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JUNE 1985

DEVELOPMENT AND ASSESSMENT OF NEW AND EXISTING CANOPY TECHNOLOGY TO LOWER COAL SEAMS

OFR 86-7

Contract H0387026
ESD Corporation
600 Meridian Avenue
San Jose, CA 95126

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

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The goal of this 42-month contract was to increase safety in low-seam underground coal mines through development and in-mine evaluation of a temporary roof support system for roof drills and floor-riding operator compartments for a loader and shuttle car. The program was performed in three phases. During Phase I, state-of-the-art canopy technology was investigated, and preliminary design and mock-up evaluations were performed for temporary roof supports for single- and dual-boom bolters and for transverse-mounted floor-riding canopies for a shuttle car and coal loading machine. The shuttle car and loader canopies were approved for further development, and the design, fabrication, testing, and certification were completed in Phase II. In Phase III, the Bureau of Mines furnished an FMC 6L shuttle car for use in the evaluation of the canopy for 45 shifts. The shuttle car canopy was evaluated at Virginia Crews Coal Company in West Virginia. Efforts to secure an evaluation site for the loader canopy were unsuccessful. The loader canopy was shipped to Bruceton for possible future evaluation.

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FOREWORD

This report was prepared by ESD Corporation, 600 Meridian Avenue, San Jose, California, under Bureau of Mines Contract Number H0387026. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Bureau of Mines, with Mr. John Bartels acting as Technical Project Officer. Ms. Lorene Allar was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period from September 1978 to March 1983. This report was submitted by the author in June 1983, and subsequently revised by the Bureau of Mines.

The author wishes to acknowledge the assistance of Mr. Bruce McClellan, Joy Manufacturing Company, Messrs. C. D. Albright and Joe Larry, FMC Corporation, Mining Equipment Division, and the Virginia Crews Coal Company for their participation in this program.

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EXECUTIVE SUMMARY

Introduction

This final report presents a summary of activities performed by ESD Corporation, Engineered Systems Development, under contract to the Bureau of Mines. Contract Ho387026 was awarded to ESD, formerly a division of FMC Corporation, in 1978 for the development and assessment of new and existing canopy technology in lower coal seams. The objective of this program was to make working conditions for miners safer through the design, development, fabrication, certification, and evaluation of temporary roof supports (TRS) for single- and dual-boom bolters, and canopies for loaders and shuttle cars.

ESD engineers worked with engineers from Joy Manufacturing Company, FMC Corporation, and others to design canopies and temporary roof supports and integrate them into coal mining equipment.

Summary

The program was performed in the following three phases:

o Phase I, Preliminary Design and Mock-Up Evaluation

During this phase, a literature search and discussions with equipment manufacturers were conducted to obtain data on the state of the art in TRS and canopy technology. After gathering this information, design concepts were developed for the following:

-- A transverse mounted canopy on a coal-loading machine for use in working heights as low as 42 inches

-- A transverse mounted, floor-riding canopy on a shuttle car for use in working heights from 42 to 48 inches

-- A TRS for a single-boom bolting machine for use in working heights as low as 42 inches

-- A TRS for a dual-boom bolting machine for use in working heights from 42 to 48 inches.

Full scale mock-ups of these concepts were made for study, refinement, and evaluation. A design review was subsequently held with represen-tatives from the Bureau of Mines, ESD, Joy, and FMC. As a result of this design review, it was decided to proceed with further development of two of the canopy concepts and one TRS. It was decided not to further pursue design of the TRS for a dual-boom bolter.

- Phase II, Design Detail and Fabrication

  Phase II work began with the incorporation of Phase I recommendations into canopy design. Emphasis on initial work was on developing TRS layouts for the FMC Model 300 roof drill. After review of these layouts, the Bureau of Mines opted to cancel additional work on the TRS, and emphasis was then moved to the design, fabrication, and certification of the loader and shuttle car canopies.

  Also during Phase II, a mine survey was conducted for a suitable underground coal mine for in-mine evaluation of the operator compartment. operating coal mines, coal mine equipment manufacturers, and Bureau agencies were contacted, and various incentives were offered mine owners for their cooperation. Although no mine was found for evaluation of the loader canopy, which was subsequently shipped to Bruceton for future evaluation, Virginia Crews Coal Company of Iaeger, West Virginia, agreed to participate in evaluation of the shuttle car canopy. At the conclusion of Phase II, options for VCCC's involvement were presented to the Bureau of Mines for review.

- Phase III, In-Mine Evaluation

  At the outset of this phase, the Bureau of Mines purchased and provided a 6L shuttle car for in-mine evaluation. The canopy was attached to the shuttle car during manufacture and was brought to VCCC's only conventional mine, where it operated for two shifts per day, five days per week, for the required 45 working shifts. The shuttle car was then transferred to a continuous mine for further evaluation.

  During this transfer, it was found that a roller bracket was missing, that the canopy guide rails were damaged, and that the 6L shuttle car body plate in the area of the canopy mounting was slightly bent. The damage was repaired, the moving parts replaced, and the additional ribbing capability was added to the car body. The shuttle car was then taken to a VCCC continuous mining section, where it has performed successfully, without breakdown.

Conclusions

During the program, a shuttle car canopy for use in lower coal seams was successfully designed, fabricated, and evaluated in a mine with working heights of 50 to 52 inches. A canopy for use with a loader was designed and fabricated, but has yet to be tested in a working mine. Development of the TRS did not proceed beyond the design phase, because it was felt that the design did not sufficiently improve on current state of the art.

Transverse mounted, floor-riding canopies are promising for future use in lower coal seams. This position was easily adapted to by operators and was preferred over in-line canopy positioning. During in-mine evaluation, response to this position was positive. Transverse mounting increases car operating width, making it susceptible to ribbing. It is thus prudent to minimize the length of the enclosure protruding beyond the car body sides and to insure that the car body side can sustain the ribbing loads.

The floor-riding canopy minimizes the amount of clearance required for an operator's protective enclosure operating in a low coal seams. Floor riding is somewhat restricted by very rocky and muddy bottoms.

Recommendations

The following recommendations are made as a result of the 42-month program:

- o Loader operator protection will always be needed in conventional low coal mines. Since the loader canopy is available for evaluation, some way should be found to interest a mine owner in evaluating the loader canopy in low coal.

- o Future design of operator compartments for shuttle cars used in lower seams should continue to use the bottom riding principle, but an alternate feature should be added by which the canopy could be lifted mechanically. This feature would give the operator the option to improve his field of vision where conditions allow.

- o Acceptable TRS systems are available as modification kits to the mining industry for between $7,000 and $12,000. These systems only allow single-pass bolting. Augmenting the capability of the single-boom bolter to two passes, as asked for originally in this contract, was judged too costly.

1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

Although advancements have been made to improve mine safety in underground coal mines, preventable fatalities resulting from rib and roof failures, cave-ins, and mine explosions continue to occur. A 1974 study[1] showed that during the period from January 1966 to May 1974, 234 of the 632 lives lost due to roof falls could have been saved through the use of cabs or canopies, because the machine operators were either at the controls or running from the controls when they were killed. Of the fatal accidents noted, it was estimated that 58 percent of the fatalities associated with shuttte cars and 69 percent of the fatalities associated with loading machines could have been avoided had adequate canopy protection been available (see figures 1, 2, 3, 4).

The Federal Coal Mine Health and Safety Act of 1969 mandated installation and use of protective cabs or canopies at operators' stations on all self-propelled electric face equipment used in underground coal mines. The Mine Safety and Health Administration (MSHA) is currently enforcing this requirement in floor-to-roof heights down to 42 inches. Compliance to this law has been hindered by a lack of operator acceptance in low seam heights.

Adequate canopy equipment has been developed for application to machines for use in seams down to 60 inches in height. Canopies are used in 48-inch to 60-inch seams, but not without problems. In seam heights less than 48 inches, previous attempts to apply canopies have resulted in adverse comments from operators. Typical problems are reduced visibility from the compartment and operator fatigue caused by unusual or cramped operator positions.

The Bureau of Mines has sponsored several programs to advance the application of canopies and to demonstrate this technology in underground coal mines. Many cabs and canopies have been developed and evaluated under these efforts. Human factors engineering, standardized operator controls, and panic bar designs that have been developed by previous research programs were utilized during this program.

Temporary Roof Support (TRS) systems have become popular items on roof bolters. They are permitted by canopy regulations and may be used in lieu of drill station canopies if the design is reviewed and approved by MSHA Technical Support in Pittsburgh. In addition to meeting the canopy requirement, some TRS systems may replace the need for temporary jacks now required

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Table 1 FATALITIES, BY YEAR

YEAR	FATALS	PODDIBLE SAVES	PERCENT SAVED
1966	110	47	42.7
1967	94	34	36.2
1968	98	38	38.8
1969	77	32	41.6
1970	84	29	34.5
1971	60	19	31.7
1972	50	18	36.0
1973	44	13	29.5
1974 (Jan.-May)	15	4	26.7
TOTAL	632	234	37.0

Table 2 FATALITIES, BY MINING MACHINE

MACHINE	TOTAL FATALS	POSSIBLE SAVES	PERCENT SAVED
Loading Machine	118	80	67.8
Continuous Miner	108	55	50.9
Roof Bolter	84	49	58.3
Cutting Machine	38	18	47.4
Shuttle Car	26	15	57.6
Face Drill	13	7	53.8
Battery Tractor	14	6	42.9
Scoop	4	4	100.0
Non-machine	227	0	0
TOTAL	632	234	37.0

Table 3 FATALITIES, BY COALBED HEIGHT

COALBED HEIGHT	TOTAL FATALS	POSSIBLE SAVES
23" or less	4	0
24"-35"	65	16
36"-47"	159	53
48"-59"	125	48
60"-71"	104	43
72" and over	175	74
TOTALS	632	234

Table 4 FALLS, BY FALL THICKNESS

FALL THICKNESS	TOTAL FALLS RECORDED OF SPECIFIC THICKNESS	PERCENT OF FALLS OCCURRING IN SPECIFIC THICKNESS
6" or less	117	19.9
7"-12"	183	31.2
13"-18"	34	5.8
19"-24"	70	12.0
25"-36"	49	8.4
37"-48"	20	3.5
49"-60"	13	2.2
61"-84"	17	2.7
85"-108"	11	1.8
109" and over	21	3.6
Not given	52	8.9
TOTAL	587	100.0

prior to bolting, thus reducing operator exposure to the hazard of unsupported roof. MSHA is currently developing guidelines for this application.

In 1978, the Bureau of Mines awarded Contract H0387026 to ESD Corporation, then the Engineered Systems Division of FMC Corporation, for the development and assessment of new and existing canopy technology in lower coal seams. Using the canopy design experience gained on the Inherently Safe Mining Systems and Optimized Operator Compartment programs, ESD engineers worked with engineers from Joy Manufacturing Company and FMC Corporation to design canopies and temporary roof supports and integrate them into coal mining equipment. Resulting canopies were not to be peculiar to these manufacturers and were to be applied to similar equipment made by other companies.

1.2 SUMMARY

This program was funded in two parts and performed in three phases: Phase I, Preliminary Design and Mock-Up Evaluation; Phase II, Design Detail and Fabrication; and Phase III, In-Mine Evaluation and Final Report.

1.2.1 Phase I Work

Canopy technology was applied to four separate vehicle configurations:

- A transverse mounted canopy on a coal-loading machine for use in working heights as low as 42 inches
- A transverse mounted, floating (floor-riding) canopy on a shuttle car for use in working heights of 42 to 48 inches
- A temporary roof support (TRS) for a single-boom bolting machine for use in working heights as low as 42 inches
- A temporary roof support (TRS) for a dual-boom bolting machine for use in working heights of 42 to 48 inches.

Information on the state of the art in canopy technology was obtained through a literature search and discussion with equipment manufacturers and coal companies. Results of previous Bureau of Mines research contracts were reviewed. See Table 5.

Various canopy concepts were generated to satisfy requirements established by the contract, MSHA, equipment manufacturers, and operator comments noted during previous development efforts. Engineering drawings supplied by Joy and FMC were used to determine mounting positions, attachment hardware, controls, and chassis rework needed to install the proposed canopies

A design review meeting was conducted at the ESD facility on February 6, 1979, where the various proposed canopy concepts were presented to the Bureau of Mines, MSHA, and equipment manufacturers. As a result, some changes were made in the program direction, and development continued on selected concepts.

Table 5 RELATED BUREAU OF MINES CONTRACTS

Loader	Shuttle car	Bolter	Contract Number	Title, Contractor
X	X	X	H0111670	Inherently Safe Mining System, FMC Corporation.
X	X	X	H0133031	Production of Equipment Design Criteria for Panic Bars, Bendix Corporation.
X			H0155192	Innovative Machine Design Concepts, FMC Corporation.
		X	H0166138	Development of a Dual Boom Semi-Automated Roof Bolter, FMC Corporation.
X	X	X	H0220031	Design and Development of Protective Canopies for Underground Low-Coal Electric Face Equipment, Including Shuttle Cars, Bendix Corporation.
X	X	X	H0230021	Standardization of Controls for Underground Electric Face Equipment, Applied Science Associates.
X	X	X	H0242020	Survey of Protective Canopy Design, Bendix Corporation.
X	X	X	H0242028	Design and Development of Protective Canopies for a Shuttle Car, Loader, and Roof Drill, Bendix Corporation.
X	X	X	H0242033	Optimized Operator Compartment, Applied Science Associates.
	X	X	H0242065	Refined Design of Protective Canopies for Shuttle Cars, Loaders, and Cutters, Bendix Corporation.
	X		H0252048	Fabrication and Evaluation of Optimized Operator Compartments, Bendix Corporation.
	X	X	H0252091	Fabrication and Evaluation of Optimized Operator Compartments, FMC Corporation.
		X	H0262016	Research and Development of a Temporary Face Support System, Foster-Miller Associates.
		X	H0346102	Low Coal Canopy Studies, Bendix Corporation.
		X	H0357090	Fabricate and Evaluate Protective Canopies for 3-foot Coal Seams, Bendix Corporation.

The major program change resulting from this meeting was the substitution of the Joy A Model loader for the B Model. The other three canopy projects received only a minor change in direction; e.g., concentrating on a retrofittable concept for the single-boom bolter TRS system and using strictly transverse seating on the shuttle car.

In the preliminary engineering phase, designers concentrated their efforts in the area of man-machine interface to optimize operator safety, task visibility, human body size accommodation, control reach, and seating comfort. Low coal height restrictions forced the operator into a position in which the seat backrest was reclined beyond normal angles. Special attention needed to be given to seat design to achieve biomechanically acceptable support. Preliminary seat and space allocation mock-ups assisted in this design area.

Full-scale wooden mock-ups were then fabricated for each development item. For machines with cabs, human factors were evaluated by the FMC Central Engineering Laboratories (CEL) Industrial Design Group. Their recommendations were incorporated into the mock-ups.

A second review meeting was conducted on May 16, 1979, where the mock-ups were evaluated by representatives from the Bureau of Mines, Mine Safety and Health Administration (MSHA), Bituminous Coal Research, Incorporated (BCR), Joy Manufacturing Company, and FMC. Much interest was shown in the shuttle car, loader, and single-boom TRS mock-ups, resulting in the decision to recommend fabrication and demonstration of these structures.

1.2.2 Phase II Work

Phase II work began in october 1979. During this phase, the recommendations and findings from Phase I were incorporated, further development was performed on the single-boom TRS, and the structures for the loader and shuttle car were designed, built, tested, and certified. Also during this phase, a search was conducted for mine sites for evaluation in working conditions.

During the search, various incentives were offered to mine owners in an effort to locate mine owners willing to participate in evaluation of the loader canopy, TRS, and shuttle car canopy. Although sites were found for evaluation of the TRS and the shuttle car canopy, no site could be found for evaluation of the loader canopy. The fabricated, tested, and certified canopy structure and its ribbing link were sent to Bruceton for storage and possible future evaluation.

The concept developed during Phase I for the retrofittable TRS was found unsatisfactory by ESD because it did not react roof drilling loads into the mine floor. Beginning in December 1979, six layouts were generated for possible Bureau acceptance. These layouts were sent to the Bureau for review in February and March of 1980.

A design review of the canopy and TRS layouts was held at Bruceton on March 28, 1980. MSHA representatives were in attendance. During this review, a decision was made to continue design, fabrication, and testing of the shuttle car canopy, but to discontinue further work on the TRS.

1.2.3 Phase III Work

Phase III work entailed in-mine evaluation of the shuttle car canopy designed and built during Phase II. The evaluation was conducted at the Virginia Crews Coal Company (VCCC) in Iaeger, West Virginia. VCCC first expressed interest in participating in shuttle car canopy evaluation during Phase II and was brought into the program by a Mine Agreement signed early in Phase III.

The shuttle car with canopy was manufactured beginning in May 1982 and was delivered to VCCC on August 26, 1982. In-mine evaluation began on August 31. The required 45 working shifts were completed by November 27 without incident.

Damage was subsequently discovered to the canopy guides, mounting brackets, and shuttle car itself after the car was taken out of the mine for transfer to a different mine site. The damage was repaired, the structural capability upgraded, and the shuttle car with canopy installed in the new mining location.

Phase III successfully demonstrated the viability of the concept of using a shuttle car canopy which rides on the mine floor with the operator sitting with his legs perpendicular to the direction of travel, while operating in 48 inches of headroom or approximately 52 inches of mine face.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

The research needed to provide mine workers with improved safety and protection can be advanced through the cooperative efforts of federal agencies, equipment manufacturers, mine owners, and mine workers. A workable plan is for federal agencies to provide innovative research, mine owners to provide direction and funding, equipment manufacturers to apply engineering and practical skills to equipment development, mine owners to promote the use of protective enclosures or safety devices whenever available, and mine workers to use the safety equipment provided.

2.1.1 Phase I Conclusions

Full-scale canopy mock-ups were built by ESD during Phase I and evaluated by personnel from the mining industry. Their comments are summarized in the following subsections.

2.1.1.1 Loader Canopy Mock-Up

This canopy was well received by reviewers, who generated many constructive criticisms. It appeared to be practical for loading machines operating in seam heights down to 40 inches. The machine mock-up was a Joy 14BU10-11A Model with 24-inch frame height which, if not equipped with a canopy, could have been used in seams 28 inches and higher.

Notable points included good vision toward the face and back to the shuttle car and the comfortable operator position in the sling seat.

Improvements were needed in the areas of vision to the gathering table, seat adjustment hardware, and ingress/egress.

This concept had good potential, and it was felt that development should be continued.

2.1.1.2 Shuttle Car Canopy Mock-Up

The shuttle car canopy was also praised by reviewers for its operator comfort and visibility while performing task functions. Designed for operation in 42- to 48-inch seam heights, adequate headroom was made available by utilizing the floor-riding canopy concept.

The adjustable seat was comfortable for a range of operator sizes. Steering seemed natural, regardless of the direction of travel, but the tram pedals needed rework. Excellent ingress/egress was noted, resulting from the large opening width.

Disadvantages were the extensive chassis and boom rework needed to fit the canopy tunnel under the conveyor, as detailed in Subsection 3.1.2.3, and the loss of 3 cubic feet of coal-carrying capacity.

Again, it was concluded that this design showed promise and should be continued through fabrication and demonstration phases.

2.1.1.3 Single-Boom TRS Mock-Up

There was considerable interest in this concept, because it could result in a practical retrofit kit for application to the many single-boom bolters in the field. Not only could it meet the in lieu of" canopy requirements, but it also had the potential of replacing, under the proper mining conditions, manual installation of roof supports.

Many comments and design suggestions were recorded for this mock-up. The major limiting factor was thought to be system weight, which needed to be minimized or counterbalanced to maintain traction drive performance.

This item was not recommended for continued work.

2.1.1.4 Dual-Boom TRS Mock-Up

Reviewers agreed with the bar-type TRS approach for dual-boom machines. However, they found that this mock-up did not offer significant advantages over existing TRS designs to warrant further development.

2.1.2 Phase II Conclusions

2.1.2.1 Loader Canopy

Locating a mine to evaluate the loader canopy presented several problems, including the following:

- The canopy had to be mounted to a Joy Model 14BU10-11A, or redesign would be required
- Loaders were in use in conventional,[1] usually small, mining operations
- Coal industry business was not doing well.

Because of these difficulties, efforts to find a mine site for evaluation were unsuccessful.

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1. The term "conventional" refers to mines in which the face is drilled and blasted and then loaded into a shuttle car or other coal conveying vehicle with a loading machine.

2.1.2.2 Shuttle Car Canopy

The 39-inch height used for this enclosure was the lower limit which would accommodate a 95th percentile man in a fairly erect seated position. Lowering this height would require the operator to take either a slouching or lay-back position.

The transverse mounted canopy configuration with the operator facing at 90 degrees to the direction of travel posed a conflict between the advantages of canopy float and the resulting rework to the structure of the shuttle car. Because the shuttle car was built with minimum ground clearance, it was necessary to cut out the car body to provide clearance for the canopy tunnel. This transverse position also resulted in the canopy protruding beyond a line along the fender wells. The protrusion could be reduced by providing a longer tunnel below the conveyor to accommodate the operator's legs. Reducing the protrusion dimension would reduce rib loadings transmitted into the shuttle car.

No solution was found to the problem of accommodating the canopy tunnel, with the exception of reworking the conveyor and car body.

The vision provided by the canopy was found to be superior to that found in standard canopies, in which the operator faces the direction of travel and looks over the wheel wells.

2.1.2.3 Single-Boom TRS

The Phase II effort to develop a single-boom TRS showed that the program goal of developing a low-cost, easily adaptable modification kit for the FMC Model 300 roof drill could not be met without changing some of the design constraints. Meeting the dimensional requirements resulted in added weight to the drill head area, causing the machine CG between the wheels to move too close to the inby wheel, causing unstable tramming. If the CG were manipulated by means of counterweights, the machine weight would increase, resulting in diminished floor-riding capability.

The estimated $30,000 production cost of the retrofittable two-pass TRS kit was the major impediment to its becoming an attractive addition to the existing FMC Model 300 drills which, assuming that they were purchased in the late 1970's, cost less than $35,000.

2.1.3 Phase III Conclusions

The shuttle car canopy was successfully evaluated without incident for 45 working shifts. During its subsequent transfer to another mine, damage to the floating mechanism was observed. The damage was repaired, and the shuttle car and canopy were sent back into the mine. Since one of the four roller brackets was discovered as missing at this time, it is uncertain when the damage occurred and what caused it. The following conclusions can be drawn from Phase III work, bearing in mind these events.

- The rib loading of the canopy structure into the car body is greater than that assumed in the design. The shuttle car body and the enclosure attachments should be designed to sustain heavier loading.

- The future design of transverse mounted canopies should attempt to reduce the dimension of the enclosures protruding from the car body. This reduction could be achieved by extending the tunnel farther under the conveyor, thus allowing the operator to move closer to the car body.

- Any parts installed in the tunnel are either maintenance-free or removable for servicing.

- Although the canopy attachments and the shuttle car body showed stress problems due to ribbing, the only parts of the enclosure that showed any stress breakdown were the guide channels in which the rollers rode and the escape hatch. These should be made heavier if used in future design.

- Floor-riding enclosures are practical and offer the most economical use of available mine height.

2.2 RECOMMENDATIONS

2.2.1 Phase I Recommendations

General recommendations from Phase I work were to continue development of the loader and shuttle car canopies through the fabrication phase. Specific recommendations recorded at the mock-up review are summarized below.

2.2.1.1 Loader Canopy

- Machine changes -- A gathering head extension pan could improve rib clean-up on right side. Methane monitor and machine lighting should be built into machine. A radius rod extending from the head to the canopy outside corner would act as bumper and could mount the lighting and methane monitor enclosures.

- Canopy structure -- The dirt gate should be replaced with a flat plate. Modify right front corner to improve vision to gathering head. Add a window in rear panel. Relocate top support posts for better vision. The long canopy creates tunnel vision, consider reducing it to 30 inches wide. Analyze ribbing load of 40,000 pounds at 1130 fpm on outside corner of canopy.

- Suspension -- A high load is needed to overcome spring force, a floating canopy would gain two inches of internal height. There is no bounce space for large operator, so springs should be damped.

- Ingress/Egress -- Cut back left kick panel 6 inches, revise framework to increase access opening. Lamp battery caught on seat edge.

- Seat -- Sling-type seat is comfortable. Adjustment levers difficult to operate and subject to maintenance problems, so replace with simple pinned mechanisms. Check need for lumbar support.

- Operator comfort -- Add knee supports to hold legs up. Elevated foot position may not be problem, seemed comfortable.

- o Tram control -- Relocate control from center position to right side. Right hand operates both levers normally. Also, relocate tram enclosures from top plate to right side. Could provide better leverage, since existing tram control has stiff springs. May reorient levers to push-pull direction.

  - o Controls -- extend center hydraulic valve handle for coding. Relocate switches from outby the canopy to improve egress.

  - o Vision -- Transverse seat position provides unrestricted vision inby and outby from the same seat position.

2.2.1.2 Shuttle Car Canopy

- o Machine changes -- Improve mudflap or extend bumper to keep wheel from throwing dirt onto the operator. Watch spacing between canopy and fender, which is a potential pinch point.

- o Canopy structure -- Alternate exits, could be through rear plate. Cut down rear plate to provide window. Delete deflector bars, roll top plate leading edges about 1 inch. Round off square corners. Base plate should be at least 4 inches high, and approach angle should be 45 degrees. Stress tunnel area to support entire shuttle car load without crushing. Expect 8-inch bumps, from 8- by 8-inch timber on floor.

- o Suspension -- Design support rails to take ribbing loads. May need more rails, probably at wheel fender. Bolts have been sheared from rails, could be totally welded as on Torkars.

- o Ingress/Egress -- Add a grab bar under top plate. Need second exits, perhaps over switch or on right side.

- o Seat -- The seat was comfortable, but adjustment was cumbersome.

- o Operator comfort - Position tram pedals to allow operator to stretch legs for rest period. Floating canopy gives better ride.

- o Tram controls -- Steering was consistent due to transverse seat position. Tram pedals would suffer from dirt accumulation. Consider suspending pedals. Let operators clean tunnel area when needed. Combined tram pedal seemed unnatural, consider one pedal with direction switch. Jogging of machine was difficult when loading if direction switch was used.

- o Controls - All controls were located within and moved with the compartment. Relocate gong outside compartment. Panic bar should not be capable of resetting the stop switch.

- o Vision - Vision is good except the opposite corner. Add indicator rods here.

2.2.2 Phase II Recommendations

2.2.2.1 Loader Canopy

On the basis of Phase II work, it was recommended that the loader canopy be evaluated for the following:

- Operator acceptance
- Field of vision
- Ease of ingress and egress
- Convenience of control locations
- Fatigue reduction
- Increased safety
- Effectiveness of the suspension system in preventing operator injury and canopy or loader damage when canopy is ribbed
- Effect of suspension on operator comfort
- Increase in productivity due to reduced operator fatigue.

