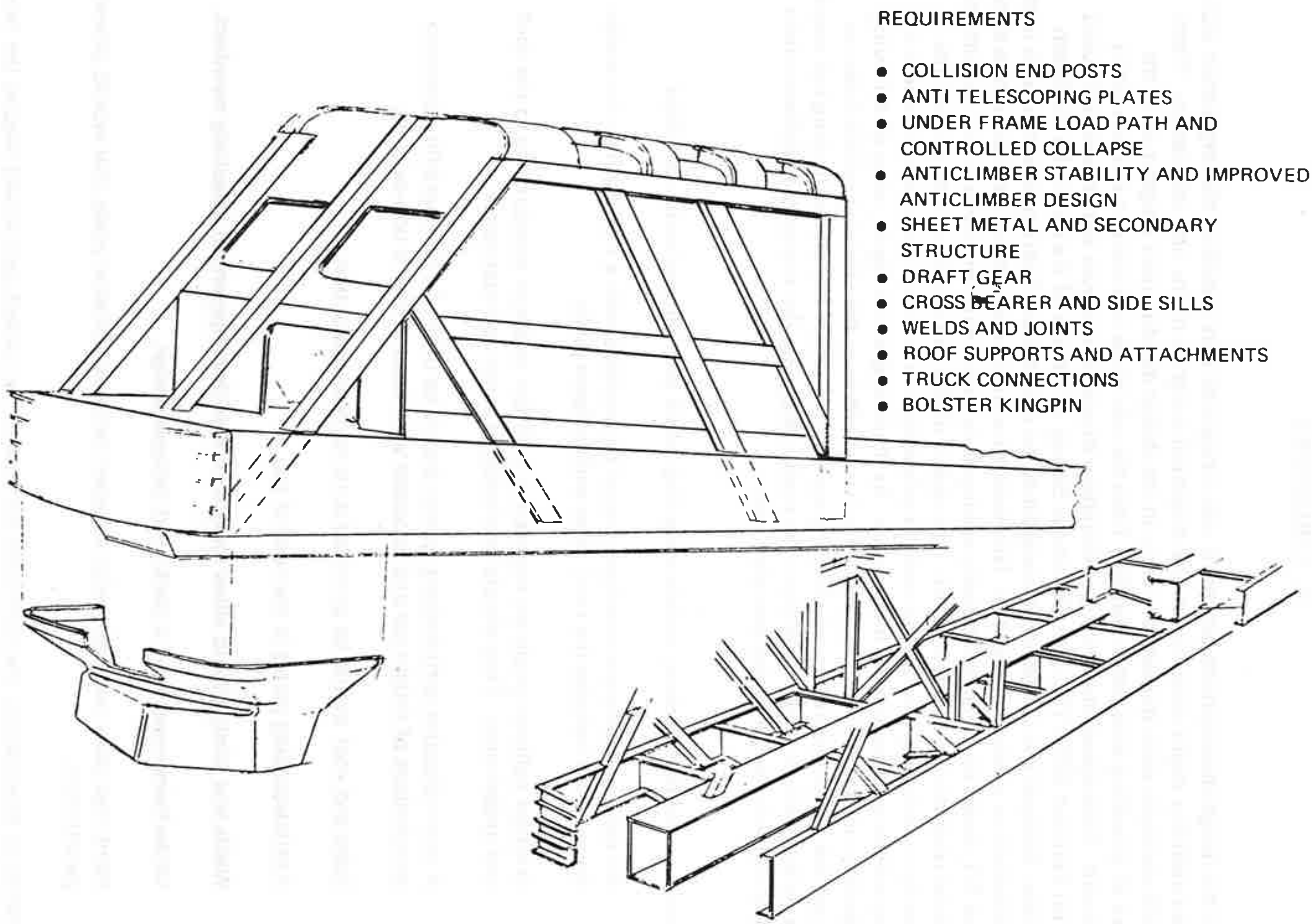


Figure 3–1. Possible Structural Layout for Baseline Crashworthy Cab

probably shear plates in the cab area. It would be very difficult to attach the cab shown in Figure 3-1 to today's underframe and have load paths to the underframe.

The approach to the crashworthy cab was to determine how much room was available for structural members as shown in the layout while maintaining cab visibility established during human engineering analysis. The idealized structure is shown in Figure 3-2. The basis of the analysis would be that collision and climbing would occur. No attempt was made to redesign the underframe. The failure load and energy characteristics would have to be determined and compared with the present locomotive.

It was determined that 8 inches x 10 inches rectangular member could be fitted in the room allowed. Wall thicknesses of these tubes were varied from 1/4 inch to 1/2 inch and material strength of 27,000 psi, and 36,000 psi were used. The geometry of the cab is shown in Figure 3-3. Figure 3-4 shows the increased failure load and energy absorbing capability for the improved cab. No attempt was made to develop the load capability into the underframe. More analyses and testing is required to really understand these concepts. Different loading cases should be looked into involving combinations of vertical and longitudinal loading on the cab. The rear bulkhead must be investigated for transferring the loads down into the underframe.

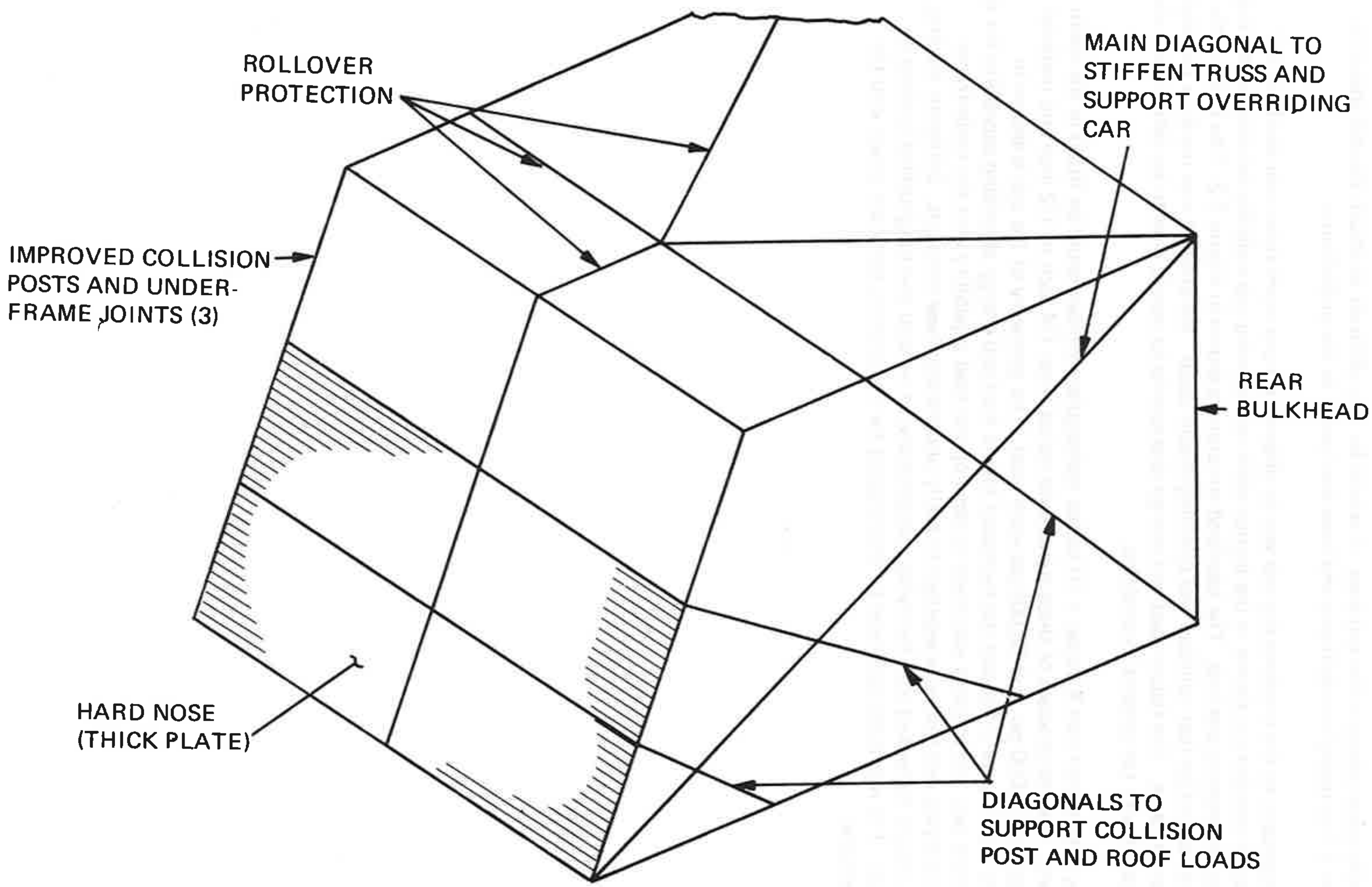


Figure 3–2. Improved Locomotive Cab Structure

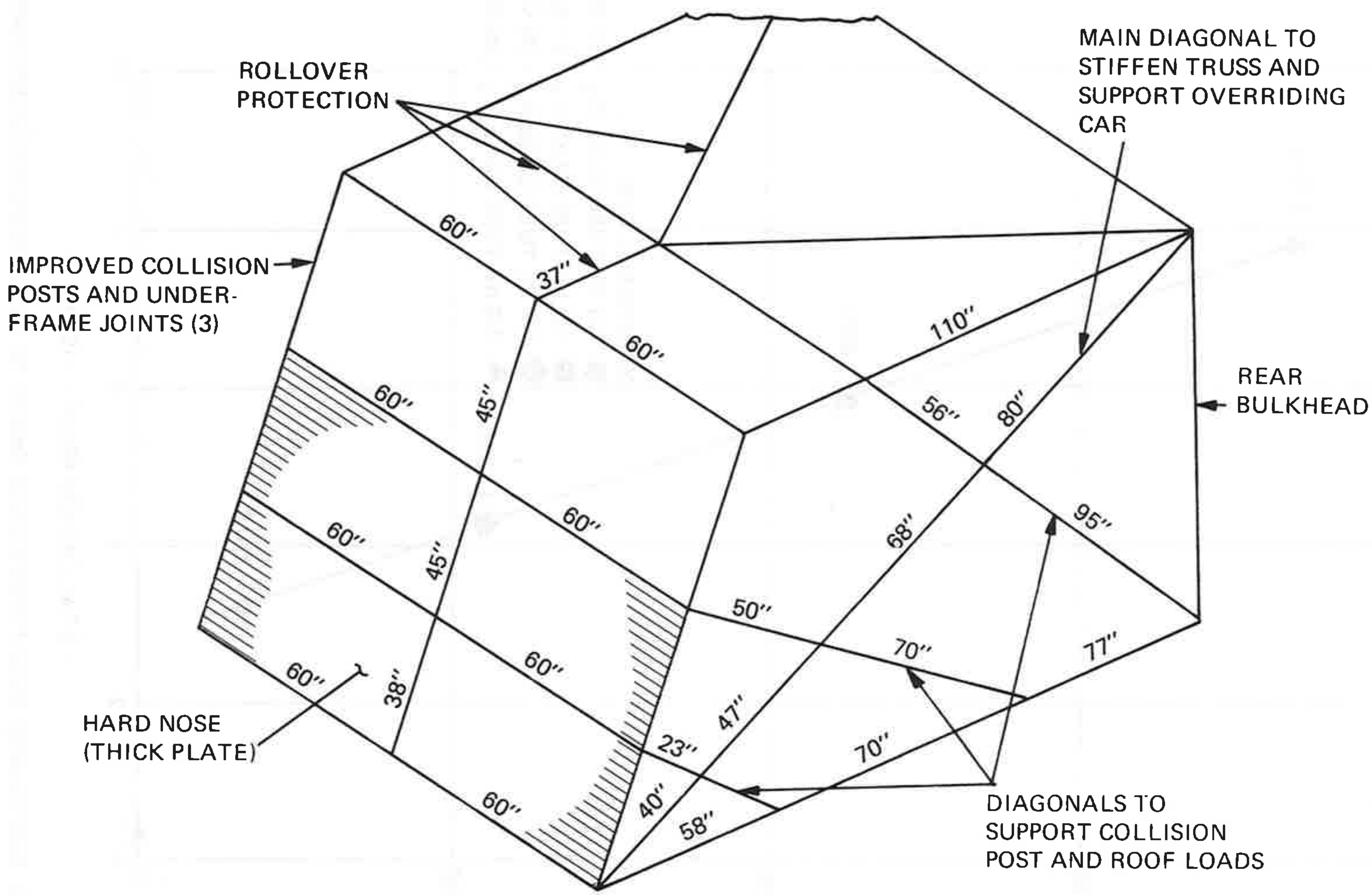


Figure 3–3. Improved Locomotive Cab Structure Geometry

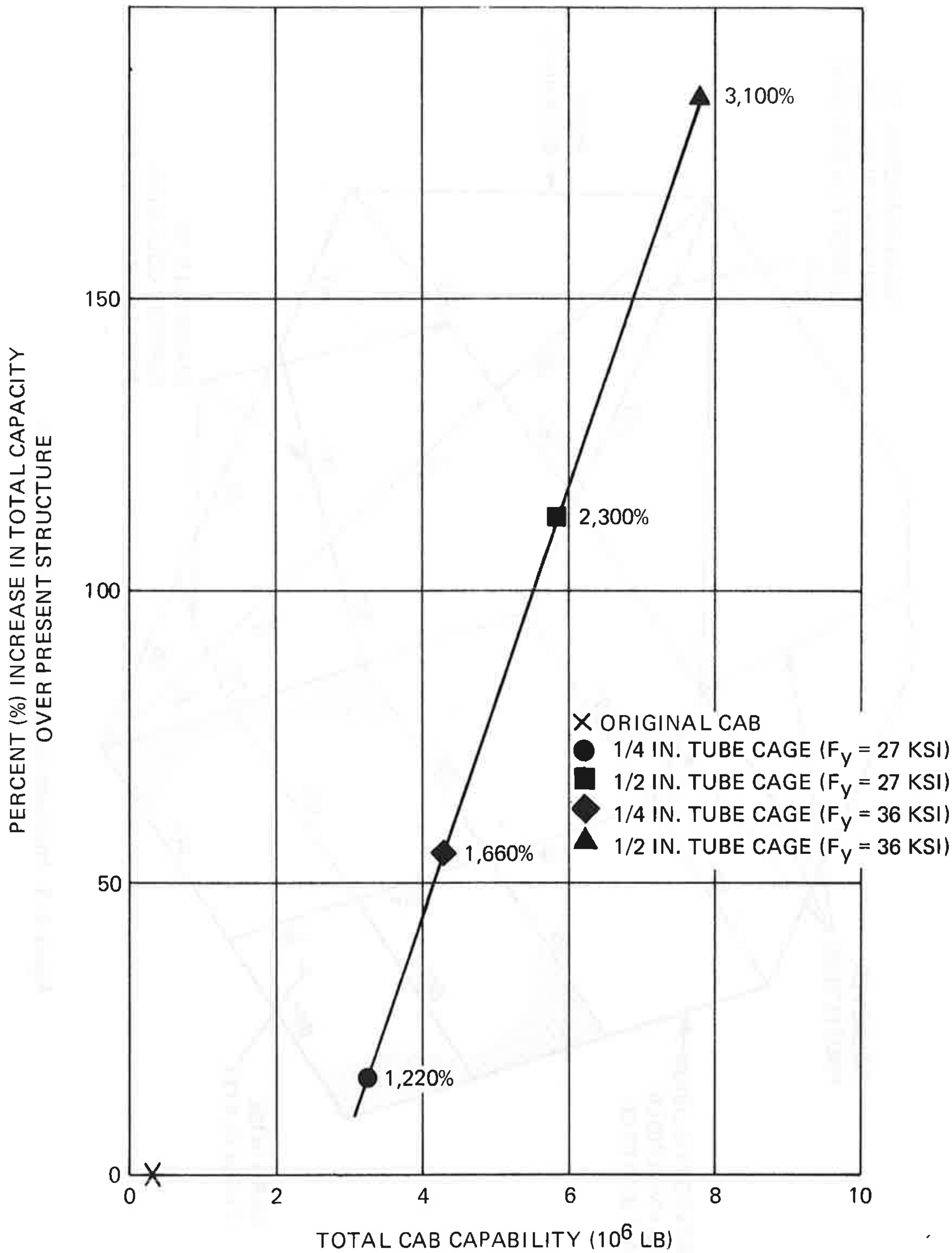


Figure 3–4. Total Capacity Versus Percent Increase Capacity for Various Improved Cab Structures

4. RELIABILITY

4.1 INTRODUCTION

To evaluate the reliability of the new cab design an analysis was made which compared the standard cab to the new cab on an item for item and subsystem for subsystem basis where applicable. The analysis was conducted using the limited data available on the standard cab and recognizing that the new cab design had not advanced beyond the conceptual stage. It should be emphasized therefore, that even though the analysis was performed and the available data used as judiciously as possible, the prediction reliability for the new cab is a best estimate constrained by these two foregoing factors.

