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Cabs and Canopies for Underground Coal Mining Equipment

Proceedings: Bureau of Mines Technology Transfer Symposium, Charleston, WV, June 22, 1983

Compiled by William W. Aljoe

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8996

(United States Bureau of Mines)

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UNITED STATES DEPARTMENT OF THE INTERIOR
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CONTENTS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

deg	degree	in	inch
ft	foot	min	minute
ft/min	foot per minute	pct	percent
h	hour	s	second

CABS AND CANOPIES FOR UNDERGROUND COAL MINING EQUIPMENT

Proceedings: Bureau of Mines Technology Transfer Symposium, Charleston, WV, June 22, 1983

Compiled by William W. Aljoe [1]

ABSTRACT

This publication contains eight papers presented at a Bureau of Mines Technology Transfer Symposium in Charleston, WV, on June 22, 1983. Five of the papers describe the results of Bureau-sponsored research on cabs and canopies for low-coal underground mining equipment. The other papers describe the efforts of three underground coal mining equipment manufacturers (FMC, Joy, and Lee-Norse) in the area of cab and canopy design.

[1] Mining engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

CABS AND CANOPIES FOR LOW-COAL UNDERGROUND MINING EQUIPMENT

By William W. Aljoe[1]

ABSTRACT

This paper reviews the history of Federal cab and canopy regulations, the problems inherent to the use of canopies in low coal, and various technical aspects of cab and canopy design. Each type of underground face equipment covered by canopy regulations is examined in terms of the cab and canopy designs presently available. Innovative design features facilitating machine operation in low coal are emphasized.

HISTORY OF LOW-COAL CANOPY REGULATIONS AND PROBLEMS

Between 1966 and 1978, 819 fatalities occurred because of roof falls[2] in underground mines. Over 500 of these involved operators or helpers on the nine major types of self-propelled electric face equipment--continuous miners, shuttle cars, scoops, tractors, ramcars, roof bolters, cutters, face drills, and loading machines. This fatality record indicated that overhead protection for operators of face equipment would be extremely helpful. Prior to 1972, however, very few machines were equipped with overhead operator protection, and these machines were used almost exclusively in coal seams higher than 72 in.

Recognition of the potential benefits of overhead protection brought about the enactment of Federal canopy regulations (30 CFR 75-710-1) in 1972. These regulations specified the deadline dates by which cabs and/or canopies would be required on the nine types of face equipment mentioned above. The requirements applied immediately to machines used in coal seams higher than 72 in; a delayed enforcement schedule was adopted for machines used in lower coal seams. The purpose of this delayed enforcement schedule was to allow time for development of cab and canopy technology for low-coal machines.

The beneficial effects of the cab and canopy regulations were immediately apparent, as canopy "saves" (occasions when the presence of the canopy saved a worker from death or injury) began to occur soon after the regulations were enacted. In the past 10 years, almost 200 canopy "saves" have been reported to the Mine Safety and Health Administration (MSHA). The actual number of "saves," however, has probably been much greater than this due to underreporting. For example, mines may have hesitated to report minor roof falls that were deflected by canopies but did not result in significant injury, property damage, or downtime. On the other hand, some roof falls were so massive that they covered entire machines and required extensive cleanup and rescue efforts to free operators who had been saved by canopies. Witnesses to canopy saves of this type were usually the strongest proponents of Federal canopy regulations.

Unfortunately, the presence of cabs and canopies can also cause three serious problems--"roofing," restricted vision, and insufficient space within the operator's compartment. "Roofing" (a collision between the canopy and an overhead obstruction) introduces three potential

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hazards: (1) roof supports (bolts, posts, crossbars, etc.) could be damaged, weakening the roof stability of the entry; (2) ventilation tubing or electric trailing cables hanging from the roof could be broken or dislodged, creating a fire or explosion hazard; and (3) the canopy itself could be knocked off its supports and onto the operator. The obvious solution to roofing would be to lower the canopy, but this usually results in the other two problems, restricted operator vision and insufficient working space. When these two problems occur, machine operators tend to lean beyond the confines of their compartments, exposing themselves to collisions with ribs, roof, and other obstacles in the mining section.

Cab and canopy problems were especially prevalent in low-coal mines for obvious reasons; as stated above, this fact was acknowledged in the delayed enforcement provisions of the 1972 canopy regulations. However, the length of time allowed for development of low-coal canopy technology proved to be insufficient, and the deadline dates for compliance were postponed three times (in 1973, 1976, and 1977). The 1977 revision stated that canopies would not be required on machines operating in mining heights (mine floor to unfinished roof) lower than 42 in, and this exemption for very low coal mines still exists today.

Mine operators, however, continue to experience numerous canopy problems in coal seams greater than 42 in in height; in fact, these problems still occur in seams as high as 60 in. The main reason for this is that the machines being used in 42- to 60-in coal seams were not designed to allow for the everyday use of canopies. Operators' compartments on many existing machines are neither long enough nor wide enough to allow a comfortable seating position with a low canopy height. Furthermore, machine controls are often arranged such that the operator must sit upright or lean forward to reach them. Unfortunately, anthropometric measurements show that the operator must assume at least a semireclining posture to remain seated beneath a canopy that is low enough to prevent roofing. Because of the prevalence of low-coal canopy problems, it became obvious that innovative designs for low-coal machines, cabs, and canopies were needed.

INNOVATIVE CAB AND CANOPY DESIGNS FOR LOW COAL

During the past 5 years, numerous attempts have been made to develop cab and canopy designs suitable for low-coal mining equipment. Many of these designs were originated by the equipment manufacturers; however, coal company personnel also played an important role in the design process. The remainder of this paper discusses the innovative cabs and canopies developed by the mining industry to help alleviate the canopy problems inherent to low-coal mines.

CONTINUOUS MINERS

Continuous miners have historically been involved with more roof fall fatalities than any other machine type (except roof bolters, which will be discussed later). Since equipment designers also recognized this problem, more design effort has been placed on cabs and canopies for continuous miners than for most other machine types. The need for overhead protection on continuous miners was obviously recognized by mine operating personnel; in many cases, problems with canopies were tolerated by continuous miner operators more readily than by operators of other machines. Consequently, continuous miners are the machines on which cabs and canopies have been most successful.

Figure 1 shows a cab and canopy on a continuous miner designed specifically for low coal seams. The cab and canopy have several innovative low-coal design features:

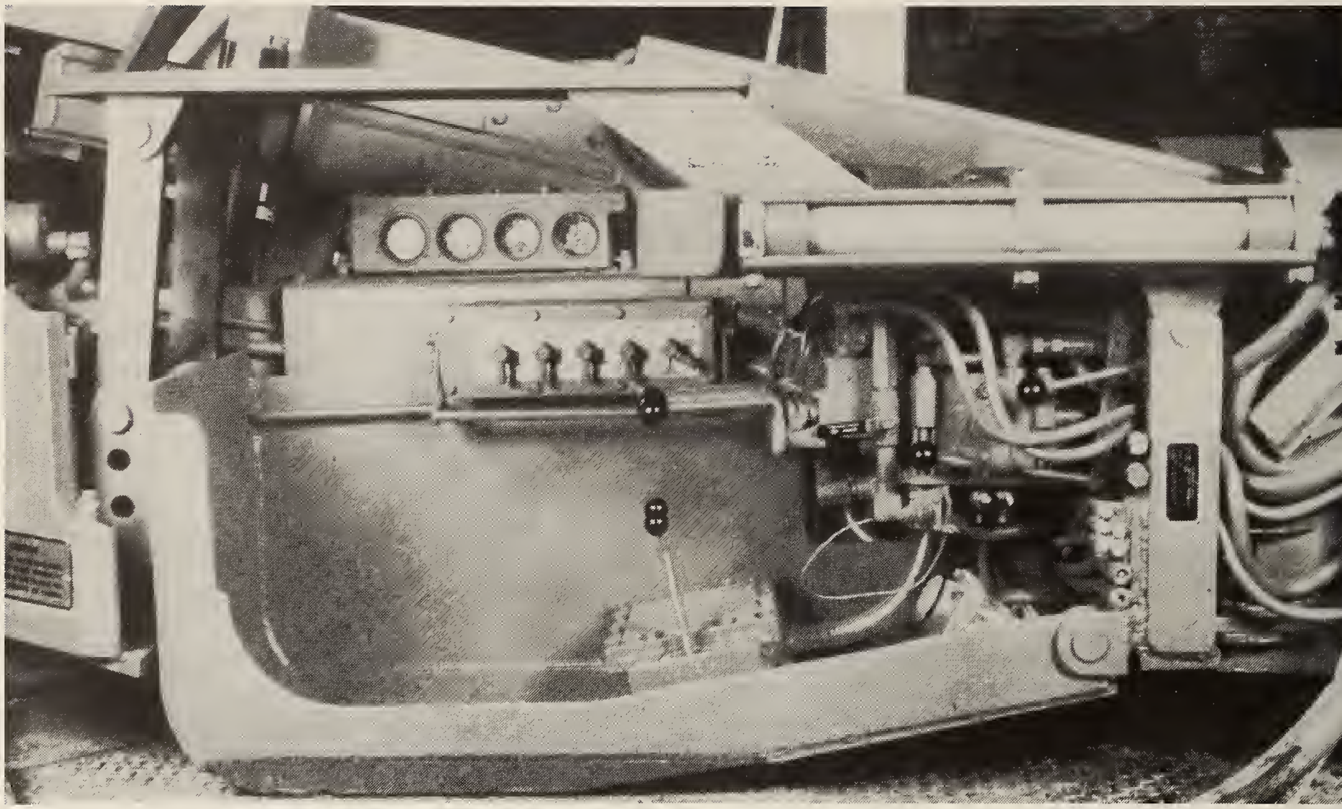

FIGURE 1. - Split-type floating canopy on continuous miner.

1. The operator's deck is hinged to the miner frame and "floats" or "slides" along the mine floor during normal operation. This design feature has been utilized on almost all recently developed low-profile continuous miners. The greatest advantage of a "floating" deck versus a "fixed" deck is that no ground clearance is needed; this allows the canopy top to be lowered by about 6 to 8 in without sacrificing operator headroom. Another advantage of the "floating" deck is that it can drop below the crawler level of the miner when tramming over an undulation, thus decreasing the likelihood of canopy roofing.

2. The canopy top is split into two sections; the upper plate covers the operator's head and torso, while the lower plate protects the operator's legs and the machine controls. The major advantage of this split-type canopy design is that the operator can look through the space between the plates to see in the forward direction.

3. The controls on this machine were designed to allow the operator to recline, thus allowing the canopy to be placed lower than if the operator were forced to sit upright. The tram controls are located in the center of the operator's deck; since the operator straddles them when seated in the deck, they are close at hand at all times. The handles of the other machine controls extend rearward, also placing them within easy reach of the reclining operator.

Figure 2 shows the same basic cab and canopy design as figure 1; however, the canopy in figure 2 was modified slightly to compensate for the effect of the light mounted on its outside edge. Although this light was needed to achieve compliance with mine illumination regulations, it created a problem because the operator was forced to lean outward, far beyond the confines of his compartment, to see down the side of the machine. Since this would have exposed the operator's head to collisions with the roof, rib, or other

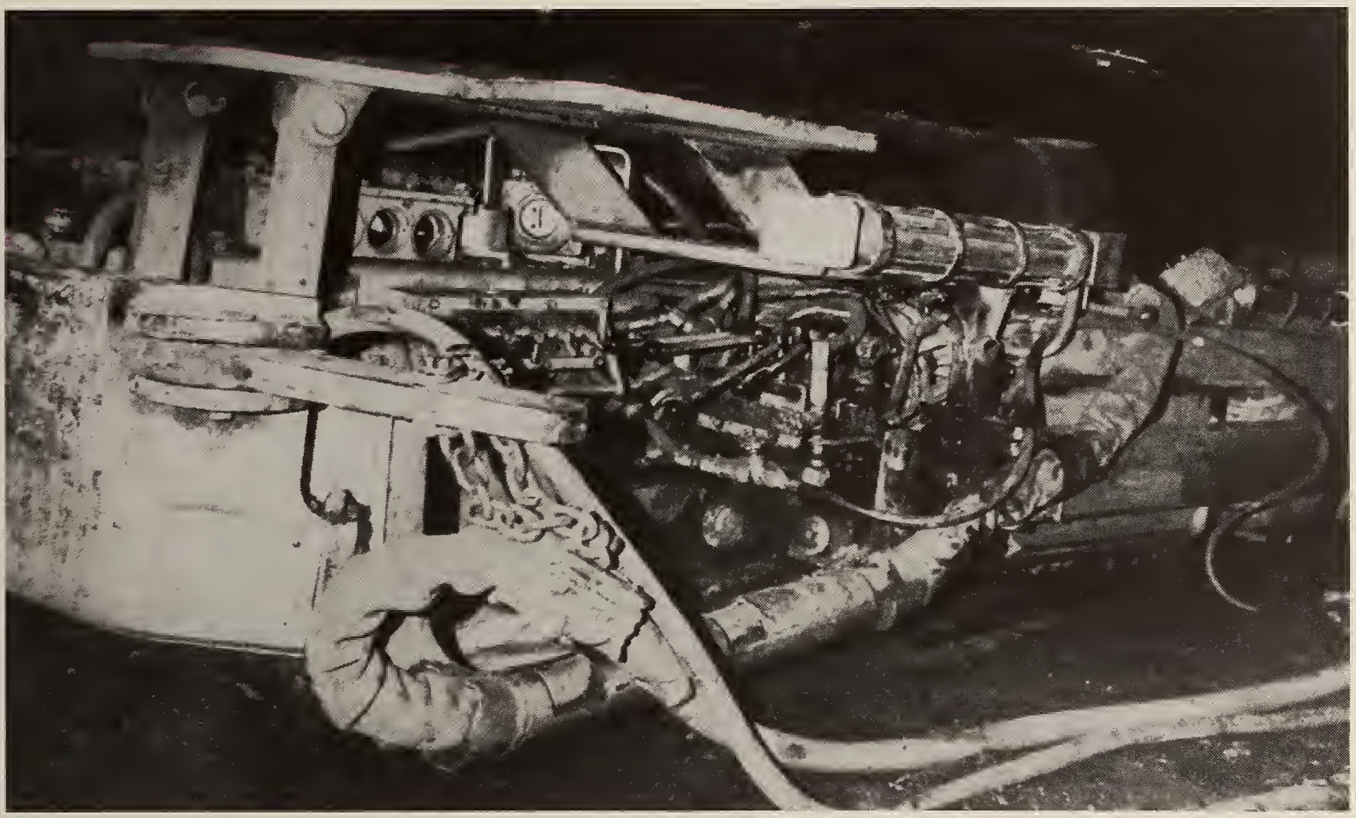

FIGURE 2. - Extension welded to outer edge of continuous miner canopy.

obstructions, the mine mechanics welded an extension plate on the outboard side of the canopy top. This extension made the canopy the widest point on the machine, causing it to strike the roof or rib before the operator's head did.