2.2.2.2 Shuttle Car Canopy

It was recommended that further mine evaluations be conducted on the shuttle car operator compartments for use in lower cool seams. The results of these further evaluations would aid in the decision whether to promote the shuttle car's use in lower seams.

As a result of Phase II work, it is recommended that operator comfort considerations be paramount when designing enclosures on equipment operating in seam heights below 40 inches.

2.2.3 Phase III Recommendations

The following recommendations are the result of Phase III mine evaluation for incorporation into future shuttle car canopy design.

- Structural Canopy

  Any operator compartment mounted on the shuttle car exposed to ribbing loads must be designed to sustain these loads.

  Operator enclosures such as the shuttle car canopy used in this program subject the car body to large moment loadings when ribbing is experienced. The FMC 6L car body's side plate is 3/8-inch thick. This plate should be increased to either 3/4-inch or 1 inch on the side where the canopy is attached to increase its resistance to these loads.

o Future Research

Tests should be made to determine the magnitude of ribbing loads encountered by transverse mounted canopies and various other existing enclosures in mine operation.

o Mechanical Changes

Provide the car operator with easy canopy lifting capability to facilitate clearing bottom obstacles. This lifting capability would also enable the car operator to raise the canopy for better vision over the front and rear while loading and unloading.

o Controls

Although all controls were easily reached by shuttle car operators and were located in acceptable positions, it was recommended that consideration to design upgrading be given to the following:

-- Allow a 2-inch-minimum clearance between the brake and tram pedals.

-- All equipment in the tunnel should be mounted somewhere other than the floor to provide easy access when cleaning the tunnel.

3.0 TECHNICAL DISCUSSION

3.1 PHASE I, PRELIMINARY DESIGN

The object of this phase of work was to evaluate the application of previously developed, as well as new canopy design technology to lower seam heights than previously experienced of the following four separate configurations:

- A transverse mounted canopy on a coal loading machine for working heights as low as 42 inches
- A transverse mounted, floor-riding canopy on a shuttle car for working heights of 42 inches to 48 inches
- A TRS for a single-boom bolting machine for working heights as low as 42 inches
- A TRS for a dual-boom bolting machine for working heights of 42 inches to 48 inches

For the purposes of this program, a transverse mounted canopy was defined as a canopy in which the operator faces in a direction 90 degrees to the direction of loader or shuttle car travel.

3.1.1 Loader Canopy

The objective of this work was to design and mock-up a transverse canopy on a coal loading machine for working heights of as low as 42 inches.

3.1.1.1 Assessment of Existing Technology

Loading machine canopies had been developed under the following Bureau of Mines contracts:

- H0111670, Inherently Safe Mining Systems (FMC)

  A cab on a Joy 14BU10-11S loading machine (30-inch frame height) was hydraulically elevatable and pivoted at a horizontal axis near the operator's feet (Figure 1). The 38-inch-high cab was mounted on the right side near the current control station with the operator facing 30 degrees from the machine centerline.

  During operation in the 52-inch-high Jenny Mine, the position of the cab did not hinder machine performance, and the operator became accustomed to the angled seat position. Visibility to the gathering head was easily obtained by raising the cab where roof clearance permitted.

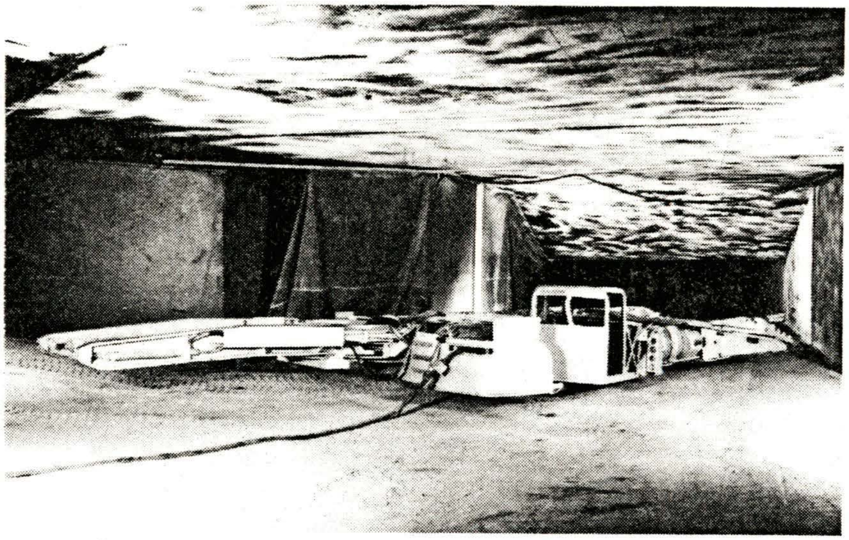


Figure 1 ISMS LOADER CAB

- o <u>H0155192, Innovative Machine Design Concepts, (Foster Miller)</u>

  A Joy 14BU10-11S loader was modified to incorporate a boom-mounted cab (Figure 2). Since extensive structural changes were required, this concept was proposed for new machines only.

  Development was taken through mock-up fabrication, where human factors and operator vision were analyzed.

- o <u>H0220031, Design and Development of Protective Canopies for Underground Low Coal Electric Face Equipment, Including Shuttle Cars, (Bendix)</u>

  A canopy was added to a 24-inch frame height Joy 14BU10-11S loader. Overall canopy height was hydraulicaaly adjustable from 32 to 40 inches with special mechanical stops to limit travel within this range. The floor pan floated on the ground, thus increasing the internal height dimension by 4 inches (ground clearance at the canopy base frame).

  This canopy was demonstrated in a 50-inch coal seam, where it was favorably accepted by mine personnel. Production was siad to increase, because the canopy protected the operator from rib contact, allowing him to concentrate on the loader function. However, the loader canopy structure was required to withstand frequent rib loading.

- o <u>H0242028, Design and Development of Protective Canopies for a Shuttle Car, Loader, and Roof Drill, (Bendix)</u>

  The loader canopy designed under Contract H0220031 (above) was revised after sustaining damage to the hydraulically adjustable canopy post system during in-mine testing. This complex adjustment feature was deemed not necessary and was replaced with simple telescoping tubes and stop pins.

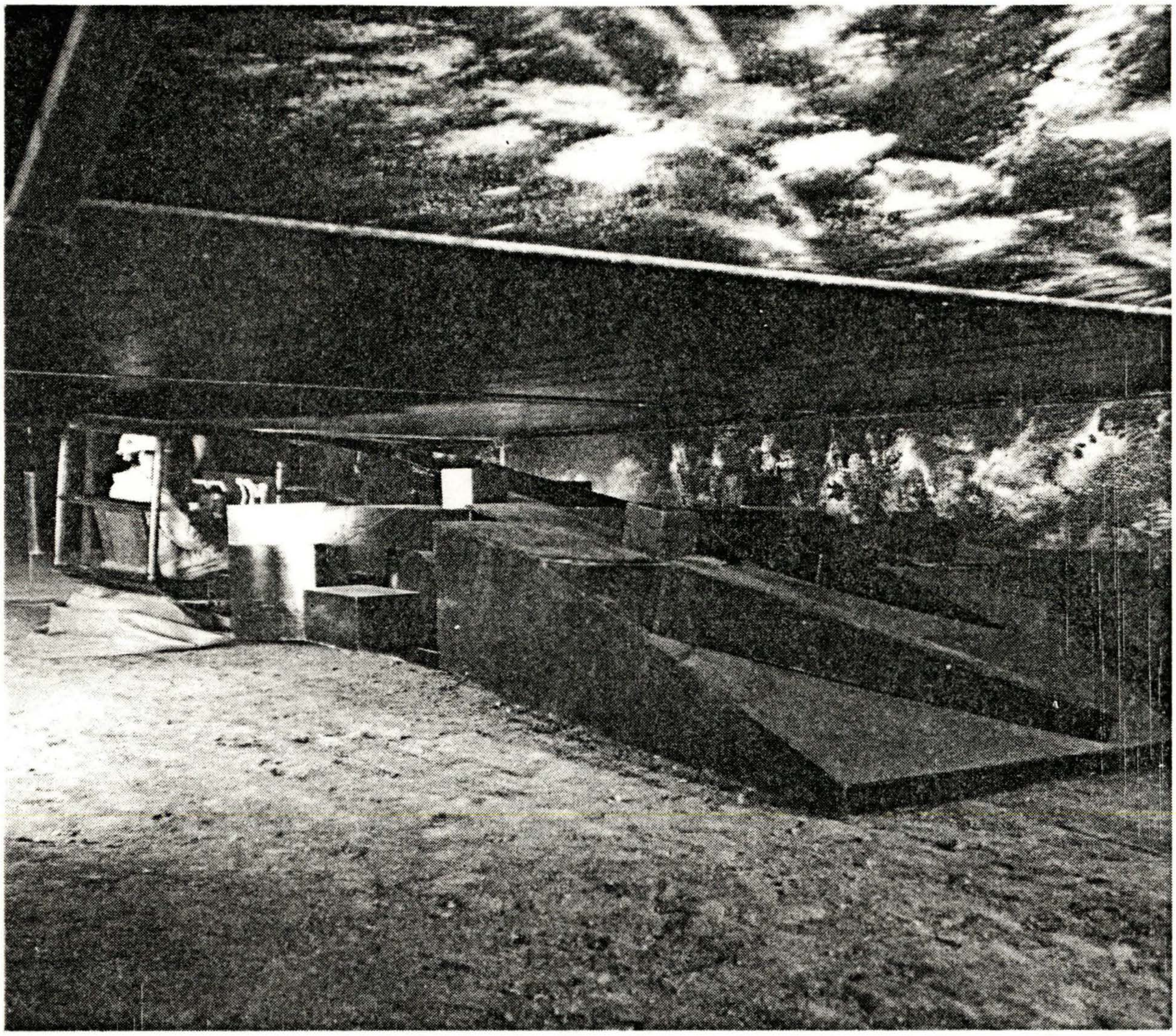


Figure 2 INNOVATIVE MACHINE DESIGN LOADER

Loader canopy technology was discussed with Joy Manufacturing Company engineers during a plant visit. They had developed transverse canopies (operator seated perpendicular to the machine centerline) for western Kentucky and Illinois mines where seam heights were about 45 inches. The majority of B model loaders (33-inch frame height) were used in these localities. Their low machine was the A model (24-inch frame height), but the mining industry had not encouraged canopy development for this machine.

In the Joy design, the transverse canopy mounted midway along the cxrawler frame (Figure 3). This gave the best vision over the gathering head and toward the shuttle car. A cab located midway along the crawler frame was protected from being slewed into the rib. There was limited space, however, for the operator's feet, and he had to assume a squatting position in low-height designs.

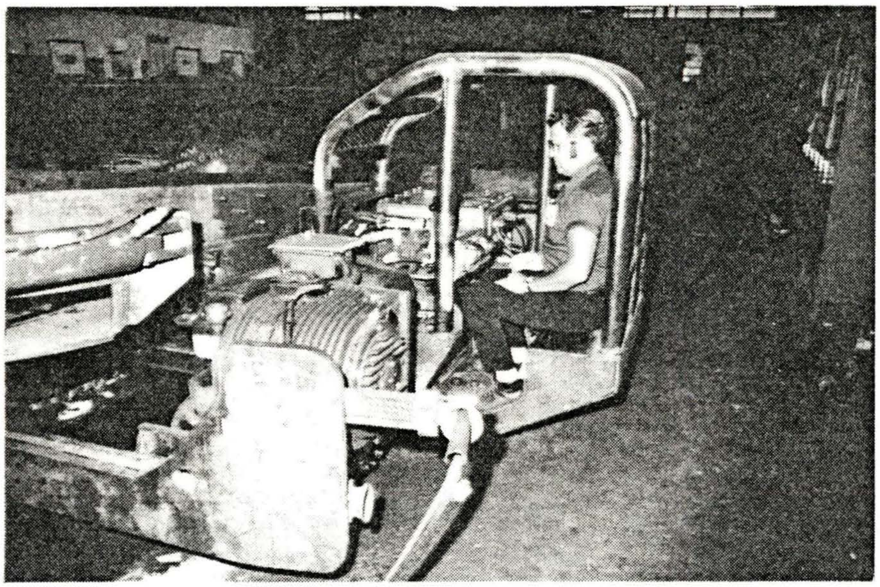


Figure 3 JOY LOADER TRANSVERSE CANOPY

Some loaders and most continuous miners had the operator's pit located next to the conveyor at the rear of the machine. This allowed deeper cuts with the miner and permitted operation close to the rib.

It was assessed that canopy technology in low coal mines was lacking. The above-mentioned contract work successfully demonstrated canopies in 48- to 52-inch seams. Other work demonstrating canopies in 3-foot coal seams produced adverse comments from operators (see Subsection 3.1.2.1) in the areas of restricted visibility and cramped operator's position. This indicated the need for special attention to human factors as the canopy was designed.

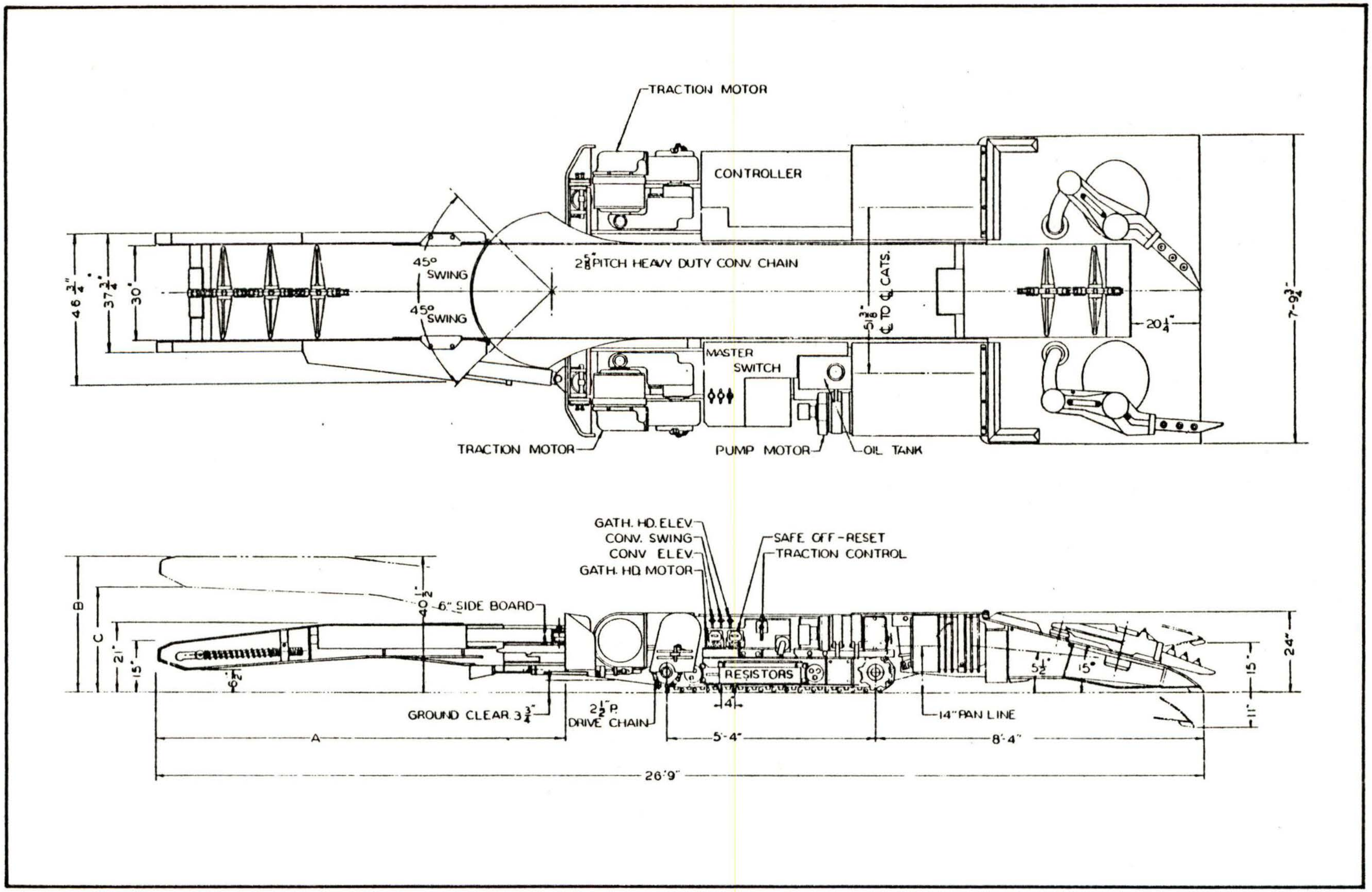


Figure 4 JOY LOADER, A MODEL

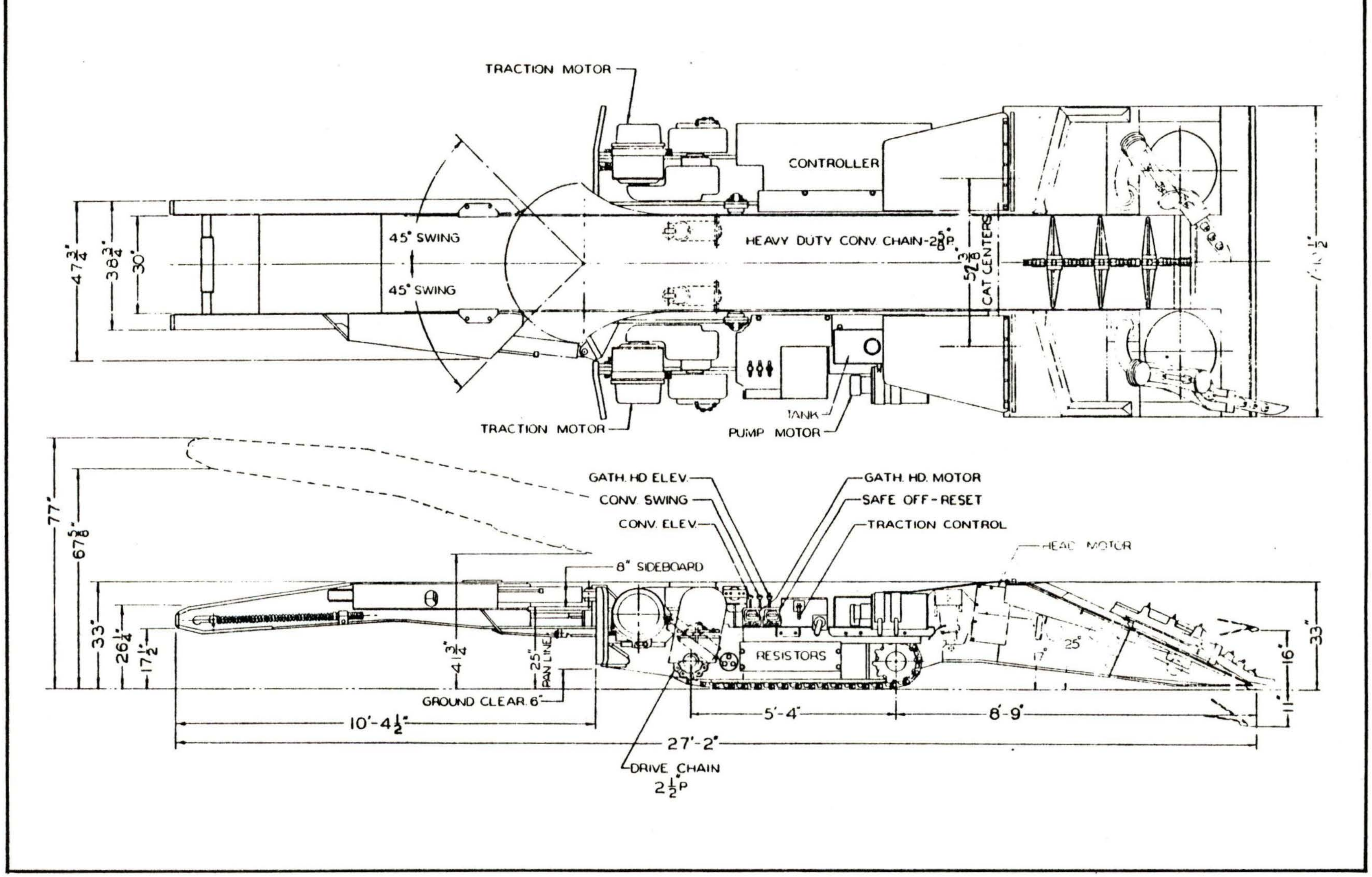


Figure 5 JOY LOADER, B MODEL

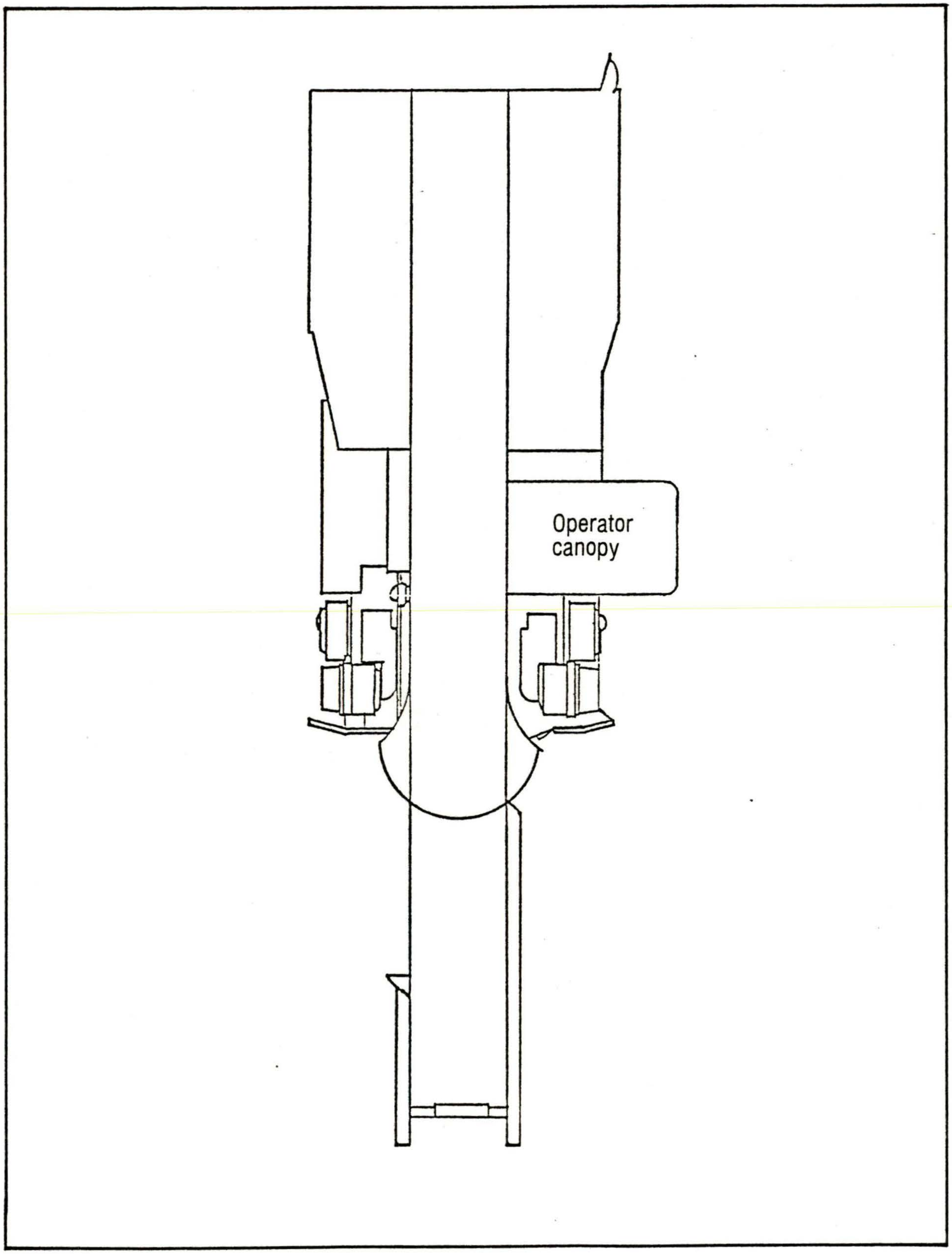


Figure 6 CONCEPT 1 -- STANDARD JOY LOADER 14BU10-11B WITH SPECIAL CANOPY

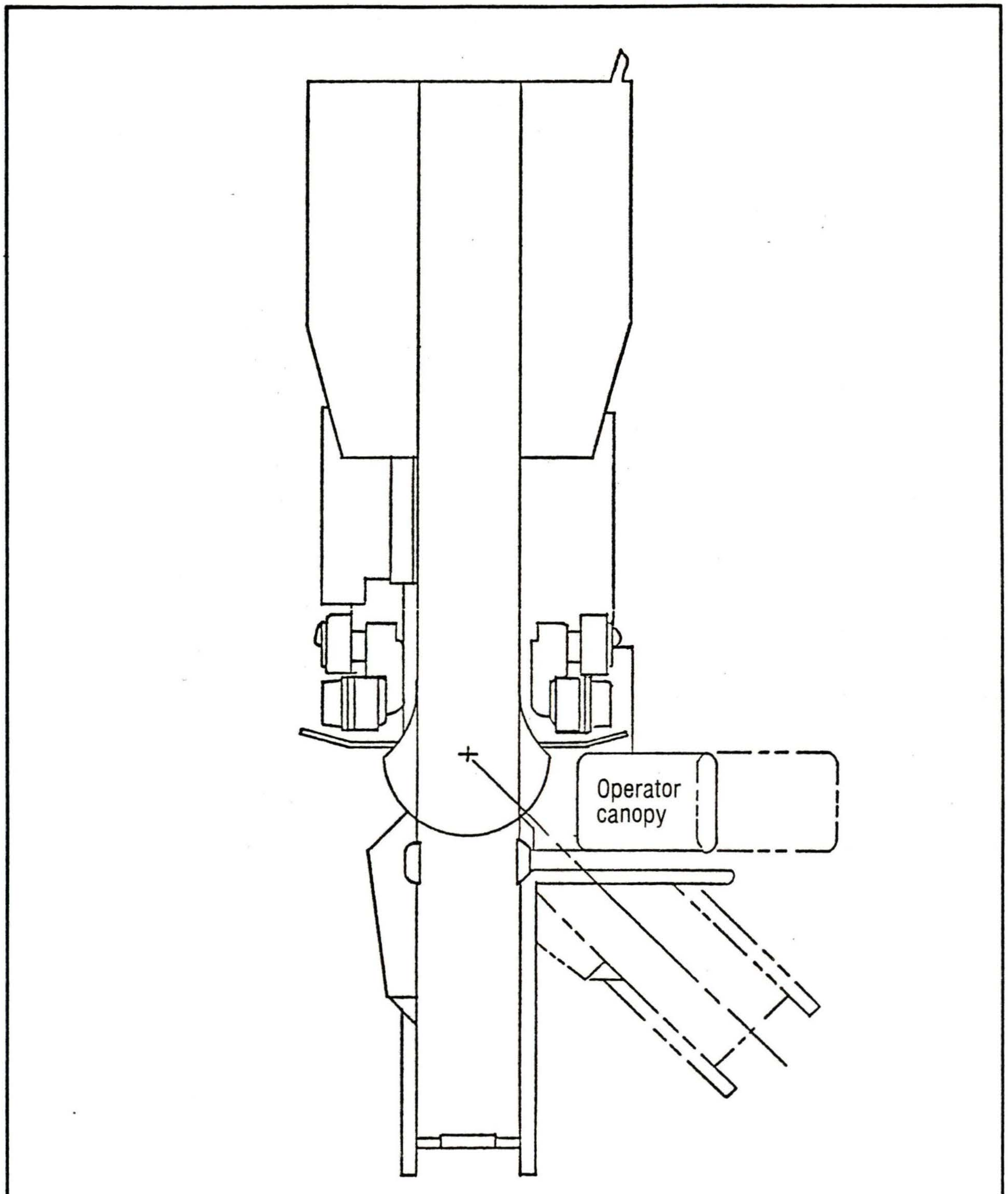


Figure 7 CONCEPT 2 -- MODIFIED JOY 14BU10-11B LOADER WITH CANOPY AND PROTECTIVE BUMPER AT END OF LOADER FRAME. MOVABLE CANOPY AND BUMPER.