4.2 DATA SOURCES AND METHODOLOGY

4.2.1 Standard Locomotive Cab

Failure data on the standard cab was acquired from the Electro-Motive Division of General Motors and included data on vehicles shown in Table 4-l.

Failure history on each of 34 cab items/subsystems was supplied by each of these operating agencies. These data were compiled from parts usage records in some instances, and from estimates made by mechanics and maintenance foremen in others. Based on recommendations from EMD, it was assumed that one locomotive averages 140 running hours per month, or 1,680 hours per year and this rate was used in the subsequent derivations.

A typical entry in the raw data sheets received from each operating agency is as follows:

"CONTROLLER MECHANISM – Two failures per month"

This converts to a failure rate of $\frac{2}{140}$ = 0.01428/hour for that operating agency's total fleet of vehicles.

The data was further reduced by weighting on the assumption that the most accurate records would be maintained by the agency having the largest fleet of locomotives.

An example of data reduction for each item/subsystem is contained in Table 4-2. The Controller Mechanism rate of 0.01428/hour given is the example above is shown as the second entry in the F/Hour columns.

Failure rates per item/subsystem calculated in the manner detailed in Table II are contained in Table 4-3.

$$\text{Total failure rate for one cab therefore} = \sum_{i=1}^{n} F_i Q_i ,$$

Table 4–1. Locomotive Data Bank Sample

No.	Operating Agency (Railway)	Shop	Locomotives Sample Quantity	Typical Operation Hours/Year
4	C&NW Ry	Proviso, Ill.	350	538,300 Hrs.
2	Chicago, Milwaukee St. Paul & Pacific	Milwaukee Shops	60	92,280 Hrs.
3	Burlington Northern Railroad	Clyde Shop Excero, Ill.	250	384,500 Hrs.
1	Illinois Central Gulf Railroad	Woodcress, Ill.	243 700*	373,734 Hrs. 1,076,600 Hrs.
		Totals	1,603	2,465,414 Hrs.

*Investigated for pneumatics items only.

where F_i = Failure rate of the "i" th component

Q_i = Quantity of the "i" th component in one cab.

i = line item/subsystem

n = quantity of adjusted rates

= 0.362811 Failures/Hour or 36.284/1,000 Hours

Table 4–2. Data Reduction Example

Abbreviations:

OA	–	Operating Agency
NOC	–	Number of Cabs
QPC	–	Quantity of Components per Cab
TN	–	Total Number
F/Hr	–	Failure rate per Hour
F/Hr/C	–	Failure rate per Hour for Component
W.F.	–	Weighting Factor derived from data sample fleet size

Controller Mechanism

OA	NOC	QPC	TN	F/Hr	F/Hr/C	W.F.	(W.F) (F/Hr/C)
1	243	1	243	0.114	0.0004703	4	0.0018812
2	60	1	60	0.01428	0.0002380	1	0.0002380
3	250	1	250	0.0148	0.0000595	4	0.0002380
4	350	1	350	0.0571	0.0001632	6	0.0009796
			903			15	0.0033368

$$\text{Controller Mechanism Failure Rate/Hr} = \frac{0.0033368}{15} = 0.0002225$$

In reviewing these field data, it appeared that 90 percent of the items were expected to fail and to be replaced over regular intervals during the first 10 to 15 years life of those locomotives. This being the case, then these locomotive components have essentially a constant failure rate after installation, consequently the exponential failure distribution has been assumed to apply.

4.2.2 Improved Human Factored Locomotive Cab (TSC 913)

Using the mockup of the new cab and a list of components and their functions, failure rate estimates of all the components in the new cab were made. Where like items were used in both cabs the estimated failure rate for the standard cab was used. In order to relate as closely as possible to the train environment, averages from the Naval Fleet Systems, Failure Rate Data Handbook (FARADA), MOBILE GROUND EQUIPMENT section were used for most other non-identical items.

Table 4–3. Standard Cab Failure Rates

Standard Cab Failure Rates* (F_iQ_i)	
Controller Mechanism	0.2224/1000 operating hours/cab
Roller Switches	0.1469
Dynamic Brake Rheostat	0.0357
Air Brake Valves	0.5504
Sanding Switches	0.0255
Bell Valves	0.0388
Air Gauges	0.5664
Brake Pipe Flow Gauge	0.3013
Speedometers	0.5543
Loadmeters	0.0547
Cab Signal Indicators	0.4584
Radio Control Head	1.1060
Generator Field Ect. Switches	0.0457
Cab Heaters	2.1641
Windshield Wipers	8.9511
Traction Motor Cutout Switch	0.0099
Isolation Switch	0.0141
MU Valve & Cutout Lock	0.2041
Light Switches	0.1025
Dimming Rheostat	0.0915
Headlight Controls	0.1628
Headlight Setup Switch	0.0165
Seats	12.3841
Flooring	No Problem
Glass	1.9917
Door Latches	1.3059
Hinges	0.6283
Slidng Sash and Hardware	1.3554
Horn Valve	0.0831
Water Cooler	0.2284
Sun Visor	2.4810
Airconditioning	Not installed
	Σ 36.2811

*Hot engine and light bulbs exhibit very high failure rates in present day cabs. Recognizing that the new cab design will likely include additional light sources, it is recommended that the use of longer life light bulbs be considered during detail design of cab components.

Table 4-4 contains a list of the new cab components and their estimated failure rates.

In all cases where failure rate estimates are given, a failure is defined as "any malfunction which requires a maintenance action to correct." Because of the limitations of the data and the conceptual nature of the new design, it is not possible to quote rates for either schedule reliability or safety. It is feasible only to address failures in these categories in a general sense. At a later stage, when the design is firmer, Failure Mode and Effects Analyses and Fault Free Analyses, which take into account the presently undefined redundancy, can be performed and estimates for schedule reliability and safety can be made.

4.3 COMPARATIVE ANALYSES

The new cab design includes the following major changes to existing equipment in the standard cab.

Component	Change and Reliability Impact
Roller Switches	*Replaced by integrated circuits designed for train environment.
Cab Heater	Removed from cab in new design to other location in locomotive.
Water Cooler	Replaced by cold water bags or bottles taken aboard at train stops.
Equalizing Reservoir and Brake Pipe Pressure	Combined into signal vertical tape instrument in new design. No significant change in reliability.
Emergency Brake Control	Separate from train brake in new design. No change in reliability.
Independent Brake Control	Controls brake cylinder pressure during brake service applications in new design. Negligible effect on reliability.
Throttle and Dynamic Brake	Both functions are controlled by a recessed wheel that enables continuous control rather than incremental. No effect on reliability.
Loadmeter and Power Force Indicator	Both are combined into a single duplex meter. Negligible effect on reliability.

NOTE: *All vital circuits in Boeing designed trains are integrated circuits.

The following items in the new cab design are additional to the standard cab parts list.

Component	Change and Reliability Impact
Cab Signal Display	Electronic device which projects images on small screen. Reliability estimate is good but test program will be required.

Table 4–4. Proposed Cab Failure Rate Prediction

Item	Component FR (F/1000 Hr/Unit)
Main Control Panel	
Air Brake Valves	0.5504/1000 operating hours
Sanding Button	0.064
Train Brake	0.121
Independent Brake	0.121
All Eng. Stop Button	0.064
Interlock Button	0.024
Remote Control Panel Switch	0.024
Throttle	0.050
Direction Liner	0.026
Emergency Stop	0.024
Bell Control	0.469
Console Lock	0.100
Feed Valves	0.098
Main Display Panel	
Ind., Brake Pipe Air Flow	0.280
Ind., Main Reservoir Pressure	0.128
Ind., Equalizer Reservoir Pressure/Brake Pipe Pressure	0.800
Ind., Brake Cylinder Pressure	0.128
Brake Condition Annunciator	0.080
Speedometer	0.277
Cab Signal	0.200
Ind., Power Drawbar Force	0.370
Timer	0.073
Secondary Display Panel	
Radio	0.725
Train Handling Display	0.574
Caution/Warning Advisory Panel	0.200
Overhead Auxiliary Control Panel	
Dynamic Brake Cutout Switch	0.020
Gen. Field Switch	0.020
Eng. Run Switch	0.020
Fuel Pump Switch	0.020
Ground Relay Reset	0.026
Cab Temp. Control	0.340
Air Conditioner Switch	0.024

Table 4–4. Proposed Cab Failure Rate Prediction (Continued)

Item	Component FR (F/1000 Hr/Unit)
Heat Switch	0.024/1000 operating hours
Class Lights Selector	0.024
Traction Motor Cutout	0.024
Eng. Condition	0.024
MU - 2 Valve Selector	0.024
Cutout Valve Selector	0.024
Windshield Wiper/ Washer Selector	0.048
Windshield Deforg/ Deice, Switch	0.020
Cab Dome Lights, Switch	0.020
Number Lights Switch	0.040
Step Lights, Switch	0.040
Platform Lights, Switch	0.020
Instruments Lights, Switch	0.024
Panel Lights Selector	0.024
Head Light Control Switch	0.040
Head Light MU Set-Up Selector	0.024
Head Lights Slew Switch	0.026
<u>Helper Consist Control Panel</u>	
Helper Emergency Brake	0.024
Lamp Test	0.024
Train Brake	0.121
Independent Brake	0.053
Alarm	0.064
Ground Relay	0.064
Ind. Drawbar Force	0.200
Interlock, Control	0.024
Throttle, Control	0.050
Override, Control	0.064
Sand, Control	0.064
Air Brake Feed Valve	0.104
System Test	0.064
MU - Ind. Control	0.024
Panel Power	0.064
<u>Remote Control Panel</u>	
Extension Arm	0.150
Emergency Stop	0.024
Direction Liner	0.026
Train Brake	0.100
Independent Brake	0.100
Throttle	0.100

Table 4–4. Proposed Cab Failure Rate Prediction (CONCLUDED)

Item	Component FR (F/1000 Hr/Unit)
Direction Liner Switch	0.026/1000 operating hours
Speedometer	0.277
Cab Signals	0.200
Lighting Switch	0.053
Heating/Air Cond. Switch	0.350
Emergency Brake Valve	0.108
Communications Handset	0.431
Toilet/Washbasin	0.400
Refrigerator	0.023
Drinking Water Faucet/ Plumbing	0.200
Sun Visors	2.000
Windows	1.593
Windshield Wipers and Motors	7.168
Doors and Latches	1.200
Flooring	---
Seats	12.3841
	34.4225

Train Handling Display	Cathode Ray tube provides information on grade, curvature, drawbar forces and brake pipe pressure to engineer. Reliability estimate is good but test program will be required.
Timer	Time speed and distance calculator to check speedometer error, short time ratings on power pointer and to time brake tests. No serious reliability problems anticipated.
Speedometer	Extra speedometer provided in new design. Will provide, in conjunction with timer, speedometer redundancy. Will improve mission reliability
Reverse Control Panel	Provides controls for operating the locomotive in reverse. The panel itself is expected to exhibit good reliability. The extension arm will be discussed later.

4.4 INTERFACE

No reliability problems are expected with either the cab signal display instrument or the train handling display instrument. The means employed however, of getting the required signals from the locomotive to these instruments may necessitate some engineering refinement. The arm which supports the reverse control panel is also of concern to reliability. The panel normally housed against the wall of the cab, is extended on an arm for reversing control. The conduits carrying the wires to the panel could be bent, pinched or dented during the extend and stow motions of the arm causing internal shorts and opens in the wiring. Careful attention to detail design during the design process will obviate these potential problems.

4.5 MAINTENANCE RELIABILITY

The comparative failure rate calculated for the standard cab is 36.28 F/1,000 hours and the comparative rate estimated for the proposed cab is 34.42 F/1,000 hours. The difference between the two rates of 1.86 can almost be accounted for by the removal from the cab of the cab heater which has a calculated failure rate of 2.2/1,000 hours. It is believed therefore, that the failure rate of the new cab will be no worse than that of the standard cab. It should be emphasized that the rates predicted for the new cab are mature rates i.e., expected failure rates after the debugging phase has ended. These reliability estimates are based on a conceptual design and would be established in more detail in the course of later design phases.

4.6 MISSION RELIABILITY

In those areas where major changes have been made and where new items of equipment have been added consideration shall be given to redundancy of wiring, control rods and the like to ensure that these changes and additions do not degrade the effectiveness of the locomotive to complete its mission. The addition of a second speedometer and the ability to check the accuracy of either of the two provided by the timer should enhance the schedule reliability of the new cab design.

4.7 SAFETY RELIABILITY

In those areas of change where the functions of the items are considered vital i.e., brake, speed and direction control, the design shall be such that no failures will occur which would endanger the safety of personnel or seriously damage the locomotive. Electronic circuits which replace the roller switches shall be designed fail safe. The reverse control panel and its supporting arm must be fail safe. The cab signal display and the train handling display shall be fail safe in that they will not give an erroneous signal or impart erroneous train handling information to the engineer.