Figure 3 shows a cab and canopy as designed and installed by coal company maintenance personnel when the miner was rebuilt in the company's central shop. Like the cabs and canopies in figures 1 and 2, the operator's deck was designed to "float" on the mine floor. However, this floating deck had another advantage--it was hydraulically adjustable. A hydraulic jack connected the rear ("floating") end of the deck to the rear bumper of the miner, allowing the operator to selectively raise or lower the deck. The deck is in the raised position in figure 3 because the mine floor in this area was particularly wet and muddy. Another unique feature of this operator compartment was that the controls were adjustable; that is, the control handles and valve banks were mounted on a pan that could be moved backward and forward to accommodate the reach of both small and large operators. The pan could also be rotated upward to permit the operator to enter and leave the cab. The seat back was adjustable also; in figure 3, the seat back is in the upright position, but it could easily be tilted and locked into a reclining position if the operator needed more headroom. Finally, the canopy top itself was hydraulically adjustable, allowing the operator to either (1) raise it to allow more headroom and vision or (2) lower it to prevent roofing. The hydraulic adjustment capabilities of the deck and canopy would be especially helpful in areas where the vertical clearance changed abruptly because the canopy would not always have to be fixed at its lowest setting.

SHUTTLE CARS

Some of the cab and canopy design features used on continuous miners have also been tried on shuttle cars; however, the design problems with shuttle cars have

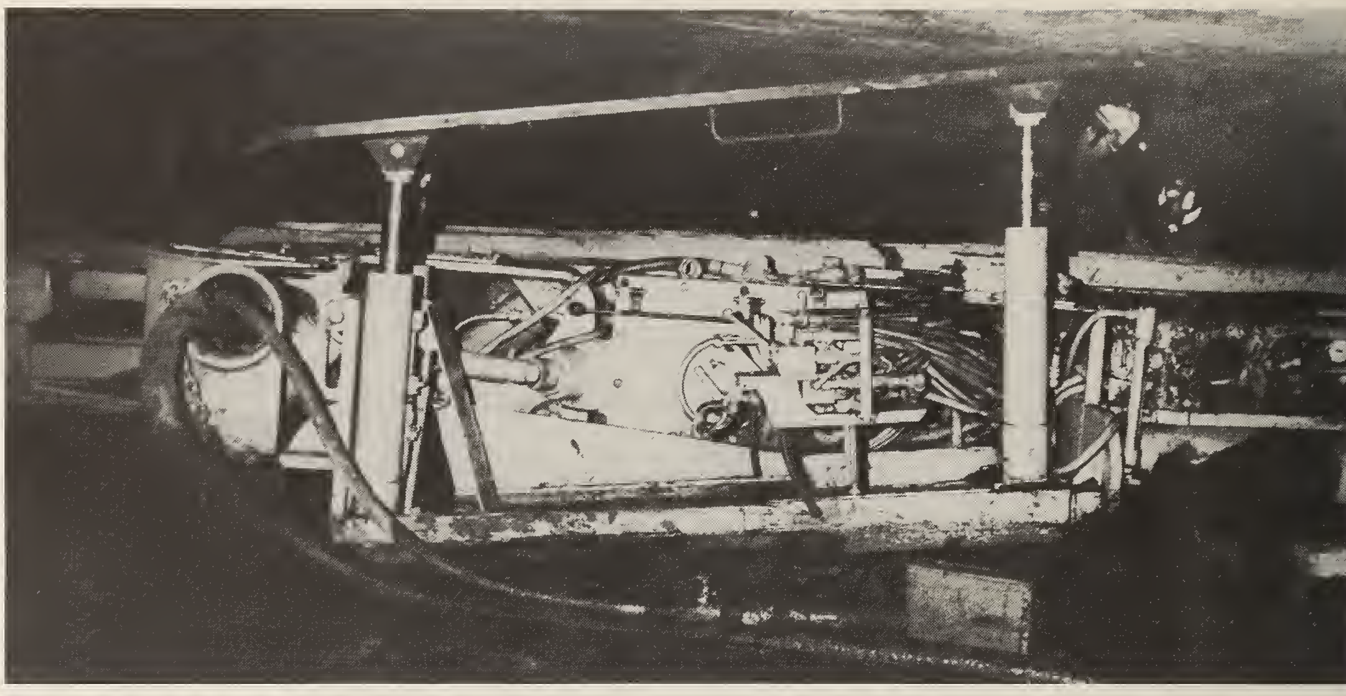

FIGURE 3. - Hydraulically adjustable continuous miner cab and canopy with adjustable controls.

been harder to solve because shuttle cars must travel faster, farther, and oftener than continuous miners. Despite these problems, innovative shuttle car design features developed in recent years have allowed the use of canopies in lower coal seams than ever before. For example, canopy roofing occurs less frequently if the operator's compartment is mounted between the tires of the shuttle car rather than at the rear end; consequently, almost all shuttle cars intended for low-coal use now have center-mounted operators' compartments. Shuttle car seats have also been improved to provide easier machine operation from a reclining position, a necessity if canopies are to be successful in low coal.

Figure 4 shows a low-profile, center-driven shuttle car with a "floating" operator's compartment. The major difference between the "floating" compartment in figure 4 and the continuous miner compartments in figures 1-3 is the means by which it is attached to the machine. Instead of being hinged to the machine frame, the shuttle car operator's deck is connected to the side of the machine through vertical T-shaped guide bars. When tramming over rough mine floors, the shuttle car compartment moves straight up and down rather than in an arc. Again the advantage of the "floating" deck is that the canopy can be lowered without sacrificing operator headroom.

Unfortunately, when mine floors are very wet, rough, or muddy, floating operator compartments experience more problems than compartments with fixed ground clearances. For example, water and mud can enter a floating compartment more easily than when the deck is raised above the mine floor. More importantly, a floating deck is more likely to become "hung up" in a rough or muddy mine floor, reducing the machine's ability to tram. Not surprisingly, these problems are worse for shuttle cars than for continuous miners; however, in fair to good bottom conditions, floating operator compartments have been quite successful on both machine types.

Figure 5 illustrates another problem that occurs when canopies are used on shuttle cars in low coal, regardless of whether the deck floats or is fixed. The presence of sideboards often eliminates

FIGURE 4. - Floating operator's deck on center-driven shuttle car.

FIGURE 5. - Operator leaning out of shuttle car cab for better vision.

operator vision to the opposite side of the entry, and the operator's natural reaction is to lean outward and upward to look over the sideboards. As shown in figure 5, the presence of a canopy makes this process more difficult and dangerous. Since vision to the opposite side of the entry is almost always negligible on low-coal shuttle cars, the machine and compartment should be designed such that the operator can easily see down the side of the machine without leaning out beyond the canopy.

A novel concept for improving operator vision on shuttle cars is shown in figure 6; this experimental operator compartment was built and tested under a Bureau of

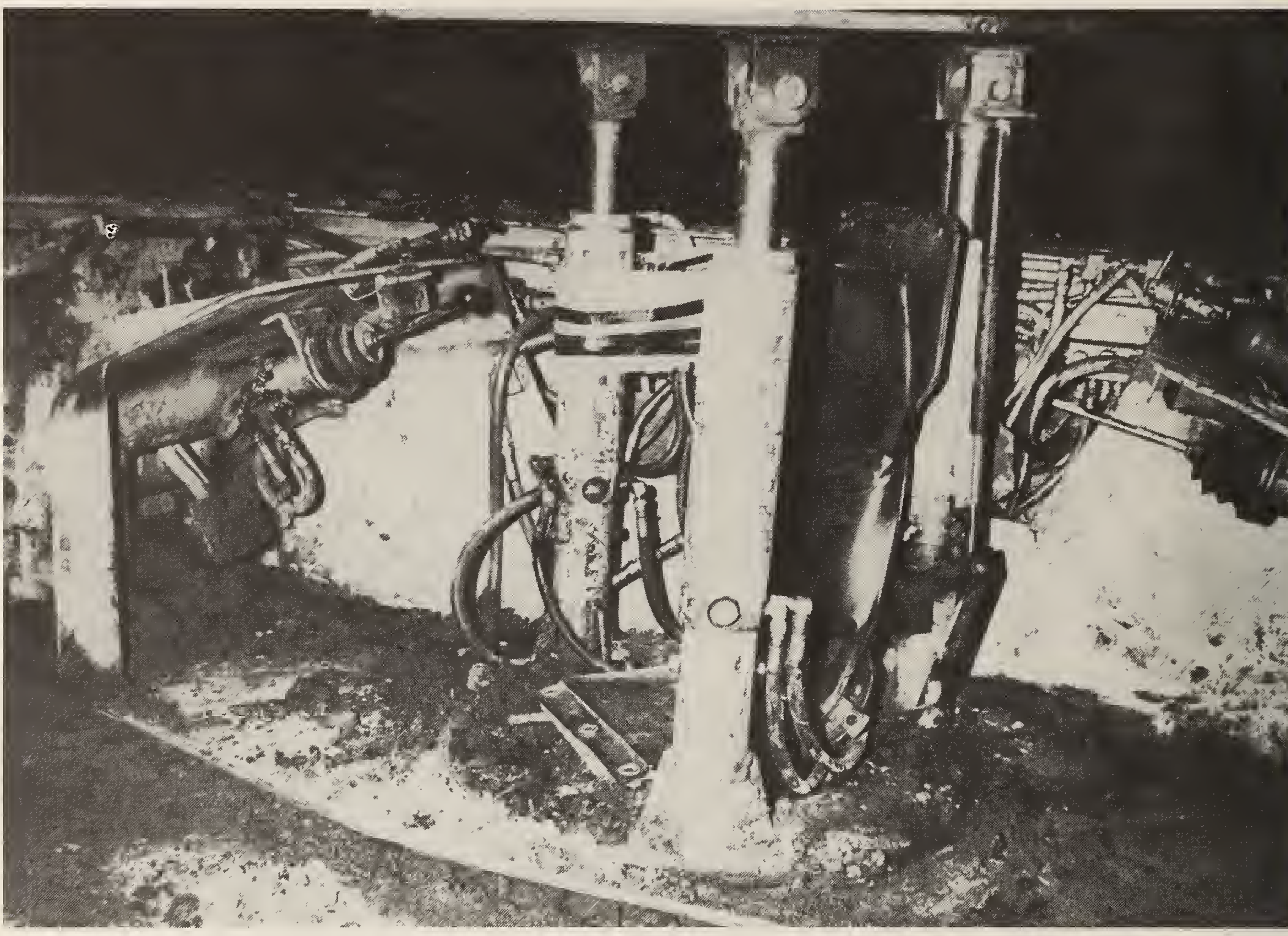

FIGURE 6. - Canopy mounted on turntable in center of shuttle car operator's compartment.

Mines contract.[3] The major difference between the compartment in figure 6 and other center-mounted shuttle car compartments is that the operator does not change seats when changing tram directions. Instead, the seat is located on a turntable in the center of the compartment, and the operator manually rotates the turntable to face forward or backward. The improvement in vision results from the use of a split-type canopy design similar to those in figures 1 and 2. In the compartment shown in figure 6, however, the center portion of the canopy is fixed to the turntable and remains above the operator's head and torso as the seat rotates. The two lower plates are cantilevered from the ends of the cab deck to protect the operator's legs and the machine controls.

[3]Kopas, P. Design and Development of Protective Canopies for Underground Low Coal 48" and Under (contract H0188014, Kogen Industries, Inc.). BuMines OFR 17-81, 1980, 89 pp.; NTIS PB 81-167533.

Figure 7 shows how this canopy design improved operator vision; the photographer was seated in the compartment in figure 6 with the canopy in its lowest position. Although vision alongside the machine is not available, it is obvious that the canopy itself does not inhibit vision at all. Furthermore, sideboards were not present on this shuttle car, which greatly improved vision to the opposite side of the entry. The need for the operator to lean dangerously outward was greatly reduced.

Several innovative cab and canopy design concepts have been used successfully on end-driven shuttle cars. For example, floating operators' decks have been successful on end-mounted operator compartments when good bottom conditions were present. However, the most promising cab and canopy concept for end-driven shuttle cars may be the "transverse" or "side-saddle" concept shown in figure 8. It has been accepted and praised by shuttle car operators as a great improvement in

FIGURE 7. - Improved vision with split-type canopy on shuttle car.

FIGURE 8. - Side-saddle tram compartment on end-driven shuttle car.

both comfort and vision. In transverse compartments, the operator faces the shuttle car conveyor at all times and merely rotates his or her head to see in the forward or reverse directions; no seat changing is required. The transverse seat configuration makes it possible for the operator to see alongside the shuttle car without leaning beyond the protection of the compartment. Extra leg room is provided by building a tunnel beneath the conveyor discharge boom and placing the tram and brake pedals at the back of the tunnel. More seating width can also be provided with the transverse compartment layout.

SCOOPS, TRACTORS, AND RAMCARS

Scoops and tractors are widely used for both coal haulage and cleanup work in low coal because they are smaller, more versatile, and less expensive than shuttle cars or continuous haulage equipment. (Ramcars are somewhat similar to scoops in design but are used primarily for coal haulage.) Although scoop and tractor operators are only occasionally involved in roof falls, improvements in cab and canopy design are needed for these machines because of the large number of injuries resulting from collisions with the mine roof and ribs. Most models of scoops and tractors have transverse operator compartments that allow easier vision along the side of the machine, but the compartments are often too small to protect the operator from collisions when she or he reclines. The problem is complicated by the presence of relatively simple post-and-plate canopies that severely restrict operator vision. These poorly designed canopies increase the potential hazard because they introduce another object against which the operator can be crushed.

Figure 9 shows a properly designed cab and canopy on a scoop; note that the cab deck extends far beyond the side of the scoop, providing both protection and unrestricted vision along its side. Note also that the canopy does not interfere with operator vision when the compartment

FIGURE 9. - Operator's deck on scoop extended beyond side of machine.

is extended in this manner. This extended type of compartment is even more critical in coal seams lower than 42 in, where canopies are not required, because it eliminates the need for the operator to sit upright, thereby reducing the danger of collisions with the roof.

Operator ingress and egress is another common problem on existing scoops and tractors. Although the machine design itself contributes to this problem, the presence of a canopy often makes it worse. Figure 10 shows a scoop canopy designed to facilitate ingress and egress; it is mounted on rollers and contained within guide rails on the sidewalls of the operator's compartment. Before entering the cab, the operator slides the canopy across the machine, creating more room for entry. Once seated, the operator pulls the canopy back into position and locks it in place.

The operators' compartments on the scoops in figures 9 and 10 were located at the centers of the machines; figure 11 shows an end-driven scoop with an improved cab and canopy design. (Operators' compartments on most tractors are also located at the ends of the machines). The canopy top on this scoop is hydraulically adjustable, and the hydraulic cylinders have been placed to minimize interference with operator vision. The back of the seat can be adjusted to allow the operator to recline comfortably, as in figure 11, or be raised to permit sit-up operation when the mine has sufficient vertical clearance. This is the same basic seat design as on the continuous miner in figure 3; it was also designed by coal company shop personnel.