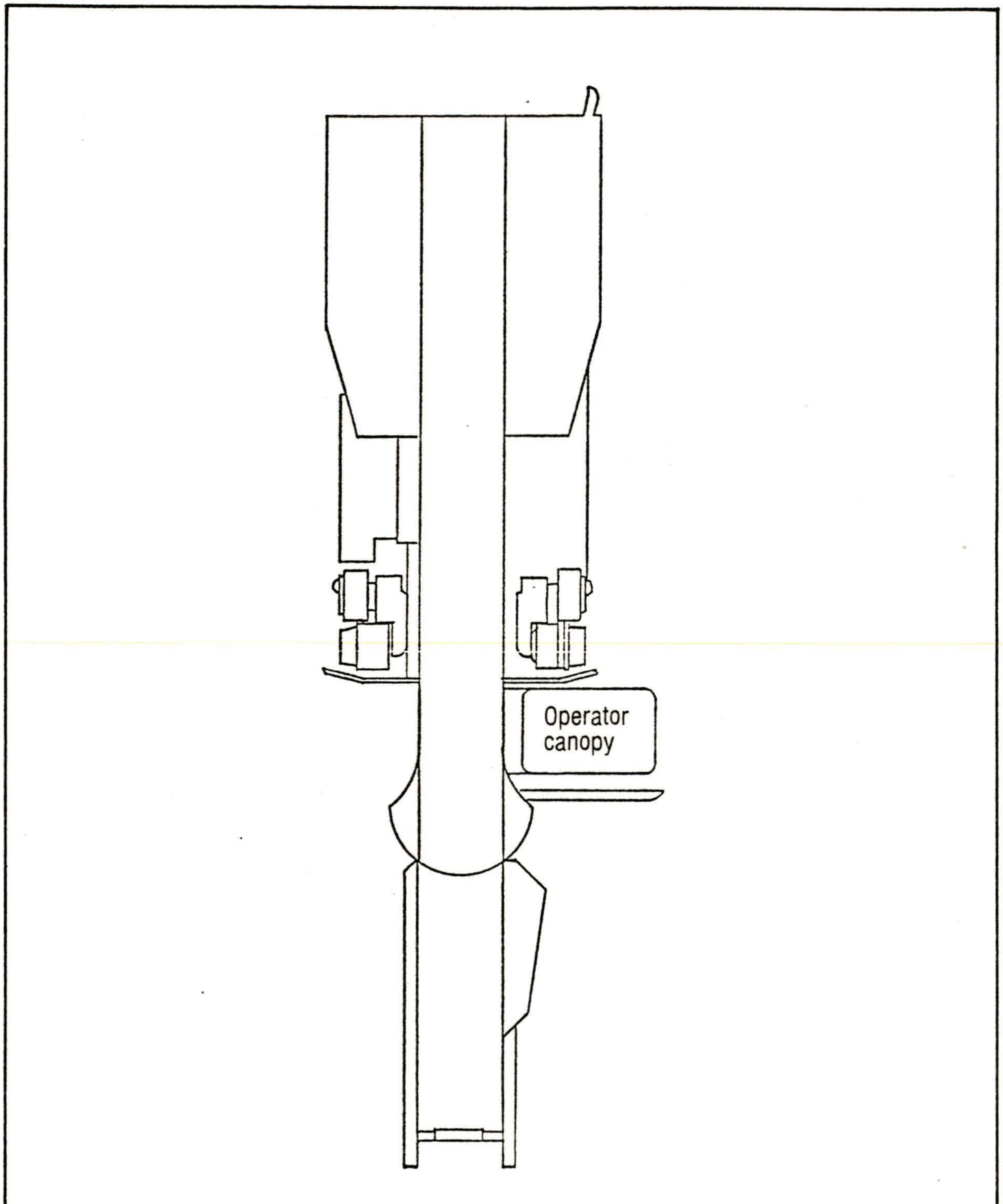


Figure 8 CONCEPT 3 -- MODIFIED JOY 14BU10-11B LOADER WITH CANOPY AND BUMPER MOUNTED ON EXTENDED CONVEYOR BOOM

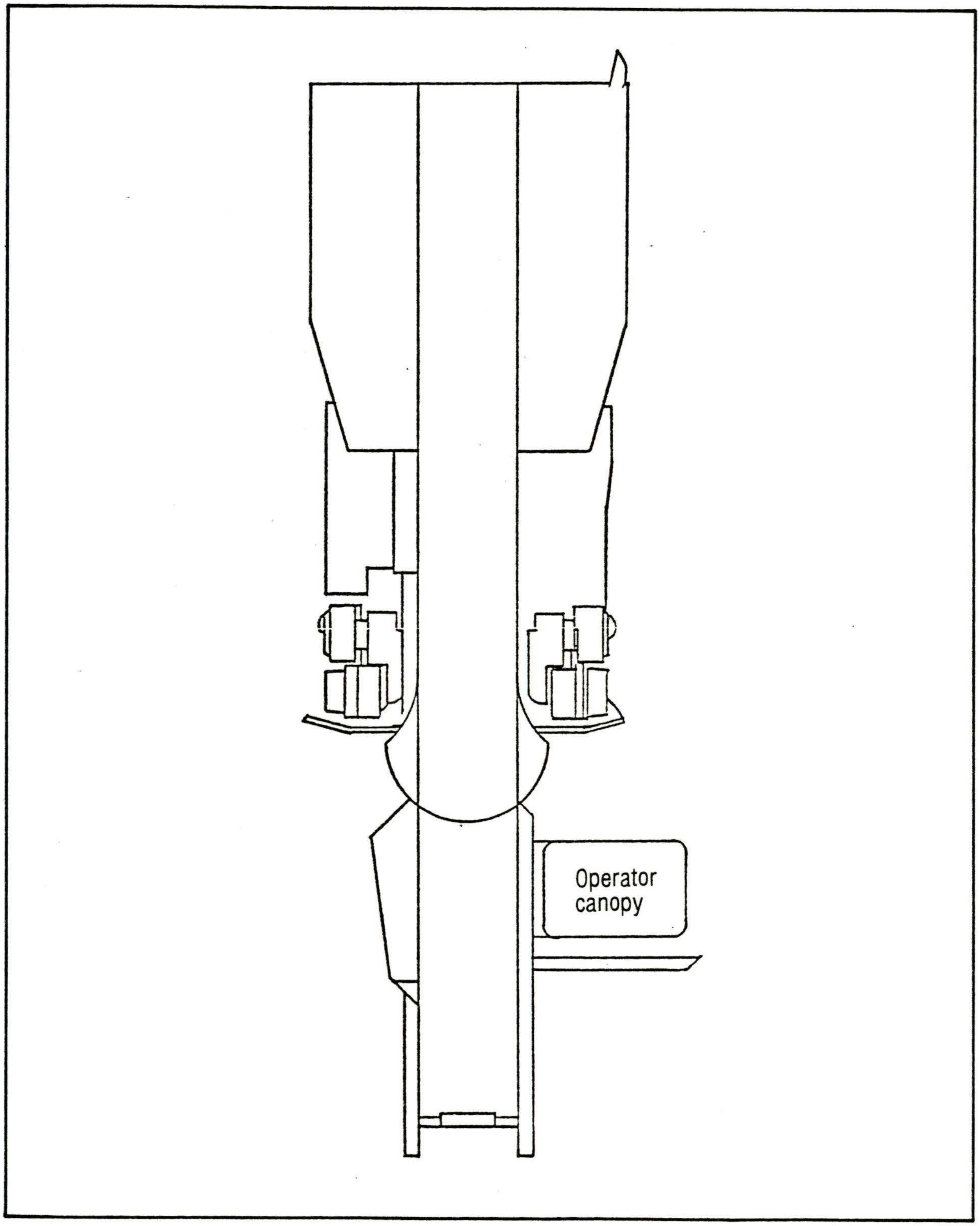


Figure 9 CONCEPT 4 -- MODIFIED JOY 14BU10-11B LOADER WITH CANOPY AND BUMPER MOUNTED ON LENGTHENED TAIL BOOM

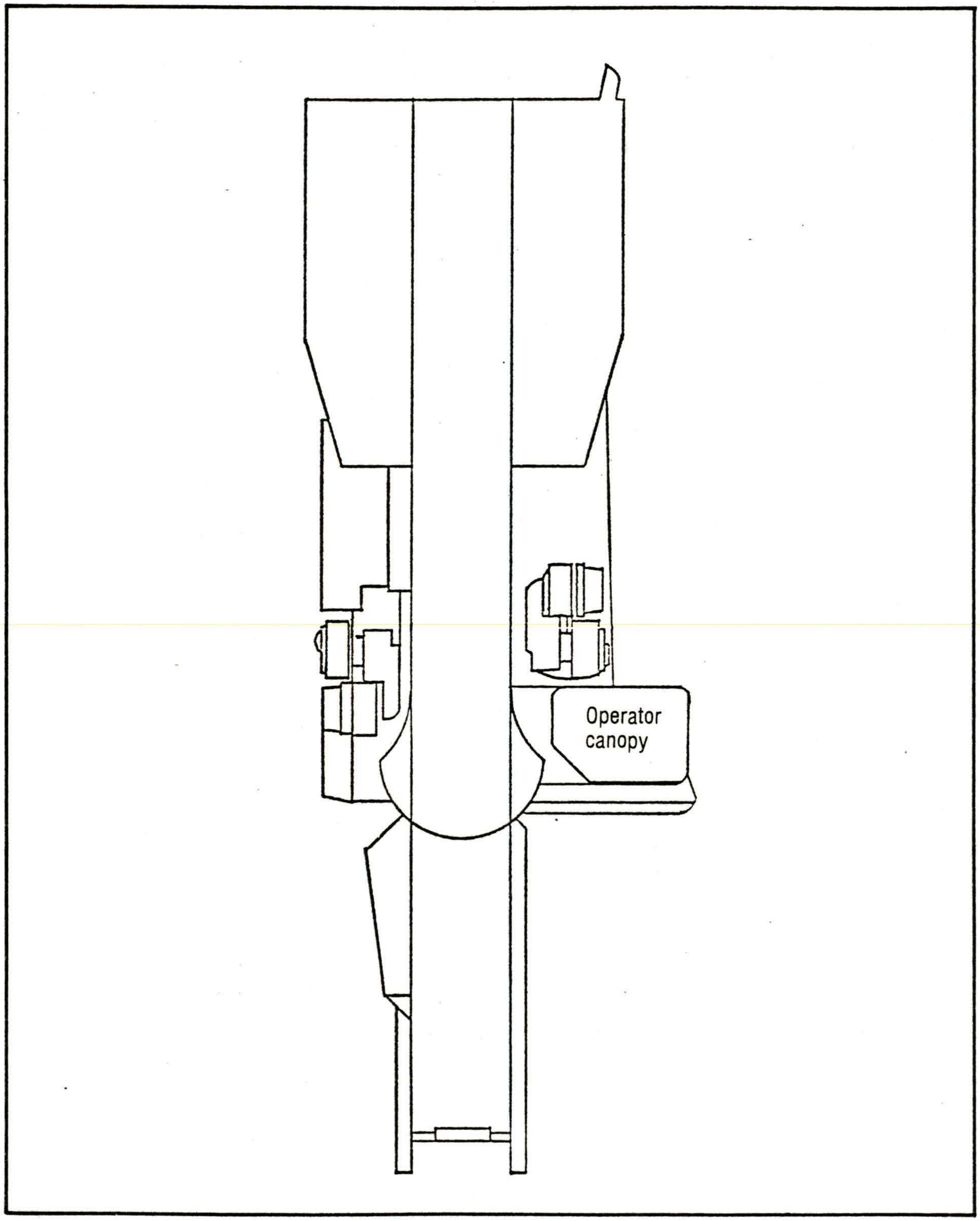


Figure 10 CONCEPT 5 -- MODIFIED JOY 14BU10-11B LOADER WITH CANOPY MOUNTED TO RIGHT REAR CHASSIS CORNER. RIGHT TRAM MOTOR AND GEARBOX REPLACED WITH LEFT UNIT.

A preliminary decision analysis matrix, Table 6, shows the five concepts with considerations and weighting factors generated by ESD engineers. In this study, Concept 4 received the highest score, although all scores were close.

The concepts were then submitted to Joy Manufacturing Company engineers for their comments. Their inputs were combined with ESD's comments and summarized as follows:

- Concept 1

  This would be the easiest retrofit to existing equipment. Operator's seating position would be cramped if he assumed the squat position. For lower canopy heights, he had to recline so that the canopy would extend a substantial distance from the machine side frame. The controls had to be relocated if the reclining position were to be used.

- Concept 2

  The concept of sliding the canopy on rails was not acceptable, due to anticipated operational and maintenance problems with the slide mechanism. Also, the operator would have been placed in the area of highest noise (conveyor pivot).

- Concept 3

  This concept was selected for further development. Although extending the conveyor boom would require extensive modification to existing loaders, this concept had the fewest objectionable points and appeared to be practical. Operator vision toward the face could be enhanced by elevating the canopy with the conveyor boom raise function Shuttle car impact loads would be transmitted through a new bumper to the conveyor pivot pins; some means of reducing this shock load or beefing up the pin bushings would be needed. A longer machine would also require more maneuvers per turn.

- Concept 4

  There were objections to swinging the operator on the tail boom. Shuttle car impact on the loader was also a problem.

- Concept 5

  This was originally judged the most practical concept However, it was found that reversing the right side traction drive gearcase would increase the machine frame height (over gearcase only) to 39 to 40 inches, making it impractical for 42-inch or lower seams.

Detail engineering drawings were received from Joy Manufacturing showing B model dimensions. Space allocation for a conveyor-mounted canopy was determined, and a preliminary structrual plan was submitted to the human engineering team at FMC Central Engineering Laboratories (CEL). Anthropometric data used on this project was derived from "Humanscale 1/2/3"

Table 6 LOADER CONCEPT DECISION ANALYSIS MATRIX

Select the optimum cab location for the Joy 14 BU10-11B loader	Weight	Concept 1 Standard Joy loader with special cab	Score	Weight x Score	Concept 2 Modified loader with cab and protective bumper at end of loader frame; movable cab and bumper	Score	Weight x Score	Concept 3 Modified loader with cab and bumper mounted on extended conveyor boom	Score	Weight x Score	Concept 4 Modified loader with cab and bumper mounted on lengthened tail boom	Score	Weight x Score	Concept 5 Modified loader with cab mounted to right rear chassis corner. Tram and gear box replaced	Score	Weight x Score
Objectives: Musts (Go/No-Go) Operator facing conveyor		Operator's legs doubled up or crossed		Go	Semireclining; legs under conveyor		Go	Semireclining; legs under conveyor		Go	Semireclining; legs under conveyor		Go	Semireclining; legs under conveyor		Go
Objectives: Wants																
Maximum height inside cab	10	32 inches, but no roof clearance	8	80	27 inches, with 5-inch roof and 4-inch bottom clearance	6	60	31 inches, with 5-inch roof clearance	9	90	31 inches, with 5-inch roof clearance	9	90	27 inches, with 5-inch roof and 4-inch bottom clearance	6	60
Minimum modification to loader	8	Add mounting brackets	10	80	Relocate conveyor swing jack to left side	8	64	Extend fan tail conveyor 42 inches	6	48	Relocate conveyor swing jack to left side	8	64	Relocate right tram motor to forward side of drive; relocate swing jack and fire bottles to left side. Increases height 2 inches at right drive motor	4	32
No increase in loader component loading	9	No change	10	90	No change	10	90	Increased load on conveyor pivot pins	7	63	Increased load on conveyor pivot pins	7	63	No change	10	90
Increased reach (face to last row of roof bolts)	6	No increase (11 feet, 8 inches total)	1	6	6-foot, 8-inch increase (18 feet, 4 inches total)	9	54	6-foot, 8-inch increase (18 feet, 4 inches total)	9	54	9-foot, 2-inch increase (20 feet, 10 inches total)	10	60	4-foot, 10-inch increase (16 feet, 6 inches total)	8	48
Easy rib cleanup (clearance angle)	5	Must angle loader into rib (7 1/2 degrees)	7	35	Must angle loader into rib (5 degrees)	8	40	Must angle loader into rib (5 degrees)	8	40	Swing cab and conveyor to left (0 degrees)	10	50	Must angle loader into rib (5 degrees)	8	40
Simple cab mounting	4	Fastened with pins and bolts	10	40	Mounted to end of chassis on horizontal slides	4	16	Fastened to conveyor with bolts	9	36	Fastened to conveyor with bolts	9	36	Fastened to chassis with bolts	10	40
Simple bumper	4	Steel plate welded to end of chassis	10	40	Bumper attached to horizontal slides; may need shock absorbers	5	20	Bumper attached to conveyor; may need shock absorbers	8	32	Bumper attached to tail boom; will need shock absorbers	7	28	Bumper attached to end of chassis	9	36
Total Point Score				371			344			363			391			346

published by the MIT Press for Henry Dreyfuss Associates, Niels Diffrient, et al., authors. A recent survey conducted for the Bureau of Mines indicated that low-coal miners fit within military anthropometric size distributions, except for their mesomorphic chests and arms. This was taken into account as seats and passageways were designed.

Exhibit E of the contract contained data for standardized controls/operator compartments which was used in the design of canopies for the loader and shuttle car. Using anthropometric data for human sizes of 5th percentile female and 95th percentile male, recommendations were made for the following factors:

- Minimum inside canopy dimensions
- Reach envelopes for control placement
- Body support points for seating design
- Vision angles from reclining position

This data was used for a preliminary canopy structural design layout. Several seat designs were proposed for the limited canopy space dimensions. Figure 11 shows a preliminary mock-up made for the purpose of seat design evaluation.

At this time, a design review meeting was held with personnel from Joy Manufacturing Company, FMC Corporation, Pittsburgh Research Center, and Mine Safety and Health Administration. A transverse canopy concept based on Concept 3 was presented. It included a hydraulically adjustable roof which could be raised for better vision. Mechanical linkages automatically adjusted the seat back to raise the operator.

Joy had a similar adjustable canopy on a 16 RB cutter with a minimum 26 inch height over the canopy. It was too small inside, and ingress/egress was restricted. Similar adjustable-height canopies had been repeatedly damaged when operated in underground mines. When this drawback was combined with the increased complexity of the raising mechanism, this feature became undesirable.

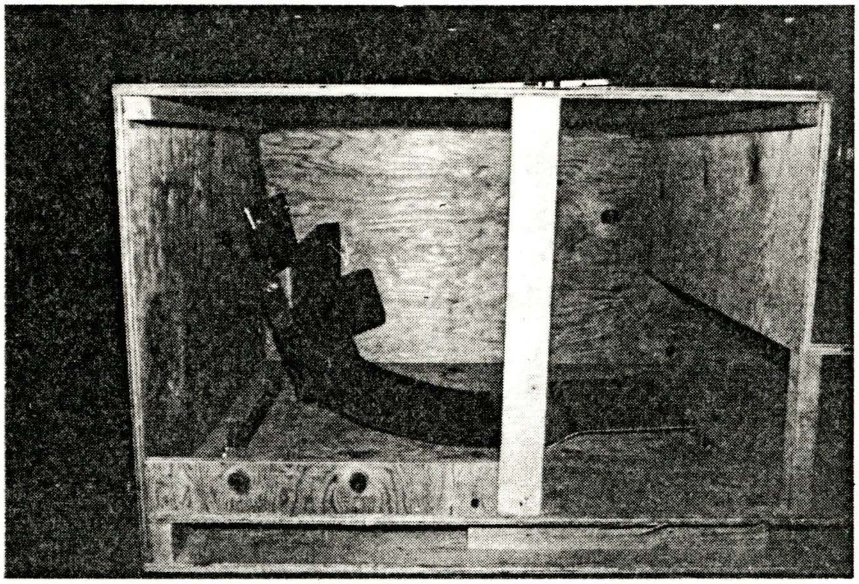
There was considerable discussion about the practicality of operating a B model machine in 40-inch coal. This model accounted for 75 percent of loader sales, but was used in 45-inch and higher seams. The A model loader would be used in the 40-inch seam range contemplated for this project.

Many coal companies purchase lower frame height machines than needed and add canopies matched to their seam heights. This approach solved the visibility problem.

As a result of this meeting, the machine was changed to an A model. Three possible canopy locations were proposed:

A. Right rear corner of loader with operator facing conveyor

B. Right rear corner of loader with operator facing forward at 45 degrees to the conveyor



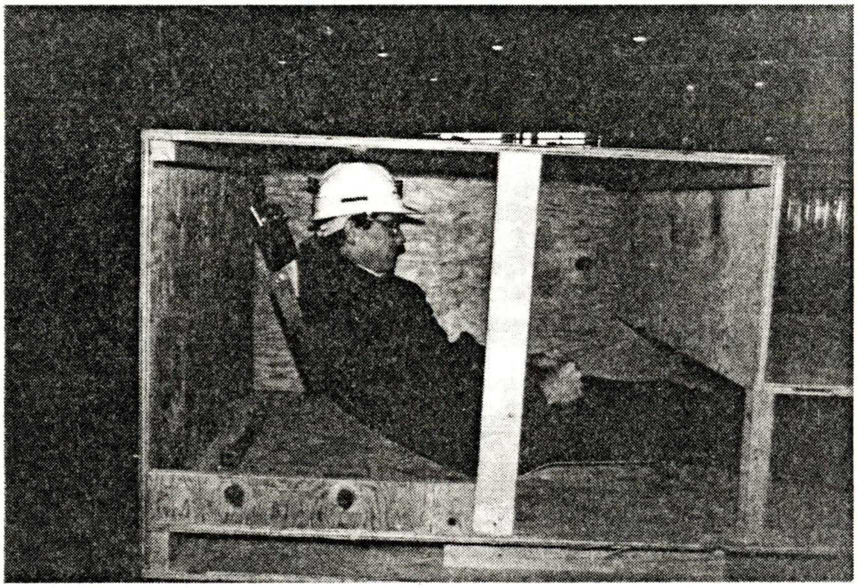


Figure 11   LOADER SEAT DEVELOPMENT MOCK-UP

C. Between right-hand drive motor gearbox and hydraulic reservoir, at the existing control station.

Table 7 summarizes the merits of each location. Concept C was chosen for development.

3.1.1.3 Preliminary Engineering

Figure 12 shows the resulting transverse canopy for a Joy 14BU10-11A loading machine. Specific features were as follows:

- Operator Protection

    1. Roof was 1-inch-thick plate

    2. Hood protected legs, feet, and controls

    3. Solid backwall provided rib protection

    4. Alternate egress point on inby side of canopy

    5. Seat backrest tilted out of way to give maximum ingress and egress opening.

- Visibility

    1. Roof and hood were plates with no stiffener ribs to afford maximum visibility from inside canopy

    2. Vision over machine enhanced by low frame height chassis

    3. Vision fore and aft was unobstructed.

- Operator Comfort

    1. Top plates designed without cross members to give operator maximum room for head and legs

    2. Seat adjustments to optimize comfort and visibility, including:

        a. Backrest position

        b. Headrest position

        c. Lumbar support position

        d. Seat sling tension.