4.8 CONCLUSIONS

The total mature failure rate of the new cab design is not expected to exceed that of the standard cab of today. In those areas where the design has been changed and when new equipment has been added, consideration should be given to redundancy to ensure mission effectiveness. Care should be taken in the design of components with vital functions to ensure that they are fail safe. There are three areas of concern where engineering difficulty may be experienced. These are the reverse control panel and supporting arm; cab signal transmission to the indicator, and the transmission of signals on grade, curvature, drawbar forces and brake pipe pressure to the train handling display unit.

These areas will require a special engineering effort and careful attention to detail design.

5. COST ANALYSIS

5.1 INTRODUCTION

The purpose of this section is to present the cost considerations associated with the development of the new locomotive cab design. In addition, information will be developed and data presented which will indicate the magnitude of the problem which the revised locomotive cab is designed to address and also provide estimates of the potential economic attractiveness of a program to introduce revised locomotive cab designs into the active locomotive fleet.

5.2 LOCOMOTIVE CAB DEVELOPMENT AND PRODUCTION COST DATA

5.2.1 Development Costs

In order to completely validate a new locomotive cab design it will be necessary to build and test an actual example in the operating environment. There are two cost components, cost to build a prototype and cost to test that prototype.

The Boeing Vertol Company has estimated the cost to build the locomotive cab design described in this report at roughly $1,000,000. This estimate assumes that a complete locomotive, complete except for cab, would be on the order of $375,000 based on EMD estimates.

The $1,000,000 effort would consist of fabricating the locomotive cab and installing that cab on the locomotive. The result would be a complete operable locomotive with a prototype new cab design installed and functional.

The second component of development costs is the cost of testing. Lacking knowledge of the extent of the desired test program and a detailed test plan no precise estimates are available. Construction of detail prototype test plans was beyond the scope of this study. Costs could run from under $100,000 for short functional demonstration tests to over $500,000 for comprehensive operational suitability tests where the locomotive would actually be used in line haul operations over various routes.

5.2.2 Production Costs

The Electro-Motive Division (EMD) of the General Motors Corporation supplied an estimate of approximately $25,000 over and above the cost of the present locomotive cab as the cost to build the locomotive cab design, developed in this report, into a new locomotive at time of manufacture on a production basis. The estimate to retrofit the new cab design into an existing locomotive was $40,000. Table 5-1 lists the EMD estimates for the revised cab features assuming installation at time of manufacture on a production basis.

5.3 CURRENT LOSSES POTENTIALLY REDUCIBLE THROUGH IMPROVED LOCOMOTIVE CAB DESIGN

A detailed breakdown of dollar losses attributable to human factors causes in the locomotive cab is not available. However, gross data is available.

Table 5–1. Revised Locomotive Cab Design — Cost at Manufacture

Boeing Vertol Drawing No. 913-007 - Display Console A

Air Gauges plus indicating lights	$ 270
Speedometer	250
Load Meter plus PFI	300
Timer	350
Cab Signal	50
Panel	50
TOTAL	$1,270

Boeing Vertol Drawing No. 913-008 - Engineer's Console A

Controller	$285
Air Brakes	300
Emergency Stop	50
Bell Valve	60
Lock	25
Panel	50
Sand Switch	25
TOTAL	$795

Boeing Vertol Drawing No. 913-009 - Display Panel B

Omit Freightmaster THA

Radio Head	$250
Engine Warning Light Assembly	250
Panel	50
TOTAL	$550

Boeing Vertol Drawing No. 913-013 - Overhead Panel

Omit Locotrol

MU2 and Cutout (1 Electric Switch)	$ 75
Windshield Wipers	10
Panel and Conduit	300
Mars Light Control	30
Rheostats	30
Temperature Control Switch	35
Toggle Switches (12)	98
Engine Condition Switch	48
Traction Motor Cutout Switch	100
Headlight Selector Switch	44
Illuminated Switches (3)	69
TOTAL	$970

Table 5–1. Revised Locomotive Cab Design — Cost at Manufacture (CONCLUDED)

<u>Boeing Vertol Drawing No. 913-02 - Rear Control Panel</u>	
Controller	$200
Brake Control	200
Bell	45
Emergency Stop	50
Changeover Switch (Location/)	60
Box and Wiring	250
TOTAL	$805
<u>Boeing Vertol Drawing No. 913-001 - Brakeman's Control Station</u>	
Fire Extinguisher	$105
Radio Handset	250
Emergency Brake Valve	135
Trash Container	35
Speedometer	250
Windshield Wiper Controls	10
Local Lights	20
Heater Controls	50
Cab Signals	50
Fusee Rack	20
TOTAL	$925
<u>Miscellaneous</u>	
Windshield Wiper System	$ 360
Cab Heater System and Air Conditioning	7,301
Cab Dome Lights	160
Desks	3,550
Seats (2)	560
Water Cooler and Refrigerator	944
Arm Rests	55
Card Holder	20
Sun Visors	40
Wind Deflectors	146
First Aid Kit	46
Electric Air Brake Interface and Electronic Control Panel	5,000
TOTAL	$18,182
GRAND TOTAL	$23,497

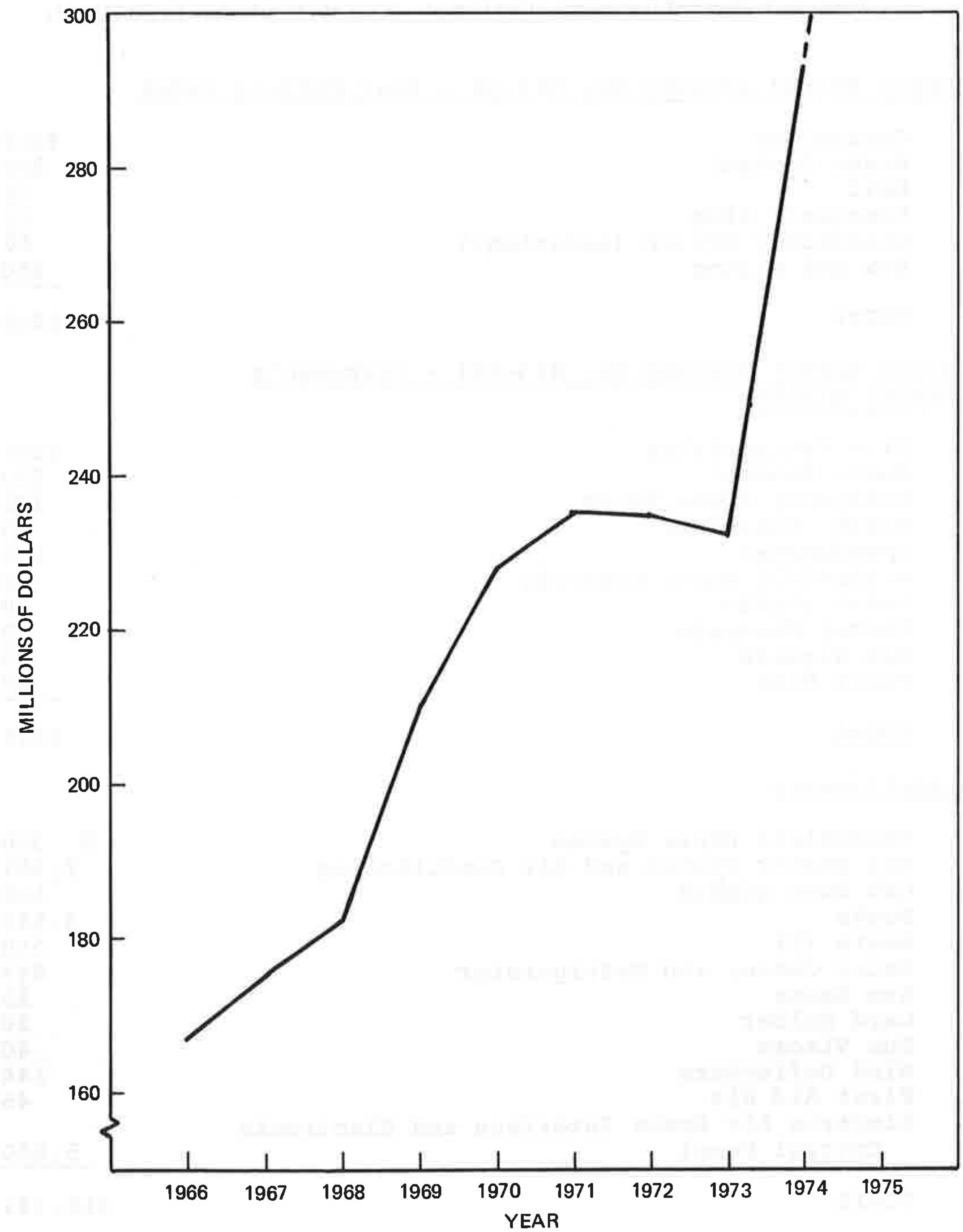


Figure 5—1. L&D Losses 1966-1974

In "A Methodology for Evaluating the Economic Impacts of Applying Railroad Safety Standards," (Reference 1) an estimate of $966.5 is given as the cost of railroad accidents in 1971.

Table 5-2 below is taken from that report and shows the cost components.

Table 5-2. Railroad Accident Costs – 1971
(Millions of Dollars)

	Category	R&I*	Soc**	Total
1.	Property Damage	109.8	5.0	114.8
2.	Wreck Clearing	38.5	0.5	39.0
3.	L&D to Lading	40.0	0.5	40.5
4.	Personal Injury and Fatality	118.1	618.6	736.6
5.	Service Delays and Disruption	7.0	1.0	8.0
6.	Community Services	1.0	4.0	5.0
7.	Non-Reportable Property Damage	22.5	0.1	22.6
	Total	336.8	629.7	966.5

*Railroad and Industry Costs
**Societal Costs

The report did not list causal factors for the accidents.

An FRA office of safety presentation to the Operating Rules Advisory Committee dated 28 February 1975, contains a breakdown of train accident causal factors. (Reference 2.) From this document as shown in Figure 5-2, roughly 24 percent of all accidents in 1973 were due to causes which a revised locomotive cab design could prevent. Thus up to ($966.5 x 0.24) $231.96 million of railroad accident losses are reducible through the improved cab design.

To this sum the loss and damage (L&D) losses resulting from damaged cargo when there was no accident must be added. Figure 5-1 taken from reference 3 shows the L&D losses from 1966 through 1974.

The L&D losses shown on Figure 5-1 include losses incurred due to accidents. Accident losses, from reference 3, amounted to 17 percent and 19 percent of the total in 1973 and 1974 respectively. Using the 17 percent figure, ($232.6 (1-0.17), $193.1 million of cargo damage losses were incurred during 1973 operations not involving accidents.

Since both the number of accidents and L&D losses are on an increasing trend, it would appear that ($193.1 + $232) $425 million is a minimum estimate of the amount of losses potentially reducible through human factors design efforts. Not all of the losses cited above are susceptible to locomotive cab improvements nor is it considered likely that, given the improvements, 100 percent reduction will be obtained. However, the total is large enough to warrant research into ways to reduce it. Improve locomotive cab design is one such way.

Cost Benefit Analysis

Lacking empirical data on the potential effectiveness of the improved locomotive cab design in reducing human factors related accidents, and an explicit breakdown of non-accident related L&D loss categories and fraction of total losses due to each, it is impossible to perform a formal cost benefit analysis. However, it is possible to calculate the level of savings which the revised locomotive cab must produce in service to justify itself on an economic basis.

It is assumed that the development costs will be $5 million and will take two years to complete. It is estimated that it will take $1 million to construct an operating locomotive with an improved cab. This implies that it will necessitate $3.5 to $4 million for the testing program. This program would permit a very comprehensive test program. Further, it is assumed that the new cab design would be introduced only as new replacement locomotives enter the fleet. It is assumed that no retrofitting will be accomplished. There are approximately 28,000 locomotives in the fleet. Of these, approximately 22,000 are road freight and multiple purpose units (reference 2). The revised cab design is optimized for line haul freight operations so that the program is based on these latter units. With a 22,000 unit fleet and a replacement rate of approximately 1,000 per year (reference 2), at least 22 years will be required for complete implementation. The cost of the program will be $5 + [22,000 x $23,497] per cab over existing cab) $522 million. Discounting returns at 10 percent per DOT order number 5000.1 dated 30 June 1972, reveals that if the revised locomotive cab design can prevent more than $167 million in losses per year then the program is economically attractive at the 10 percent rate. Total savings over the 22 year program would equal $1.903 billion assuming savings proportional to the fraction of the fleet equipped with the new cab.

Minimum required savings of $167 million implies that the revised locomotive cab must be at least (167/425) about 40 percent effective in reducing the total of L&D and human factors related accident losses when fully implemented in the fleet.

5.4 CONCLUSIONS

The revised locomotive cab will cost about $23,500 more than the present cab in production.

A prototype locomotive can be constructed with the new cab installed and functional for less than $1,375,000.

Testing must show that the revised cab design is more than 40 percent effective improving train handling and safety thereby reducing human factor errors in order that a program to install the cabs in the fleet be economically attractive.

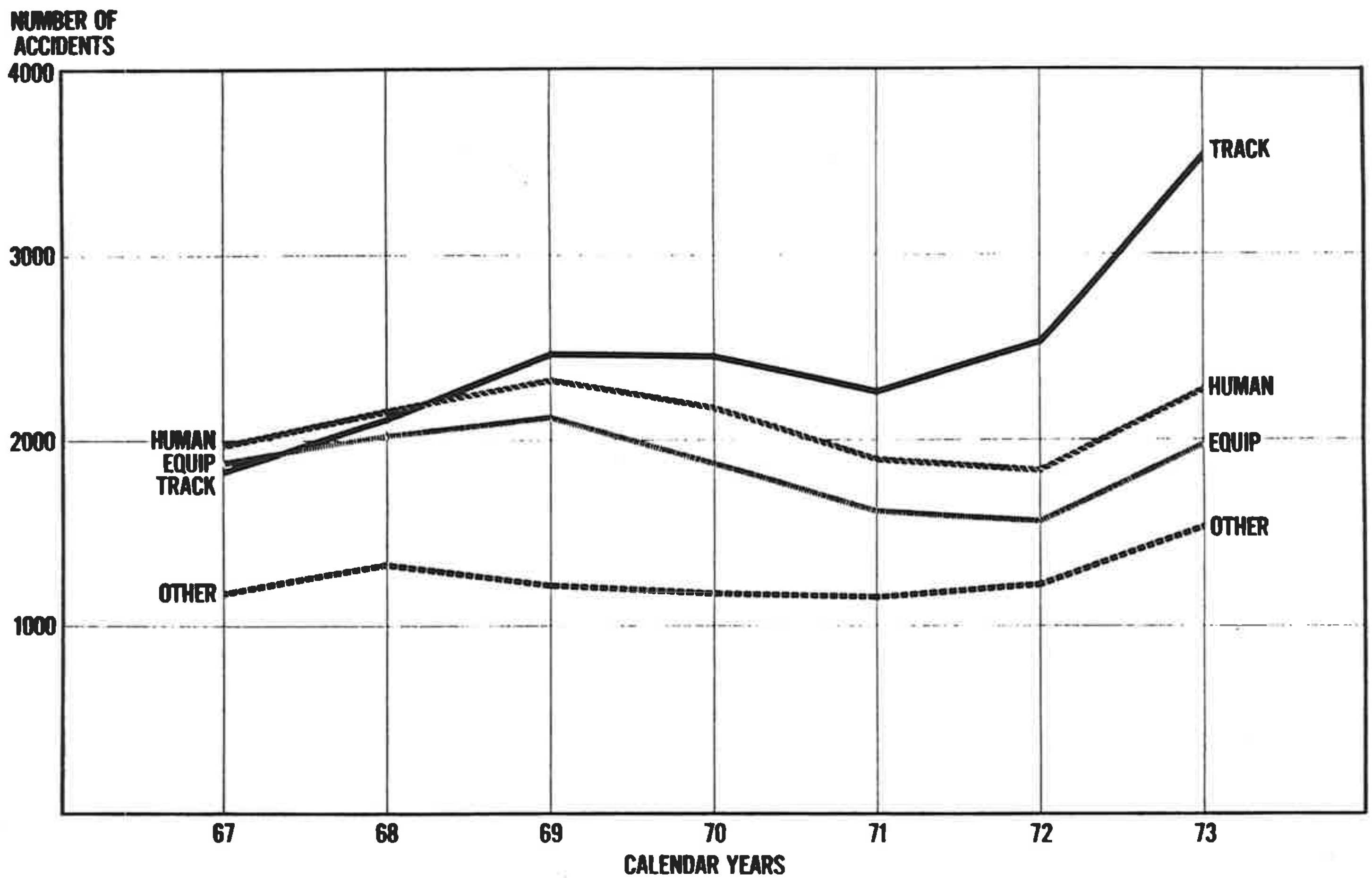


Figure 5-2. Train Accidents by General Cause

6. MOCKUP DEVELOPMENT

The development and fabrication of a full scale hard mockup for test and evaluation is a major objective of this program. The developed mockup incorporates the features of the design that were recommended in Interim Technical Report No. 2, D339-10017-1. The developmental process was initiated early in the concept definition phase of the program. The resultant mockup is the end product of several design iterations. These iterations included soft mockups and a 1/10 scale model.