ROOF BOLTERS

Roof bolters are probably the hardest types of machines to describe in terms of cabs and canopies because of the wide variety of roof bolter designs in use today. The development of automated temporary roof support (ATRS) systems for roof bolters has made the subject of cabs and canopies even more complex. This paper involves only the tramming station of the roof bolter because this is the only location where a complete operator compartment is required. However, some

FIGURE 10. - Sliding canopy top on scoop for easier ingress and egress.

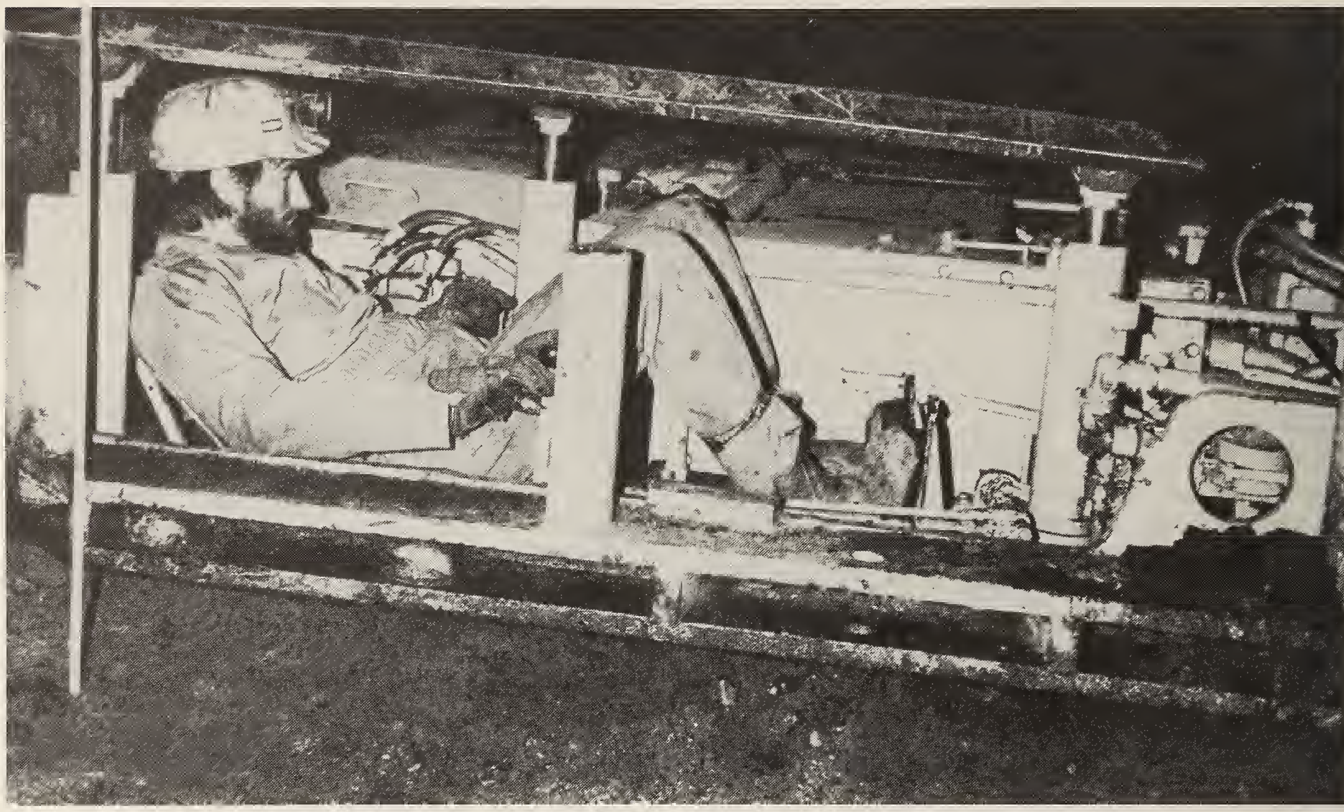

FIGURE 11. - Hydraulically adjustable canopy on end-driven scoop.

type of overhead protection must also be provided at the drilling station--either a canopy, an ATRS, or both.

Operator compartments on single-head roof bolters can be divided into two basic types: (1) drill-and-tram compartments and (2) tram-only compartments. Perhaps the most innovative cabs and canopies on existing single-head roof bolters are drill-and-tram compartments that were retrofitted to the machines (figs. 12-13). These compartments are somewhat similar to the continuous miner compartments in figures 1-3 because they are hinged to the machine frame at one end and "float" on the mine floor at the other. During drilling and bolting, the hydraulic jacks on these cabs and canopies are extended vertically as far as possible, thus wedging the compartment between the mine floor and roof. When tramming these bolters between holes or to and from the face areas, the operators can raise the tram decks above the floor to prevent them from hanging up in rough or muddy areas. On the compartment in figure 12, this is accomplished by attaching the deck mechanically to the drilling boom, then raising the boom. The hydraulic jacks on the compartment in figure 13 are double-acting, allowing the deck to be raised upward and suspended from the canopy during tramming. The canopy in figure 13 is also hinged to the machine frame.

Note also in figure 13 that an extra hydraulic jack is located on the opposite side of the drill head from the operator's compartment. This jack is connected to the inboard edge of the canopy through a cantilevered arm that extends across the drilling boom and behind the head. During drilling and bolting, the jack is emplaced against the roof to provide additional roof support; during tramming, the jack is retracted and suspended from the cantilevered arm.

Almost all dual-head roof bolters have tram compartments that are attached rigidly to the machine at a fixed distance above the mine floor. Figures 14 and 15 show two of the better low-coal tram compartments on existing dual-head roof bolters. The compartment in figure 14 is located between the tramming wheels on the right side of the machine and is large enough to allow the operator to assume a reclining position. However, the

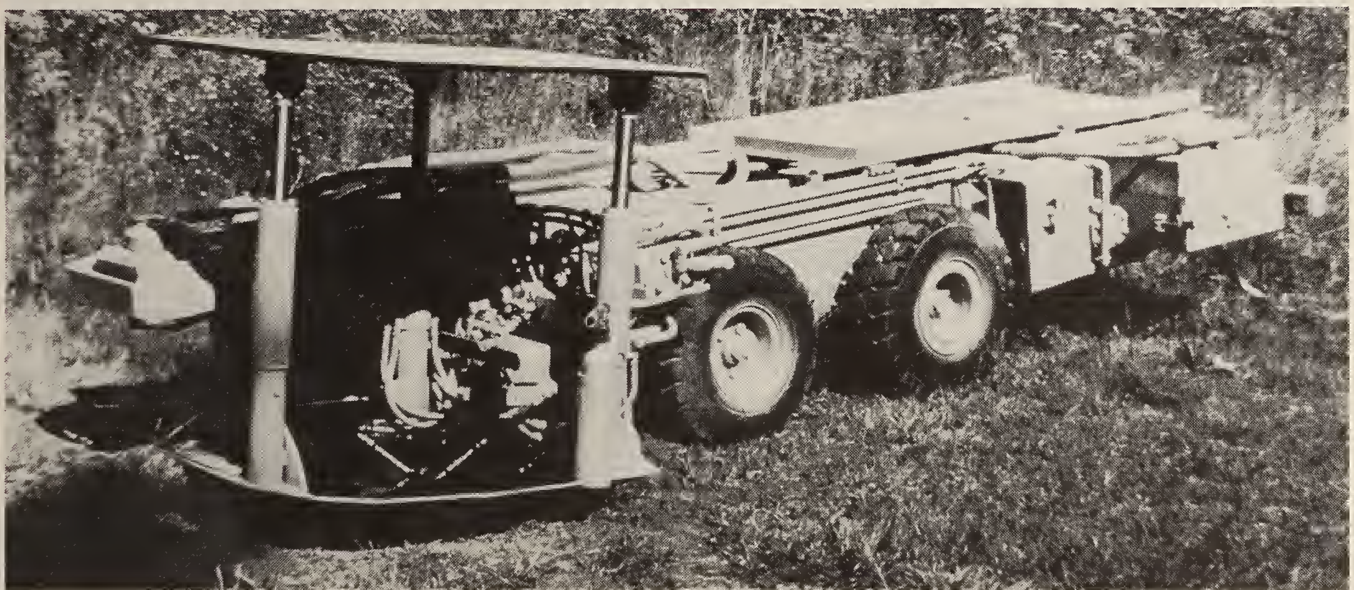

FIGURE 12. - Floating, hydraulically adjustable canopy on single-head roof bolter.

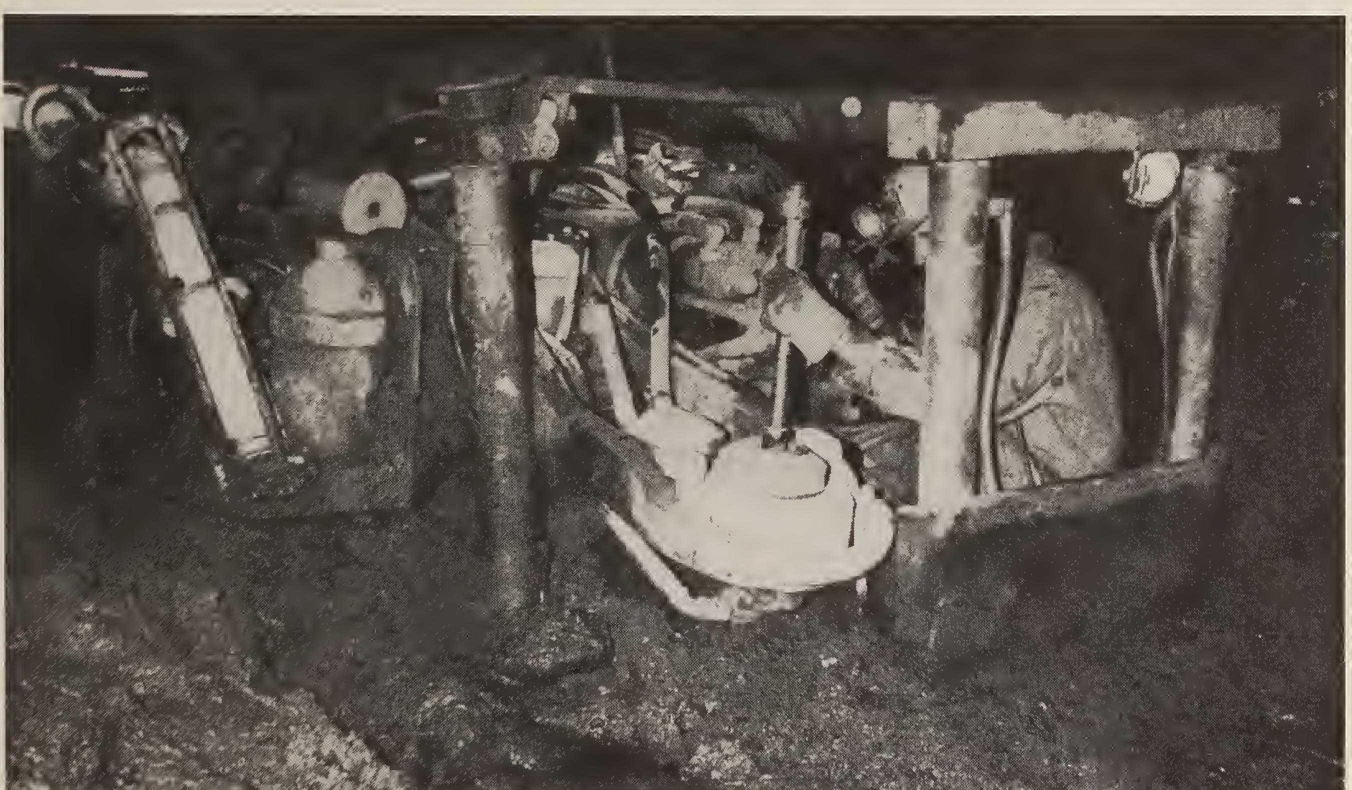

FIGURE 13. - Extra safety jack attached to floating, hydraulically adjustable canopy on single-head roof bolter.

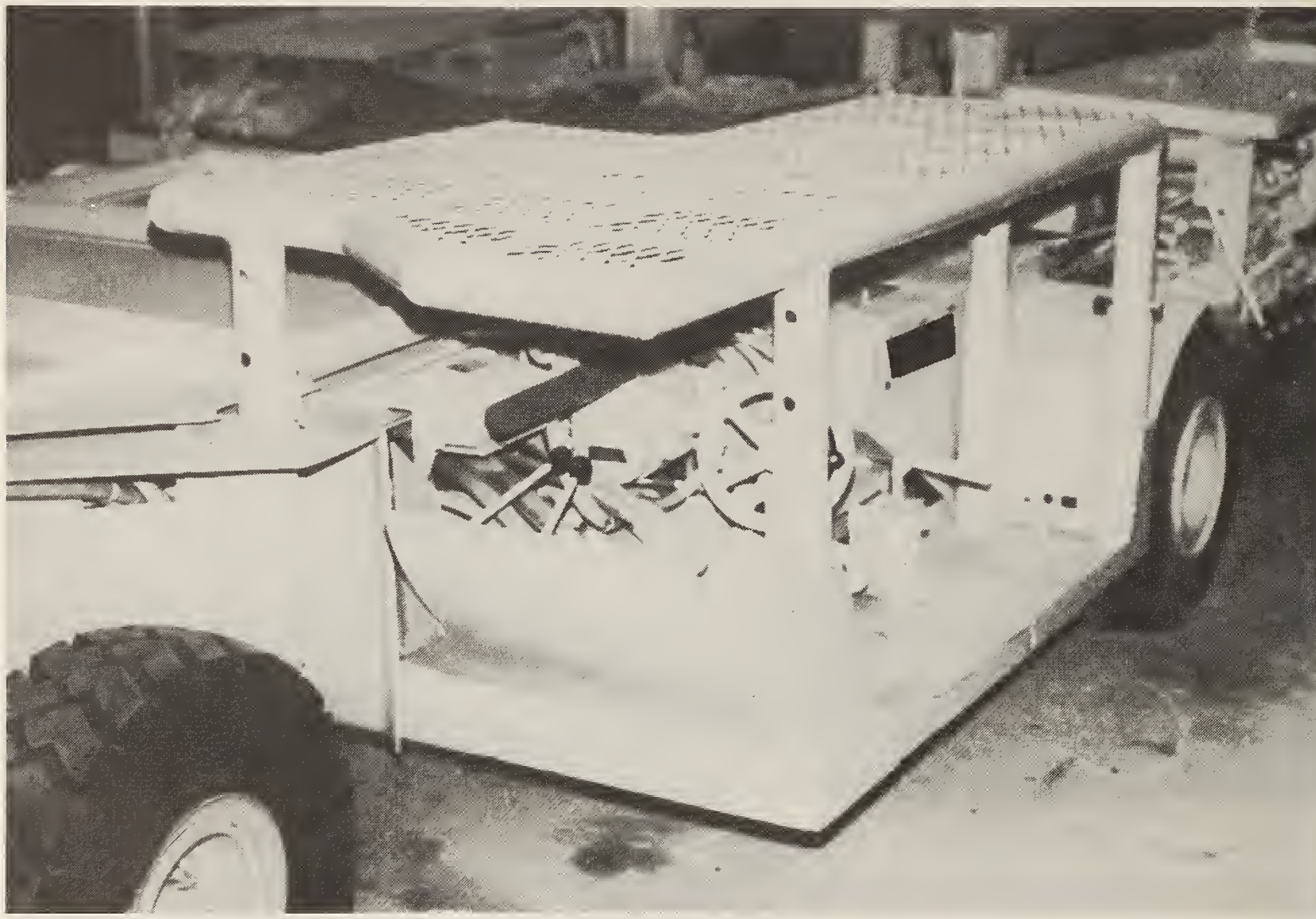

FIGURE 14. - Long tram deck on dual-head roof bolter permits reclining operation.