Table 7 CANOPY LOCATION FOR MODEL A LOADING MACHINE

Description	Canopy location		
	A: Right rear cab at 90 degrees	B: Right rear cab at 45 degrees	C: Between motor and hydraulic reservoir
1. Effect on loader reach under unbolted roof	Increase approximately 4 feet, 6 inches	Increase approximately 4 feet, 6 inches	No change
2. Availability of attachment points for cab	Must be added	Available	Available
3. Availability of attachment points for suspension system	Must be added	Must be added	Avaliable with modification
4. Distance: Centerline of conveyor to extreme point on cab	6 feet, 6 inches	6 feet	6 feet, 6 inches
5. Effect on cabs vertical clearance resulting from loaders pitching as crawlers go over bumps	Amplified effect	Amplified effect	Almost no effect
6. Drive motor rework	Locate opposite hand drive to existing operator station area	Locate opposite hand drive to existing operator station area	None
7. Conveyor swing cylinder relocation	Required	Required	Not required
8. Conveyor elevator cylinder relocation	Required	Required	Not required
9. Drive frame rework	Must extend	Must extend	None, except mounting brackets
10. Bumper rework	Extensive	Very extensive	None
11. Proximity to loud noise source (conveyor swing pivot	4 feet	3 feet	6 feet
12. Operator controls rework	Required	Required	Required
13. Reference layout	D-5136176	D-5136176	D-5136177

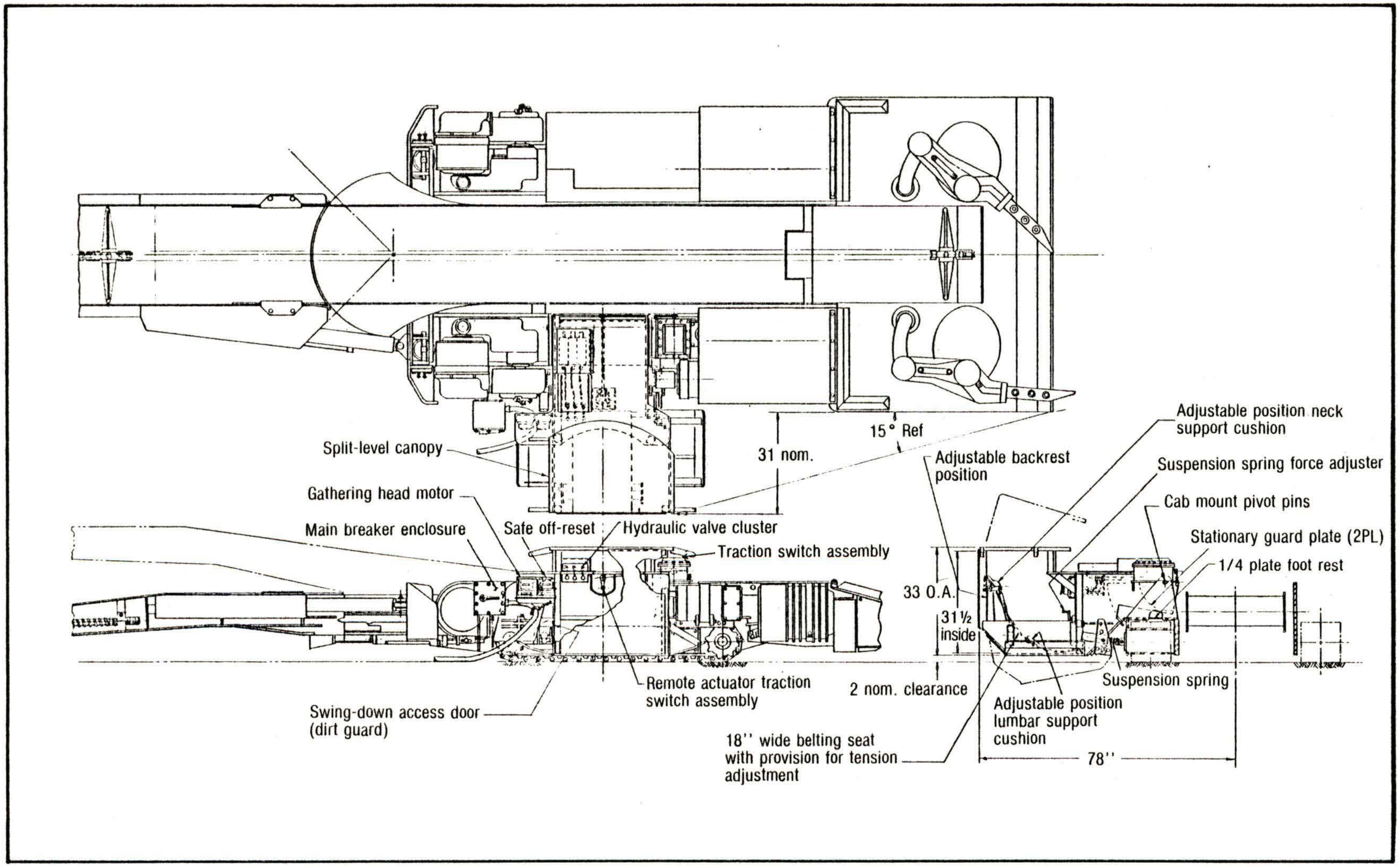


Figure 12 GENERAL ARRANGEMENT, CANOPY FOR MODEL A LOADING MACHINE

- Machine Lighting System

  The effect of machine lighting on visibility could not be assessed during this phase, because the configuration of the lighting system was unknown. Due to the added structure, any existing machine lighting system would require changes to maintain light levels within standards. Light fixtures would be added and relocated to interface with operator vision requirements once the canopies were installed.

- Controls Location

  1. Same relative locations for controls as those existing
  2. Tram control in front of operator for right-hand operation
  3. Hydraulic control levers to left front for left-hand operation
  4. Motor switches on left side of canopy for left-hand actuation and from outside on the outby side of the canopy.

- Canopy Suspension System

  1. Pivoted at upper "front" (relative to operator) end of canopy
  2. Suspended by preloaded spring to hold floor of canopy 2 inches above mine floor
  3. In case of "roofing," spring allowed canopy to be pushed down
  4. Inby and outby sides of canopy equipped with plow to help slide over bumps
  5. Pivot allowed the canopy to lift freely when it bottomed.

3.1.1.4 Mock-Up Fabrication

A full-scale mock-up of the proposed loader canopy was fabricated in the ESD shop facility. It consisted of the following components:

- Loading machine -- reworked from previous program. This was a plywood mock-up of a Joy 14BU10-11S revised to the A model configuration.
- Canopy -- wood mock-up of the entire canopy structure and mounting provisions.
- Seat -- steel and conveyor belt materials. Because this was a critical area for the low coal canopy program, the mock-up seat included all of the recommended adjustments, headrest, and lumbar support.
- Controls -- boxes and moveable levers represented all controls required for normal loader function.

Figure 113 shows the completed loader mock-up.

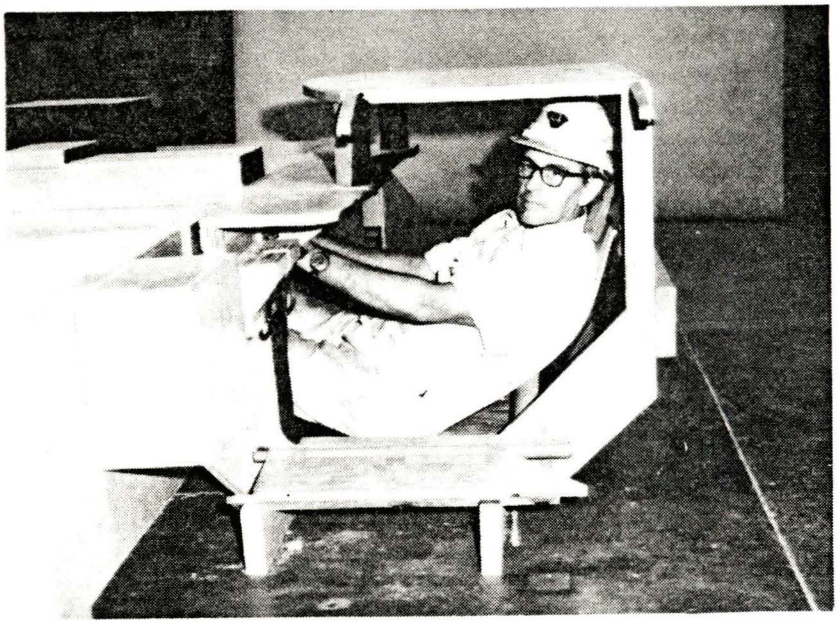


Figure 13   LOADER MOCK-UP

3.1.1.5 Evaluation

The mock-up was built for two purposes: human factors evaluation and concept validation by industry and government representatives.

Mechanical engineers and human factors specialist evaluated the mock-up as construction was nearing completion. The following comments were noted:

- Visibility

  Vision toward the face and rearward to the shuttle car was unobstructed. Control valves and the tram switch enclosure protruded from the canopy deck, blocking vision into the conveyor. It was felt that the need for this vision should be investigated.

- Operator Comfort

  Knees should be protected from the steel side walls through the installation of padding.

  Two adjustments were provided for the sling seat. Both belt tension and back rest angle adjustments were needed to obtain a comfortable seating position. However, the actuating levers for both adjustments were difficult to operate.

  A headrest and a lumbar support were attached to the belting so that they could be easily moved. The headrest was too large and could not be moved high enough on the sling seat for large men. Also, the lumbar support was too large and needed padding. The need for these additional supports needed to be evaluated, and existing designs needed to be revised.

It was felt that there might be a problem with the elevated feet position. Recent aircraft seat research found it undesirable to elevate the feet above the hip pivot point for more than 15 minutes. Unless there was some foot activity, such as light pedal action, there would be a lack of blood circulation to the feet. Fortunately, the loader operator needed to remain seated for only about 15 minutes at a time.

- Anthropometric Size Accommodation

  There was adequate space within the canopy structure for the 95th percentile male. An adjustable backrest and sling tensioner did provide the changes necesssary to accommodate the desired range of anthropometric size individuals.

- Controls Layout

  All controls were hand operated and within easy reach. Actuation forces would be low. Tram switch levers were centrally located to provide room for the operator's legs on both sides. It was noted, however, that it might be desirable to move these switches to the right, since they would be operated by the right hand. Electrical safe-off switches were outside the canopy structure, but were well guarded from rock falls. A guard should be added under the hydraulic valve handles to prevent unintentional actuation. Labels were needed at all controls.

- Ingress/Egress

  To gain entrance, the operator had to crawl feet first into the canopy. It was felt that he should become accustomed to this after a few tries. Exits would be the reverse, and the operator would be heading away from the face on egress. No protrusions were found to limit ingress/egress. An alternate escape route was provided in case the rear exits were blocked.

- Pinch Points

  Three areas of concern were pointed out. Overlapping plates were needed at the inside canopy walls to cover holes. Belting should be placed over the gap under the operator's knees, since it opened when the canopy elevated. Also, one evaluator hit his elbow on the left side dirt gate (near seat base) when retracting his arm from the electrial switch.

The mock-up was reviewed by personnel from Joy Manufacturing Company, FMC Corporation, Pittsburgh Mining and Safety Research Center, Mine Safety and Health Administration, and Bituminous Coal Research, Inc.

3.1.2 Shuttle Car Canopy

The objective of this work was to design and mock-up a transverse mounted, floor-riding canopy on a shuttle car for working heights of 42 to 48 inches. It was important to demonstrate canopy technology in coal seams as low as possible.

Although the contract specified this limited range, it was important that resulting canopy designs not be limited to a 42-inch minimum seam height by inherent design features. Restrictions of the proposed design are described in Section 3.1.2.3.

3.1.2.1 Assessment of Existing Technology

o H0111670, Inherently Safe Mining Systems, (FMC)

A cab mounted on a National Mine Service Lokar Model 30-9 shuttle car was hydraulically elevatable. The entire cab would swing to face the direction of travel. the 36-inch-high cab was designed for operation in a 46-inch coal seam. Other features were special seat design and automotive style controls. After operating this vehicle in Jenny Mine, the drivers complained about the cramped quarters, specifically poor head room, and tiring leg position. Figure 14 shows an operator seated in the cab. Note the high knee position and lack of support for his legs.

Figure 14 ISMS CAB IN JENNY MINE

o H0220031, Design and Devopment of Protective Canopies for Underground Low-Coal Electric Face Equipment, Including Shuttle Cars, (Bendix)

A canopy structure was added over the standard operator's station. Hydraulic cylinders within the support posts allowed top height adjustment from 32 to 40 inches above ground level. Rib protection consisted of a nerfing bar at the cab floor level and a swing-away bumper midway between cav floor and roof (the bumper was not installed).

The canopy was fitted to a Joy 21SC shuttle car (frame height 28 inches, loaded) for operation in a 48-inch seam height. The hydraulic canopy height adjustment feature was considered necessary to provide maximum inside clearance consistent with the mine roof height. Mechanical position UP and DOWN stops similar to those used on the loader canopy (Subsection 3.1.1.1) were also incorporated.

Two modified shuttle cars were tested in underground coal mines. Poor visibility from the compartment was the major objection voiced by operators. Forward vision was restricted by the long top structure which created a tunnel-vision effect. A split canopy would reduce this and allow better vision to the roof.

- <u>H0242028, Design and Development of Protective Canopies for Shuttle Car, Loader, and Roof Drill, (Bendix)</u>

The shuttle car canopy developed above was revised to split-level configuration with two dished canopies over the operator's head (one for each direction of travel) and a lower canopy over the operator's legs. All were cantilevered from the machine frame, and the head covers were hydraulically elevatable from 32 to 47 inches above the ground level. The canopy opposite the operator would be lowered to improve visibility. When demonstrated in a 52-inch seam height coal mine, operators accepted this approach to visibility improvement, but only when the canopies were used in a height range of 38 to 47 inches, as would be the case in a 52-inch seam.

- <u>H0242065, Refined Design of Protective Canopies for Shuttle Cars, Loaders, and Cutters, (Bendix)</u>

The canopy installation described above was modified to reduce the length of the center deck over the operator's legs and reinforce the canopy support structure mounting at the shuttle-car fender. Fixed seats replaced the adjustable style (backrest angle), because "past experience" showed that the adjustment would not be used by the operator. Review by mine personnel resulted in positive comments.

- <u>H0252048, Fabrication and Evaluation of Optimized Operator Compartments, (Bendix)</u>

The shuttle car operator's compartment recommended by prior research (H0242033, Optimized Operator Compartments, Applied Science Associates, Inc.) was fabricated and installed on two National Mine Service Model 48A-36 Torkars. Features included automotive style controls with right-side tram, left-side brake pedal for both travel directions, dual steering wheel to keep rotation consistent with the direction of travel, warning bell outside the compartment, wider compartment, and seats angled slightly for better vision.

These compartments were well received by mine personnel, especially the dual steering wheel feature. National Mine Service picked up these features and applied many on their production shuttle car compartments.

o <u>H0252091, Fabrication and Evaluation of Optimized Operator Compartments, (FMC)</u>

Optimized operator compartments were prepared for FMC Mining Equipment Division (MED) Model 6L and 10L shuttle cars. Features included wider, adjustable-height canopy; steer, tram, and brake controls consistent with the direction of travel; fold-down pedals and seats for increased leg room; and torsialastic seat suspension for comfort. See Figure 15.

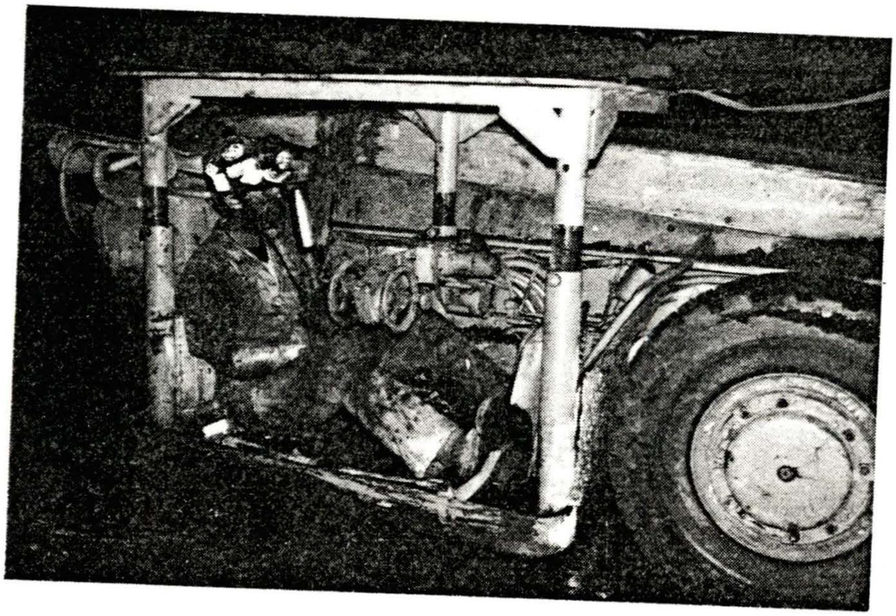


Figure 15 OPTIMIZED OPERATOR COMPARTMENT ON SHUTTLE CAR

The 6L compartments were evaluated in a West Virginia coal mine, where operators praised the seat suspension and controls consistent with tram direction. The adjustable canopy was difficult to operate. It consisted of telescoping tubes with pin-to-post height adjustment.

FMC decided to incorporate some of these features into new production shuttle cars and offer these features to rebuild shops.

Another interesting concept recently developed under a Bureau of Mines program had a unique swing-around canopied pedestal with protective shields over the operator's legs (see Figure 16). Visibility was optimized in this concept, because no canopy or support posts obstructed vision. The operator would not leave the protection of the canopy when changing directions.

This was similar to the swinging cab used in the ISMS program and had the same restriction: because the seat was centrally located, leg room was needed at both ends of the compartment. Existing shuttle car compartments were not long enough for low coal applications where the operator had to recline. However, this canopy had been successfully demonstrated in seam heights as low as 39 inches.

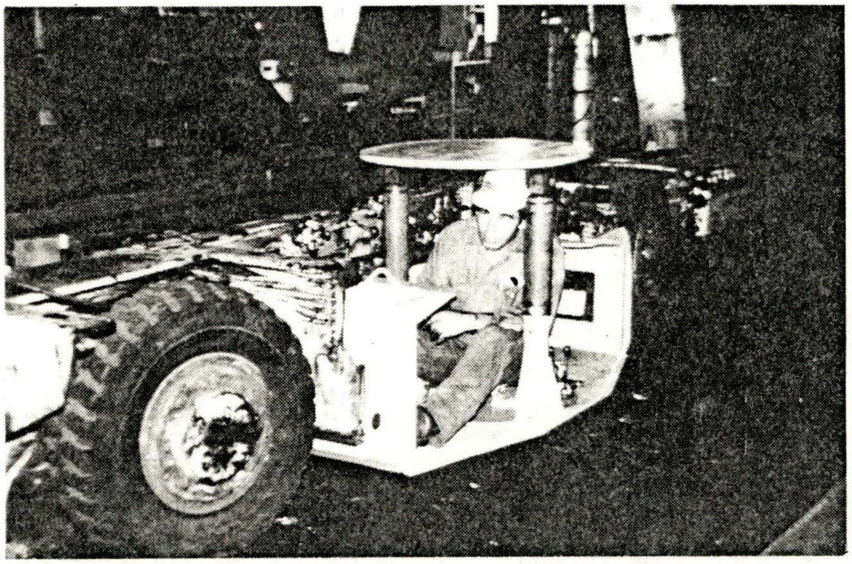


Figure 16 SWING-AROUND PEDESTAL CANOPY

For application of canopies to low coal seams, the camopy-to-floor height inside compartments had to be maximized. A means of accomplishing this had been sucessfully demonstrated by the Lee Engineering Division of Consolidation Coal Company, which developed a floating canopy where the entire compartment rested on the mine floor. Normal ground clearance (6 to 12 inches) could be used inside the compartment, adding to the internal height dimension. When tramming, the compartment floated over the undulating bottom, rather than bouncing with the vehicle. It was felt that this concept would be especially helpful on cars with end-mounted operator pits where fixed canopies were frequently roofed.

Consolidation Coal Company had outfitted several shuttle cars with these floating canopies. They received a patent for "Vertically Movable Operator's Compartment for a Self-Propelled Mine Vehicle," Number 4,078,629, and had licensed National Mine Service Company to use the design on their shuttle car line.

The transverse seating pisition where the operator faces the conveyor had been tested by U.S. Steel Corporation. This position had several advantages over the two-seat configuration then used on most shuttle cars. Protection from falls of roof or rib and elimination of seat change time were major reasons for U.S. Steel's decision to pursue this concept. Controls were simplified, the operator remained under the protection of the canopy, rib roll protection was easily incorporated, and the car did not need to be lengthened to accommodate canopies for low coal mines. Disadvantages farther from the side of the car (as would be expected in low coal, where the operator must recline) and loss of carrying capacity if the operator's feet were located under the conveyor.

U.S. Steel had applied for a patent on this design.

Mining equipment manufacturers were developing new canopy technology in response to industry demands. Many of the above designs were becoming available on new and rebuilt shuttle cars.

3.1.2.2 Concept Development

A trip was made to Joy Manufacturing Company, FMC Corporation, and a Kentucky coal mine, where recent equipment developments were discussed. Shuttle car engineering drawings were received for the FMC Model 6L and the Joy Model 16SC-6. These were very similar in layout and had frame heights of 34-12 and 34 inches, respectively.

A shuttle car with transverse operator's pit was observed in a 60-inch seam at the Kentucky mine. The canopy posts consisted of parallel bars so that the top could be elevated or lowered by a single hydraulic cylinder. During an interview, the driver was seated with the transverse seating position and said that he needed only a short time to adapt to the controls. We were concerned about the visibility into a crosscut behind his back, but he managed to turn into these areas without difficulty.

A small tunnel was cut under the conveyor boom for the control pedals. This required a modification to the conveyor return path and a small bulge in the top deck, resulting in a slight loss of coal-carrying capacity. Two pedals were used, one brake and one tram. Both directions of travel were controlled from the single tram pedal; depressing the right side engaged tram to the right relative to the driver's seat position, and the left tram was actuated by pushing on the left side of the pedal. Because of the excellent reception by mine personnel and good performance of the transverse canopy concept, this coal company intended to order this concept on new and rebuilt shuttle cars.

3.1.2.3 Preliminary Engineering

On this development program, both the transverse seat position and the floor-riding canopy concept were applied to low coal shuttle cars. Several concepts were initially generated, showing the most viable options. Among them were the following:

1. Placing operator's feet under the conveyor. This required considerable rework to the conveyor boom and could result in loss of coal-carrying capacity.

2. Transverse seat with operator assuming a cross-legged sitting position. Little chassis rework would be needed, but tram controls would have to be hand operated.

3. Swinging seat with operator facing 45 degrees to the direction of travel. Tram controls could be made consistent with the direction of travel, and machine rework would be minimal.

Preliminary mock-ups were constructed for evaluation purposes. See Figure 17.

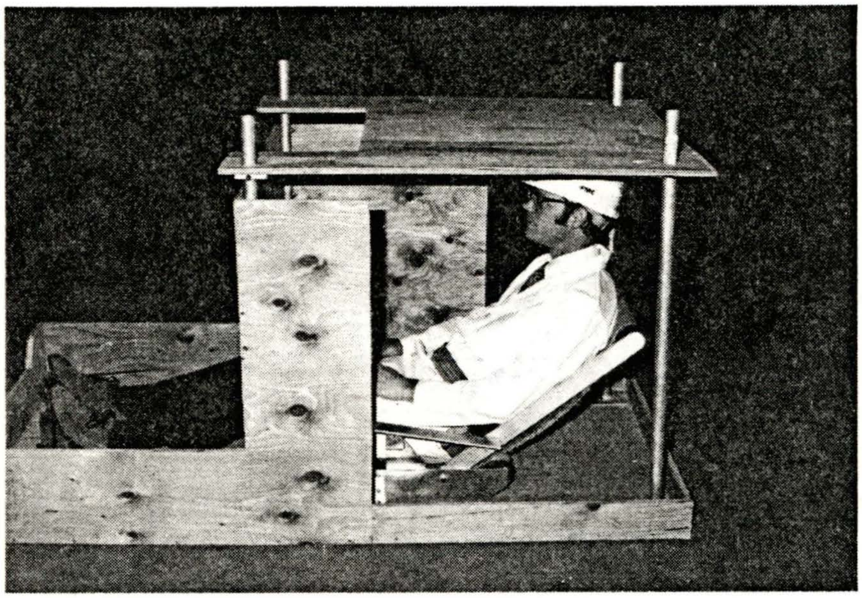


Figure 17 SHUTTLE CAR PRELIMINARY MOCK-UP

These ideas were presented at a design review meeting. Concept 2 was unacceptable from a human factors standpoint, and Concept 3 was not considered a true transverse canopy as specified in the contract. Development work continued on variations of Concept 1.

Space allocation was determined and given to the human engineering team at FMC. They defined appropriate seat positions for 5th percentile female and 95th percentile male anthropometric size manikins. This information was used for seat design, controls placement, and structural layout.

Early in the development work, proper seat design was recognized as the most important human factors consideration for this program. Because vertical height from canopy to floor had to be decreased in low coal seams, the seat backrest needed to be reclined to provide headroom. Currently available seating design data, such as the Dreyfus Humanscale charts, were concerned with backrest angles up to 28 degrees from vertical; the low canopy backrest angles were as steep as 60 degrees.

A sling-type seat had been succesfully used in low coal portal buses. Advantages were simple construction from readily available materials (belting) and adequate support along the backbone. It was felt, however, that the sling seat might not be desirable from a biomechanical standpoint in shuttle cars. Control pedal actuation force was normally transmitted perpendicular to the spine into the lumbar region of the backrest. A sling seat would flex in this area, so the force would be carried along the spine to the upper backrest. This was an unnatural loading condition.

Several seat mock-ups were constructed to let designers evaluate different approaches. Figures 18 and 19 present these mock-ups.