Initially, soft mockups were constructed of Fome-Cor with knives, hot-melt glue and tape. Fome-Core is a 1/8 inch or 1/4 inch sandwich with styrofoam in the center and two sheets of craft paper. These mockups served as full scale three dimensional drawings. Their special advantages are low cost, speed of construction and ease of modification. Because of these advantages they are a handy, versatile engineering tool that a designer or analyst can use to checkout a design as it progresses. They are particularly effective in workspace evaluation. The use of soft mockups is discussed in Section 6.2.

The next step in the development process was the design and development of a 1/10 scale model. The model was made of wood and designed to reveal details of work station arrangement, general cab layout, windows, egress and ingress, auxilliary equipment details stowage provisions, and structural concept. It was constructed with a hinged cover so that the roof of the cab could be raised thereby allowing cab details to be viewed. The model was of exhibition quality to enable DOT/TSC to demonstrate and evaluate the design concept. The details of the model are presented and discussed in Section 6.3.

The final step in the development process was fabrication by the full scale hard mockup. The mockup is constructed of wood and fiberglass. As the mockup manufacturer was allowed considerable leeway in constructing hidden parts a series of polaroid snapshots were taken during construction depicting significant structural features. The mockup primary controls are operable through their normal throws while secondary controls are simulated.

Instruments are simulated and color coded. All instruments and panel legends are transillluminated. The mockup is mounted on a wooden platform ten feet wide, twenty feet long and five feet high so as to position it at its proper operational height above the rails. The platform was placed over a section of track located in the Boeing Vertol complex to provide some visual realism. The mockup details are presented in Section 6.3.

6.1 SOFT MOCKUPS

As stated in the introduction to this section, soft mockups were constructed. A virtue of this technique is that only enough detail is required to determine adequacy of size, shape, arrangement and panel content of the equipment to be used by man and related human engineering problems. Some typical examples of the use of the technique during the cab design development are shown in the following sequence of photographs.

Figure 6-1 — Early Version of Cab Exterior. This rudimentary design was developed very early in the study and was dubbed "Chief Pontiac" by the technicians who constructed it. This unit was constructed before the crew visibility requirements and occupant protection criteria had been established. It served as a tool to examine the gross human engineering aspects of control stand and cab structural interfaces. Note, for example, the poor use of space in the left corner.

Figure 6-2 — Later Version of Cab Exterior. This design was developed after the visibility and occupant protection criteria were established. Note the large collision posts that have been simulated, the change in the windshield from a three to a two panel concept and the better utilization of space in the left hand corner.

Figure 6-3 — Preliminary Cab Arrangement. This photograph depicts the view forward from behind the engineer's control console. At this point in the design development a three piece wrap around console was being evaluated but, as will be shown later, this idea was discarded because it posed a potential impediment to rapid egress from the seat. The button visible on the floor under the console simulates a foot operated horn. Note also that at this point some consideration is being given to a second crew station on the left side of the cab.

Figure 6-4 — Preliminary Engineman's Work Station. This is an early version of the controls and displays. On the upper panel at the extreme left is an early version of a slack/buff indicator. Various gages and annunciator lights are also shown. The backs of the placards are magnetized and can be moved on magnetic board to study a variety of arrangements. The Fome-Cor controls are movable and the toggle switch in the lower right hand corner is an early version of the direction lever.

Figure 6-5 — Preliminary Anthropometric Evaluation. As work station console development proceeded, preliminary man ratings of the configurations were done. Fifth through ninety-fifth percentile personnel located in the mockup construction area were seated at the controls and a preliminary evaluation made of reach and vision envelopes. These evaluations permitted these significant variables to be studied and designs corrected prior to proceeding to the next stage of the design. The engineman's control station geometry is shown in Figure 6-6.

Figure 6-7 — Preliminary Design of Cab, Rear Wall. This photograph shows the rear wall of the Fome-Cor cab. At the left is a lavatory. To the right, from top to bottom, there is a refrigerator, shelved storage compartment and general storage closet.

The preceeding photographs illustrate the use and utility of the soft mockup technique in solving human factors design problems. They were also used as aids during design reviews by Transportation Systems Center (TSC) personnel.

6.2 SCALE MODEL

The next stage in the design process was the development and fabrication of a 1/10th scale model of the cab design. The model was designed to reveal details or work station arrangement, general layout, windows, egress and ingress, auxiliary equipment details and stowage provisions. It was constructed with a hinged cover so that the roof of the cab could be raised thereby allowing cab details to be viewed within its envelope. A set of drawings and sketches were prepared showing fabrication, layout and included representations of 5th to 95th percentile adult male figures. The scale model subassemblies are shown in Figure 6-8.

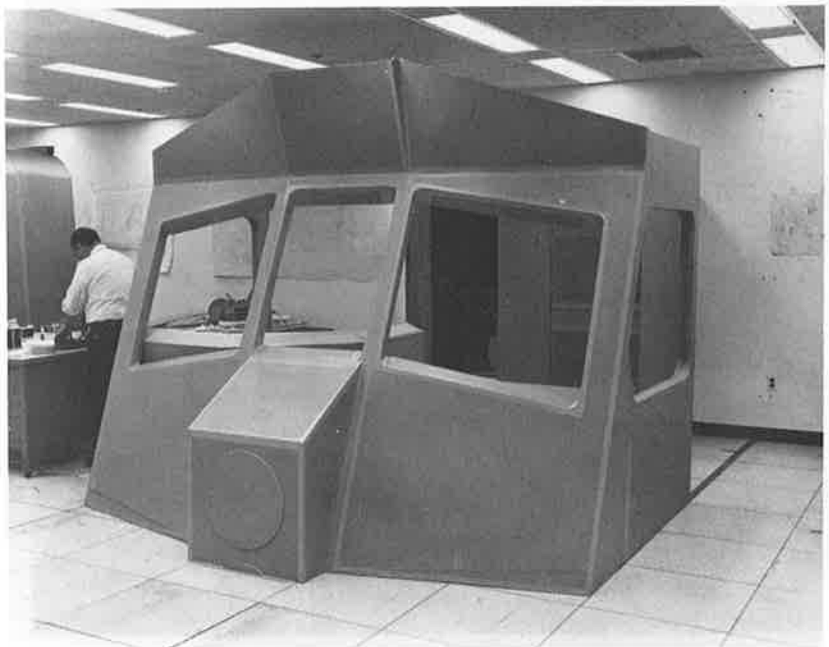


Figure 6–1. Early Version of Cab Exterior

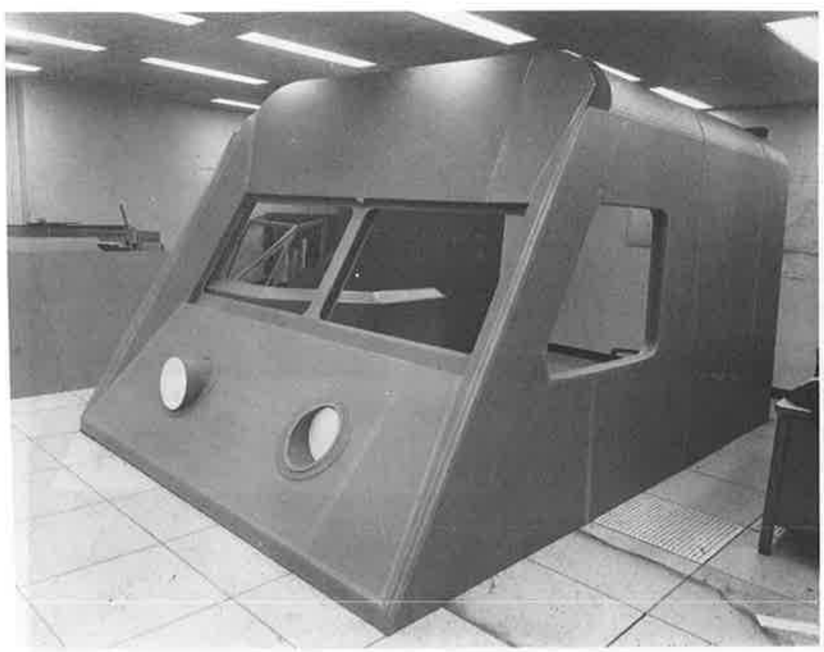


Figure 6–2. Later Version of Cab Exterior

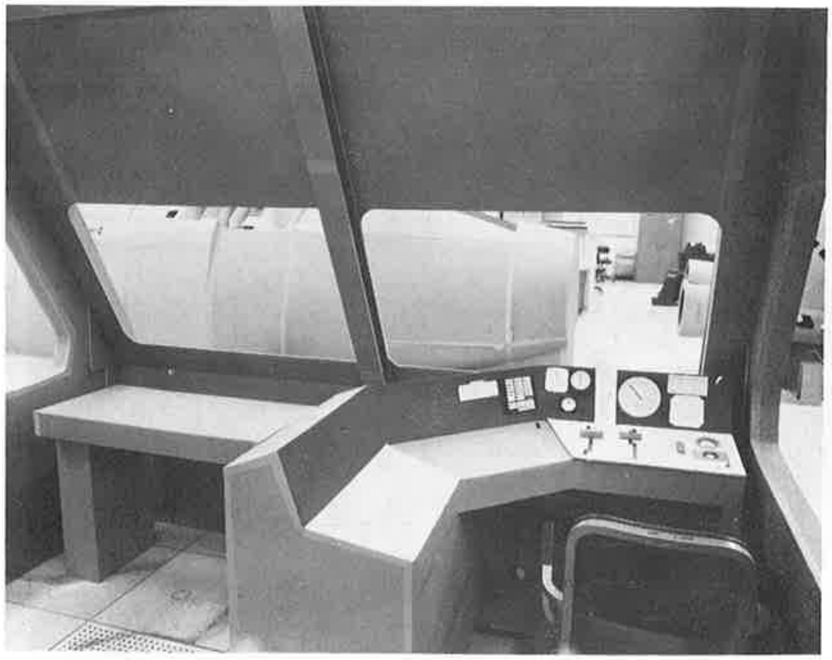


Figure 6–3. Preliminary Cab Arrangement

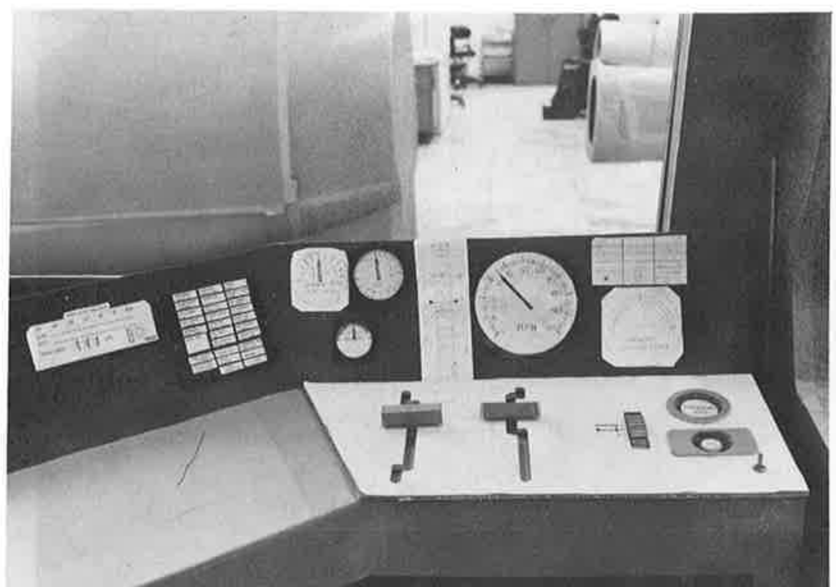
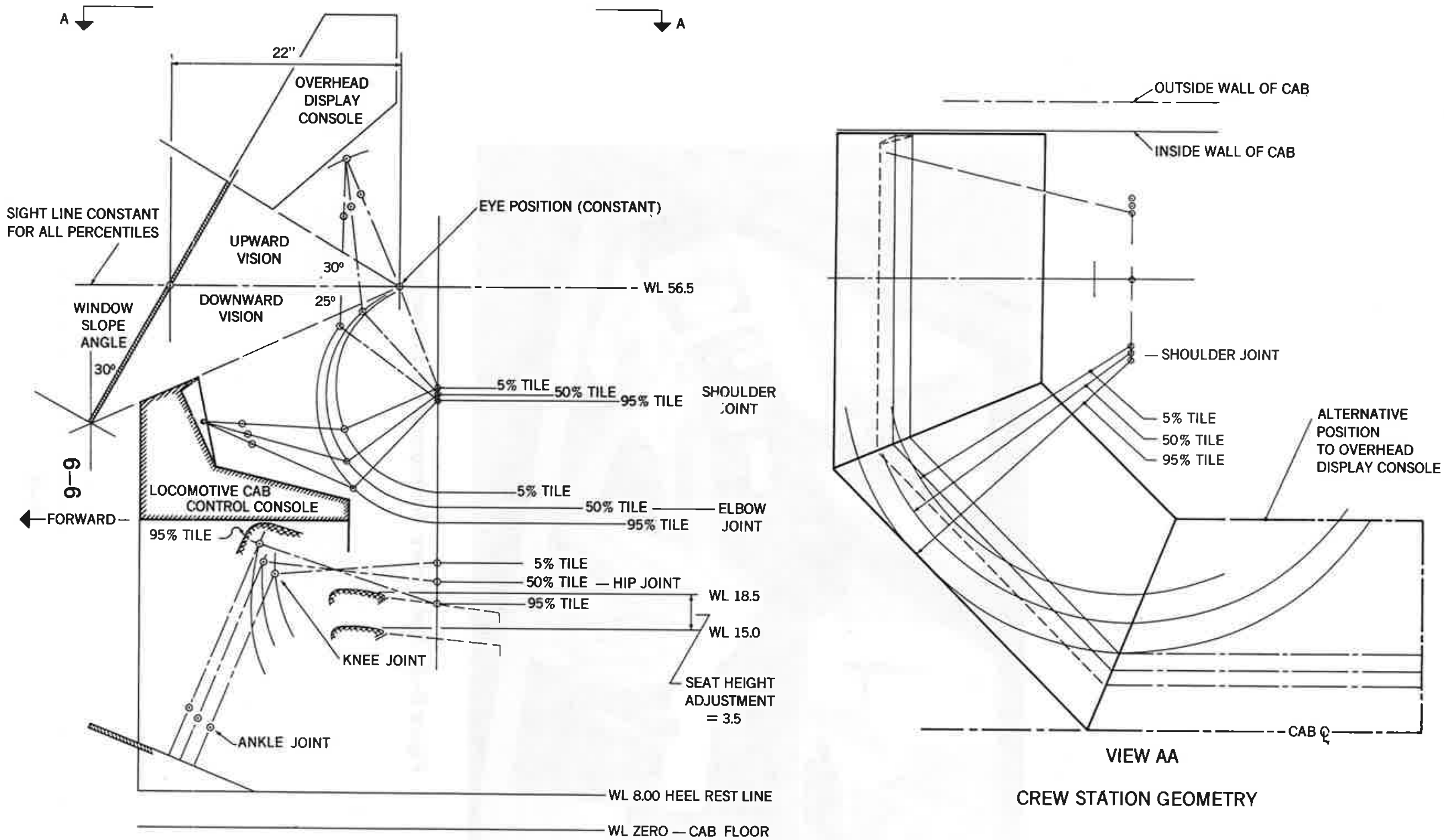