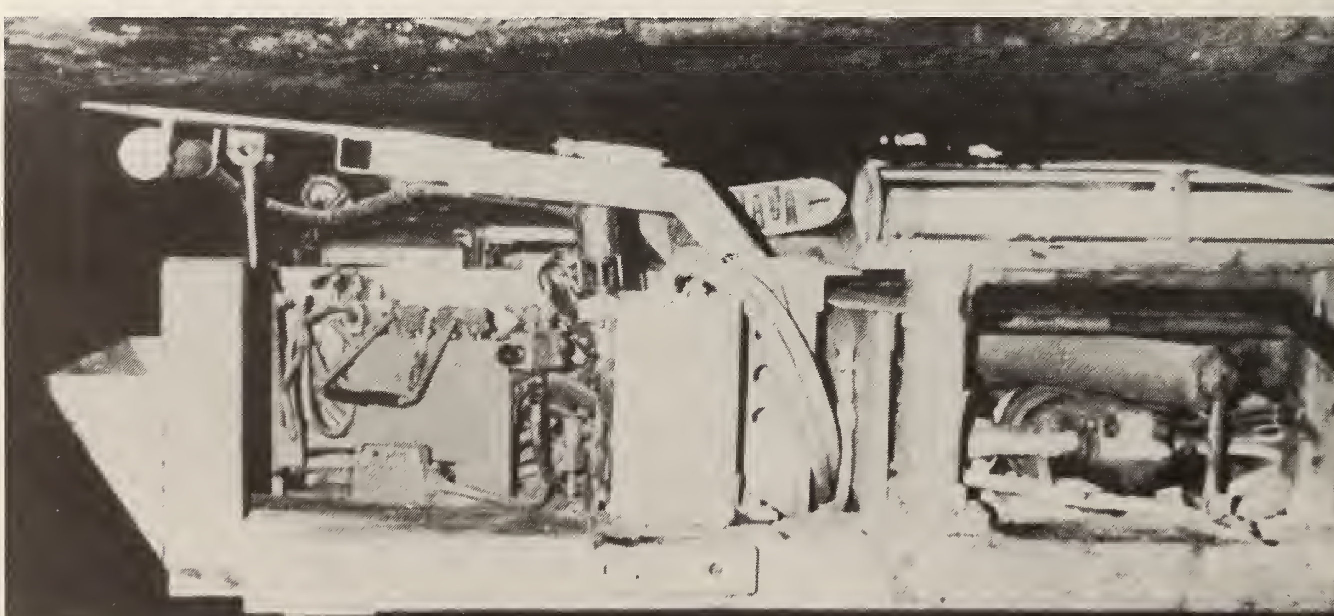

FIGURE 15. - Extended tram deck and hydraulically adjustable canopy on dual-head roof bolter.

operator often has to lean outward to see down the side of the machine and must turn around and look backward when tramming in reverse. The compartment in figure 15 is mounted transversely and is extended beyond the side of the machine to improve operator comfort and vision, and the canopy top is hydraulically adjustable. The major disadvantage of this tram compartment is that it is located on the rear corner of the machine, which causes the canopy to move farther upward in undulating conditions.

Figure 16 shows one of the few "floating" tram compartments on dual-head roof bolters. This is a rather unique roof bolter because it has two operators' compartments, both at the front of the machine. The compartment on the left side of the bolter (right side of figure 16) contains controls for both drilling and tramming; the other compartment contains only drilling controls. Unfortunately, this particular machine was designed for medium coal seam heights and does not contain a reclining seat to facilitate canopy use in low coal.

CONVENTIONAL MINING EQUIPMENT

In general, the operators' compartments on conventional face equipment--cutters, face drills, and loading machines--were not designed for low-coal canopy use. "Floating" compartments are virtually nonexistent, and present compartments are usually too short and narrow. Furthermore, substantial machine redesign would probably be needed to provide a suitable low-coal cab and canopy configuration. For this reason, fewer canopies are used on low-coal conventional equipment than on most other machine types.

Cutters and Face Drills

Figures 17 and 18 show the typical operator seating positions when canopies are used on cutters (fig. 17) and face drills (fig. 18) in low coal. Obviously, operator comfort and vision are less than adequate. In addition, the machine controls were designed to accommodate operators in an upright, seated position; therefore, proper machine operation would be difficult even if the compartments were long enough to allow the operators to recline. Although operator vision could be improved somewhat by installing the two-post, cantilevered canopy shown in figure 19, the basic designs of most cutters and face drills would have to be altered substantially to allow problem-free canopy use in low coal. Fortunately, cutters and face drills move rather slowly and are not often involved in roof falls, so the lack of canopy protection in low coal creates fewer hazards than the lack of canopies on other machine types.

FIGURE 16. - Dual operator stations at front of dual-head roof bolter.

FIGURE 17. - Operator cramped within tram compartment on cutting machine.

Loading Machines

Figure 20 shows an operator's position while he is seated beneath a canopy on a typical low-coal loader--his legs are crossed, his neck is bent, and his knees nearly touch his chin during "normal" operation. This situation is not surprising considering that the overall design of the operator's station on the loading machine has not changed substantially in over 20 years. In fact, many of the loaders in use today were originally designed for "walk along" operation, with cabs and canopies added after the machines were built.

Unlike cutters and face drills, loaders are relatively mobile machines and are frequently involved in roof falls; therefore, cab and canopy protection in low coal is much more critical. For this reason, loader operators are more tolerant of "inadequate" cabs and canopies than operators of cutters and face drills. Several coal companies have made improvements on existing loader compartments while rebuilding the machines (e.g., widening and/or lengthening the operators' decks). However, substantial machine redesign would be necessary to provide a truly workable low-coal cab and canopy.

The Bureau of Mines has sponsored one project to achieve an improved cab and canopy design for a loading machine.[4] This project is described in more detail on page 48. To install the operator's compartment developed under this program (fig. 21), significant modifications to the loader itself must be made. However, if this compartment is installed, it will represent a substantial improvement over existing loader compartment designs.

[4]Mantel, J. Extension of Cab and Canopy Technology to Low Coal Seams. Ongoing BuMines contract H0387026; for inf., contact J. R. Bartels, TPO, Pittsburgh Research Center, BuMines, Pittsburgh, PA.

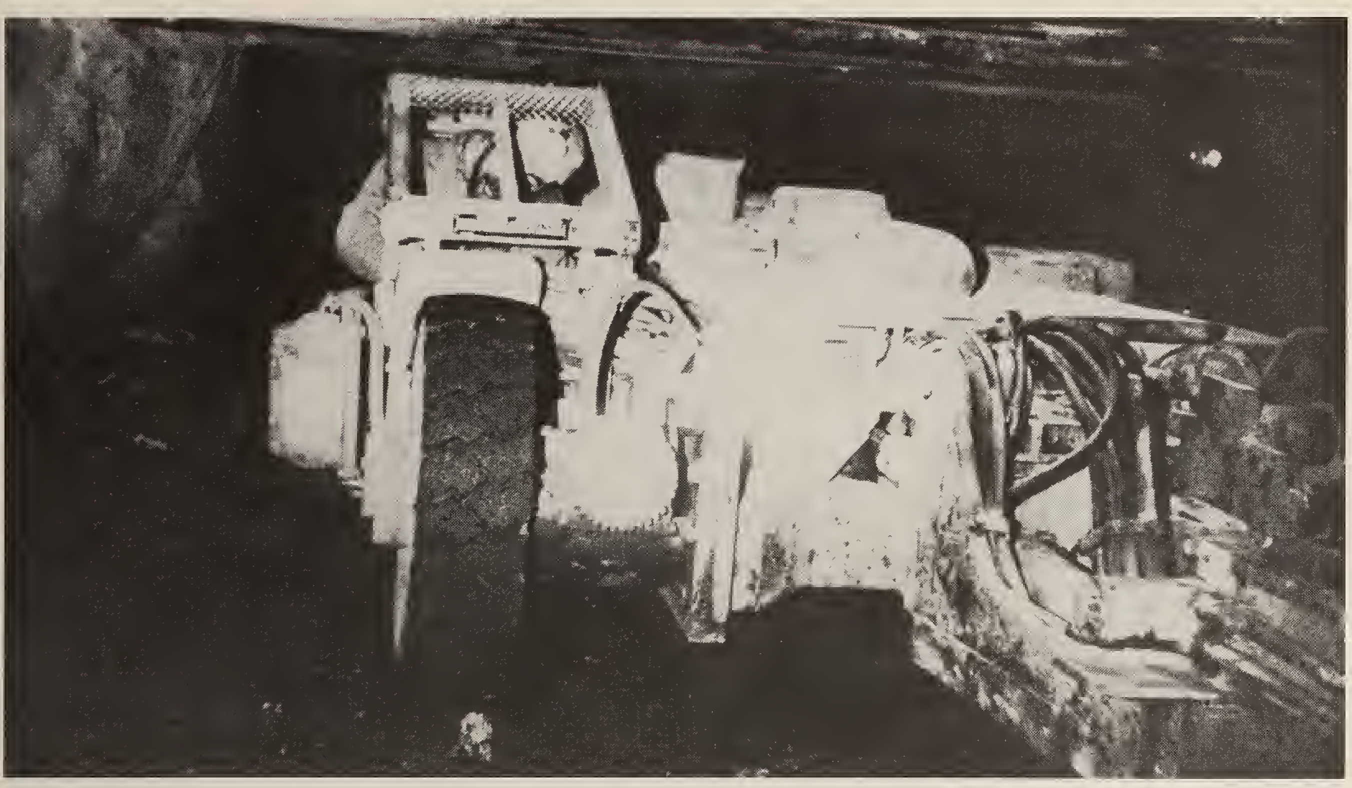

FIGURE 18. - Operator cramped within tram compartment on face drill.

FIGURE 19. - Mockup of two-post cantilevered canopy for cutter and face drill.

FIGURE 20. - Operator cramped within tram compartment of loading machine.

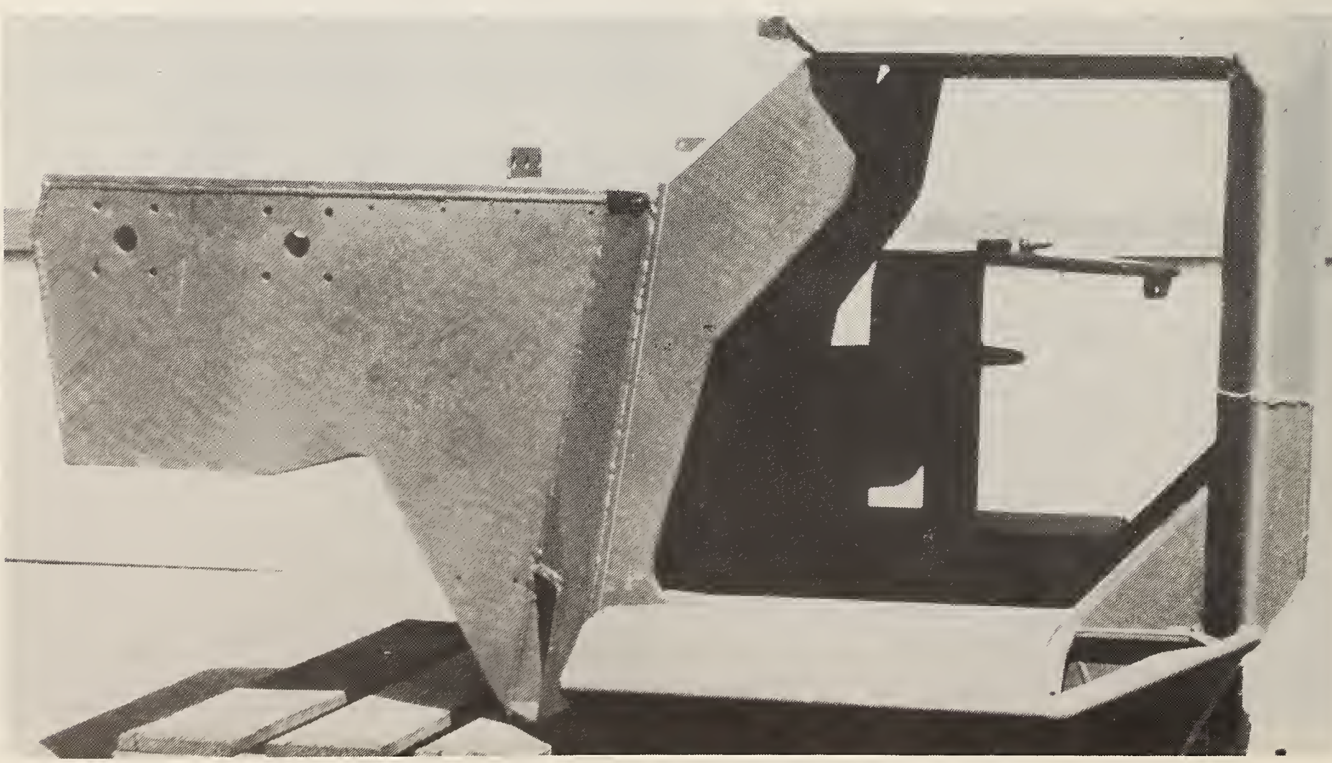

FIGURE 21. - Mockup of improved loader tram compartment.

SUMMARY AND CONCLUSION

Coal mining equipment manufacturers have undoubtedly made improvements in low-coal cab and canopy design during the past 5 years. The designs shown here represent a few of the better ideas incorporated into existing machines, but none is the ultimate answer to low-coal cab and canopy problems. Because of the inherent physical constraints of low-coal mines, machine operators will always experience comfort and/or vision problems; however, through equipment redesign and efficient use of existing cab and canopy technology, the severity of these problems can be reduced.