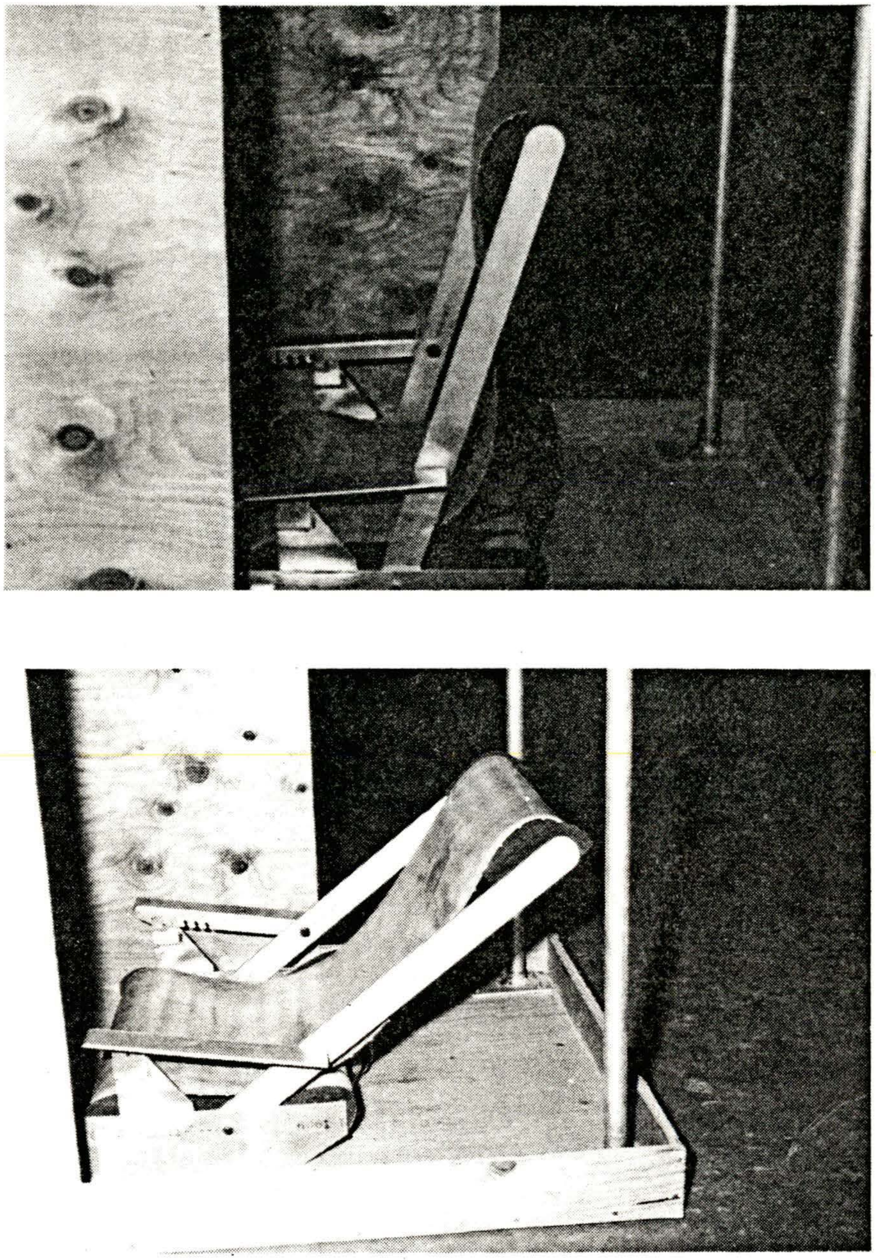


Figure 18 SHUTTLE CAR SEAT MOCK-UP

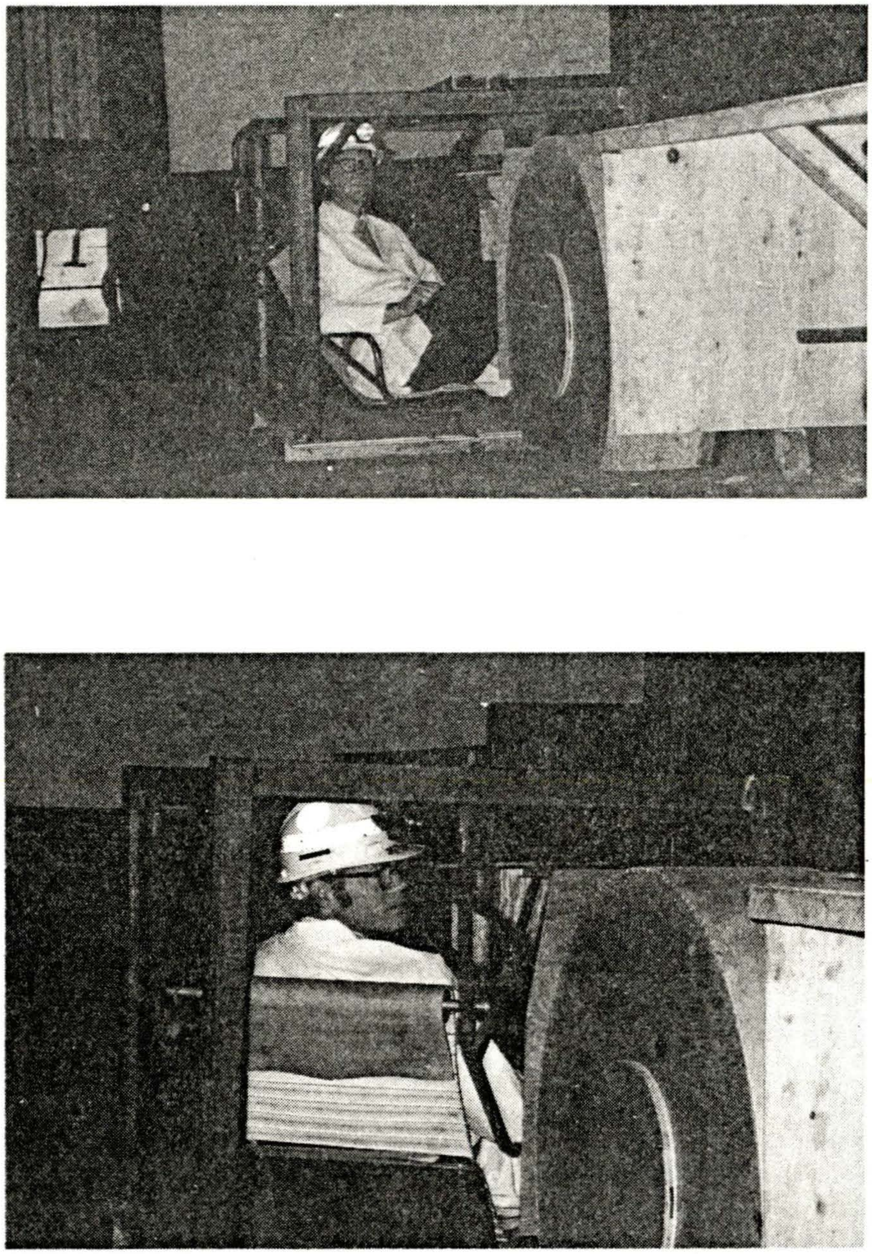


Figure 19 SHUTTLE CAR SEAT MOCK-UP, SWING-AROUND TYPE

For a canopy with the operator's feet located under the conveyor, upward travel would be limited by the boom structure and conveyor return path. Preliminary mock-ups of the control pedal area established a minimum internal height requirement of 11 inches. Vertical travel of 4 inches upward would provide the same clearance angle (slope change) as the existing conveyor boom.

To provide room under the car for the canopy pedal tunnel, both the body and conveyor frames had to be modified. Additional stiffeners and plates would be needed to maintain structural integrity after sizeable cut-outs were made in the framework. The body had to resist torsional loading from the boom lift jack and impact loads from the bumper, while the conveyor had to support the weight of coal and maintain the torsional rigidity of the box frame under the car. The conveyor return path was raised, resulting in a slight bulge in the conveyor top plate. A loss of 3 cubic feet in carrying capacity was unavoidable for 4 inches of upward canopy float.

The following controls are normally used in shuttle cars:

- Tram pedal, each direction
- Brake pedal, each direction
- Speed switch, may be part of tram pedal
- Steering wheel
- Parking brake
- Backup capability (part of tram linkage)
- Pump switch
- Panic switch
- Fire extinguisher actuator
- Headlight switch (front, rear, both)
- Conveyor switch
- Boom lift valve
- Gong.

Because the operator's compartment floats relative to the chassis, all of these controls must be located within the canopy structure. Adequate space was provided as the canopy was designed. Control placement was determined by reach envelopes for the anthropometric size range between 5th percentile female and 95th percentile male. Actuation force limits, control sizes, and labeling followed guidelines were provided with the contract.

Special consideration was required for the tram and steering controls. When seated transverse to vehicle, the automatic controls could not be made consistent with the direction of travel. For ESD's design, a single steering wheel and the bidirectional tram pedal were used based on reported success with this configuration in transverse shuttle car operations.

The canopy structure consisted of a flat top plate supported by telescoping tube-in-tube posts. Edges of the floor plate were curved to allow the canopy to ride over uneven bottom. A floor-riding canopy requires less clearance height than those mounted rigidly to the machine frame. For a 42-inch operating height mine, a canopy with overall height of 39 inches floating on the floor was thought to be practical. Thus, the proposed canopy had this outside height dimension.

Telescoping tubes were provided to raise the canopy if operating height permitted. However, it was considered advantageous from a visibility standpoint to raise the entire canopy structure. This could be added as an optional design by providing a hydraulic cylinder and control valve. A relief valve would allow the canopy to lower in the event of roof impact.

By careful placement of the support members, maximum ingress/egress clearance was obtained on the outby side. An alternate escape route was provided toward the inby side.

Vision inby and outby were maximized by placing the operator beyond the side of the car. A split level canopy enhanced roof visibility. The conveyor sideboard height would determine vision over the car toward the opposite rib.

3.1.2.4 Mock-Up Fabrication

A full-scale mock-up of the proposed shuttle car canopy was fabricated in the ESD shop facility. It consisted of the following components:

- o Shuttle Car -- wooden mock-up of the FMC 6L shuttle canopy, detailing areas visible from the canopy and modified for the proposed canopy
- o Canopy -- wood and metal tubing mock-up of the entire canopy structure and mounting provisions
- o Seat -- sling-type seat with supportive pan and adjustable backrest
- o Controls -- blank control boxes were supplied by FMC. Other controls were mocked-up from wooden boxes, etc. Lever motions and resistive forces were incorporated where appropriate to the human factors evaluation. Figure 20 shows the completed mock-up.

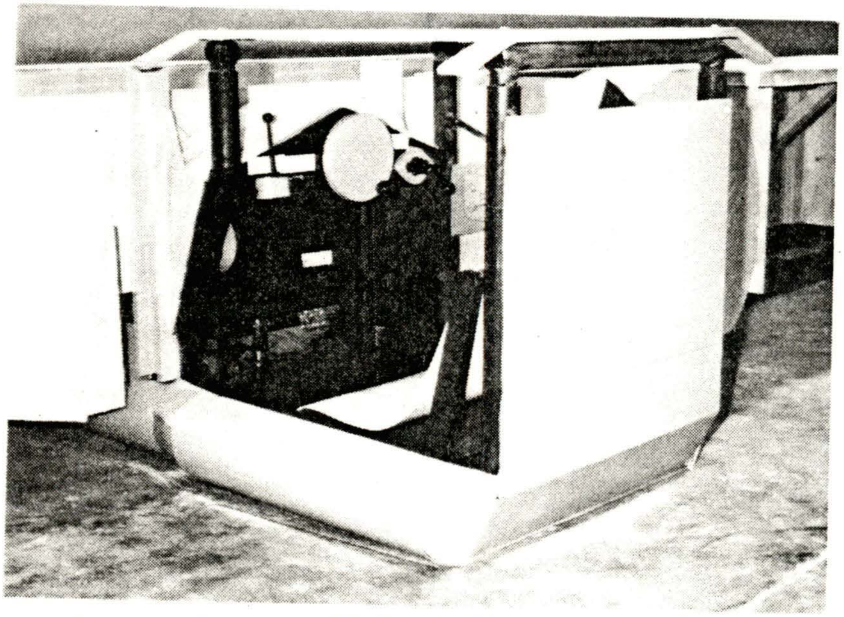


Figure 20 SHUTTLE CAR CANOPY MOCK-UP

3.1.2.5 Evaluation

A preliminary mock-up evaluation was conducted by design engineers and human factors consultants. The following comments were noted:

- Visibility

  There was unobstructed vision along the side of the car to the face and good vision outby. Seat adjustments to accommodate different size individuals kept the eye level as high as practical, enhancing vision across the car. Canopy posts did not block necessary vision.

- Operator Comfort

  Knees hit the control mounting panel on ingress and egress. Pedals were too close to the seat, so knees were elevated to a position where constant muscle tension was required to hold them upright.

  Most of the reviewers found the sling seat to be comfortable.

  A mud flap should be added to the wheel fender to keep debris out of the canopy.

- Anthropometric Size Accommodation

  Seat backrest adjustment provided the space and support needed to accommodate individuals in the range of 5th percentile female through 95th percentile male. Canopy structure was adequate, but head clearance was minimal for larger individuals.

- Controls Layout

  Steering seemed logical in both directions of travel. Since the operator was sitting perpendicular to the car, he would turn his head to face the direction of travel. This would reverse the visual inputs he used to steer the car, so the steering seemed consistent, as with a scoop steered by a tiller bar. All controls were within reach of both large and small individuals. However, control pedals were too close to the seat and had to be moved about 2 inches farther away. The tram pedal had to be revised to prevent the foot from sliding off. Also, the steering wheel had to be relocated to a position directly in front of the operator. Proper labels needed to be added. Some controls were missing: parking brakes, panic bar, and fire extinguisher actuator.

- Ingress/Egress

  There were no difficulties getting into or out of the canopy.

- Pinch Points

  Clearance around steering wheel needed to be checked for gloved hand operation. A pan should be added under the steer and conveyor controls to protect the knees. Also, the sharp edge at the pedal cover where it joined the nose plate needed to be padded to protect the shins.

The mock-up was reworked to correct noted shortcomings; then, a mock-up review meeting was held with personnel from Joy Manufacturing Company, FMC Corporation, Pittsburgh Mining and Safety Research Center, Mine Health and Safety Administration, and Bituminous Coal Research, Inc.

3.1.3 Single-Boom-TRS

The objective of this work was to design and mock-up a TRS for a single-boom bolting machine for working heights as low as 42 inches.

3.1.3.1 Assessment of Existing Technology

Most roof bolters had two operator positions: a tram station located on the machine frame and a drilling station located within easy reach of the chuck. The tram station could be easily protected by a simple flat-plate-style canopy, but it was difficult to cover the drilling station with a canopy. Many practical canopy designs had been built by manufacturers and mine shops, but most were rejected by operators in low seam mines. Major objections were loss of head space to these massive structures and the potential safety hazard of being crushed between canopy and rib when moving the boom or machine.

Canopy regulations did provide alternatives by allowing operators to develop devices to be used "in lieu of" substantially constructed canopies. Designs had to be reviewed by MSHA Technical Support for approval. The TRS system, when developed to meet specific criteria, had been accepted by machine operators and MSHA to provide protection at the drilling control station. In addition, certain TRS systems might be used in place of manually installed temporary jacks then required prior to bolting, if approved by the local MSHA district manager. With the trend toward eliminating exposure to unsupported roof when installing temporary jacks, the latter capability was becoming attractive.

Two types of TRS systems then in common use were the single-bolt style where a protective ring supported the roof around the drill head and the bar-type where an entire row of support could be provided. Single-bolt TRS systems were well suited to small single-boom machines, and bar systems could be easily adapted to dual-boom machines by adding a third boom. It was difficult to adapt the TRS system to small single-arm bolters without substantial redesign. Because they represented the majority of roof bolters then used by the coal mining industry, it was felt that a practical TRS system easily adaptable to small machines would greatly enhance the acceptance of these safety devices.

Single-boom bolter canopies and TRS systems had been developed on these research programs:

- o <u>H0111670, Inherently Safe Mining Systems</u>

  Two single-boom remote control roof bolters were demonstrated in underground coal mines. A simple stabilization pad mounted on a telescoping framework surrounding a Fletcher mast was held against the roof by a cylinder. This pad was intended to provide a stable drilling platform, not roof support. For operator protection at the chuck control station, a canopy was provided Because this was a remote control bolter, the substantially constructed cab provided primary protection for the operator.

- <u>H0220031, Design and Development of Protective Canopies for Underground Low-Coal Electric Face Equipment, Including Shuttle Cars</u>

  A canopy was mounted to a Galis (FMC) 300 roof bolter and demonstrated in a 35-to 38-inch seam height underground coal mine.

  Both tramming and bolting stations were combined, placing the operator's pit ahead of the control valve bank and to the left of the boom. A hydraulically elevatable canopy covered the station while the operator reclined on a flexible floor pan that floated on the mine bottom.

  A weight was added at the rear of the machine to counterbalance the canopy. This was needed to get the center of gravity between the wheels, a requirement imposed by the squirm steer system.

  During in-mine testing, this canopy was not well accepted by machine operators due to operational difficulties; canopy weight and cantilevered floor support structure impaired maneuverability, and the flexible floor tended to plow the mine bottom rather than float.

- <u>H0242028, Design and Development of Protective Canopies for a Shuttle Car, Loader, and Roof Drill</u>

  The above canopy installation was modified to eliminate tram difficulties. A more flexible flooring material greatly improved performance.

- <u>H02423065, Refined Design of Protective Canopies for Shuttle Cars, Loaders, and Cutters</u>

  The above bolter canopy was modified to incorporate a solid top plate, the flexible floor redesigned to provide more ingress/egress room, and canopy height adjustment increased to 52 inches maximum (38 inch minimum, same as before). The forward canopy jack contacted the roof, thus acting as a safety jack. Additional temporary face supports were required with this configuration.

  With adequate head room under the canopy, operators accepted this design, including the flexible flooring. It provided increased operator protection and comfort, while not interfering with bolter functions.

- <u>H0262016, Research and Development of a Temporary Face Support System</u>

  Many existing single-boom bolters could be retrofitted with this system consisting of ironing board TRS arms and a slide mounted mast bolter unit. See Figure 21. With this design, a full row could be bolted from one machine position, Operators were protected by the TRS in entries up to 20 feet wide.

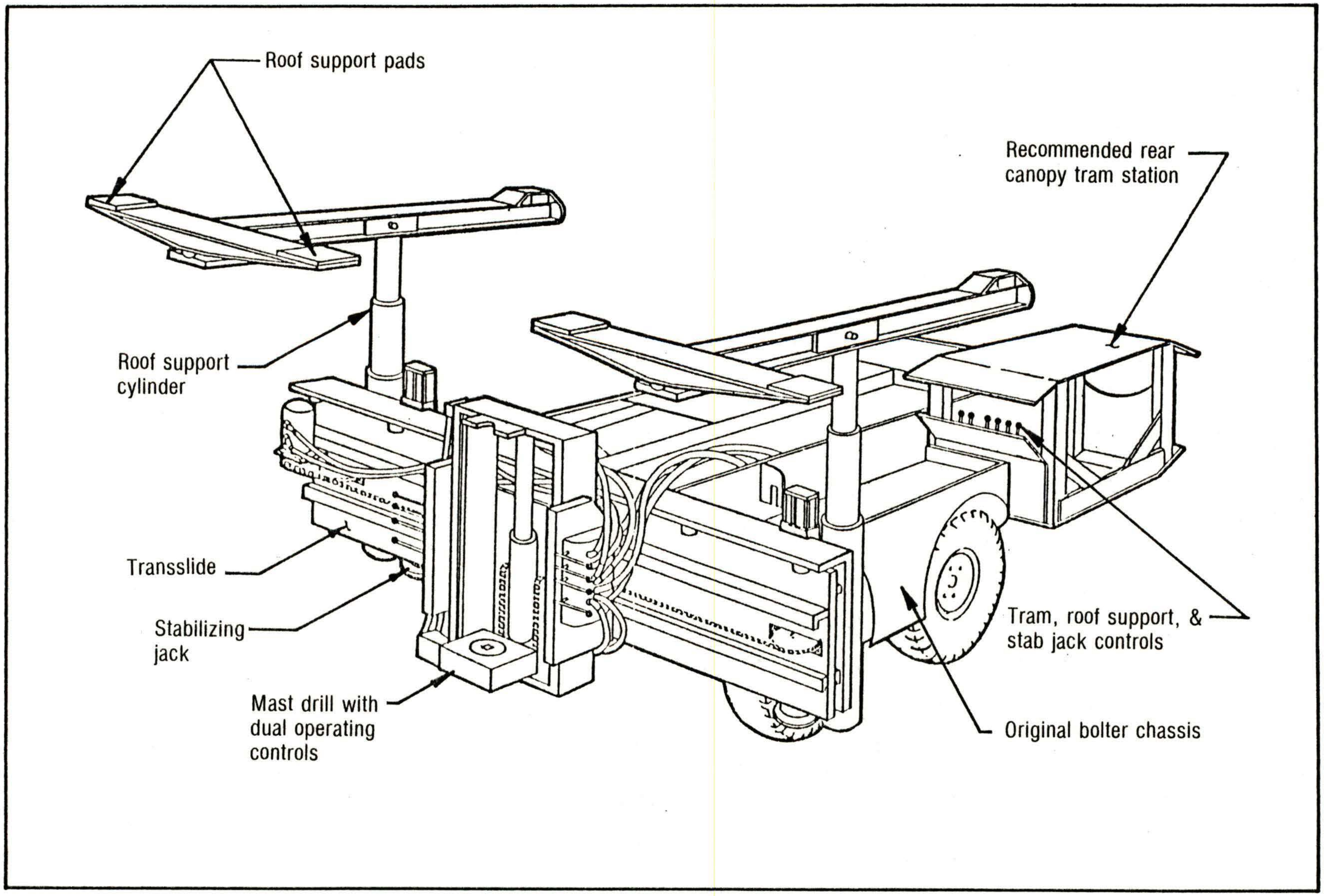


Figure 21 RETROFITTABLE TRS CONCEPT

Because this concept had not been carried through to fabrication or demonstration, no comments could be offered concerning its practicality. However, it represented current technology available to the coal mining industry.

- H0262091, Fabrication and Evaluation of Optimized Operator Compartments

  An FMC 320-A roof bolter was modified to incorporate cantilevered canopies over separate drill and tram control stations A spring-loaded lip at the outer edge of the canopy would retract for bolting close to the rib.

  These canopies were accepted by mine personnel in evaluations conducted at an underground coal mine. A unique joystick, combining drill rotate and boom lift functions, was also praised as an outstanding improvement.

- H0346102, Low Coal Canopy Studies and H0357090, Fabricate and Evaluate Protective Canopies for 3-Foot Coal Seams

  A flat-plate canopy was installed on a Wilcox bolter and evaluated by operators. This rotatable canopy could be pinned in position over either the tram or the boom control stations It was hydraulically adjustable from a frame height of 24 inches to contact the roof up to 30 inches.

  Tramming-induced pitching motions caused the canopy to move vertically through the area occupied by the operator. Also, cylinder placement interfered with access to controls. This design was not acceptable to operators.

Roof-bolter manufacturers and mine shops had devised many canopy and TRS systems for their equipment. Current industry trends favored bar-type TRS systems combined with stab jacks at bolter control stations and adjustable height flat plate canopies over the tram station. Single-bolt-type TRS systems were popular in the Illinois area on both single-and dual-boom bolters.

TRS systems brought the bolter into compliance with the canopy law, and it was believed that they might replace the requirement to manually install temporary jacks prior to bolting.

3.1.3.2 Concept Development

Several concepts generated for TRS systems were applied to the FMC Model 300 roof bolter. Most concepts required extensive rework or new machine configurations to support the additional TRS system.

At the mid-program design review, it was decided to concentrate on easily retrofittable systems for small, single-boom bolters.

General design criteria established by MSHA Technical Support for "in lieu of" TRS systems included the following:

- Load capacity -- must elastically support weight of rock, 150 pounds per cubic foot, with dimensions 3 feet high, 2-1/2 feet from TRS centerline inby and outby, and 2-1/2 feet from ends. For single-bolt TRS, load equals 5 times 5 times 3 times 150 equals 11,250 pounds. For bar-type TRS, load equals 29,250 pounds for 8-foot bar and 33,750 pounds for 10-foot bar.

- Coverage area -- no limit, but TRS should cover at least 6 inches forward from bolt hole to protect the operator.

- Boom control station -- add stab jack to protect the operator. Small canopy desired but not mandatory.

- Hydraulic protection -- integral check valves in support cylinders to prevent loss of support if a hose fails.

- TRS control and tram inching controls (limit to 50 feet per minute) -- locate this station so operator is under supported roof. No canopy needed here.

- Streamline boom controls to allow 18-inch-minimum unobstructed escape path when bolting 24 inches from the rib.

- MSHA Technical Support reviews applications for approval of TRS systems "in lieu of" canopies per 30 CFR 75.1710-1(f).

Various concepts were possible. Either bar-type or single-bolt-type TRS systems could have been applied to small bolters. The less massive single-bolt, ring-style TRS could have been fitted over existing bolter booms but would have increased machine frame height, an undesirable feature for low coal. Ironing boards could also have been easily adapoted but could be used only in lieu of canopies, not as temporary support. All single-bolt systems needed additional cycle time to install and release the TRS for each bolt.

For temporary face support, a full-width beam (5 feet from each rib, 5-foot-maximum span between support points) would have been ideal, but this device would have been too heavy and cumbersome for use on small, lightweight bolters. Also, to install a full row of bolts using the existing drill boom would have necessitated either moving the bolter across the entry or a new machine configuration with a long, swinging boom. Both concepts were considered but rejected due to their impracticability for retrofit.

A detachable TRS beam had been demonstrated by Lee Engineering Division of Consolidation Coal Company. Because we could not improve on this concept, we continued searching for alternatives.

The possibility of using a short-bar-type TRS for two-pass bolting was suggested and seemed to have merit. Further development led to the final concept: a TRS frame supporting a mast bolter that traversed laterally across the beam. This two-bolt machine could be easily adapted to many existing small bolters that may otherwise have been obsoleted by impending legislation.

3.1.3.3 Preliminary Engineering

Figure 22 shows the proposed TRS concept. As a retrofit kit, the TRS would replace the existing drill chuck and bolter control station. Hydraulic power and machine lighting circuitry would be supplied from the chassis.

In this preliminary stage, the roof contact structure was depicted as rocker beams attached to the ends of the framework. Two hydraulic cylinders held the frame against the roof with the bolter boom used for transport only. Attachment to the boom would be through a horizontal pivot with leveling cylinder and could incorporate another pivot parallel to the machine centerline to allow the framework to adapt to sloping roof without unduly loading the boom attachment yoke.

Rails connecting the end-mounted rocker beams could be stressed as the structure for a beam-type TRS. A new mast-type drill unit suspended from wheels riding these rails could be power-traversed by a simple hydraulic motor-driven chain arrangement. Bolting controls would be located on this traveling mast. The mast was derived from the twin-cylinder drill unit used on the new FMC 370 series roof bolter. Some redesign would be necessary.

A screen was suspended from the inby rail to prevent the operator from moving forward into unsupported roof areas.

System width could be selected to provide lightest structure for the needed bolt pattern. Collapsed and working height had to be tailored to the seam height by telescoping jack selection. Initial projections showed a total weight of about 1,600 pounds, which could be reduced by using lightweight materials such as aluminum. However, these had to be replaceable parts, due to a general lack of aluminum welding capabilities in coal mine repair shops. Possible relocation of existing machine components was suggested as a means of counterbalancing the machine to maintain squirm steer capabilities.

It was felt that other machine modifications might be required to bring it into compliance with current laws. TRS controls needed to be located so that the operator was under supported roof, and a canopy would still be needed over the tram control station.

It was assessed that detailed studies would be needed following mine demonstration to optimize design parameters such as operating width, weight, mast performance, control station layout, and operator interface.

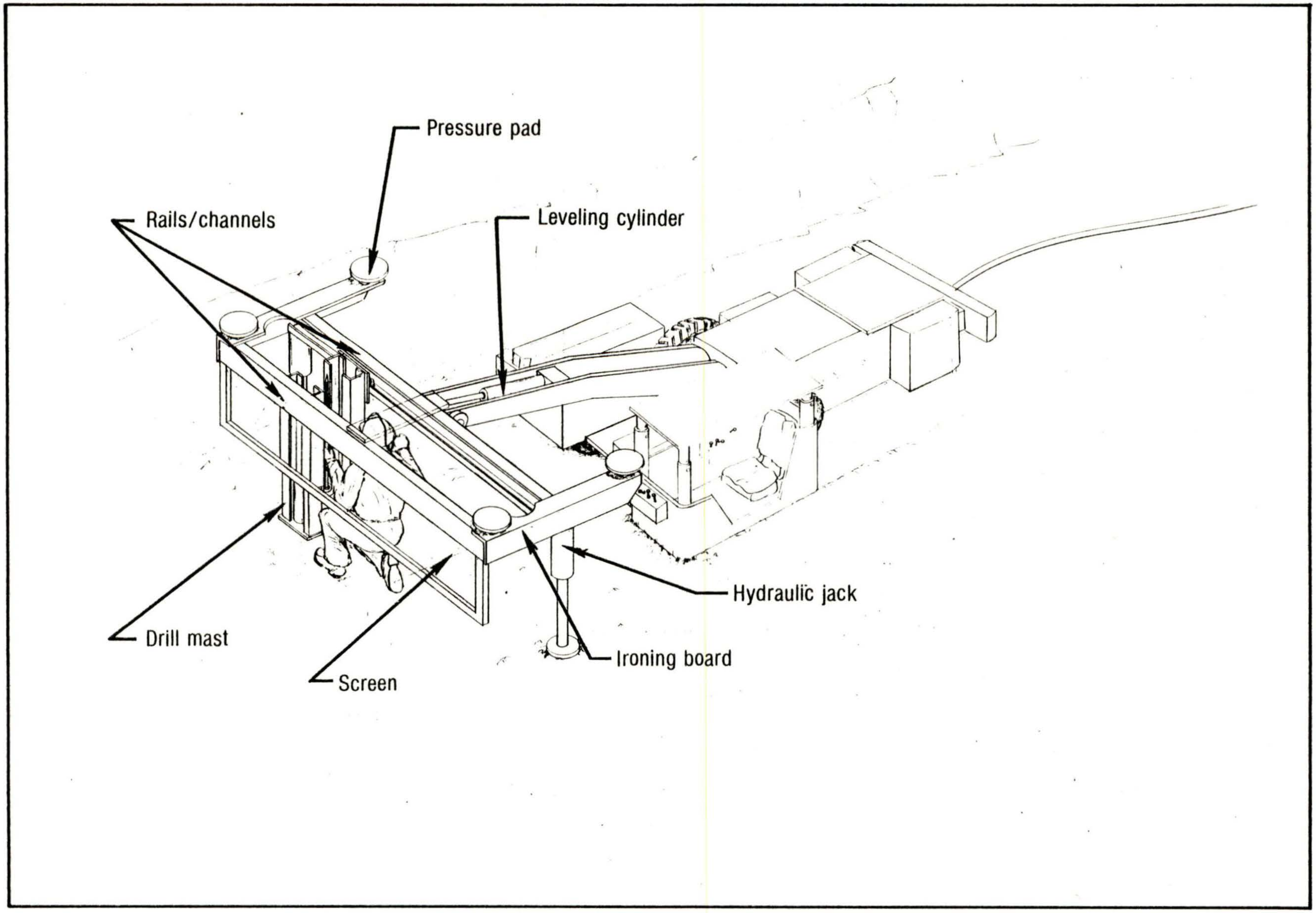


Figure 22   SINGLE-BOOM BOLTER TRS CONCEPT

3.1.3.4 Mock-up Fabrication

A full-scale wooden mock-up of the proposed TRS system was fabricated from the preliminary sketches. Figure 23 shows the mock-up as presented for evaluation.