Figure 6–4. Preliminary Engineman's Work Station

Figure 6–5. Preliminary Anthropometric Evaluation



SIDE VIEW OF CREWMAN'S CONTROL STATION

Figure 6–6. Engineman's Control Station Geometry

Figure 6–7. Preliminary Design of Cab, Rear Wall

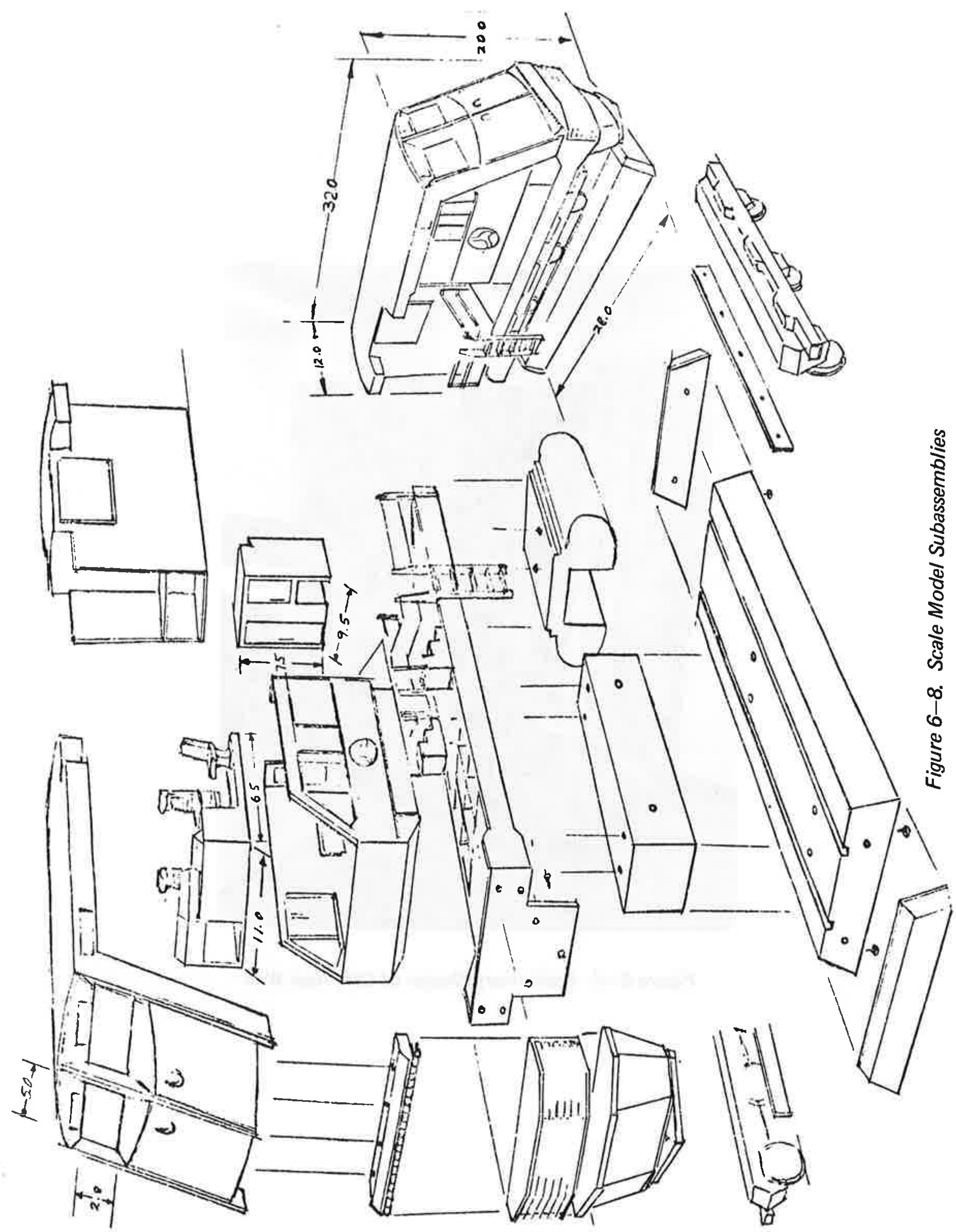


Figure 6–8. Scale Model Subassemblies

adult male figures. The scale model subassemblies are shown in Figure 6-8. The external details of the model are shown in Figure 6-9.

Figure 6-9 – Scale Model (Constructed 1/10 actual size). In this photograph, there is a deflecting anticlimber located above the coupler. The collision posts above the anticlimber are at a 30 degree angle and of sufficient strength to allow a locomotive to ride up them without crushing the cab. The windshields allow approximately 25 degree downward vision and 30 degree upward for the design eye location.

The open panel on the side provides access to items such as batteries obviating the necessity to have a trap door in the cab which has been a source of injury to crewman.

There are two doors at the rear of the cab, one on each side. To leave the cab the crewman walks down a flight of skid proof steps to the level of the side sill and then down the ladder to the ground. It should be noted that the ladder as shown on the model protrudes excessively and exceeds plate "C" of the AAR clearance envelope and would be redesigned in the event a prototype cab was constructed.

Figure 6-10 – Model Interior View. Figure 6-10 shows the interior of the model looking toward the rear wall. The two rear doors are shown as are the lavatory, refrigerator and storage area.

Figure 6-11 – Model – View of Crew Station. The left side of the cab contains a work station for a second crewman. To the rear of this work station, a seat was installed for a third crewman. Between the two forward seats are receptacles for storing cab equipment such as a fire extinguisher, torpedos and fuses.

The engine's work station is at the right. It should be noted that the wrap around console concept shown in the soft mockup photographs has been reduced to provide ease of egress. The platform is provided to raise the crew as high as possible to provide maximum forward visibility.

In addition to the model, a soft mockup of the controls and displays are shown in full scale. This mockup was lighted using simulated white back lighting technique. Both instruments and panel legends were lighted. The purpose of this soft mockup was to demonstrate that a balanced lighting presentation could be achieved over the range from dim to bright which would be acceptable to the crew.

On September 11, 1975 a presentation was made in Washington, D.C. to members of the Locomotive Control Compartment Committee and DOT/TSC and both the model and lighted soft mockup were displayed for the purpose of soliciting comments. A discussion of these comments elicited at this meeting is presented in Section 7.

6.3 FULL SCALE HARD MOCKUP

Upon approval of the recommended design shown in the previous section, a full scale mockup was developed and fabricated. The purpose of the mockup was to provide, in logical sequence, the next tool in the human factors engineering evaluation of the cab design.

Figure 6–9. Scale Model (1/10 Size)

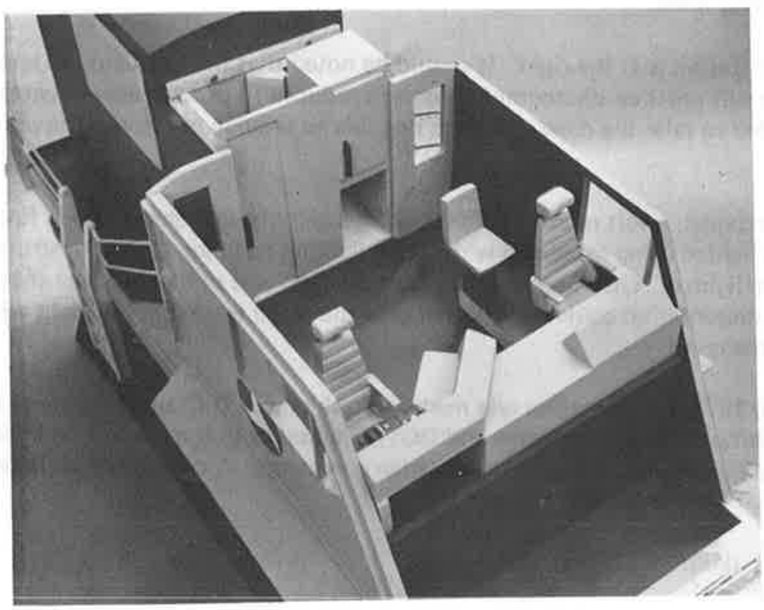


Figure 6–10. Model, Interior View

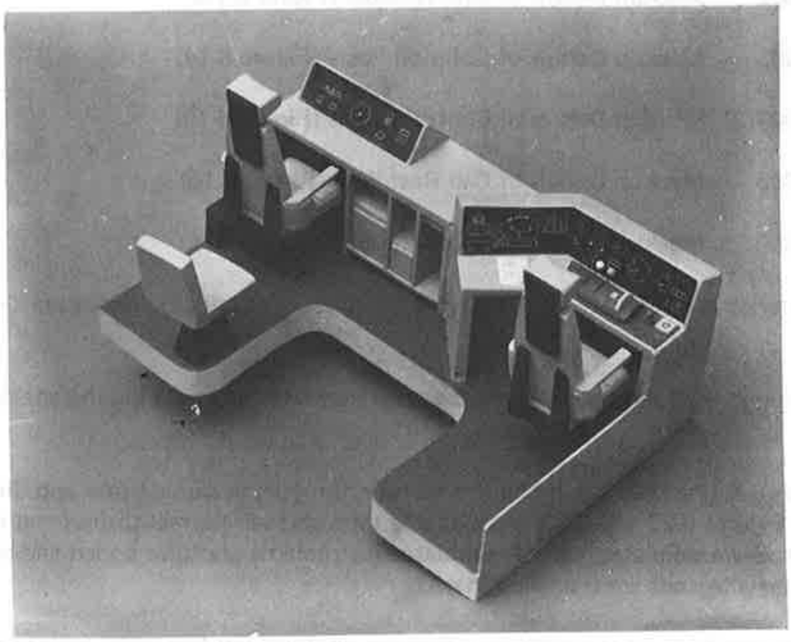


Figure 6–11. Model, View of Crew Station

To procure the mockup, a series of drawings were prepared showing mockup details and assembly. Crew station arrangement for the 50th percentile adult male operators were included. These drawings are shown in Figures 6-12 through 6-17. The drawing numbers and titles are:

a. 913-301 Mockup Details of Control Console (Figure 6-12)

b. 913-302 Mockup Details of Side Window (Figure 6-13)

c. 913-303 Mockup Details of Collision Posts (Figure 6-14)

d. 913-304(3) Mockup Details of Control Panels (Figure 6-15)

e. 913-305 Mockup Details of Cab Rear Wall (Figure 6-16)

f. 913-306 Mockup Details of Cab Exterior (Figure 6-17).

The mockup exterior is constructed of wood and fiberglass. Overall dimensions are shown in Table 6-1.

Figures 6-18 through 6-23 show various photographs that were taken during the construction phase.

The primary controls (independent brake, train brake, throttle, dynamic brake and direction lever) shown in Figures 6-22 and 6-23, are operable through their normal throws and the secondary controls are simulated. Static simulated instruments are color coded and all instruments and panel legends are transilluminated.

The construction mockup was mounted on a wooden platform ten feet wide, twenty feet long and five feet high so as to locate it at the proper operational height above the rails as shown in Figure 6-24. The platform was placed over a section of track to provide some visual realism as shown in Figure 6-25.

The crew work stations are shown in Figure 6-26. It should be noted that the crewmen's chairs are not, in a strict sense, a part of the present design development. The chairs installed in the mockup are adjustable fore and aft, rotate 180 degrees and may be raised or lowered to accommodate the 5th to 95th percentile crewman. The detailed description of the various items at the crew stations is contained in report D339-10026-1, Locomotive Cab Design Development Operator's Manual.

Figure 6-27 shows the seat rotated 180 degrees and the reverse control panel extended and in place for rearward movement of the train.

The rear wall of the mockup is shown in drawing 913-305 (Figure 6-16).