COST BENEFIT ANALYSIS FOR LOW-COAL CABS AND CANOPIES

By K. L. Whitehead[1]

INTRODUCTION

In general, the use of canopies over operators' compartments of underground coal mining equipment has proven to be beneficial as protection against both falling roof rock and the operator's head striking against projections from the roof line. However, experience has shown that in lower working heights, particularly 42 in and lower, existing canopy technology can be difficult to apply successfully. In these low-seam height conditions, there is frequently inadequate roof clearance to operate the machines and/or the operator compartments become too cramped and uncomfortable for personnel to function efficiently and safely. Because of these problems, MSHA has, by policy, suspended enforcement of the canopy regulations in seam heights of 42 in and lower. As a result, accidents potentially preventable by the use of overhead or lateral protection are still occurring.

The Bureau of Mines is, therefore, initiating action on a program to develop technology that will eliminate, or at least minimize, these machine-related accidents. However, the Bureau must decide whether or not to continue a development program for machine-mounted protective devices; establish a program to develop alternate technology such as remote control, robotics, etc.; or fund a program including aspects of both technologies. A final decision on the type of research program to establish must be based on several factors, one of which was the study conducted by Bituminous Coal Research (BCR) under the Bureau contract "Cost Benefit Analysis of Low Coal Cabs and Canopies" and summarized herein.

PROCEDURE USED IN COST-BENEFIT ANALYSIS

The general procedure used in the analysis was to compare the cost to the coal industry of fitting both old and new mining equipment with protective structures to the dollar value assigned to the injuries and fatalities that could have been prevented by the use of properly designed cabs and canopies. In performing this analysis, several assumptions and qualifying statements were used:

1. For those accidents considered "canopy preventable," the death or injury was assumed to have been prevented, not just reduced in degree of severity.

2. Even though adequate low-coal canopy technology is not available, it was assumed that canopies could be successfully installed on all equipment regardless of working height.

3. Philosophically, a dollar value cannot be placed on the death or injury of a worker. However, for purposes of analysis and comparison, a consistent method of assigning dollar values to accidents had to be used. For the purpose of this project, the Accident Cost Indicator Model (ACIM) developed by MSHA's Health Safety and Analysis Center (HSAC) in Denver, CO, was selected.

4. The only ACIM accident analyses available to BCR were for the years

[1]Supervising engineer, Bituminous Coal Research, Monroeville, PA.

1975-78. It was therefore assumed that the average cost calculated for canopy-preventable fatal and lost-time accidents during 1975-78 could be used to calculate a dollar value for preventable accidents occurring in the other years of the analysis period.

To carry out the analysis, two sets of data had to be developed--the cost to install overhead and lateral protective structures and the benefits realized from the use of these structures.

COSTS OF INSTALLING CABS AND CANOPIES

The installation costs were established by requesting equipment manufacturers and rebuild shops to supply estimates of the cost to install these structures on new and rebuilt machines. Cost figures for six different protective structures were requested to reflect equipment designs and accident causes. For example, a roof bolter would require both a tram canopy and a drill-station canopy to protect the operator from roof falls and would also require side protection to guard against injuries from rib rolls or collisions with other equipment. Table 1 summarizes average installation costs by type of machine and protective structure type. A comparison of these figures shows that retrofitting is generally more expensive than new installations, indicating that, if possible, the protective structures should be included when a new machine is ordered.

Calculation of installation costs to the entire industry obviously requires knowing the equipment population. Unfortunately, these statistics are not readily available, particularly for the period after 1978. Since the analysis was to cover 1971-80, an estimate of equipment population and its distribution with respect to seam heights had to be made.

TABLE 1. - Average estimated installation costs and number of cost estimates received for protective structures on new and rebuilt equipment

Equipment type	Type of protective structure						Number of estimates received
	Tram deck	Side protection	Tram canopy	Drill deck	Drill canopy	ATRS	
Continuous miners:							
New..................	$2,500	$585	$2,690	NAp	NAp	NAp	12
Retrofit.............	3,886	1,060	2,990	NAp	NAp	NAp	
Shuttle cars:							
New..................	3,100	435	1,568	NAp	NAp	NAp	9
Retrofit.............	6,471	765	1,897	NAp	NAp	NAp	
Tractors and/or scoops:							
New..................	15,000	278	1,538	NAp	NAp	NAp	7
Retrofit.............	19,625	278	1,961	NAp	NAp	NAp	
Roof bolters:							
New..................	640	302	2,520	$717	$4,794	$8,816	10
Retrofit.............	1,095	352	2,615	1,528	4,326	7,866	
Cutting machines:							
New..................	600	610	1,300	NAp	NAp	NAp	1
Retrofit.............	1,000	1,340	2,270	NAp	NAp	NAp	
Face drills:							
New..................	486	283	945	NAp	NAp	NAp	2
Retrofit.............	486	453	1,378	NAp	NAp	NAp	
Loading machines:							
New..................	1,000	455	1,500	NAp	NAp	NAp	1
Retrofit.............	1,750	795	2,625	NAp	NAp	NAp	

NAp Not applicable.

The procedure used to develop the population statistics can be summarized as follows:

1. For 1971-78, the population of continuous miners, cutting machines, mobile loading machines, face drills, and roof drills was based on statistics published in the National Coal Association publication "Coal Data."

2. Population estimates were made for all equipment types during 1979-80, and for shuttle cars and scoops for 1971-80. These estimates were based on several factors, including--

a. Coal production by mining method for each year in the period 1971-78.

b. The productivity or tons mined per cutting machine for continuous and conventional mining.

c. Equipment ratios used over the period 1971-78.

d. The ratios of shuttle cars and tractors and/or scoops to continuous miners and loading machines based on MSHA equipment compliance data.

The resulting population data were broken down for each year by equipment type used in seam heights of 42 to 48 in and 42 in and lower (table 2).

Establishing the industry cost for installation of protective structures required that the population data reflect annual changes in the number of new machines introduced, old machines continuing to operate, and machines retired. This provided a means to estimate the annual number of machines requiring installation of either new or retrofit operator-protective structures. An estimate of the average machine life for each type of face equipment was developed from data provided by coal companies and resulted in estimated machine replacement schedules. Table 3 is an example of the estimated continuous miner replacement schedule for the two seam height ranges of interest.

The installation costs (table 1) were then applied to the population data (tables 2 and 3) to estimate total costs to the industry (table 4). For the analysis, the machines were assumed to require all applicable protective structures (lateral *and* overhead protection).

BENEFITS OF CAB AND CANOPY PROTECTION

The second factor in the analysis, the "benefits," was calculated using accident data obtained from the ACIM file. Since data were only available for 1975-78, these had to be used to establish a statistical basis for classifying accidents

TABLE 2. - Equipment population as a function of seam heights of 43 to 48 and ≤42 in

Year	Continuous miners		Cutting machines		Mobile loaders		Face drills		Roof bolters		Shuttle cars		Tractors and/or scoops	
	43-48	≤42	43-48	≤42	43-48	≤42	43-48	≤42	43-48	≤42	43-48	≤42	43-48	≤42
1971	178	338	288	617	248	454	329	506	300	573	694	625	430	1,180
1972	185	351	265	567	235	431	298	459	308	589	684	618	424	1,165
1973	187	354	215	460	242	443	232	358	313	597	699	630	433	1,187
1974	196	372	212	455	258	473	266	410	416	794	740	667	458	1,259
1975	220	418	223	478	206	379	281	432	407	777	694	630	430	1,187
1976	236	449	252	541	198	364	295	454	440	840	707	642	438	1,211
1977	268	508	209	448	190	348	265	408	507	967	746	676	462	1,275
1978	282	536	200	430	170	313	237	364	491	938	736	670	456	1,265
1979	312	593	195	417	162	298	231	356	530	1,013	772	704	479	1,327
1980	342	650	186	399	151	277	221	341	570	1,088	803	732	498	1,381

TABLE 3. - Continuous miner replacement schedule, 1971-80

Year	Original machines (1971 and older)	+	Replacement machines (added after 1971, but not new machines)	+	New machines	=	Total machines	Machines retired
SEAM HEIGHT ≤ 42 in								
1971	363						363	40
1972	323	+	0	+	54	=	377	40
1973	282	+	54	+	45	=	381	41
1974	242	+	99	+	59	=	400	40
1975	202	+	158	+	89	=	449	40
1976	161	+	247	+	75	=	483	41
1977	121	+	322	+	103	=	546	40
1978	81	+	425	+	70	=	576	40
1979	40	+	495	+	103	=	638	41
1980	0	+	598	+	101	=	699	40
SEAM HEIGHT 43 TO 48 in								
1971	153						153	17
1972	136	+	0	+	23	=	159	17
1973	119	+	23	+	18	=	160	17
1974	102	+	41	+	25	=	168	17
1975	85	+	66	+	38	=	189	17
1976	68	+	104	+	30	=	202	17
1977	51	+	134	+	45	=	230	17
1978	34	+	179	+	29	=	242	17
1979	17	+	208	+	42	=	267	17
1980	0	+	250	+	43	=	293	17

TABLE 4. - Cost to industry to install cabs and canopies on face equipment, 1971-80[1]

Equipment type	Seam height			
	42 in and lower		43 to 48 in	
	Retrofit	New	Retrofit	New
Continuous miners..........	$2,880,768	$4,036,725	$764,951	$1,692,075
Cutting machines...........	3,033,380	409,130	933,709	153,110
Face drills................	1,281,301	267,384	509,647	13[illegible] 264
Loading machines...........	2,528,130	523,035	869,956	244,580
Tractors and/or scoops.....	27,133,224	19,203,872	5,856,928	5,633,360
Shuttle cars...............	6,612,292	2,704,590	3,912,577	2,184,084
Roof bolters...............	9,278,192	16,562,934	2,825,782	6,927,406
Total..................	52,747,287	43,707,670	15,673,550	16,944,879
Total cost by seam height..	$96,454,957		$32,618,429	

[1]Based on 1981 dollar value as supplied by manufacturers and rebuild shops.

and assigning dollar values to accidents in other years of the analysis period. This was based on the assumption that the percentage of cab-or-canopy preventable accidents, grouped by seam height and type of equipment involved, did not change significantly from year to year.

Nonfatal disabling and fatal accidents of all types numbered in the thousands during the 1975-78 period, but certain parameters were established by BCR to limit the accidents included in the analysis to those potentially preventable with overhead or side protective structures. These parameters were--

1. Machine type - the study included only those machines covered under the cab and canopy regulations.

2. Degree of injury - only fatalities and "lost-day" accidents were included.

3. Type of accident - only accidents involving haulage operations, face machinery, or falls of roof, rib, or face were included.

4. Mine worker activity - only such activities as roof bolting-drilling, operating shuttle car, operating continuous miner, etc., where a cab or canopy could have been helpful, were included.

5. Cost of accident - only those accidents with costs of at least \$1,000 were included. Accidents costing less than \$1,000 represented 32 pct of the number of accidents but only 0.5 pct of the total cost.

Review of the ACIM information resulted in the selection of 616 accidents to be included in the analysis. These were grouped into 11 categories, based on the need for tram decks, side protection, overhead protection, and combinations of these structures (table 5). Grouping the accidents in this manner emphasized the type of protective structure that would prevent the most accidents. The 616 accidents were also grouped according to seam height and equipment type, as shown in table 6.

TABLE 5. - Classification of "cab or canopy preventable" accidents

Class	Type of protection required
1......	Tram deck only.
2......	Side protection only.
3......	Tram canopy only.
4......	Tram deck and canopy.
5......	Tram deck and side protection.
6......	Tram deck, side protection, and canopy.
7......	Drill station deck only.
8......	Drill station canopy only.
9......	Drill station deck and canopy.
10......	ATRS system only.
11......	ATRS system and drill station canopy.

TABLE 6. - "Cab or canopy preventable" injuries (1975-78), grouped by equipment type, preventability classification, and seam height

Equipment type	Preventability classification											
	1	2	3	4	5	6	7	8	9	10	11	Total
SEAM HEIGHT ≤42 in												
Continuous miners........	2	12	35	0	0	0	0	0	0	0	0	49
Cutting machines.........	3	4	0	0	1	0	0	0	0	0	0	8
Face drills..............	1	1	3	0	0	0	0	0	0	0	0	5
Loading machines.........	2	9	4	1	2	0	0	0	0	0	0	18
Tractors and/or scoops...	1	14	45	1	0	0	0	0	0	0	0	61
Shuttle cars.............	0	32	39	1	0	1	0	0	0	0	0	73
Roof bolters.............	3	8	9	0	1	0	2	88	0	39	6	156
Total..................	12	80	135	3	4	1	2	88	0	39	6	370
SEAM HEIGHT 43 TO 48 in												
Continuous miners........	0	10	16	0	0	1	0	0	0	0	0	27
Cutting machines.........	0	1	1	0	2	0	0	0	0	0	0	4
Face drills..............	0	1	2	0	0	0	0	0	0	0	0	3
Loading machines.........	1	3	5	0	1	1	0	0	0	0	0	11
Tractors and/or scoops...	0	5	17	0	0	0	0	0	0	0	0	22
Shuttle cars.............	0	24	43	1	1	1	0	0	0	0	0	70
Roof bolters.............	2	3	7	0	1	0	76	0	0	15	5	109
Total..................	3	47	91	1	5	3	76	0	0	15	5	246

Since the cost benefit analysis covered a 10-year period (1971-80), some method had to be developed for estimating the preventable accidents that occurred during the years not included in the ACIM data, i.e., 1971-74 and 1979-80. The development of this information was based on (1) the accident-injury reports in the MSHA publications and (2) the assumption that the percentage of preventable injuries, grouped by seam height and type of equipment involved, does not change significantly from year to year. The estimated number of preventable accidents by year, seam height, and type of equipment is summarized in tables 7 through 10. Tables 7 and 8 cover nonfatal disabling injuries; tables 9 and 10 cover fatalities.