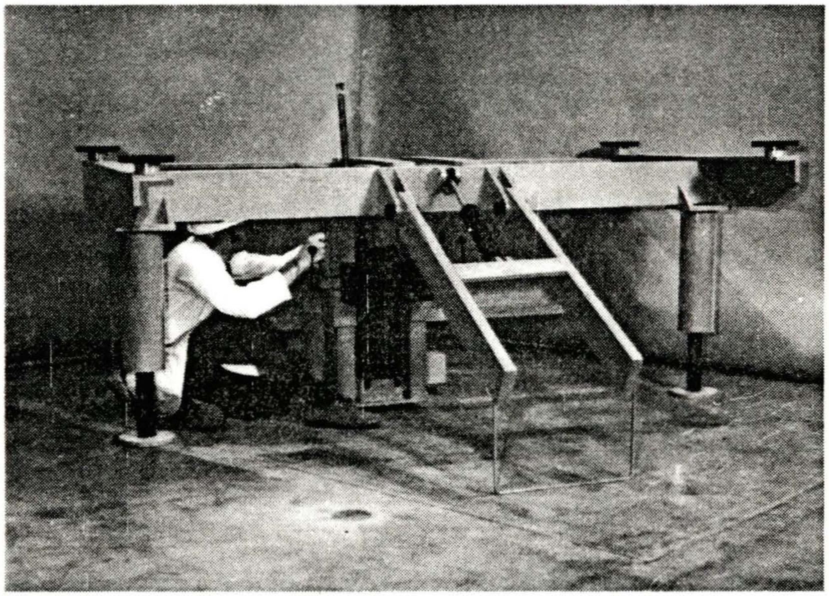


Figure 23 SINGLE-BOOM TRS MOCK-UP

3.1.3.5 Evaluation

Evaluations were conducted at the mock-up review meeting previously mentioned.

3.1.4 Dual-Boom TRS

The objective of this work was to design and mock-up a temporary roof support (TRS) canopy for a dual-boom bolting machine for seam heights 42 to 48 inches.

3.1.4.1 Assessment of Existing Technology

Refer to Section 3.1.3.1 of this report for TRS history and definition which applies equally to this section.

A dual-boom TRS system had been developed under this Bureau of Mines contract:

- H0166138, Development of a Dual-Boom Semi-Automated Roof Bolter

  Single-bolt type TRS units were applied to each boom. See Figure 24. Rocker arms surrounding the drill chuck were supported by telescoping tubes with internal cylinders. These were mounted on the sides of another telescoping channel framework driven by a single cylinder located directly inby the chuck. Overall operating range was 5 feet, collapsed, to 10 feet, extended. The entire system was certified to support elastically a static load of 11,250 pounds.

The TRS provided roof support at the drill chuck control station, acted as a stabilizing jack for the drill mast, and mounted the centralizer arm needed for remote drill/bolt handling.

This machine was demonstrated in an underground coal mine where other dual-boom machines were being operated with single-bolt-type TRS systems. No problems developed with the TRS concept or its application.

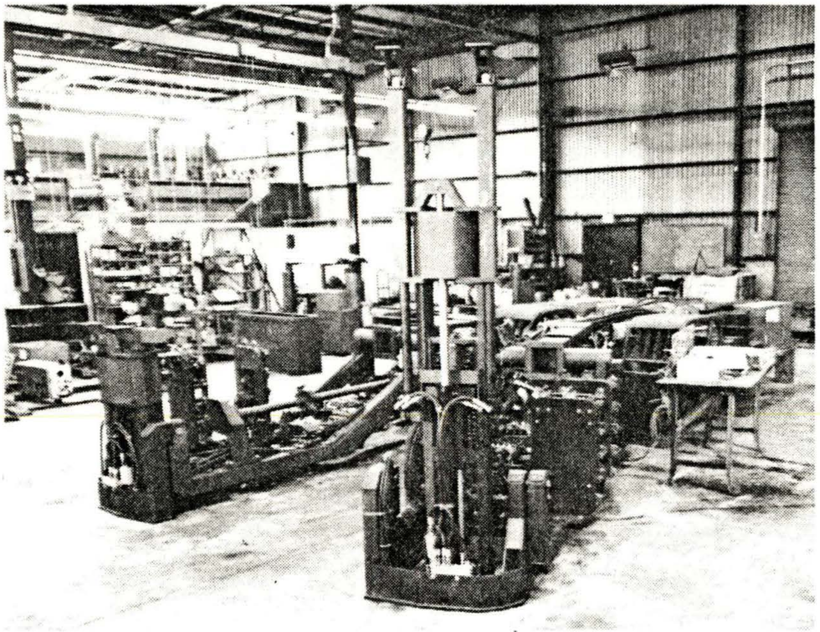


Figure 24 DUAL-BOOM BOLTER TRS UNIT

Bar-type TRS systems were easily added to existing dual-boom bolters by attaching a third boom to the front of the chassis. Single-bolt TRS systems took the form of rings or arms extending around the drill chuck and held against the roof by telescoping stab jacks or cantilevered booms attached to the drill boom.

Concurrent with this project, FMC had been developing their own version of the bar-type TRS. It consisted of two multistage telescoping cylinders angled from the base pedestal with a central telescoping guide framework. With a working height range of 29 to 67 inches and a tram height of 18 inches, it was felt that it could fit the objective of this contract.

Roof-bolter manufacturers then had these TRS systems available for most dual-boom machines, and retrofit kits were being implemented by rebuild shops. Depending on the MSHA district and the mining roof control plan, these TRS systems could be used to bring the machine into compliance with the canopy regulations and might allow bolter operation without the manually installed face supports then required by most roof control plans.

3.1.4.2 Concept Development

Discussions with roof-bolter manufacturers, MSHA Technical Support, and coal companies indicated a trend toward bar-type TRS systems for dual-boom bolters, primarily because they could provide support across the entire entry width. Various configurations were suggested and then reduced to two practical concepts:

A. Bar-type TRS cantilevered off the machine frame and powered by a single jack

B. Bar-type TRS on a multistage cylinder guided by telescoping guide channels. The assembly was supported on a boom and could be folded over to reduce tram height.

Concept B was selected for development at the mid-phase design review meeting.

3.1.4.3 Preliminary Engineering

The fold-over TRS concept was continued through preliminary engineering stages, where functions were designed to meet performance parameters. Refer to Section 3.1.3.2 for general design criteria.

This 10-foot bar-type TRS would support a static load of 33,750 pounds. Dual rocker beams could be reversed for use in either 10- or 8-foot entries. See Figure 25. A box-girder center section supported the rocker beams and was attached to the main load carrying cylinder by a pin through a spherical bearing in the rod end. This allowed the beam to deflect for roof compliance while loading the cylinder in an axial direction only. Belleville springs located in four positions around the upper attachment framework held the beam in a level position while tramming.

A two-stage telescoping cylinder moved the TRS to the roof and supported the load. Guide channels on either side held the bar perpendicular to the machine centerline. To eliminate the possibility of damage to this mechanism when moving the machine, the bar could rotate on a thrust plate attached to the upper end of the channels. Springs were used to return the bar to the operating position.

The TRS bar, cylinder, and channel unit were attached to the support boom at two pivots. The lower pivot ran in a track and the upper pivot was attached by links to the boom. A stow cylinder located within the boom structure moved the pivot in its track to rotate the structure from the vertical operating position to a horizontal tram position Protection from loads imposed by collision with the roof when tramming with the TRS erect was provided by a special spring-loaded rod end on the stow cylinder.

A boom carrying the TRS unit attached to the sump frame at a horizontal pivot. The boom support cylinder could raise or lower the TRS for tram clearance through undulating seams.

A track welded to the machine chassis supported cam rollers mounted on the sump frame. One cylinder connected the sump frame to the chassis and provided 10 inches of travel.

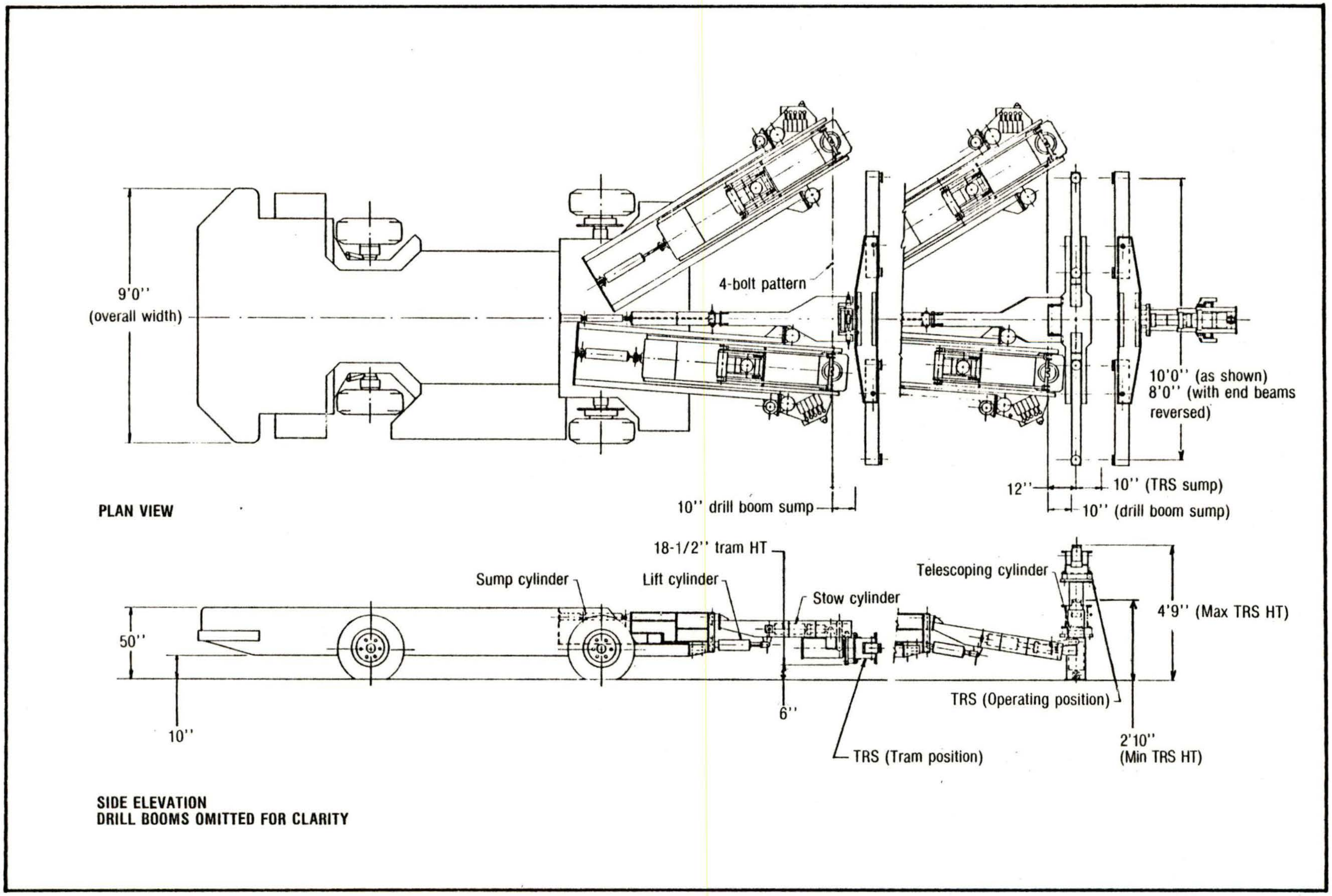


Figure 25 DUAL-BOOM TRS GENERAL ARRANGEMENT

It was assessed that other modifications would be required on the roof bolter itself. Stab jacks would be needed at the boom control stations, tram inching and TRS controls needed to be located so the operator would be under supported roof, and a canopy had to be used over the tram control station.

3.1.4.4 Mock-up Fabrication

A full-scale wooden mock-up was built including the rocker beams, support bar, telescoping channels, cylinder, thrust plate, stow links, and the front end of the boom. Figure 26 shows the completed mock-up.

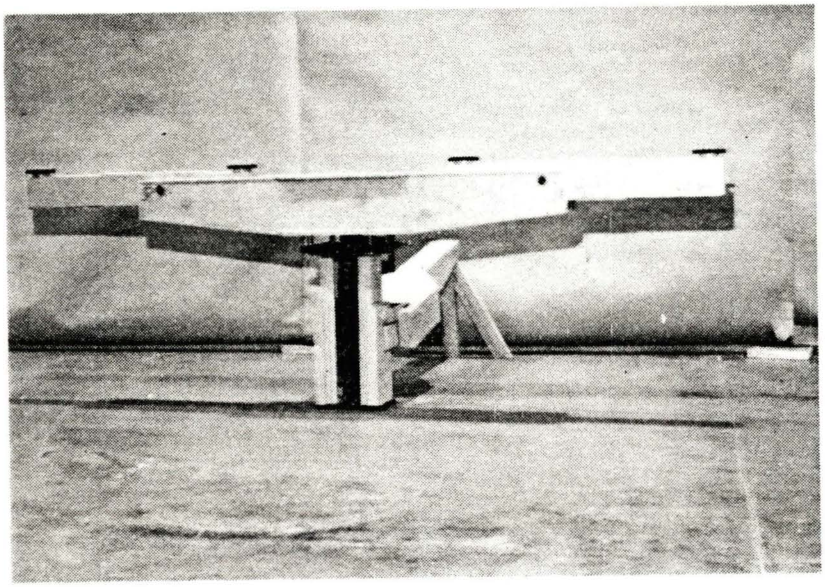


Figure 26 DUAL-BOOM TRS MOCK-UP

3.1.4.5 Evaluations

Evaluations were conducted at the mock-up review meeting previously mentioned. See also Subsection 2.1.

3.2 PHASE II, DESIGN DETAIL AND FABRICATION

Work performed during this phase included the following:

- Development of a retrofittable TRS kit for the FMC model 300 roof drill
- Design and fabrication of a canopy for a Joy 14BU10-11A loader
- Design and fabrication of a canopy for an FMC 6L shuttle car
- Location of mine sites for evaluation of the loader canopy, and shuttle car canopy
- Testing and certification of the loader and shuttle car canopies.

3.2.1 Loader Canopy

On the basis of the Phase I evaluation, the loader canopy was de4signed and built incorporating the comments and recommendations made on the mock-up. The canopy was redesigned to be capable of sustaining more severe lateral loads from ribbing than had been previously anticipated. An artist's sketch of the loader canopy (Figure 27) depicts the canopy mounted on the coal loader.

3.2.1.1 Structural Changes

The following structural changes were made and incorporated into the Phase II design. Figure 28 and 29 present two different views of the loader canopy structure.

- o The roof of the canopy was a 3/4-inch-thick T-1 steel plate with both edges bent down slightly to form sloping leading edges. These edges served as ramps in case the canopy top ran into protrusions in the mine roof. the front edge of this flat top was curved (a convex curve) to increase the operator's view of this mine roof at the corners of the canopy. The top width was reduced to 31 inches to increase the operator's view of the roof at the sides.

- o The 2-inch-square roof support columns of the mock-up were replaced by 3/4-inch-thick plate posts positioned so that only the 3/4-inch-thick edge was in the line of vision of the operator at the front, and the 4-inch by 4-inch by 1/4-inch-wall square tube columns were reinforced with vertical wedge-shaped lead-in edges at the back.

- o The heavier columns in the back were intended to withstand ribbing forces when the canopy ran into the rib.

- o The hood over the operator's legs and feet was made of 1/2-inch-thick T-1 steel plate on top and 1/2-inch-thick mild steel plate on the sides.

- o In the mock-up, part of the hydraulic valve bank and the entire tram control switch box were located on top of the hood. This was deemed undesirable, because it obstructed the operator's view of the loader conveyor.

- o In the Phase II design, both the valve bank and the tram control switch box were relocated outside the canopy cavity to the control equipment cluster at the lower right-hand front corner. This relocation left the top of the hood free of obstructions in the operator's line of sight into the conveyor, except for a small cover that protected the linkage for the hydraulic valve actuators.

- o The pinch point in the mock-up caused by a discontinuity on the floor under the hood was eliminated by making the floor continuous. The resulting smooth hump created under the operator's calf area seemed to add to operator comfort.

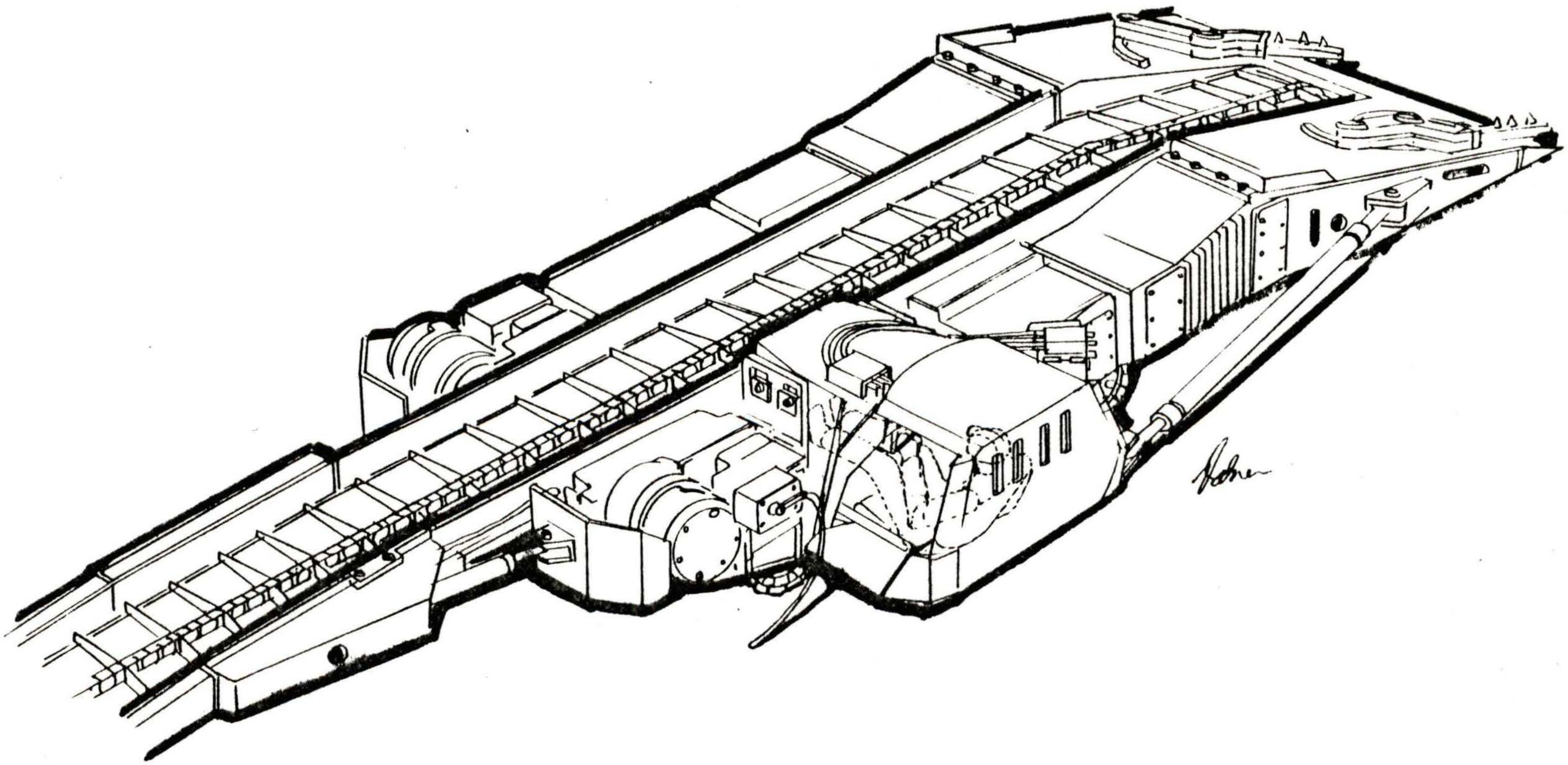


Figure 27 LOADER CANOPY, ARTIST'S CONCEPT

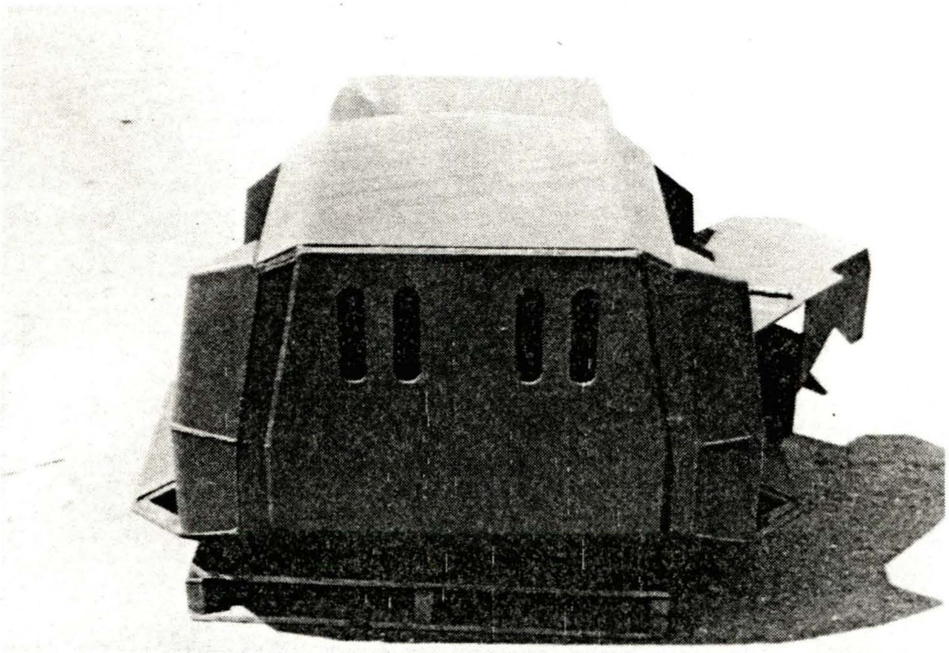


Figure 28 LOADER CANOPY STRUCTURE -- VIEW LOOKING FROM INBY

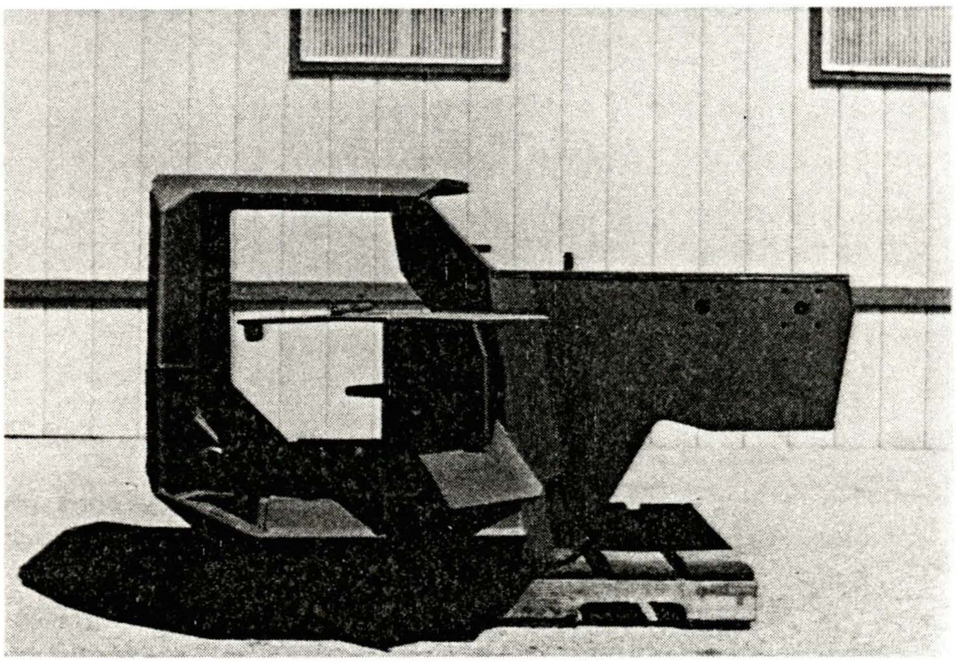


Figure 29 LOADER CANOPY STRUCTURE -- VIEW LOOKING INTO CANOPY FROM INBY SIDE

- In accordance with the evaluators' recommendations, padded cushions were added to the sidewalls of the hood to serve as operator knee rests.

- To improve ease of ingress and egress to and from the canopy, the hinged dirt gates were eliminated and the fixed sidewall incorporated with the canopy floor. This construction also greatly enhanced the strength of the plow.

- Four brackets were welded to the crossbar frame to provide a canopy attachment to the loader and strengthen the rear wall.

- A link was added between the outboard, inby corner of the canopy and the gathering head to help react ribbing loads on the canopy.

- Four 2-inch by 8-inch vertical slots were added to the rear panel to enable the operator to see the rib.

- The loader canopy was furnished with controls for each of the moving controllable functions. All controls were operated with the hands and arms completely protected. The loading-head raise and lower, conveyor-boom swing, and conveyor-boom raise and lower were controlled by underhanging levers in front of the operator and could be operated with both hands. At the operator's right hand in a control cluster were the two tram controls, one for each track. Pushing forward activated the selected track forward, while pulling back imparted reversed actions to the track.