Visibility from the engineman's design eye position, from left to right, is shown in Figure 6-27. Figure 6-28 depicts the view out of the left side of the cab at about 45 degree angle from the

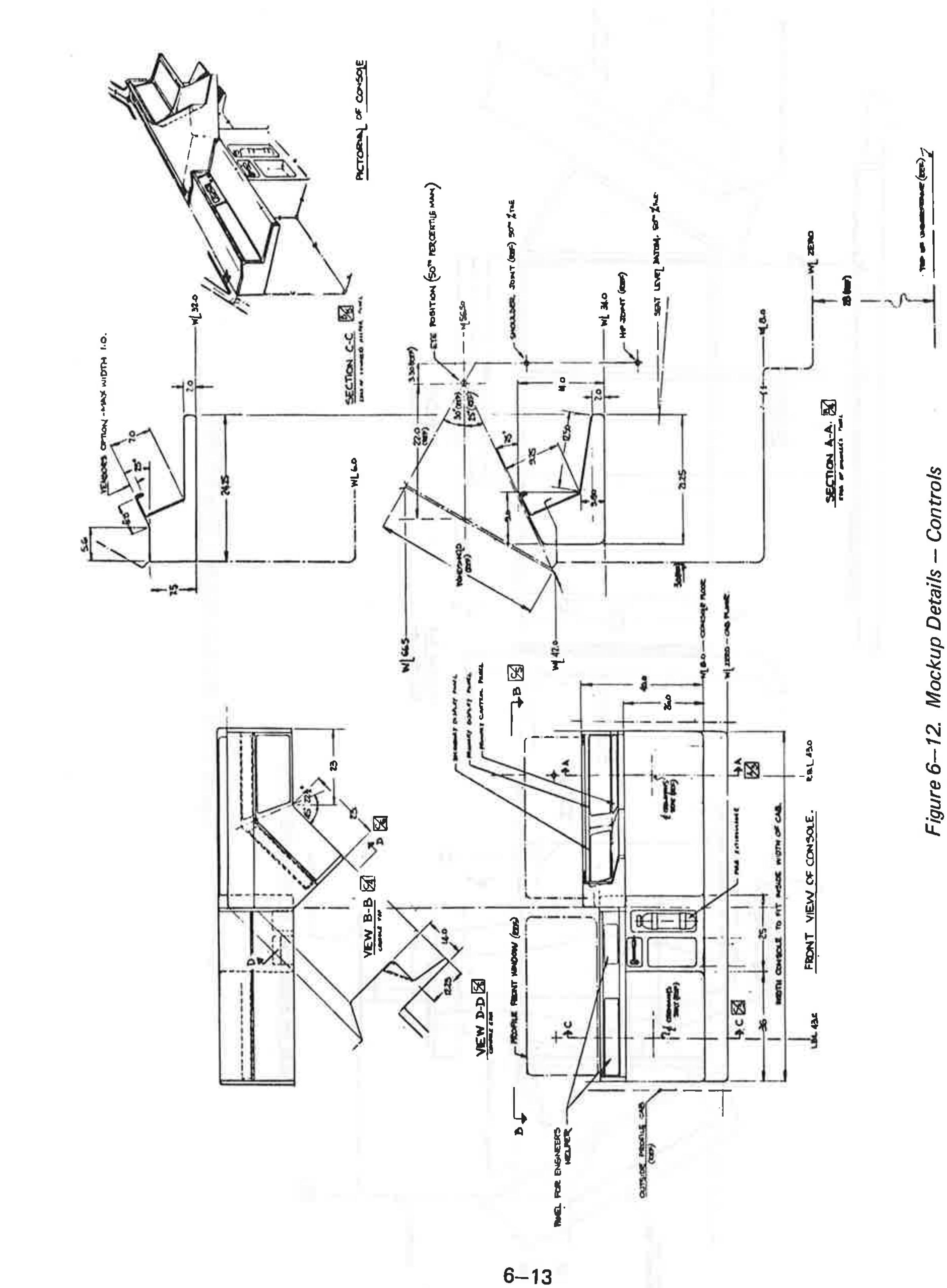


Figure 6–12. Mockup Details – Controls

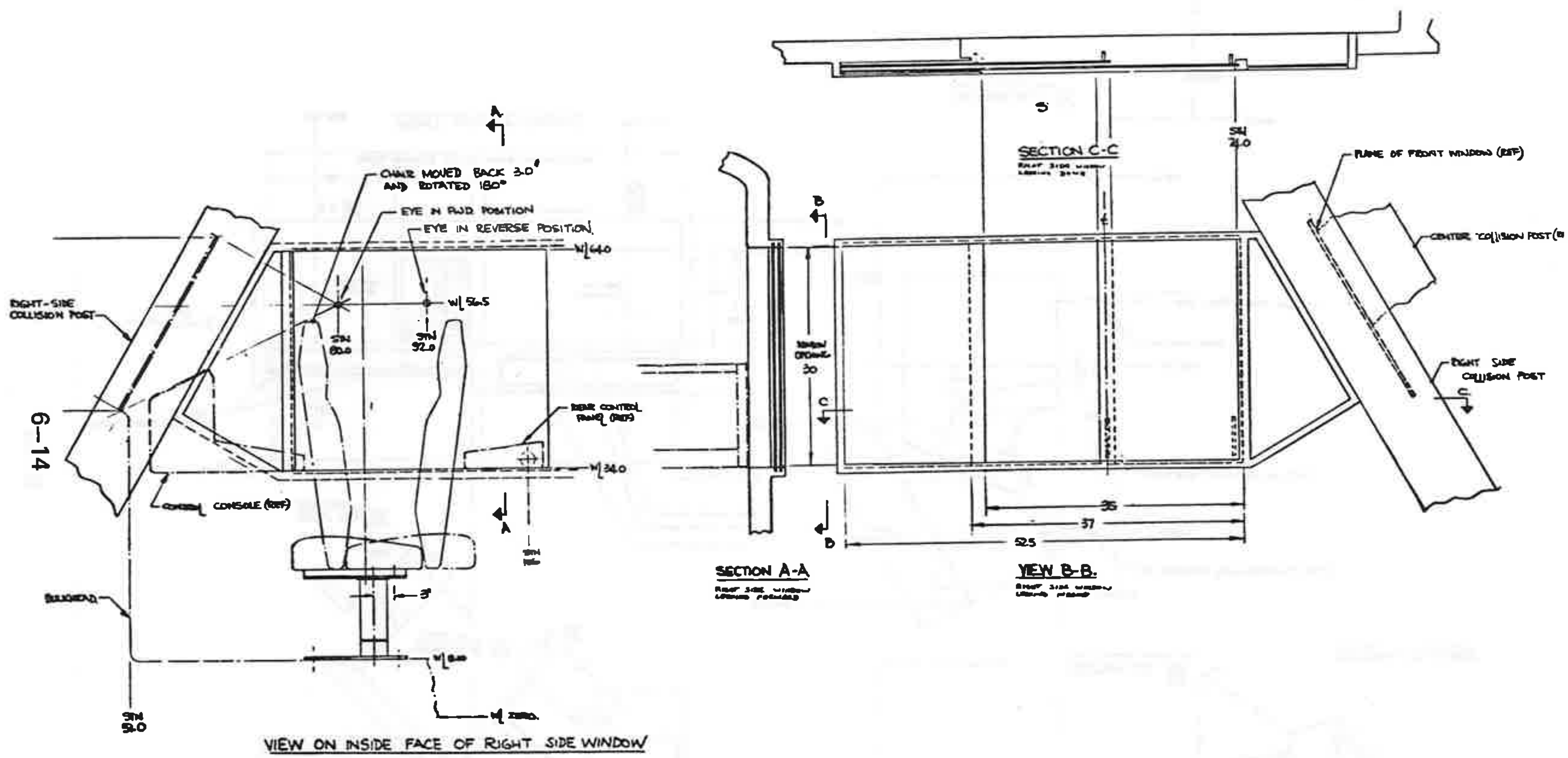


Figure 6–13. Mockup Details – Side Window

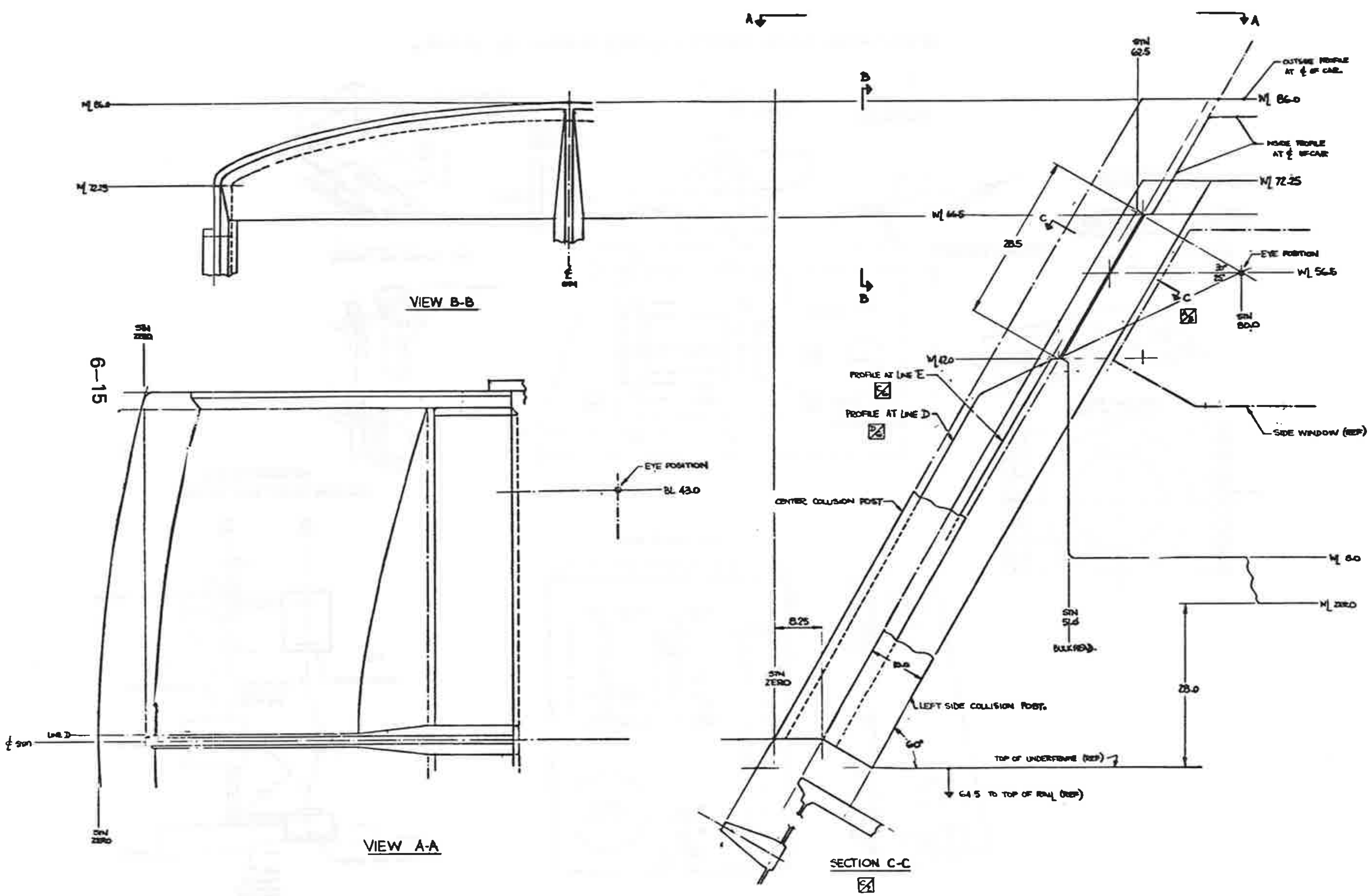


Figure 6–14. Mockup Details – Collision Posts

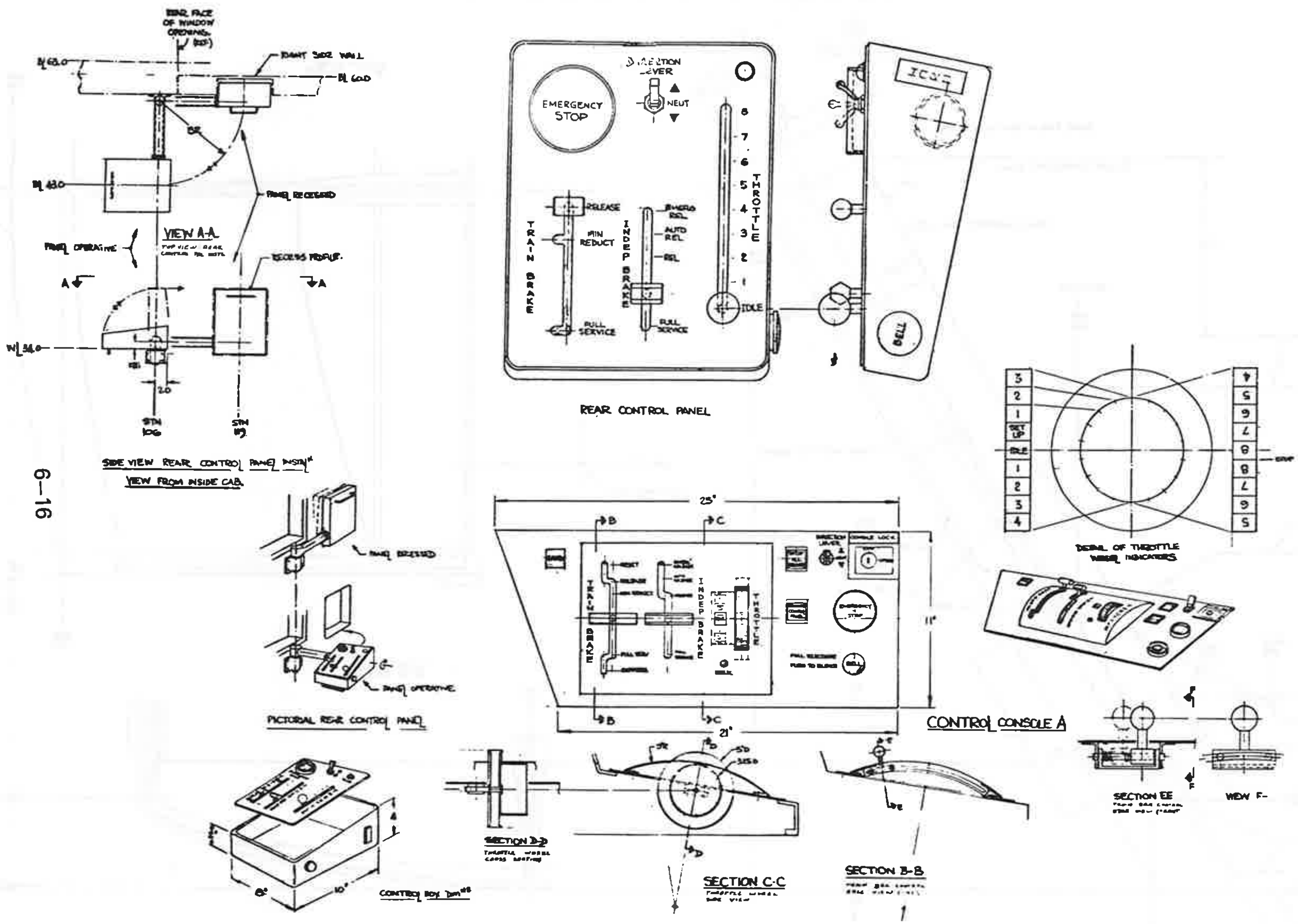


Figure 6–15. Mockup Details – Control Panels (Sheet 1 of 3)