The cost associated with the accidents was handled in two ways. For 1975-78, the costs calculated by the ACIM system were available and were used as the "benefit" for the analysis. For 1971-74 and 1979-80, the benefits were calculated

TABLE 7. - Number of preventable nonfatal injuries in 42-in and lower seam heights, 1971-80

Equipment type	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	Total
Continuous miners.	10	12	9	7	8	12	13	13	16	17	117
Cutting machines..	2	2	2	1	0	1	1	6	3	3	21
Face drills.......	2	1	1	1	1	1	1	2	2	2	14
Loading machines..	3	4	3	3	4	6	5	0	5	5	38
Tractors and/or scoops...........	10	11	9	7	9	9	14	12	15	15	111
Shuttle cars......	16	17	16	11	17	18	19	17	25	25	181
Roof bolters......	32	36	32	22	27	36	47	37	52	50	371
Total...........	75	83	72	52	66	83	100	87	118	117	853

TABLE 8. - Number of preventable nonfatal injuries in 43- to 48-in seam heights, 1971-80

Equipment type	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	Total
Continuous miners.	5	7	6	4	7	6	8	6	9	10	68
Cutting machines..	1	1	1	1	1	2	0	1	1	1	10
Face drills.......	1	0	1	1	0	1	1	1	1	1	8
Loading machines..	3	3	2	1	7	2	0	1	4	3	26
Tractors and/or scoops...........	3	5	4	3	3	5	5	6	7	7	48
Shuttle cars......	15	17	14	11	18	15	25	10	24	24	173
Roof bolters......	23	25	23	16	35	25	29	17	37	36	266
Total...........	51	58	51	37	71	56	68	42	83	82	599

TABLE 9. - Number of preventable fatal injuries in 42-in and lower seam heights, 1971-80

Equipment type	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	Total
Continuous miners.	2	1	1	0	0	1	0	2	1	1	9
Cutting machines..	0	0	0	0	0	0	0	0	0	0	0
Face drills.......	0	0	0	0	0	0	0	0	0	0	0
Loading machines..	0	1	1	1	1	1	0	1	1	0	7
Tractors and/or scoops...........	8	6	5	4	5	4	2	6	5	5	50
Shuttle cars......	1	0	0	1	1	1	0	0	1	0	5
Roof bolters......	3	3	3	2	3	3	0	3	3	2	25
Total...........	14	11	10	8	10	10	2	12	11	8	96

TABLE 10. - Number of preventable fatal injuries in 43- to 48-in seam heights, 1971-80

Equipment type	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	Total
Continuous miners.	0	0	0	0	0	0	0	0	0	0	0
Cutting machines..	0	0	0	0	0	0	0	0	0	0	0
Face drills.......	0	0	0	0	0	0	0	0	0	0	0
Loading machines..	1	0	0	0	0	1	0	0	0	1	3
Tractors and/or scoops...........	0	1	1	1	0	1	1	1	1	0	7
Shuttle cars......	0	2	0	1	0	1	1	0	0	1	6
Roof bolters......	2	1	1	1	2	1	0	1	1	1	11
Total...........	3	4	2	3	2	4	2	2	2	3	27

TABLE 11. - Estimated benefits paid for injuries preventable with cabs and canopies, 1971-80

Equipment type	Seam height		
	42 in and below	43 to 48 in	Total
Continuous miners......	$5,760,969	$1,553,181	$7,314,150
Cutting machines.......	234,944	61,500	296,444
Face drills............	147,000	119,200	266,200
Loading machines.......	4,677,948	1,771,500	6,449,448
Tractors and/or scoops.	28,376,958	5,181,442	33,558,400
Shuttle cars...........	6,653,080	7,066,855	13,719,935
Roof bolters...........	15,624,840	12,536,535	27,801,375
Total................	61,115,739	28,290,213	89,405,952

using the average cost, by machine type, for "fatal" and "nonfatal disability" accidents during 1975-78. For 1971-80, the estimated "benefits," by machine type and seam height, are summarized in table 11.

COST-BENEFIT RATIOS

The cost-benefit ratio is simply the industry cost to install protective structures divided by the "benefits"--that is, the accident costs that could have been averted by the use of these structures. The calculations were made for two periods--1971-80 and 1975-78. The calculated ratios, along with the corresponding cost and benefit values, are summarized in tables 12 and 13. Two analyses were conducted because--

1. The 4-year study more accurately reflects the "benefit" factor since the values come directly from the ACIM program.

2. The 10-year study takes into account machine replacement experience, and, therefore, more realistically spreads the installation costs over the machine life. The cost-benefit ratios of the 10- and 4-year studies are very similar and show that the loading machine has the most favorable cost-benefit ratio, while the cutting machine has the least favorable. This indicates that from the standpoint of providing maximum personnel protection per dollar spent on protective structures, highest priority should be given to further development of protective structures for loading machines. On the other end of the scale, the cost of protective structures per dollar of benefit is so high for cutting machines that continued development of current technology would seem inappropriate and alternate technology should be considered.

TABLE 12. - Cost-benefit ratios for installing cabs and canopies, 1971-80

Equipment type	Cost of installing cabs and canopies	Accident benefits paid	Cost-benefit ratio
SEAM HEIGHT ≤42 in			
Continuous miners	$3,679,517	$5,760,969	0.63
Cutting machines	1,831,122	234,944	7.79
Face drills	823,768	147,000	5.60
Loading machines	1,622,960	4,677,948	.34
Tractors and/or scoops	24,647,391	28,376,958	.86
Shuttle cars	4,955,788	6,653,080	.74
Roof bolers	13,742,280	15,264,840	.90
Total or average	51,302,826	61,115,739	.83
SEAM HEIGHT 43 TO 48 in			
Continuous miners	$1,306,928	$1,553,181	0.84
Cutting machines	578,095	61,500	9.40
Face drills	340,378	119,200	2.85
Loading machines	582,200	1,771,500	.32
Tractors and/or scoops	6,111,855	5,181,442	1.17
Shuttle cars	3,242,904	7,066,855	.45
Roof bolters	5,187,866	12,536,535	.41
Total or average	17,350,228	28,290,213	.61

TABLE 13. - Cost-benefit ratios of installing cabs and canopies, 1975-78

Equipment type	Cost of installing cabs and canopies	Accident benefits paid	Cost-benefit ratio
SEAM HEIGHT ≤42 in			
Continuous miners	$2,554,859	$1,982,900	1.28
Cutting machines	1,253,010	89,500	14.00
Face drills	617,763	52,500	11.76
Loading machines	1,122,000	1,999,100	.56
Tractors and/or scoops	17,947,738	9,706,000	1.84
Shuttle cars	4,033,336	2,645,800	1.52
Roof bolers	9,536,577	5,598,600	1.70
Total or average	37,065,286	22,074,400	1.67
SEAM HEIGHT 43 TO 48 in			
Continuous miners	$868,792	$616,700	1.40
Cutting machines	455,861	24,600	18.53
Face drills	269,410	44,700	6.02
Loading machines	400,646	599,100	.66
Tractors and/or scoops	4,212,989	2,207,700	1.90
Shuttle cars	2,546,180	2,429,700	1.04
Roof bolers	3,284,567	4,636,500	.70
Total or average	12,038,448	10,559,000	1.13

ESTABLISHING RESEARCH PRIORITIES

The final decision on what technology to pursue and which machine should receive priority should not be based on the cost-benefit ratio alone. Seven factors were identified as relevant to the future direction of the Bureau's cab and canopy research program (tables 14-15). These seven factors varied in importance among different machine types; for example, the loading machine had the lowest cost-benefit ratio, so it would be the preferred research target if the cost-benefit ratio were the only criterion used to assign research priorities. However, preventing a fatality or very serious injury would also be a desirable goal; since the tractors and/or scoops were involved in more "canopy preventable" fatalities and severe injuries than any other machine type, they would be the preferred target if the Bureau's main goal were to prevent only these types of accidents. Tractors and/or scoops would also be the preferred target if the Bureau's goal were to address the most popular low-coal machine; however, the roof bolter would receive highest priority if the machine population *trend* were considered most important.

Therefore, the seven different machine types considered in this analysis were ranked for each of the seven factors that could influence Bureau research priorities. Tables 16 and 17 show the results of this ranking procedure; for each factor, the machine type demanding the greatest amount of attention was ranked number 1, and the type demanding least attention was ranked number 7. Note that tables 14 and 16 cover machines in seam heights of 42 in or less; tables 15 and 17 show the rankings obtained for machines in 43- to 48-in seams. An overall "average" ranking was then calculated for each equipment type, with the low numbers again corresponding to the machine deserving the highest priority.

In addition, each factor was ranked according to its importance in the overall analysis (bottom row of tables 16 and 17). The ranking of the factors was not included in the calculation of the overall average but could be used to establish priority for two or more machines with the same or very similar ranking. For example, in 42-in and lower seams, the "average ranking" criterion would give continuous miners, tractors and/or scoops, and bolting machines equal priority. However, considering only the top-ranked factor, preventable fatal injury population, tractors and/or scoops would be the top-priority machines. The analysis for 43- to 48-in seams identified the roof bolter as the top-priority machine according to the "average ranking" criterion; again, tractors and/or scoops ranked first in terms of preventable fatal injuries.

CONCLUSIONS AND RECOMMENDATIONS

The final decision to continue or discontinue cab and canopy development for any face-equipment type will depend on (1) the cost-benefit ratios considered to be the lower and upper limits for justifying the expenditures required to continue cab and canopy development and (2) the ranking given the seven parameters used to prioritize, by equipment type, the need for development of operator-protection technology. Since decisions on these two items may depend on factors not considered in this analysis, only the following general recommedations for the continued development of cab and canopy technology can be made:

1. There is an immediate need to develop some type of operator-protection technology, particularly for continuous miners, tractors and/or scoops, and roof bolters in seam heights of 48 in and lower.

2. In seams 42 in and lower, the higher cost-benefit ratio values generally indicate that future cab and canopy development is marginally justified. In view of past experience with attempts to use canopies in these seam heights, BCR recommends consideration of alternate technologies.

3. For 43- to 48-in coal seams, where canopies have been used successfully, the cost-benefit ratio values indicate that further development of canopy technology is warranted.

TABLE 14. - Seven factors influencing the priority of installing cabs and canopies on different types of face equipment in 42-in or lower seam heights

Equipment type	Cost-benefit ratio, 1971-80	Preventable fatal injury population, 1971-80	Preventable nonfatal injury population, 1971-80	Severity of injury, 1971-80	Low-coal machine population, 1980	Machine population trend,[1] 1971-80	Average cost of low-coal operator protective structures[2]
Continuous miners.......	1.201	9	117	$45,722	699	336	$6,514
Cutting machines........	14.652	0	21	11,188	426	-232	4,193
Face drills.............	10.535	0	14	10,500	373	-180	2,184
Loading machines........	.652	7	38	103,954	299	-190	4,581
Tractors and/or scoops..	1.632	50	111	176,312	1,452	211	19,445
Shuttle cars............	1.400	5	181	35,769	847	123	7,430
Roof bolters............	1.693	25	371	38,548	1,169	553	14,998

[1]The machine population trend was computed by subtracting the machine population in 1971 from the machine population in 1980 for each equipment type.

[2]This cost was calculated by dividing the total cost of installing operator protective structures by the population of new and retrofit machines equipped with these structures for each machine type during the 1971-80 period.

TABLE 15. - Seven factors influencing the priority of installing cabs and canopies on different types of face equipment in 43- to 48-in seam heights

Equipment type	Cost-benefit ratio, 1971-80	Preventable fatal injury population, 1971-80	Preventable nonfatal injury population, 1971-80	Severity of injury, 1971-80	Low-coal machine population, 1980	Machine population trend, 1971-80	Average cost of low-coal operator protective structures
Continuous miners.......	1.582	6	68	$20,989	293	140	$6,316
Cutting machines........	17.672	0	10	6,150	159	-88	4,117
Face drills.............	5.368	0	8	14,900	189	-93	2,162
Loading machines........	.618	5	26	57,145	129	-84	4,486
Tractors and/or scoops..	2.218	36	48	61,684	427	58	19,055
Shuttle cars............	.863	5	173	39,701	688	93	7,122
Roof bolters............	.778	20	266	43,846	489	232	14,982

TABLE 16. - Ranking of equipment types by seven factors influencing the priority for installing cabs and canopies in 42-in or lower seam heights

Equipment type	Cost-benefit ratio	Preventable fatal injury population, 1971-80	Preventable nonfatal injury population, 1971-80	Severity of injury, 1971-80	Low-coal machine population, 1980	Machine population trend, 1971-80	Average cost of low-coal operator protective structures	Overall average ranking
Continuous miners	2	3	3	3	4	2	4	3.00
Cutting machines.	7	6	6	6	5	7	2	5.57
Face drills......	6	7	7	7	6	5	1	5.57
Loading machines.	1	4	5	2	7	6	3	4.00
Tractors and/or scoops..........	4	1	4	1	1	3	7	3.00
Shuttle cars.....	3	5	2	5	3	4	5	3.86
Roof bolers......	5	2	1	4	2	1	6	3.00
Relative importance of each ranking.........	4	1	2	3	6	5	7	

TABLE 17. - Ranking of equipment types by seven factors influencing the priority for installing cabs and canopies in 43- to 48-in seam heights

Equipment type	Cost-benefit ratio	Preventable fatal injury population, 1971-80	Preventable nonfatal injury population, 1971-80	Severity of injury, 1971-80	Low-coal machine population, 1980	Machine population trend, 1971-80	Average cost of low-coal operator protective structures	Overall average ranking
Continuous miners	4	3	3	5	4	2	4	3.57
Cutting machines.	7	6	6	7	6	6	2	5.71
Face drills......	6	7	7	6	5	7	1	5.57
Loading machines.	1	4	5	2	7	5	3	3.86
Tractors and/or scoops..........	5	1	4	1	3	4	7	3.57
Shuttle cars.....	3	5	2	4	1	3	5	3.29
Roof bolters.....	2	2	1	3	2	1	6	2.43
Relative importance of each ranking.........	4	1	2	3	6	5	7	

CANOPY PROTECTION FOR OPERATORS OF CONTINUOUS HAULAGE SYSTEMS IN LOW-SEAM-HEIGHT COAL

By R. J. Gunderman[1] and A. J. Kwitowski[2]

ABSTRACT

Placing an operator of a mobile continuous haulage conveying system under a protective canopy was investigated using the latest technology for both canopies and floating compartments. Investigations first considered how to position the operator in the low compartments and included unobtrusive observation of human subjects repositioning themselves when confined to the compartment. Locations for such a compartment on the crawler-mounted machine were considered using both small-scale and full-scale mockups.

A floating operator compartment was designed in conjunction with the new design for an improved machine. Evaluation of the compartment for human factors was made at the manufacturer's facility prior to installing the machine in an underground coal mine. Subjects representing the male 5th, 50th, and 95th percentile sizes were used along with photographic techniques for recording data.

Operation of the new machine with operator compartment in a coal mine with seam heights typically between 40 and 46 in was monitored for 10 months. The practical feasibility of this operator protection was adequately demonstrated for coal seams as low as 40 in.

INTRODUCTION

This program was one of several initiated by the Bureau of Mines to investigate the applicability of canopies and cabs to coal mining machines operating in seam heights below 48 in. A study contract was awarded to the Jeffrey Mining Machinery Division, Dresser Industries, Inc., to investigate the feasibility of placing the operator of a model 506C-5 double-bridge carrier, shown in figure 1, under a protective canopy. This crawler-mounted carrier supports a bridge conveyor on the inby end (seen to the left of the operator), which is linked to the discharge boom of the continuous mining machine. A similar bridge conveyor links between the carrier and the pan line. If there are more than three entries, a second bridge carrier and an additional bridge conveyor may be added to lengthen the reach. The operator of the double-bridge carrier maneuvers the machine to follow movements of the mining machine and controls operation of the conveyor. This machine is used in seam heights as low as 28 in.

The inby bridge conveyor is supported on a carriage or dolly that rides on the receiving conveyor of the double-bridge carrier. This carriage, which is free to move approximately 6 1/2 ft, provides flexibility for small movements of the continuous miner. The operator of the double-bridge carrier must move the carrier to assure that the carriage is adequately positioned to allow movement of the continuous miner in either direction.

Using technology and ideas applied in previous Bureau of Mines contracts as well as concepts developed by manufacturers and coal companies, the feasibility of a protective operator compartment was investigated. As shown in figure 1, the controls on the 506C-5 are on the side (or fender), and the operator usually squats or kneels next to the machine.