  To increase the operator's field of vision and maximize operator space inside the canopy, an area just outside the canopy at the lower right-hand front corner of the canopy's inby side opening was selected for mounting most of the control equipment.

  This location was selected for several reasons:

  -- It is low enough that it does not impair the operator's field of vision critical to operating the loader.

  -- The tram control box of the loader can be mounted without modifying the box and can easily be operated with the right hand in this location.

  -- The valve bank remains close to its original location on the loader. (This does not eliminate the need for new lines to the valves.)

  -- Mounting the electrical switch box in this location increases space for operator entry on the outby side of canopy.

Since this cluster was located outside the area protected by the canopy roof, a 1/2-inch-thick cover was placed over the cluster to protect the operator's hand and arm as he reaches to operate the controls. This cover extends over the entire canopy opening. It is hinged at the middle to enable it to be raised for the operator to leave the cab from the inby side of the canopy when necessary.

3.2.1.2 Control Unit Relocations

As mentioned in Subsection 3.2.1.1, all of the control units were located together in the control equipment cluster at the lower front right-hand corner, just outside the canopy opening.

In the canopy mock-up, the tram control box was located on top of the hood, and the control levers were located between the operator's knees. This arrangement required additional hardware to actuate the controls, because the control levers were located remote from the box.

This initially selected location of the levers in the middle of the canopy created a possible safety hazard for the operator By hitting it with his knees, he could not only injure his knees, but could also accidently tram the loader.

The mock-up demonstrated these objectionable features. Both convenience and safety were enhanced when the tram control box was relocated in the cluster. The cluster was designed around the tram control box after it was positioned for optimum operator convenience.

The electrical control box was relocated from the outby side of the canopy to under the tram control box. This relocation increased ingress and egress room.

The hydraulic valve bank was mounted vertically on the support structure of the cluster cover. These valves were actuated remotely through push-pull cables from levers hanging from the top of the hood on the left-hand side of the canopy.

A protective shroud was installed under the valve levers to prevent accidental actuation while the operator was entering or leaving the canopy.

3.2.1.3 Suspension System

The canopy suspension system consists of a cantilevered pivot with an adjustable spring support and a shock absorbing radius arm. The system permits movement of the canopy upward, downward, or sideways under load. This resiliency minimizes injury to personnel upon impact with the rib or other objects. It also minimizes damage to the canopy and loader attach points. This freedom of movement was obtained by three features in the method of attachment to the loader.

- Pivot System

  The pivot support is at the upper, inboard end of the canopy structure. Two pins extend from each side through large square holes in the supporting structure. Extensive clearance between the pins and the square holes provide freedom of movement between the canopy and the support structure.

- <u>Springs</u>

  There are two horizontal springs beneath the canopy at right angles to the direction of travel. These springs force the bottom of canopy outward, forcing the pivot pins against the square holes in the supporting structure. The combination of spring force, canopy, and operator weights bias the four pins to the lower, outboard corners of the holes. Hydraulic cylinders adjust spring compression to provide seat height adjustment and operator weight compensation. A manually operated hydraulic pump supplies pressure for actuation of the cylinders.

- <u>Shock Absorbing Radius Rod</u>

  This rod connects the back end of the canopy to the side of the gathering head on the loader. Its function is twofold. It holds the back end of the canopy in position and absorbs the impact caused when the canopy runs into the rib or another object. A double-acting shock absorber in the radius rod is designed to absorb the energy from a 3-mile-per-hour impact in either direction.

3.2.1.4 Seat Design

The conveyor belt sling-type seat of the mock-up, which featured an adjustable backrest position, adjustable sling-seat tension, and adjustable lumbar support position, was retained with the following modifications:

- The mechanism for positioning the backrest was changed from a lever operable by the operator seated inside the canopy to a simplified pin-locked adjustment plate adjusted by the operator while outside the canopy.

- The neck support location was raised, and the parallel bar mechanism that holds the neckrest above the top of the backrest at all positions of the backrest was retained.

- The neck support was changed from a rigid piece to a sling-type belt mounted between pivoted anchor points.

- The size of the lumbar support was reduced.

3.2.2 Shuttle Car

Each of the recommendations resulting from Phase I evaluations was reviewed, and the following design changes were made. An artist's concept of the completed shuttle car with canopy is given in Figure 30.

3.2.2.1 Car Body Rework

The following car body rework was performed:

- o The car body was notched, and the conveyor boom was reworked to provide clearance for upward movement of the floor-riding canopy.
- o An extension was added to the outby side of the outby wheel well fender to keep mud from being thrown from the turning wheel into the canopy.
- o Plates were added to the outside of the car body side to strengthen the notched portion for car roller bracket mounting.
- o In the area of the cutout of the side plate, the design called for a formed stiffener section on the shuttle car which had to be removed. To compensate for this removal, a section of 4-inch by 6-inch by 3/8-inch tubing was added near the car longitudinal centerline between car body sections.

3.2.2.2 Conveyor Room Rework

To provide room for the canopy tunnel and its upward movement, the following rework was performed on the conveyor boom:

- o The top plate supporting the conveyor flights on the bottom was raised approximately 3 inches.
- o The bottom edge of the conveyor side plate was cut out 4 inches by 30 inches on the canopy mount side to accommodate the canopy tunnel and its upward movement.
- o The space for the conveyor flight return support was reduced by raising the side plates.
- o The angle cable guides on the inside of the conveyor vertical plate were replaced with 6-inch channels. These channels also act as guides for the conveyor flights when the conveyor top is raised.

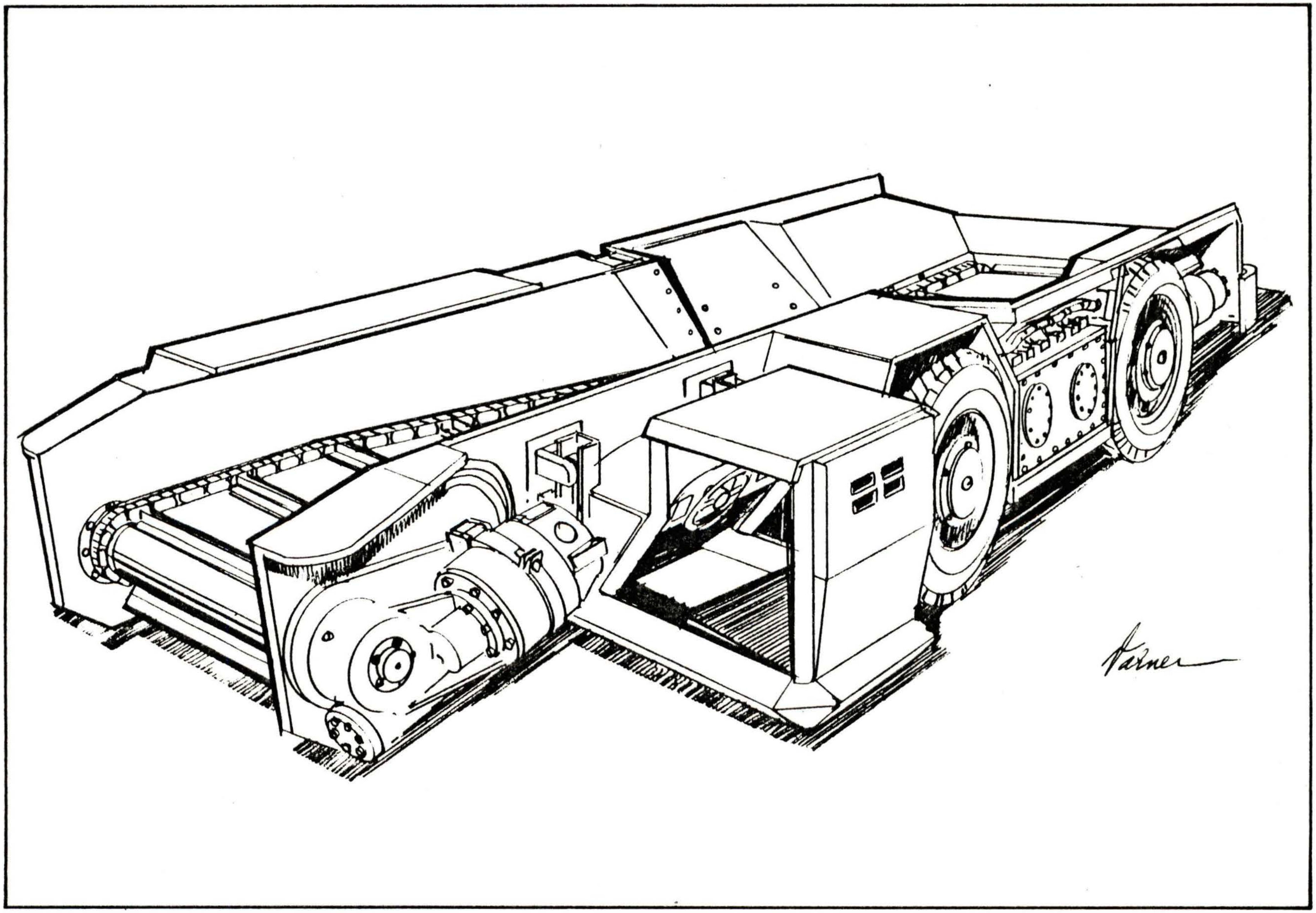


Figure 30 SHUTTLE CAR AND CANOPY, ARTIST'S CONCEPT

3.2.2.3 Canopy Structure

This structure was designed in accordance with Title 30 structural loading requirements. Efforts were made to provide adequate inside operating space for a 95th percentile man. It was constructed entirely of readily available steel plate channels and pipes. See Figures 31 and 32 for inby and outby views of the shuttle car structure.

The canopy structure as redesigned has the following features:

- The canopy base plate is 0.63-inch-thick steel plate, with a yield of 50 ksi. It is flat, with turned-up ends to act as a sled as it slides on the mine floor.
- The canopy roof plate is also 0.63-inch-thick steel plate, with a yield of 50 ksi. It is flat, with the edges bent down slightly on the operator's right and left to form a smooth surface for potential roof contact.
- The canopy framework uprights supporting the roof are 2-1/2-inch-OD steel tubing with 1/4-inch wall.
- The canopy roof height is adjustable to match the working height of the mine. The roof is adjusted by manually raising the canopy and installing pins through the support posts and selected holes in the telescoping inner support tubes.
- A second canopy section extends over the operator's thighs and knees.
- The third and lowest canopy section encloses the operator's calves and legs. It extends below the shuttle car conveyor and contains the brake pedal, master cylinder, and tram switch and actuation pedal. The tunnel is designed to carry the rated shuttle car wheel load.

3.2.2.4 Canopy Guide Assembly

The canopy was attached to the car body through an interface between four cam roller brackets bolted to the car body and channels welded vertically to the canopy sides nearest the car body. Each cam roller bracket has a 3-inch-diameter roller to react loading in the vertical plane and a 1-1/2-inch-diameter roller to react loading in the horizontal plane. Stops were provided on the channels to keep the rollers in the channels.

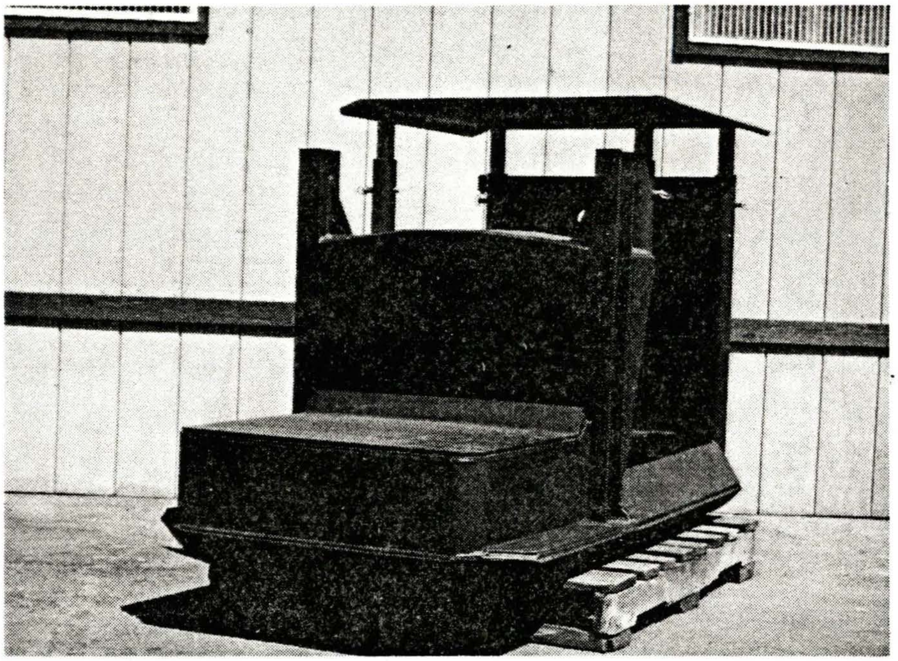


Figure 31   INBY VIEW OF SHUTTLE CAR CANOPY STRUCTURE

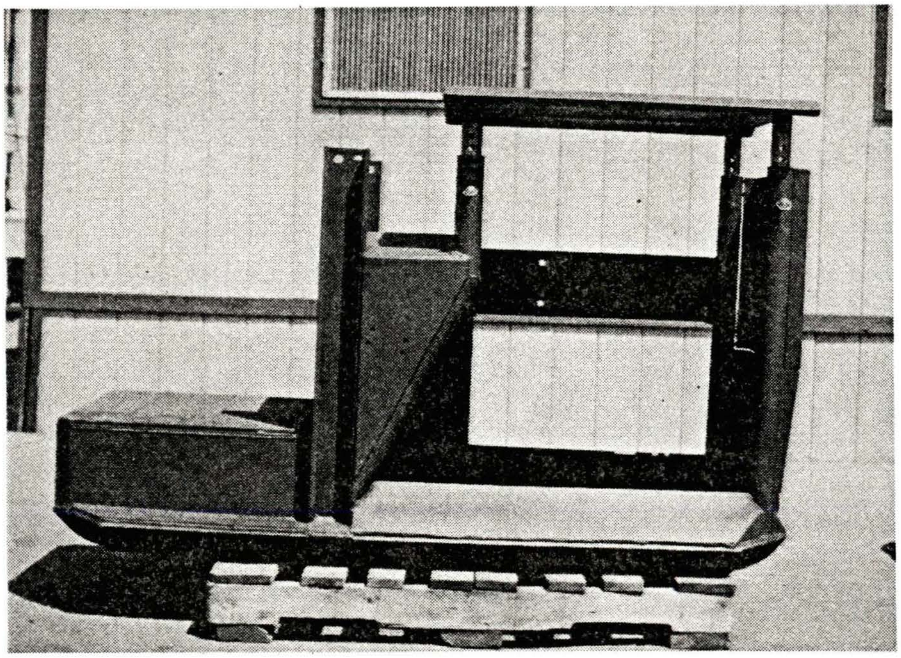


Figure 32   SHUTTLE CAR CANOPY STRUCTURE FROM FRONT OUTBY POSITION

3.2.2.5 Brake Assembly

The brake foot pedal and brake master cylinder were mounted in the tunnel on the operator's left. The entire assembly was bolted to a plate welded to the floor to facilitate removal during servicing.

3.2.2.6 Ingress/Egress

The opening provided in the canopy side for the operator was enlarged in the area where the operator's legs and feet require more space as he bends down to enter or gets up from a sitting position to exit. This provides the operator easy ingress/egress. The operator aids his entry and exit by grasping the canopy roof support members.

The suggestion that a second exit be provided over the tram switch on the car operator's.inby side was judged impractical, because it would have required raising the canopy height and extending it out further from the car to provide adeqate exit space. This design change would have undermined the intent of using the canopy in low coal seams.

3.2.2.7 Seat

The operator's seat was designed to reduce operator fatigue and provide optimum operator comfort. The seat is mounted on rollers and on a flat plate which pivots in the plane of the floor about a vertical axis on the canopy's longitudinal centerline. The seat can be located to provide the operator's straight-ahead vision either on the centerline, or 5 degrees to each side of it. The soft support part of the seat consists of 1/8-inch by 18-inch-wide cotton webbing formed into a sling to support the operator's seat and back. The seat can be adjusted to the operator's height by pivoting and locking the back seat in the desired position.

3.2.2.8 Operator Comfort

Human engineering and industrial design studies were made for operator comfort and optimum control arrangement. The canopy interior space accommodates a 95th percentile man's torso-to-toe seating requirements. The brake pedal and tram switch pedal were rearranged for improved operator foot access and operating comfort (see Figure 33). The tram switch's single pedal pivots about a vertical pin. Pushing the pedal on the inby side of the pivot causes the car to move at the selected speed inby. Conversely, pushing on the pedal on the outby side results in outby tramming control. It was learned that U.S. Steel uses this switch arrangement very successfully with good operator acceptance and adaptation. The brake and tram pedals and control assemblies were made removable for servicing and, if necessary, to facilitate cleaning of the tunnel.

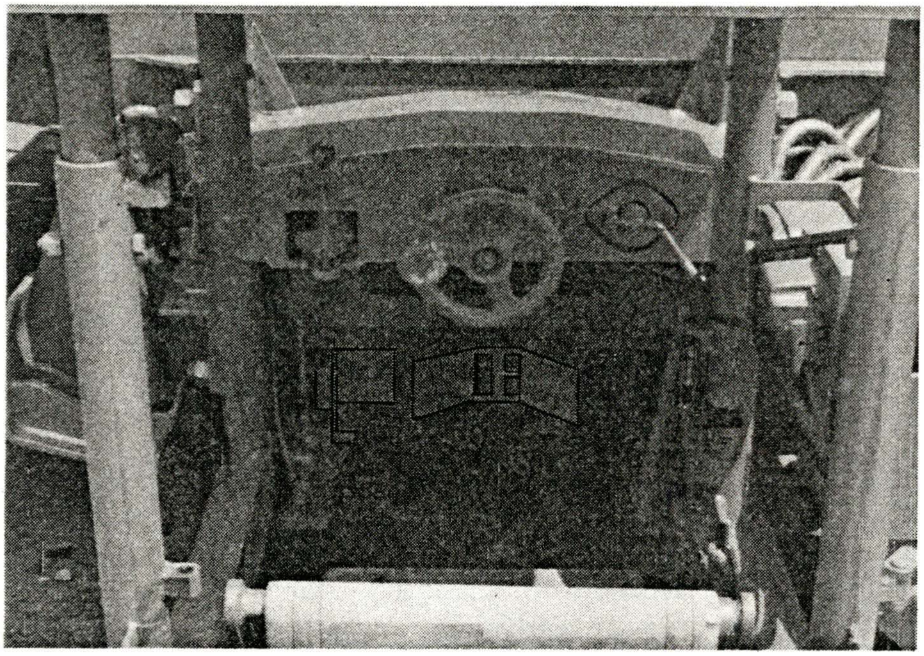


Figure 33   SHUTTLE CAR BRAKE AND TRAM SWITCH PEDALS

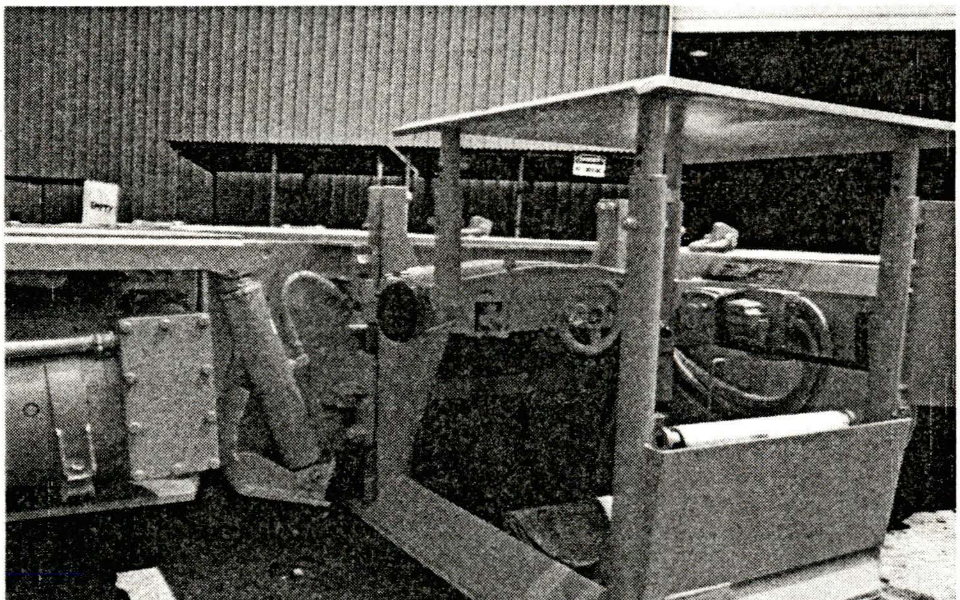


Figure 34   SHUTTLE CAR CONTROLS

3.2.2.9 Controls

The controls on the shuttle car were relocated from their location on the car body side to within the protected area of the canopy (see Figure 34). All FMC standard controls were retained.

- The conveyor lift, orbital power steering, and conveyor controls were mounted on the panel in front of the operator, at mid-chest sitting position.
- The enclosure containing the pump ON/OFF and light switch were mounted on the operator's right, at the same level as the conveyor controls.
- A top pivoted elongated "U"-shaped bar was moved over the pump ON/OFF switch for emergency panic cutoff of the pump switch.

3.2.2.10 Vision

Outby vision is unrestricted. Over the conveyor tail, however, vision is obstructed.

Inby vision is unrestricted in a line of sight outside the wheel wells (Figure 35). Vision over the car inby is restricted.

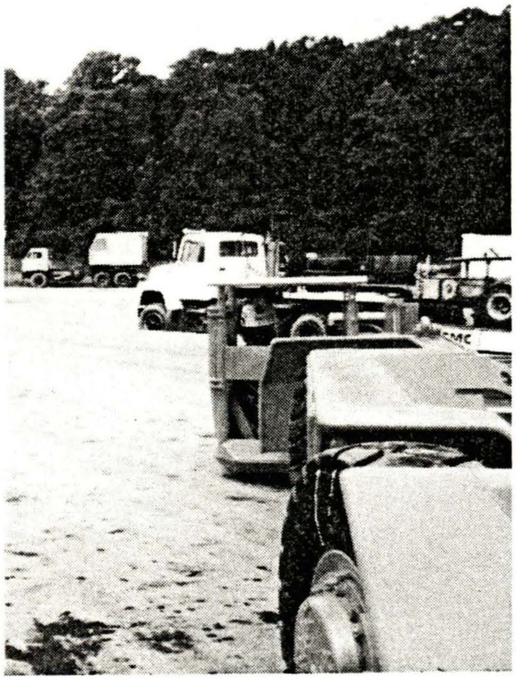


Figure 35 VISION FROM SHUTTLE CAR CANOPY

3.2.3 Single-Boom TRS

Early in Phase II, approximately four months were devoted to development of a single-boom TRS (see Figure 36). This effort included investigations into the viability of the TRS developed under Phase I and the concepting of other TRS configurations. The Phase I TRS concept had two serious flaws: the roof drilling loads did not react into the mine floor, and the design incorporated the use of a prototype roof drill mast, which was undeveloped and nonexistent on existing FMC Model 300 roof drills. This concept was thus abandoned and new TRS concepts were developed, using the following guidelines:

- Make the TRS retrofittable to existing FMC Model 300 drills
- Make the design as light as possible
- Provide centerline drill-pot-to-face dimension of 18 inches or less
- Bolt two holes in one TRS setting
- Provide bolting on 4 feet plus a few inches, and to 3-foot centers
- Assume a production cost of approximately $10,000.

Several concept layouts were generated, each of which met some of the design criteria, but all concepts fell short in three areas. The lowest-cost layout design was estimated at over twice the desired $10,000 cost. The CG of the machine shifted too far inby, making tramming difficult. Also, the retrofit became impractical, because it was more costly than providing an entirely new boom. A summary of the salient points of the TRS layouts is presented in Table 8.

Late in March 1980, a design review was held with Bureau representatives, at which time a decision was made to delete the TRS from the program.

3.2.4 Certification

The loader and shuttle car canopy roofs were certified according to the requirements of Title 30, Part 75.1710-1(d) (see Appendix B). Compliance to these requirements was confirmed by the calculations of registered professional engineers and by test loading. Test setups for the loader and shuttle car canopies are given in Figures 37 and 38. Copies of the tests have been included in the job file.

3.3 PHASE III, IN-MINE EVALUATION

During this phase, the design and construction of the shuttle car rework and the concepts applied to the canopy were assessed As a part of preliminary coordination, an experimental test agreement was drawn up for Bureau of Mines, ESD, and VCCC approval.