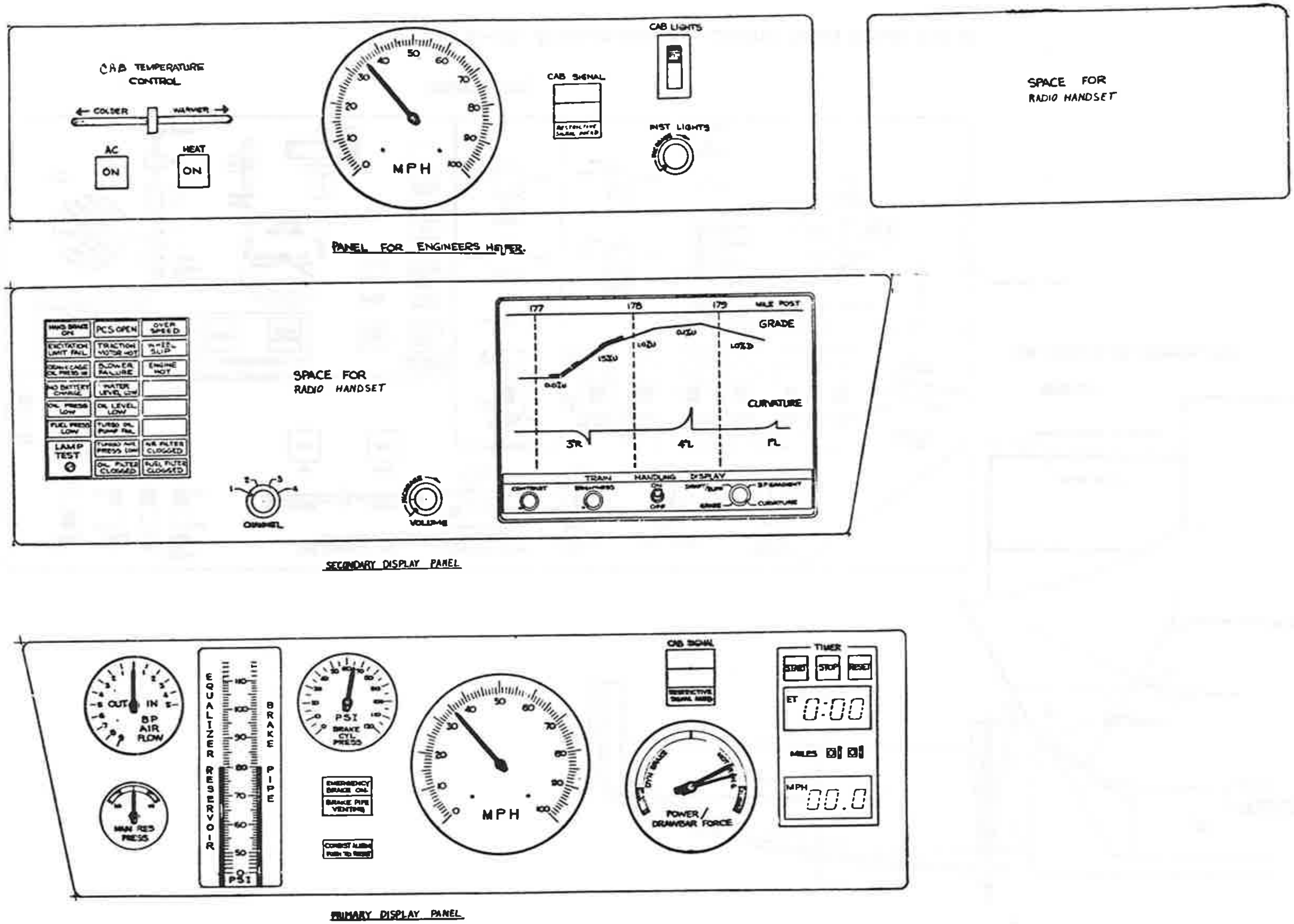


Figure 6–15. Mockup Details – Control Panels (Sheet 2 of 3)

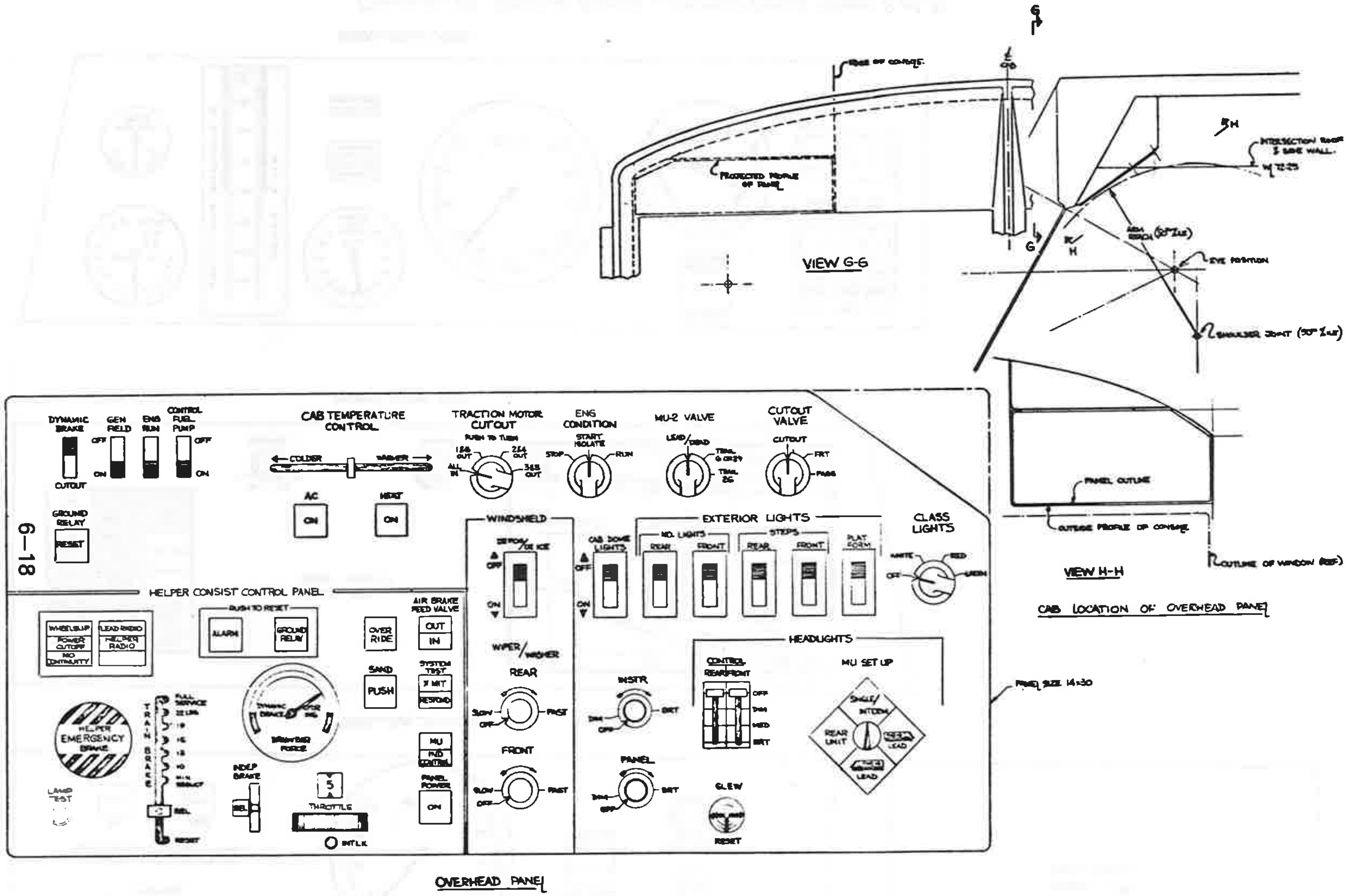


Figure 6–15. Mockup Details – Control Panels (Sheet 3 of 3)

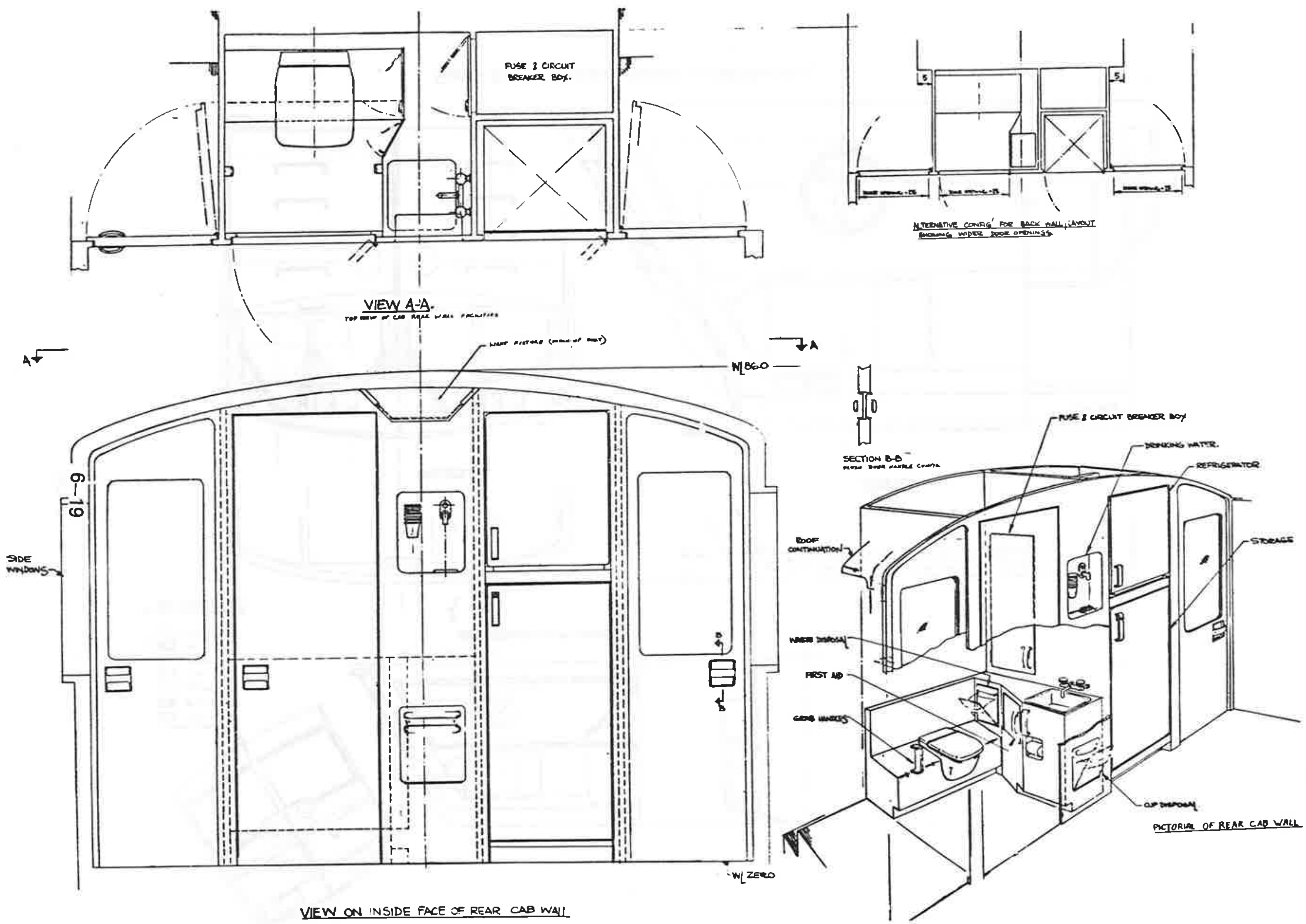


Figure 6–16. Mockup Details – Cab Rear Wall

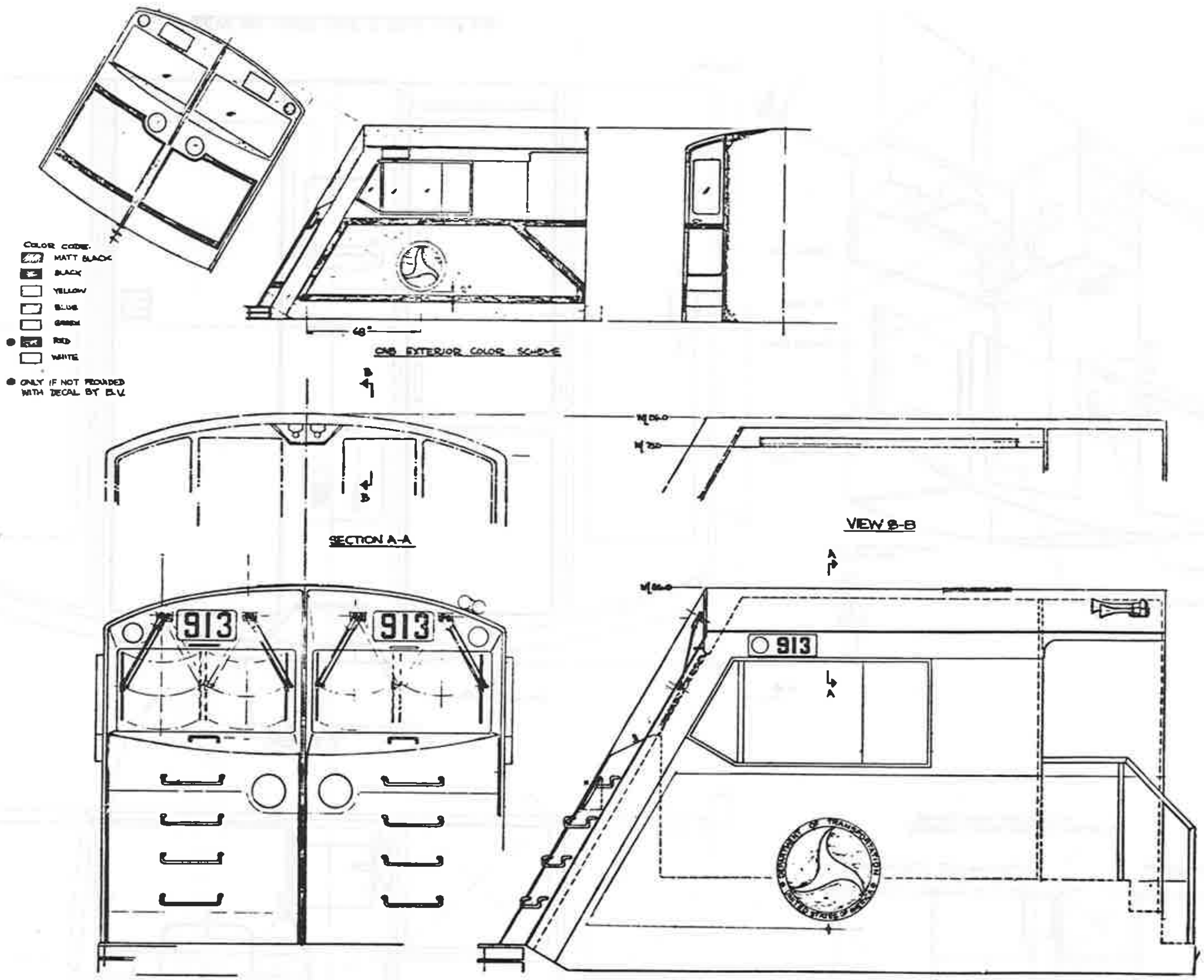


Figure 6–17. Mockup Details – Cab Exterior

Table 6–1. Mockup Dimensions

OUTER

WIDTH:	10'8"
HEIGHT:	14'9.5" (From top of rail)
LENGTH:	9'3" (Front bulkhead to rear wall)