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FIGURE 1. - Operator at controls of 506C-5 double-bridge carrier.

This gives the operator good visibility and mobility. However, this position is vulnerable in the event of a roof fall or if the bridge carrier is inadvertently pushed by the mining machine, which could possibly pinch the operator against a rib.

ACKNOWLEDGMENT

The work described in this paper was performed under Bureau of Mines contract H0387027[3] to the Jeffrey Mining Machinery Division, Dresser Industries, Inc., Columbus, OH. The in-mine evaluation was performed under a cooperative agreement between the Solar Fuel Co., Somerset, PA and the Jeffrey Mining Machinery Division.

PRELIMINARY DESIGN

All possible operating positions for the human body were considered because of the severe space restrictions in low seams. Studies were conducted on six subjects to evaluate each one's response to postures within the confines of a compartment 30 in high, 24 in wide, and 70 in long. A video camera recorded their positions and movements on tape for later analysis. Each subject was told to position himself in the compartment and to go through simulated functions of operating controls and observing both inby and outby operation for periods of 1 h. These subjects tried lying down, squatting, sitting cross legged, sitting in a very reclined position, etc., and needed frequent postural relief. The consensus favored the reclined seat position.

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[3]Gunderman, R. J. Canopy Technology for Low Seam Continuous Haulage. Final Report USBM Contract No. H0387027, Feb. 1980, 72 pp.; for inf., contact A. J. Kwitowski, TPO, Pittsburgh Research Center, BuMines, Pittsburgh, PA.

Required dimensions for an operator compartment were thus determined to be approximately 5-1/2 ft long and at least 2 ft wide in the shoulder area. A detailed consideration of the 506C-5 bridge carrier showed that there was no possibility of locating such an operator compartment on that machine. However, Jeffrey was starting design of a new bridge carrier with increased haulage capacity and greater tram speed. Effort was then directed at locating an operator compartment on the new machine so that the resulting design would allow adding the compartment, if desired. Fender-mounted controls would be retained in the standard design because of mine operator preference, especially in seam heights less than 36 in.

Many potential locations for the compartment on the machine were examined using a small-scale model. Because of the requirement for frequent ingress and egress, along with maintaining a properly located machine center of gravity, the side-rear compartment position was preferred.

A full-scale mockup was constructed from cardboard and wood (fig. 2). Only significant portions of the bridge carrier were included in the mockup since it was used primarily to determine operator fit, functional movement, and visibility. The canopy on the mockup and the items inside the operator compartment were moved until satisfactory locations were established empirically. Figure 3 shows a 50th percentile operator in the mockup.

Results from the mockup evaluation showed feasibility with canopy heights adjustable between 30 to 42 in above the floor. Depending upon seam conditions and undulations, a bridge carrier of this type could operate in seams from 48 to 36 in high. Jeffrey agreed to constrain the design of the new machine to allow for this compartment as an option.

OPERATOR COMPARTMENT DESIGN

Considerable effort went into the design of the operator compartment and attachment to the bridge carrier. Also, the controls of the new bridge carrier were relocated to the right side of the machine instead of the left side because the operator of the continuous mining machine is on the right side. The resulting design is shown in figure 4.

The newly designed machine is 9 in wider and almost 4 ft longer than the 506C-5 in order to accommodate the compartment and the fact that the outby conveyor must swing as much as ±90°. This also required longer crawler tracks. Therefore, the compartment has to float on the floor in order not to impede mobility.

The operator compartment is attached to the main frame by two pivots with horizontal axes. Figure 5 is a closeup of this attachment taken during tests for mobility. The compartment side of the pivots consists of steel collars that slide vertically on the two front canopy support posts. This slide travel is limited to 8 in by the support members at the bottom and fixed collars on top. Angular movement of the compartment is limited with respect to the discharge conveyor in the upward direction by a stop on the conveyor and in the downward direction by a link chain.

Selection of an operator seat was limited by the practical factor of availability. In this case a seat was selected that has a seat unit separate from the back rest. A new adjustable seat mount was designed using data from the functional mockup evaluation. A single lever on the seat back retracts dual pins that engage in holes in the seat mount. This provides positions reclining from the vertical of 25°, 34°, 43°, 51°, or 60°. A similar arrangement allows separate adjustment of the seat cushion to angles from the horizontal of 10°, 20°, or

FIGURE 2. - Looking down on the mockup from the receiving end.

FIGURE 3. - Operator seated in the mockup.

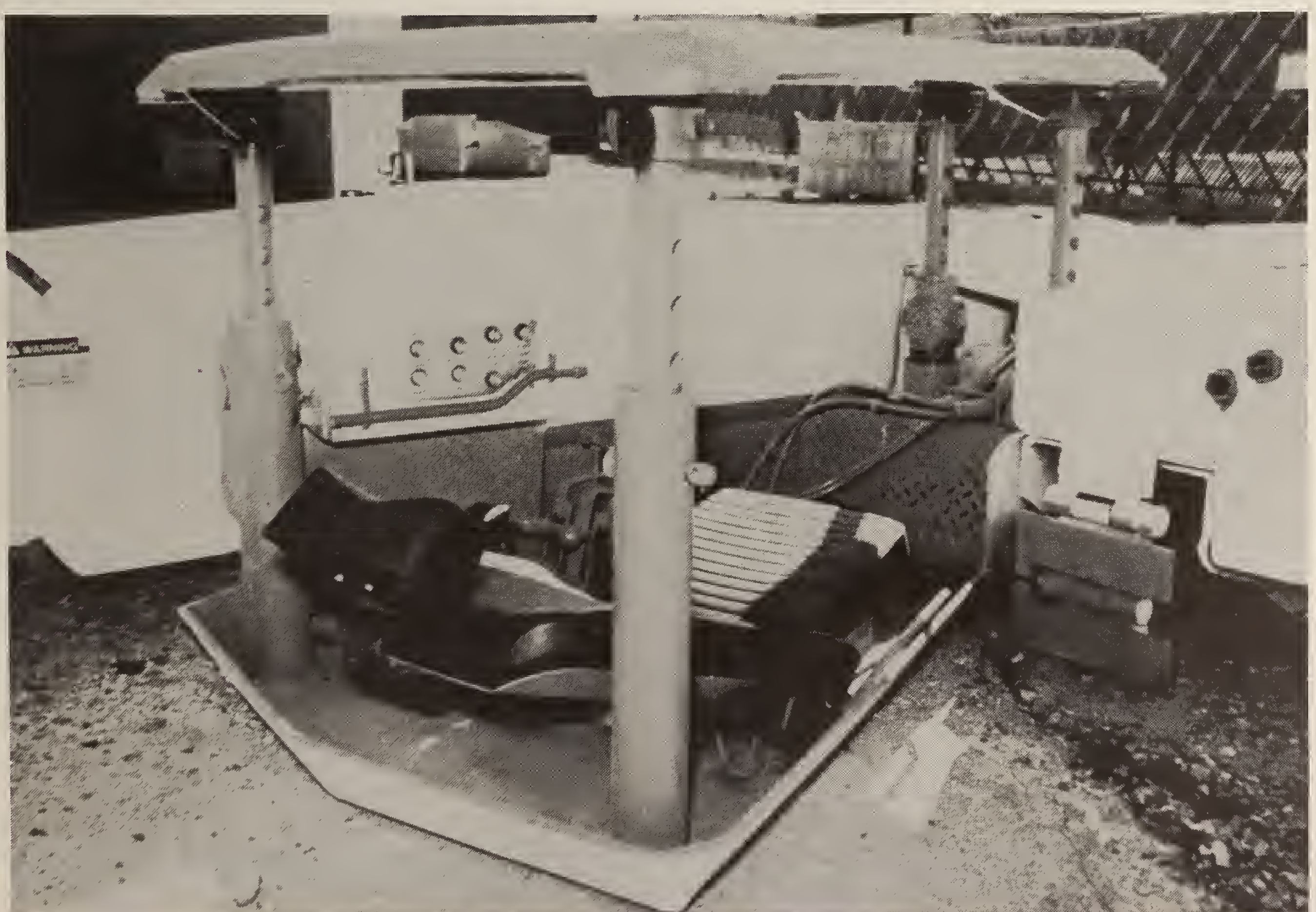

FIGURE 4. - Completed operator compartment on new machine.

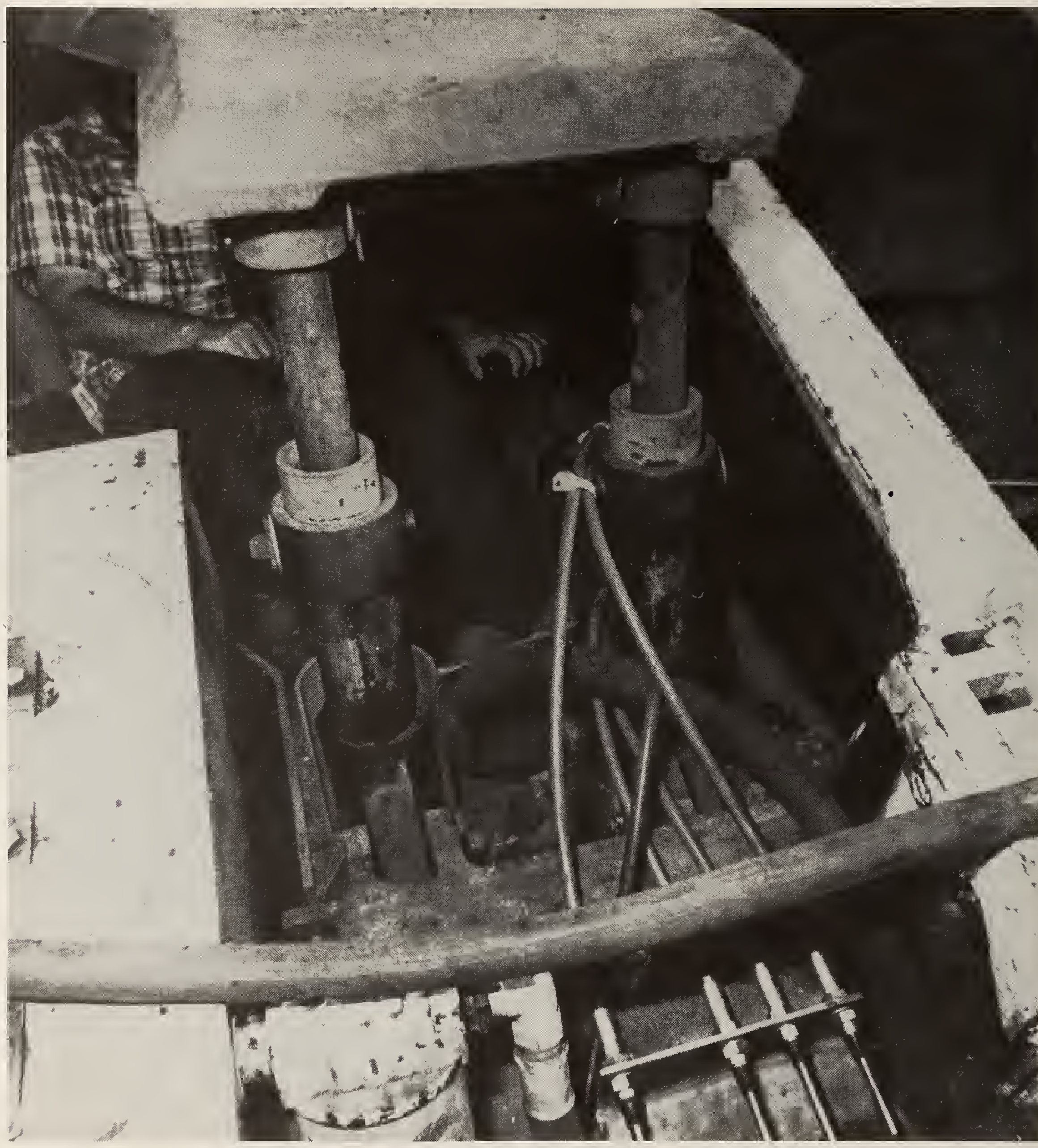

FIGURE 5. - Attachment of compartment to mainframe.

30°. The adjustment holes are indicated by arrows in figure 6. The mount with the seat slides forward and back on the track bar shown in figure 7. A clevis pin through holes in the seat mount allows nine fore and aft position selections in 1-in increments.

Arm rests that tilt back for ingress and egress were provided. However, the left arm rest was deleted when it was found to interfere with both arm movement and other items in the compartment.

As noted in figure 1, the operator kneeling and facing the machine only has to turn 90° to see either inby or outby operation. Unfortunately, there is not enough room in the entries to place a compartment so that the operator faces the machine the same as with the 506C-6. The compromise in the new design is to

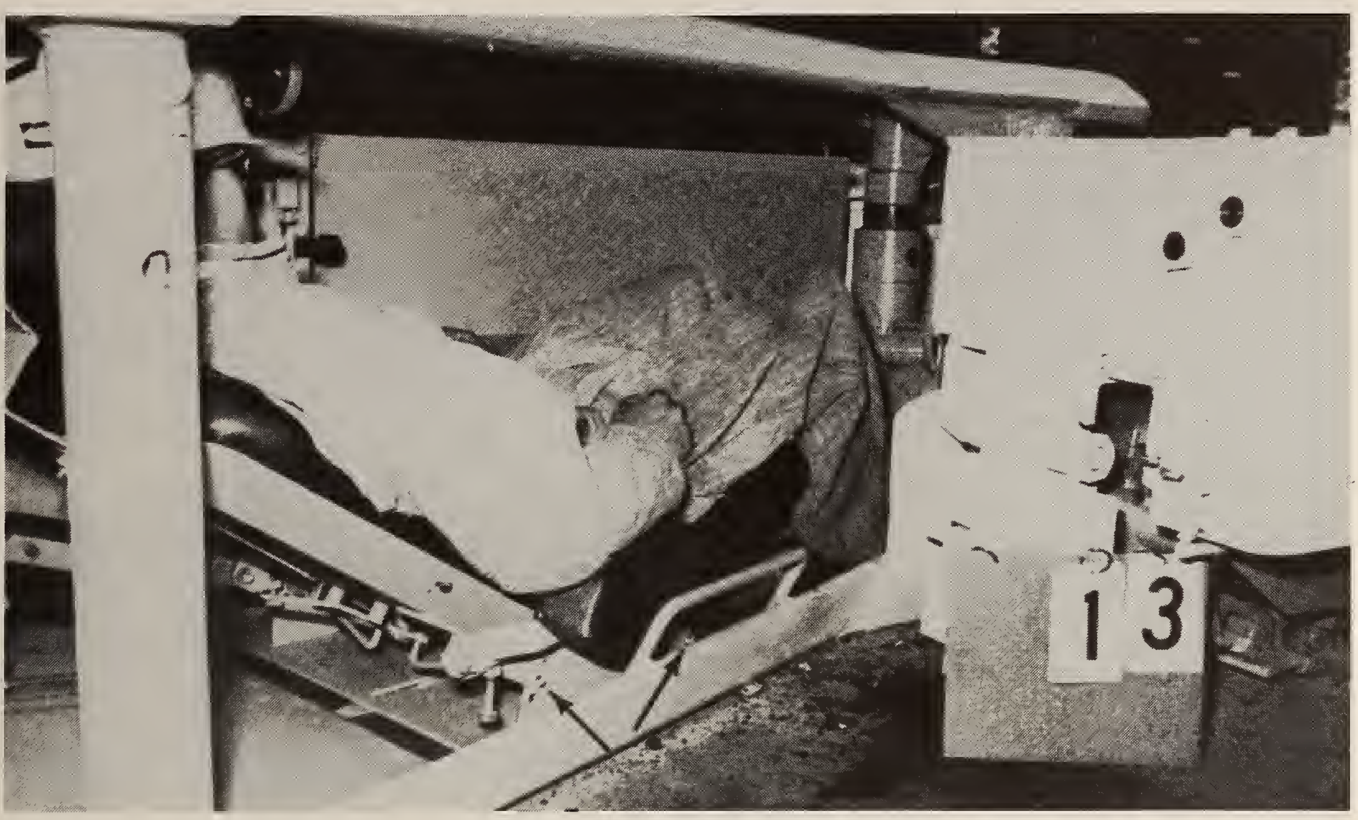

FIGURE 6. - Seat adjustment.