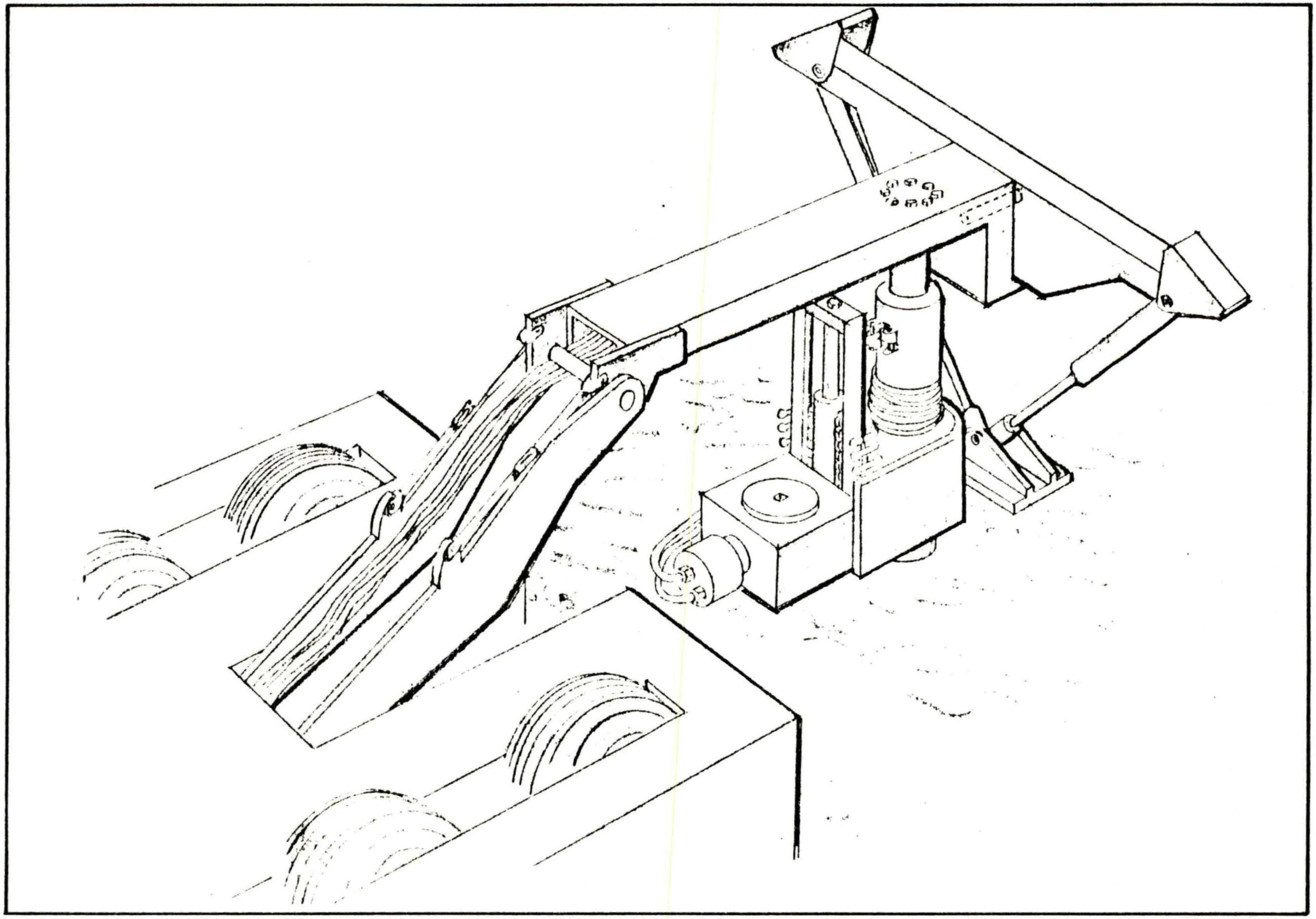


Figure 36 SINGLE-BOOM TRS, ARTIST'S CONCEPT

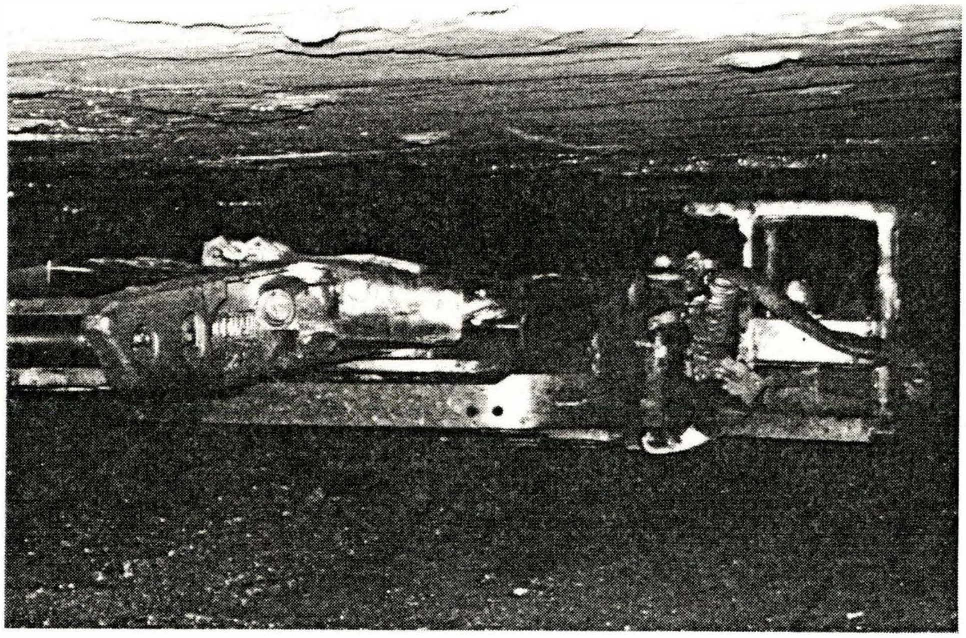


Figure 40 GOODMAN LOADER IN A CONVENTIONAL MINE

3.3.5.1 Operator Comments

Initial reaction to the shuttle car and canopy was mostly favorable. Comments on the following were particular positive:

- Smooth ride
- Comfortable seat
- Roomy canopy
- Easy ingress/egress
- Unrestricted vision inby and outby
- Transverse mounted canopy position
- Easily oriented steering
- No difficulty with pivoted, foot-operated tram switch
- No change in sitting position required when changing between inby and outby tram.

3.3.1 Shuttle Car Purchase

The Bureau of Mines furnished the shuttle car, a specially deisnged FMC 6L, with ESD's canopy replacing the formerly used canopy for use in the program. Negotiations between the Bureau of Mines and FMC Corporation for the shuttle car with the special canopy mounted on it were coordinated by ESD.

3.3.2 Shuttle Car Manufacture

Manufacture of the specially designed shuttle car began in May 1982, and the shuttle car with mounted canopy was ready for delivery to the evaluation site in late August 1982. During manufacture, representatives from ESD provided advice, both by telephone and by visits to the manufacturing site, to clarify special construction requirements for mounting the canopy. See Figure 39 for a photograph of the manufactured shuttle car with canopy, taken at the manufacturing plant.

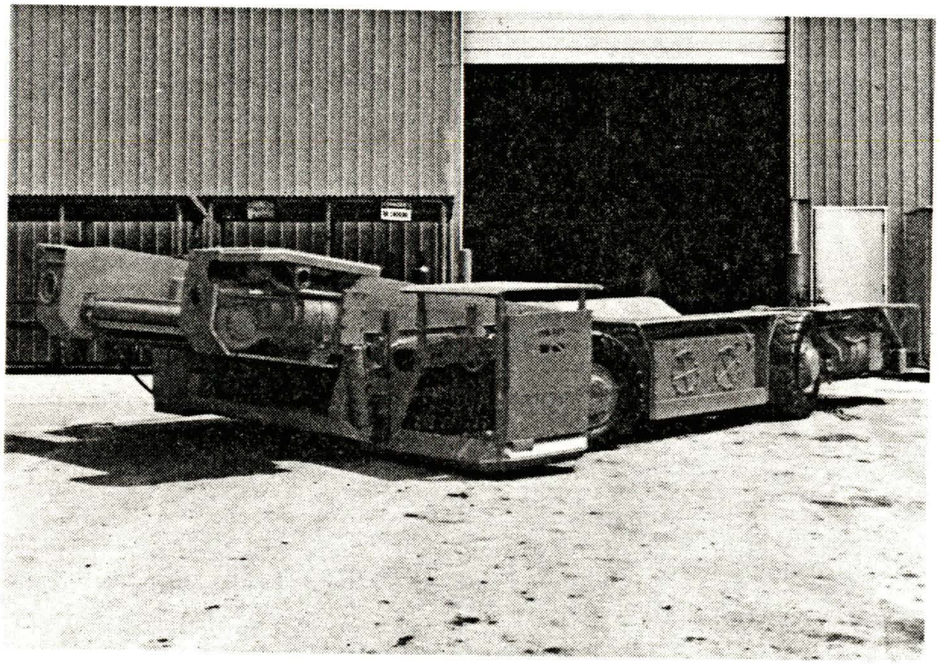


Figure 39 COMPLETED SHUTTLE CAR AND CANOPY

3.3.3 Experimental Test Agreement

To ensure common understanding regarding the evaluation requirements and obligations between Virginia Crews Coal Company, the Bureau of Mines, and ESD, an Experimental Test Agreement was drawn up and subsequently endorsed by VCCC and ESD on June 4, 1982. See Appendix C for a copy of this agreement.

3.3.4 Evaluation Site

Virginia Crews Coal Company, the site for the shuttle car evaluation, is a West Virginia hilltop coal mining operation with seven mines, all located in a 5-square-mile area. It is owned by Voest-Alpine, a large German corporation. This operation produced 350,000 tons of coal in 1979, and production through October 1982 reached 447,015 tons. Of its seven mines, five use continuous mining, and the remaining two use conventional methods. Three sections are mined in the 29- to 30-inch Red Ash Seam, four sections 30-inch Sewell Seam. The mine presnetly employs 199 people. Production is performed two shifts per day, five days per week.

3.3.5 Canopy Evaluation - Conventional Mine

Evaluation of the shuttle car canopy commenced in September 1982, upon installation of the shuttle car in VCCC's Number 5 mine. Mine Number 5 is a conventional mine with a seam height averaging 52 inches. the roof is bolted, and the floor is relatively smooth, dry, and pitching at 4 percent. Mine working height varies from 47 to 49 inches. during normal shuttle car operation, a typical cycle includes:

- o Loading at the face
- o Tramming load to the unloading station
- o Positioning for unloading
- o Unloading
- o Tramming back to the loading station
- o Positioning for loading next load.

At the loading station, the shuttle car either operates alone or in conjunction with a scoop for hauling, or the scoop alone is used. A Goodman loader (see Figure 40) retrieves the coal and loads either the shuttle car or the scoop. The load is then trammed to the breaker for loading onto the conveyor belt. The operator then trams approximately 200 yards to the breaker station, at which time the operator encounters two or three relatively sharp turns, which usually results in some ribbing of the canopy.

Upon unloading, the operator trams back to the loading station and positions the car to receive another load. Time for a complete cycle is 4 minutes, with 40 seconds each allotted for loading and unloading.

During the evaluation, the loading operation went smoothly. The canopy's transverse mounting provided the operator with a good view of the loader conveyor, enabling him to control shuttle car movement when receiving a load and when pulling away from the loader. At the unloading station, the operator had an unrestricted view of the breaker station as the conveyor boom was trammed into position over the breaker. Overflowing coal posed a problem. Coal from the mine floor entered the canopy from the side, because of overspill from the scoop as it unloaded to the breaker. This overspill occurred because the scoop bucket opening was wider than the breaker.

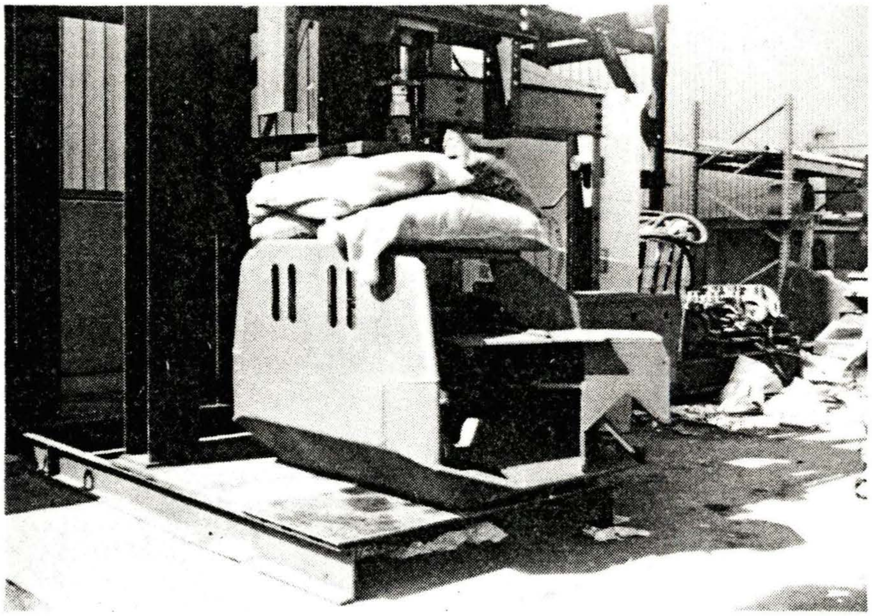


Figure 37 TEST SETUP, LOADER CANOPY

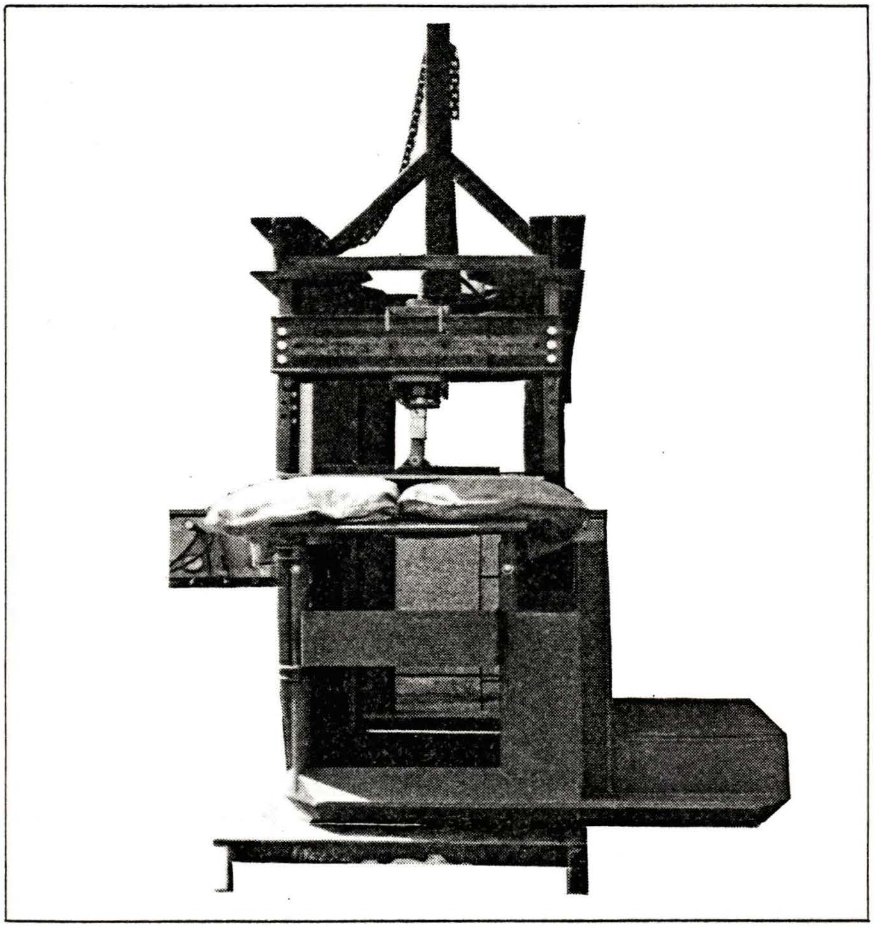


Figure 38 TEST SETUP, SHUTTLE CAR CANOPY

The following negative comments were expressed:

- o The operator sits too low (resulting in impaired vision).

- o Coal comes in at the floor level on the entry side when backing into position to unload at the breaker. this porblem was corrected by adding 6-inch-high plate on the cap entry side (see figure 40).

- o Coal comes in the window in front of the operator. This problem was corrected by adding a 6-inch-high plate between canopy posts (see figure 41).

- o There should be another inch separation between the tram switch and brake pedal. This was not a common complaint and, because it was not easily corrected, it was left unchanged.

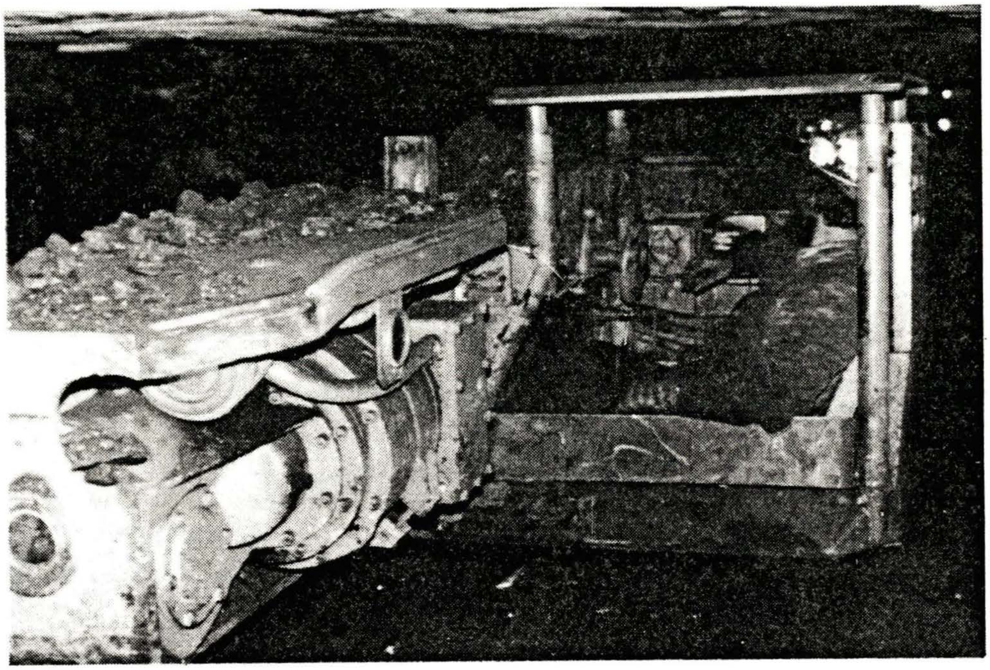


Figure 41 CANOPY ENTRANCE -- VIEW FROM OUTBY

The operators felt that the canopy should have a jack to raise it before backing the shuttle car into the dumping position. They felt that this would alleviate the problem of coal entering the canopy operator's compartment and would also raise their line of sight when desired. Although this was considered a good addition, it was questionable whether it would keep the coal out fo the canopy, since raising the canopy 4 inches would only raise the level the pile at the dumping station would have to reach in order to enter the canopy. It was felt that a daily cleanup of this overflow pile with the scoop would probably keep the unloaded area sufficiently clean to keep the coal from entering the canopy. When the shuttle car was used alone, this problem did not occur.

Evaluation Data Sheets (Appendix D) presnet a summary of production data taken during mine evaluation of the shuttle car and canopy in the conventional mine from August to November of 1982. Following this data is a sample record sheet filled out by the operator at the conclusion of his shift.

3.3.5.2 Mine Management Comments

Mine management liked the floor-riding canopy becuase of its low profile, which allowed them to use a 6L shuttle car where normally they would have used a 5L. Using a 6L shuttle car increased car trip capacity on a water level basis of 64 percent over the 5L with a similar conveyor width.

In the first month of use (September 1982), the car averaged 232 tons per shift, with a maximum of 242 tons per shift. the most trips per shift was 57. Based upon a 7-1/4 hour shift, the car averaged 52.4-percent usage for the month.

3.3.5.3 Transfer of the Shuttle Car

Late in December 1982, while the shuttle car was being taken out of the Nubmer 5 mine for transfer into one of the continuous mining sections, it was discovered that the outby lower bearing bracket normally attahced to the car body was missing. The bolts that retained this bracket were broken off, and port remained in the tapped hole (see Figure 42). The bracket was replaced, and all damaged parts were repaired and returned to their as-built condition. Additional members were then added to improve the strength of the shuttle car.

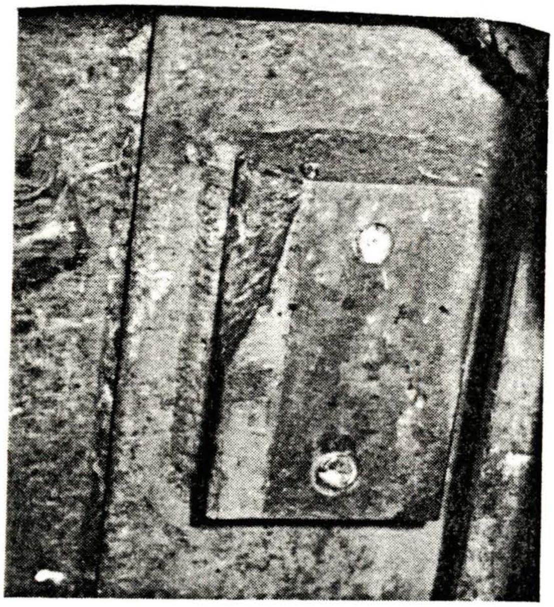


Figure 42 DAMAGED CAR BODY

A 1/2-inch plate was welded to the top 9-3/8 inches of the car body between the two canopy guide brackets. A sliding arrangement was attached to the extreme outside edge on the inby side of the canopy. This arrangement transfers ribbing loads into the car body frame through the large plate supporting the control box on the bottom and a gusset plate at the car body top.

It is not known what caused this damage to the shuttle car. It is unclear whether the bracket was ripped from the car body or if the bolts backed out gradually, causing the bracket to move on the 2-3/4-inch diameter grade 5 cap screws and thus cause a shear failure. A copy of the trip report which describes the shuttle car damage is given in Appendix E.

It is unknown whether the damage to the guide channels described in Appendix E was present before the bracket failed, or whether the damage was caused by the absence of the bracket. The assumption was made, however, that the parts indicating failure had to be strengthened. Also, it was believed that addition of a sliding shaft arrangement would add to the car body's and canopy's ribbing capability and would decrease the load on the rollers and guide channels caused by ribbing.

3.3.6 Canopy Evaluation -- Continuous Mine

3.3.6.1 Operator Comments

Operator comments in the continuous mining evaluation were similar to those offered during the conventional operation. The following were operators' positive comments:

- The ride was generally smooth, even though the bottom was irregular.
- The seat was comfortable.
- Vision was good to fair and unrestricted at either side of the canopy front.
- They liked the transverse mounted canopy position and were easily oriented to steering from this position.
- They had no difficulty with the foot-operated tram switch.

The following were recommended improvements:

- The seat should adjust more easily.
- Operator vision directly to the front should be improved. The vision window immediately to the operator's front, i.e., the opening over the steering wheel, was substantially decreased by installation of a vertical plate during the conventional operation, because coal was entering the canopy at that point and loading the compartment.

The problem of coal entering the canopy bottom at the conventional mine breaker did not occur in the continuous operation, because only the shuttle car was used in loading.

An Evaluation Data Sheet summarizing daily operator records for the period from January to February 1983 is in Appendix D.

3.3.6.2 Mine Management Comments

Mine management comments on the continuous mining operation evaluation were the same as those given during conventional operation evaluation. See Subsection 3.3.6.2.

4.0 SUBJECT INVENTIONS

By definition, "Subject Inventions" means any invention, discovery, improvement, or development (whether or not patentable) made in the performance of the experimental, developmental, or research work under this contract.

No subject invention claims are being made by ESD.

Appendix A Evaluation Data Sheets

Evaluation Data - 6L Shuttle Car with Floating Cab

20' Entry Mine #4 - Continuous Operation

Section #265

Date	Car Operator	Shift	Car Trips	Car Tons/ Shift	Seam Height	Clearance Height	Shift Tons	Car Hours Used
1-24-83	D.C.	1	30	180	48	47	400	6
1-25-83	D.C.	1	40	240	48	47	600	6
1-26-83	D.C.	1	45	270	48	47	600	6
1-27-83	D.C.	1	50	300	48	47	660	6
1-28-83	D.C.	1	50	300	48	47	660	6
1-31-83	M.H.	1	30	180	48	47	350	4
2-01-83			NO HAULAGE					
2-02-83	D.C.	1	52	312	48	47	660	7
2-03-83	D.C.	1	46	276	48	47	660	7
2-04-83	D.C.	1	25	150	48	47	500	4
2-07-83	D.C.	1	20	180	48	47	400	3
2-08-83	D.C.	1	55	330	48	47	660	7
2-09-83	D.C.	1	50	300	48	47	660	7

Evaluation Data - 6L Shuttle Car with Floating Cab

20' Entry Mine #5

Date	Car Operator	Shift	Car Trips	Car Tons/ Shift	Seam Height	Clearance Height	Shift Tons
8-31-82	#1	2	32	192	52	47	N.R.*
9-01-82	1	2	6	36	52	47	36
9-03-82	1	2	45	270	52	47	N.R.
9-04-82	1	2	6	36	52	47	560
9-07-82	1	2	52	312	52	47	320
9-08-82	1	2	57	342	52	47	500
9-09-82	2	2	39	240	52	47	600
9-09-82	1	2	32	192	52	47	500
9-10-82	1	2	20	120	52	47	540
9-13-82	1	2	43	258	52	47	504
9-14-82	1	2	36	225	52	47	400
9-15/16/17		Not In Use (Roof Bolting)					
9-20-82	1	2	50	300	52	47	300
9-21-82	3	2	40	240	52	47	400
9-22-82	1		51	306			
9-23-82	4	1	38	228	52	47	546
9-23-82	1	2	47	282	52	47	546
9-24-82	1	2	43	258	52	47	N.R.
9-27-82	1	2	57	342	52	47	500

N.R. = Not Recorded

Evaluation Data - 6L Shuttle Car with Floating Cab

20' Entry Mine #5 - Conventional Operator

Date	Car Operator	Shift	Car Trips	Car Tons/ Shift	Seam Height	Clearance Height	Shift Tons	Car Hours Used
09-28-82	M.L.	2	52	312	52	47	(N.R.)*	6
09-28-82	W.A.	1	56	336	52	47	560	6.5
09-29-82	M.L.	2	40	240	52	47	400	4
09-29-82	W.A.	1	60	360	52	47	720	6.5
09-30-82	M.L.	2	51	306	52	47	712	7.25
09-30-82	-	1	-	-	52	47		
10-01-82	M.L.	2	55	33	52	47	660	7.25
10-02-82	W.A.	1	30	180	52	47	360	5
10-02-82	M.L.	2	51	306	52	47	612	N.R.
10-03-82 thru 10-11-82			(N.R.)		52	47		
10-12-82	W.A.	1	24	144	52	47	288	N.R.
10-14-82	W.A.	1	49	294	52	47	588	7.25
10-14-82	M.L.	2	43	258	52	47	516	7
10-19-82	W.A.	1	50	300	52	47	400	6
10-19-82	M.L.	2	45	270	52	47	450	N.R.
10-21-82	M.L.	2	62	372	52	47	744	6
10-21-82	W.A.	1	45	270	52	47	540	7
10-22-82	M.L.	2	53	318	52	47	530	N.R.
10-27-82	W.A.	1	40	240	52	47	480	7
10-27-82	M.L.	2	52	312	52	47	520	N.R.
11-02-82	W.A.	1	50	300	52	47	N.R.	7
11-03-82	W.A.	1	48	288	52	47	480	N.R.
11-03-82	M.L.	2	24	144	52	47	260	N.R.
11-04-82	W.A.	1	70	420	52	47	N.R.	6
11-04-82	M.L.	2	48	278	52	47	N.R.	N.R.
11-05-82	W.A.	1	45	270	52	47	N.R.	7
11-15-82	M.L.	2	75	375	52	47	N.R.	6.5
11-16-82	W.A.	1	56	280	52	47	280	7
11-16-82	M.L.	1	48	288	52	47	288	6
11-17-82	W.A.	1	44	265	52	47	265	7
		30 Shifts						

(N.R.) Not Recorded

Appendix B Loader and Shuttle Car Certifications

FMC Corporation

Engineered Systems Division
328 Brokaw Road Box 450
Santa Clara California 95052
(408) 289 0111

FMC

September 23, 1980

U. S. Department of Interior
Bureau of Mines
Cocherans Mill Road
P.O. Box 18070
Pittsburgh, PA 15234

Attention: John Bogus

Subject: USBM Contract H0387026
Low Coal Cabs

Dear John:

With this letter I hereby certify that the shuttle car cab part number 5150715 designed and fabricated on subject contract has been load tested and satisfactorily meets the requirements of Title 30 Part 75.1710-1(d). A copy of the test report is a part of subject engineering job file.

Sincerely,

Jack R Mantel

Jack R. Mantel
California Reg #M013134
Mechanical Engineer, P.E.

cmm