INNER

	CAB HEIGHT	
	CAB CENTERLINE	CREW STATION CENTERLINE
1st Level	7'1"	6'8"
2nd Level	6'8"	6'0"

FLOOR AREA:	170 ft^2
FREE VOLUME:	590 ft^3

WINDOWS

FRONT (Each)	WIDTH:	50"	19.5 ft^2
	HEIGHT:	28"	
SIDE (Small)	WIDTH:	15"	
	HEIGHT:	28"	
SIDE (Large)	WIDTH:	36"	
	HEIGHT:	28"	
REAR	WIDTH:	15"	
	HEIGHT:	34"	

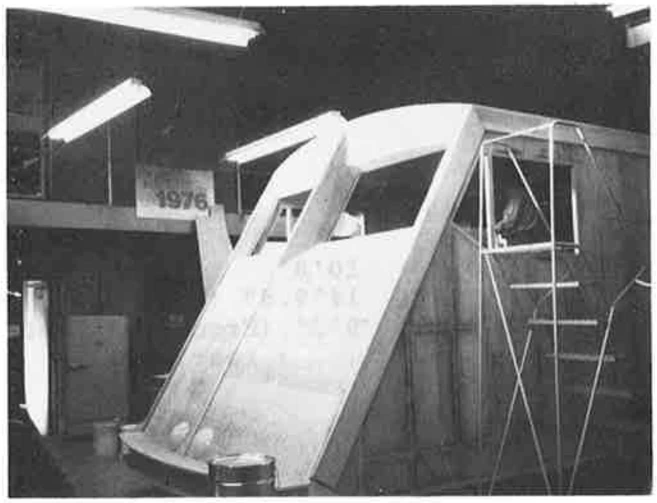


Figure 6–18. Mockup Construction Photograph

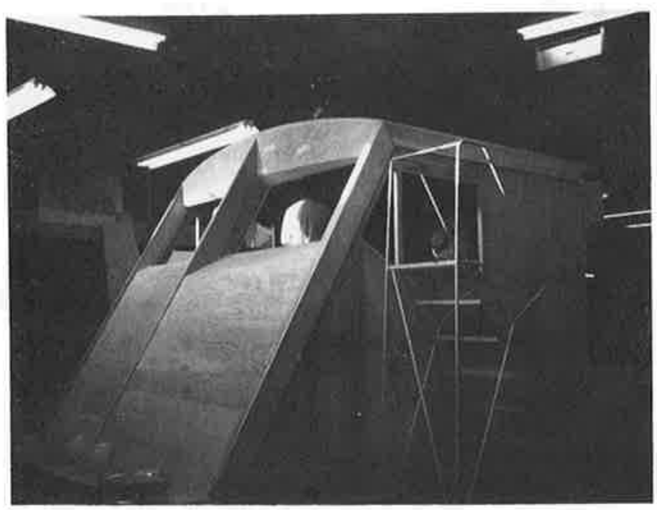


Figure 6-19. Mockup Construction Photograph (continued)

Figure 6-20. Mockup Construction Photograph (continued)

Figure 6-21. Mockup Construction Photograph (continued)

Figure 6-22. Mockup Construction Photograph (continued)

Figure 6-23. Mockup Construction Photograph (continued)

Figure 6–24. Mockup in Position Over Rails

Figure 6–25. Mockup Visual Realism

Figure 6–26. Crew Work Station

Figure 6–27. Reverse Control Station

engineman's work station. It should be noted that during normal trail operations the engineman will shift position and move his head, thereby, minimizing the presence of the collision posts within the field of view. Figure 6-29 shows the field of view directly forward. When standing at this location, the engineman can see small objects on the rail at a distance of nine feet in front of the cab or eight feet in front of the coupler. (Note that the tail light tower shown on the right in the previous photo is now at the far left.) Figure 6-30 shows a view to the right and forward. For reference, note the position of the collision post with respect to its position as shown in Figure 6-28. Figure 6-31, shows the view looking directly out of the side window. (Note the position of the tail light tower at the left compared to its position as shown in Figure 6-29.) Figure 6-27 depicts a scaled engineman with the reverse control panel pulled out and locked in the 90 degree position. When not in use, the panel is stowed in the recess shown in the wall. Finally, Figure 6-32 shows the view straight back through the rear window in the door on the engineers side of the cab. It is the view obtained from the position shown in Figure 6-31. The window is larger than that found in production locomotive cabs. However, because in the new design, the engineman is seated farther away from the door the actual visibility achieved is about the same. (Note that the glare spots in the photograph are artifacts of the camera flashbulb.)

6.4 CAB CONSPICUITY

The external paint scheme of the mockup was considered from a safety standpoint. The paint scheme selected was based on experiments conducted for the Federal Railroad Administration by John P. Aurelius and Norman Karobow. (The Visibility and Credibility of Trains Approaching Rail and Highway Grade Crossings, Systems Consultants Incorporated, FRA-RP-71-2, May 1971.) It was concluded, based on the experimental evidence, that the use of bright colors improves locomotive conspicuity during daylight. Based on these findings, high contrast (hue and brightness) colors were chosen and applied to the mockup as shown on drawing 913-306, Figure 6-17. The mockup is painted blue with wide yellow band along the front and sides with a black border around the yellow.

Figure 6–28. Field of Vision – Left

Figure 6–29. Field of Vision – Forward

Figure 6–30. Field of Vision – Right Forward

Figure 6–31. Field of Vision – Side Right

Figure 6–32. Field of Vision – Rear

7. DESIGN CRITIQUE

The design was presented on two occasions to the Locomotive Control Compartment Committee during development for their review and comment. The committee also inspected the mock-up. During these sessions many comments and suggestions were made by the individual committee members on ways to improve various features of the design. The comments were classified according to subject matter and have been reviewed against the human factors criteria governing the design. The categories discussed in the following sections are:

a. Work station

b. Displays

c. Controls

d. Vision

e. Communications

f. Noise, vibration, and odor

g. Safety

h. Clean cab developments.

7.1 WORK STATION

The location of the remote control unit (RCU) on the engineman's overhead panel was discussed in detail. Although there were only approximately 600 of these units installed in locomotives, these units perform a vital train handling function. The tasks performed by the engineman are critical in controlling the train's behavior and the consequences of a severe mistake. Therefore, it is recommended that the RCU be relocated in proximity of the main control and display panels to facilitate its use.

Due to the length of the cab, blank spaces exist on each side of the cab between the side windows and the rear doors. It has been suggested that additional doors and windows be added. It is presently not feasible to add additional doors at the sides of the cab because it may interfere with the load carrying structure. However, a small window on each side could be added. The utility of such a window will be studied further during the test program to determine if implementation is warranted.

Cab floors are of a grooved non-skid type linoleum with a rubber base. It has been pointed out that most rubber based linoleum materials are susceptible to attack by detergents and greases which are present in the railroad environment. The emphasis should be on grooved and non-skid floor only. This method of attachment is beyond the scope of the study.

The bi-level floor concept has been criticized as dangerous. This concept was adapted as a solution for locating seating crew members as high as practical above the rails while also permitting crew members to stand and move about the cab without having to crouch. The raised platform provides an additional function. If the seals around the doors lose their integrity, rain, dust, wind, snow, etc. is allowed into the cab. The raised platform precludes that the engineman doesn't have to keep his feet in all the aforementioned weather hazards. To minimize the danger, it will be recommended that the step be painted with colored stripes of high brightness and hue contrast, be pencil lighted at night and that light switches be provided just inside each of the rear doors so that a crewman can turn on the secondary lighting immediately upon entering the locomotive cab.

7.2 DISPLAYS

It has been suggested that the cab signals be combined with a distance to signal readout. This feature will be reviewed and, if required, will be included in the cab design with the appropriate metric.

Warning devices for detectors such as hot box and dragging equipment, should be included in the design. Two methods of conveying this information to the engineer have been considered. The first, is to present this information on the train handling video display at the precise location at which it occurs. An alternate solution, is to present the information via the annunciator panel. A milepost counter/register could be added to the video train handling display to prevent this information from getting lost when a variety of events are shown simultaneously. Recommendations will be made in the final report.

It has been suggested that the one mile per hour graduations and half mile resolution provided on the speedometer is not necessary for main line freight operations, not technically practical and probably very costly. The systems analysis of the engineer's tasks revealed that the speed of the train is one of the most significant bits of information the engineer has. Present day locomotive speedometers are often inaccurate. With the increased sensitivity of the new propulsion control systems and the ability to "fine tune" the system it is concluded that the requirement for an accurate high quality speedometer is reasonable from a human factors standpoint.

7.3 CONTROLS

The train brake lever in the new design does not now have labeling to indicate the pounds reduction beyond the minimum application position. It was suggested that labels be provided so that the engineman could set the lever at the precise value he desires rather than by an educated guess. This is consistent with good human factors design practice decrements will be determined and a recommendation made in the final report.

The present design does not provide the engineer with the capability to manually shut down individual units in the locomotive consist. The necessity for such a control is unclear at this point because locomotives shut themselves down in the event of a system malfunction. This question is still under evaluation.

7.4 VISION

It has been noted that the large front windshields may allow too much light to enter the cab. It is recommended that the material selected for the windshield possess some thermal insulating properties. Crew protection is also of some concern. It is also recommended that the windshield be designed to that it doesn't shatter and spray glass on the crew upon impact. It should withstand an impact with a cinder block suspended from a bridge. Comment has also been made to the effect that the collision posts may restrict visibility for collision course speeds of locomotives and vehicles. It is true that the collision posts provide "blind spots" from either side of the cab. However, it is also true that with two men observing complete coverage of the forward and lateral visual fields is possible.

7.5 COMMUNICATIONS

The sketches and drawings depicting the telephone — hand set type radio application — runs counter to many railroads' desire to eliminate a separate hand set. The AAR has recently standardized on a four-inch high, ten-inch wide, nine-inch deep radio location which can incorporate either a built in microphone, a hand held microphone or a telephone hand set. The new cab design will be modified to incorporate these dimensions. In addition, if a built in microphone concept is selected, the radio will be placed closer to the engineman.

7.6 NOISE, VIBRATION AND ODORS

The present cab design will include protection of the crew against engine generated gases, fumes and odors. This will be accomplished by the placement of seals in appropriate areas such as the floor, doors and windows.

The new design also incorporates a sound insulated cab. There is a possibility that torpedoes and whistles may not be heard by the crew. A solution to this problem is to provide external cab sensors that are sensitive to these sounds and which in turn trigger cab audible signals. The feasibility of this solution will be examined and a recommendation included in the final report.

Vibration has been demonstrated to contribute significantly to operator fatigue. The vibration criteria for providing an environment that is comfortable for the crew will be developed from human engineering standards and included in the design handbook.

7.7 SAFETY

It was noted that the engineer must be protected, if slack runs out quickly, from striking the control/display console with his head. The present design provides padded contours. However, an important design issue is raised here, namely, that padding and protection devices must be considered early in the design stages and integrated into the total system concept for optimum design rather than as an after thought when the hardware has been firmed up.

7.8 CLEAN CAB

The locomotive Control Compartment Committee has recently made a study of locomotive cabs. As a result of this study, some features have become standard on production locomotive cabs. These features are being incorporated in production cabs in two phases as follows:

1. PHASE I
   Outside Number Box
   Rubber Handle — Wiper Motor
   Padded Sun Visors
   Padded Horn Valve
   Door Handle
   Hinge Guard
   Windshield Wiper Cover
   Head Bump Pads
   Rounded Latches
2. PHASE II
   Extended Short Hood
   Round Defroster Duct
   Recessed Cab Lights and Valves
   Provision for Radio
   Platform Extension (GP and SD45 Models Only).

These features will be considered and included in the new cab design as appropriate.

8. CONCLUSIONS AND RECOMMENDATIONS

It is concluded, based on the work accomplished to date, that additional engineering development of the locomotive cab design is needed. One area requiring serious attention is the transmission of more information to the engineman than he now receives. The advanced technology required to do this is not only readily available but, in some cases, is already operational on the railroad properties. The Southern Pacific's classification yard at Colton, California is a case in point. Some advanced technology is incorporated in this modern marshalling yard. For example, computers, CRT message display units and hard copy printouts are installed at the crest control tower. The communications network includes a 420 channel capacity microwave system, base radio stations, teletypes, and talk back speakers. The signal interlocking, retarder and electronic systems include features such as electronic wheel detectors, electronic train sensors, radar units, electronic coupled-in-motion freight car scale, dragging equipment indicator, power operated safety derails, hot box detectors, and high-wide load detectors. Some of this technology has already been applied along right of ways. There is no reason to believe that, in the future, further application of existing devices will not take place on trains and locmotives. For example, train orders could be presented to the engineman via the CRT installed in the cab. The engineman could read the message, acknowledge it and either erase it or store it for future reference. A hard copy, including the acknowledgement, could be made by the originator for the record. This kind of development requires hardware and software that is both reliable and accurate. As indicated in this report, if a prototype vehicle is developed, the cab component failure rates are, by the most conservative estimates, not expected to exceed the rates identified in present day cabs. However, an additional issue is raised. Some new items installed in the locomotive cabs environment do not work properly. Sometimes this is due to a defect in the design of the particular item, other times the failure to perform properly may be due to interference from other components in a system.

This is especially true of electronic circuits and radio frequency transmissions. Problems may arise in areas where, for example, track switch circuits, signal circuits and radio usage create electromagnetic phenomena that may serve to degrade one or more of these systems. This means that as advanced technology is applied, a total systems approach must be considered that includes not only the cab and locomotive interfaces as they affect the crew but total systems compatibility, both over the road and in modern yard operations.

A second area that requires attention is the locomotive cab structure. Although the structural concepts described in this report are attractive to both Vertol and EMD, extensive structural analysis, test and design will be required and additional trade studies performed. For example, from a strictly crashworthiness standpoint, collision posts set at a lesser angle, may be more advantageous in providing a survivable cab volume than the present sixty degree angle. However, the trade is against visibility lost by reducing windscreen size. A reduction in the size of the windscreen may in turn be reasonable if it is assumed that tomorrow's cabs will all have cab signals governing speed in a particular signal block or even track signals showing the position of track switches.

Finally, the preliminary cost analysis indicates that the potential savings in cost payouts, due to improved train handling for personnel safety equipment loss and cargo damage, is considerable.

It is concluded, based on the preliminary analyses, that while some development problems must be resolved, the concept is entirely feasible not only from a human engineering standpoint but related engineering disciplines as well.

Therefore it is recommended that the design concept be tested and evaluated in the present mockup and refined on the basis of the test results.

9. REFERENCES

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2. Unpublished Presentation made by the FRA Office of Safety to Operating Rules Advisory Committee, February 28, 1975.

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