FIGURE 7. - Seat fore-aft adjustment track.

place the operator at a small angle (19°) with respect to the longitudinal axis of the machine. This angle helps considerably when turning the head to see the outby transfer point. Most operators, sitting in the reclining position, roll the body slightly off the seat when turning to see outby.

Four posts are used to support the canopy because of the size and loads. The posts telescope, and each is adjustable with a pin for canopy heights from 30 to 42.5 in in 2.5-in steps. During the compartment design phase, the Solar Fuel Co. became interested in this program and agreed to an in-mine evaluation of the machine at its mine No. 9. Because the seam heights there have considerable variation, as well as undulations, they desired a method to change canopy height without the need for extra equipment, such as a jack. Two hydraulic lift cylinders were added, one at the left rear as shown in figure 8 and the other at the opposite corner. A small pump with oil reservoir and a reversing valve comprise the rest of the canopy raise system. The pump is operated by stroking the handle, and the flow direction is set by the valve. The first step in adjusting the canopy height is to pump up the circuit to lift the weight of the canopy off the four pins so that they may be removed. The four adjustment pins must all be replaced for the desired height setting before the operator enters the compartment. Figure 9 shows, left to right, the support post, raise cylinder, flow direction valve, and hydraulic pump.

FIGURE 8. - Operating the canopy adjusting pump and flow valve.

Both the electrical and hydraulic controls are located to the left of the operator so as not to impede ingress and egress. Figure 10 is a side view of the operator compartment taken during the in-mine evaluation. Note that the arm rest is tilted back. The handhold on the compartment floor adjacent to the seat aids the operator during ingress and egress.

Operator visibility in order to safely and comfortably accomplish all functions was a major concern. This was investigated using the full-scale mockup shown in figure 2. Markers indicating the height above the floor were placed at four locations--the inby end of the bridge conveyor loading boom, the inby ends of both the right and left crawlers, and the outby end of the conveyor discharge boom. Data were collected for each size operator in the mockup with canopy heights of 30, 32, 34, and 36 in, and at each key direction from his eye location. Higher canopy settings were considered to be no problem, so data were not collected for these. Visibility at the loading boom, discharge boom, and near-side (left) crawler positions for the minimum canopy height was 17, 25, and 25 in respectively. The minimum visible height across from the operator and in front of the right crawler ranged from 24 to 35 in. As the canopy was raised, so also was the operator's head, which gave a lower minimum visible height.

FIGURE 9. - Canopy adjusting system.

FIGURE 10. - Side view of operator compartment.

Variations in the highest visible height were relatively small. These variations were dependent upon how the operator positioned the seat, both in angle and in fore-aft direction. The highest visible measurements ranged from 38 to 50 in at the four aforementioned positions.

EVALUATION PRIOR TO SHIPMENT

These visibility measurements were repeated for the actual machine before shipment to the mine. As shown in figure 11, the operator compartment was located on the right rather than the left side (fig. 2) of the machine. A camera was positioned at the operator eye location, and pictures were taken of the visibility of the inby loading boom position. With the canopy set at 30 in above the floor (fig. 12), the limits of visibility were 34 to 47 in. When the canopy was raised to 35 in (fig. 13), the visibility range was 23 to 56 in; at a canopy height of 40 in (fig. 14), the visibility range was 22 to 75 in.

When the operator looks back at the bridge carrier outby transfer point, the angles are limited. However, the operator does not have to see over a large vertical angle, as long as the coal flowing across the transfer point is within the visible angle. In figure 15 the limits are 14 to 34 in with the canopy at 30 in. In this case the discharge end boom was lowered to the floor. The boom can be raised 7° or lowered 6° with respect to the mainframe, but if the seam height requires the canopy at 30 in, it is not likely that the boom would be raised more than 12 in from the conditions shown in figure 15.

Another visibility consideration is toward the general outby direction when tramming the system outby. In this case, the operator will usually turn in the opposite direction, as when observing the outby conveyor transfer. There is very little visibility obscuration in that direction. However, as shown in figure 16, the operator has to strain somewhat even with the canopy at 35 in.

In general, the visibility is reasonable at most canopy heights, except for 30 in. If the operator size is not much over the 50th percentile rank and the mine conditions are good, then operation with the canopy at 30 in should be possible. Table 1 summarizes the visibility data collected with subjects in the machine before shipment to the mine.

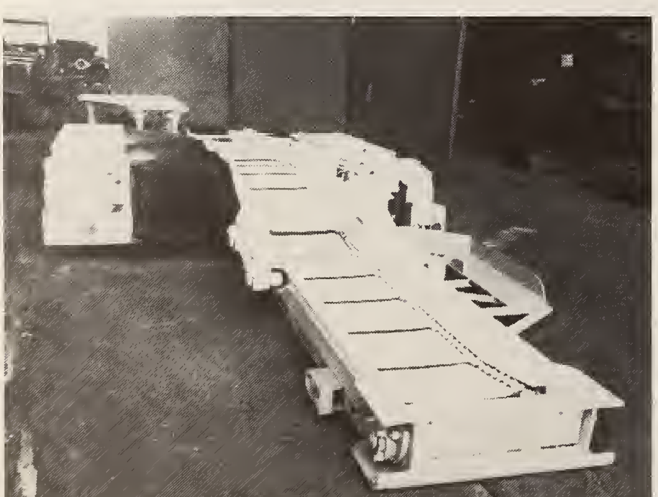

FIGURE 11. - New machine ready for human factors evaluation.

FIGURE 12. - Looking forward under 30-in canopy height.

FIGURE 13. - Looking forward under 35-in canopy height.

FIGURE 14. - Looking forward under 40-in canopy height.

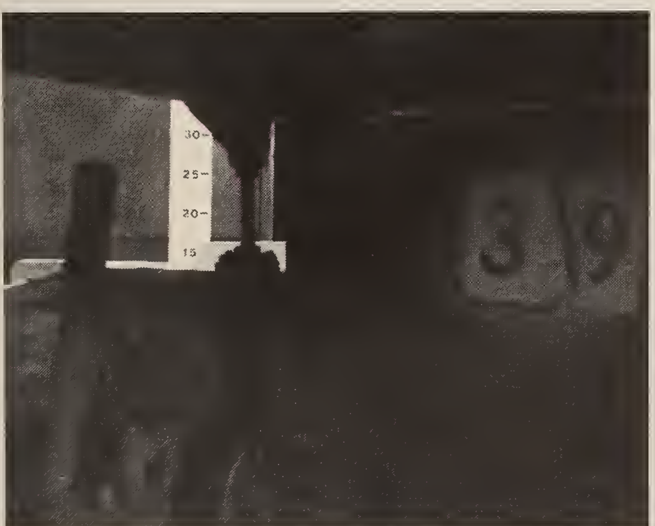

FIGURE 15. - Looking at outby transfer point under 30-in canopy height.

FIGURE 16. - Operator under 35-in canopy tramming outby.

TABLE 1. - Summary of collected visibility data

Operator size, percentile	Canopy height, in	Seat back angle from vertical, deg	Seat cushion angle from horizontal, deg	Visibility range, inches above floor, measured at noted location[1]				Seat cushion to bottom edge of foot rest distance, in	Legs and knee position
				1	2	3	4		
5th.....	30	43	30	NM	34-47	NM	NM	15.5	Knees bent, feet on floor.
	32.5	34	30	NM	25-46	NM	NM	15.5	Do.
	35	34	30					18.5	Do.
	40	25	30					18.5	Knees bent, feet on rest.
50th....	30	60	30	30-41	28-38	26-34	14-34	18.5	Do.
	35	51	30	NM	23-56	NM	NM	21.5	Do.
	40	34	30	24-56	22-75	24-57	16-56	23.5	Do.
95th....	30	60	20	NM	27-35	NM	NM	18.5	Feet crossed on floor under thighs.
	32.5	60	20	NM	22-42	NM	NM	18.5	Knees bent, feet on floor.
	35	51	20	NM	21-50	NM	NM	19.5	Do.
	40	34	10	NM	16-64	NM	NM	23.5	Feet crossed on floor under thighs.

NM No measurement.
[1]Visibility locations:
1 - Inby left crawler (opposite operator).
2 - Inby end of loading boom.
3 - Inby right crawler.
4 - Outby end of discharge boom.

Paired numbers indicate the height range, in inches above the mine floor, visible to the operator at each location.

Canopy heights at 35 in or more appear reasonable on this particular mobile bridge carrier. The effective window is large enough for good visibility angles. A perspective on this window may be obtained from figure 17, which is a photograph looking at the 5th percentile operator in the compartment with the canopy set at 35 in.

A large operator finds the compartment a tight fit, as shown in figure 18. This subject's favorite position for his legs was crossed and on the floor. In this scene, the canopy height is 40 in and the backrest angle is 34° from the vertical. Another view of this operator position is shown in figure 19. Note that he uses the headrest to support his shoulders rather than his head.

Control operation is primarily with the left hand. As shown in figure 20, there are four levers located in a console on

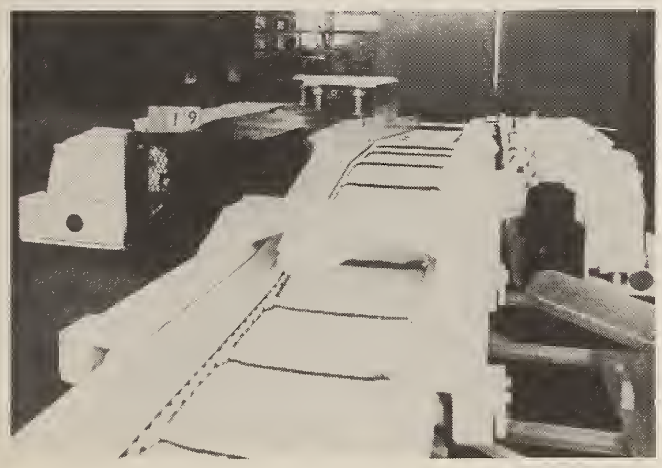

FIGURE 17. - Looking at operator under 35-in canopy from inby end of loading boom.

FIGURE 18. - Large-size operator with legs crossed.

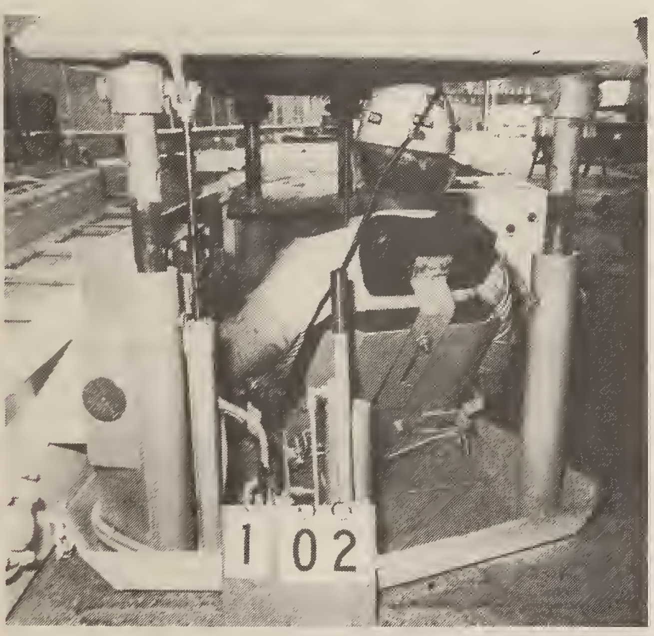

FIGURE 19. - Large-size operator supporting shoulders with headrest.

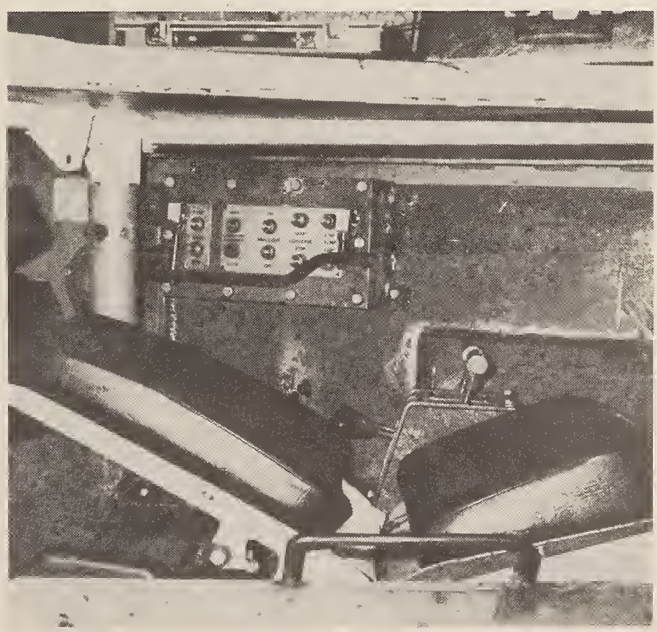

FIGURE 20. - Closeup of controls in compartment.

the floor of the compartment to the left of the operator. These levers work hydraulic levers on the mainframe in front of the operator through cables. The two upper levers are for the left and right tram. Pushing them forward moves the machine inby, and pushing them rearward reverses the tram.

There are two lower controls on this console that work the receiving and the discharge conveyor booms. The left control raises the discharge conveyor when it is pushed up and lowers it when pushed down. The receiving conveyor works similarly with the right control lever.

The electrical controls, also shown in figure 20, are all located within the enclosure mounted high on the left wall of the operator compartment. This was an existing control box used on another machine which had already been approved by MSHA. The fire extinguisher is located below the electrical control case, and the actuator knob is visible just above the backrest. Note that the panic bar must be operated either with the left shoulder or a hand.

IN-MINE EVALUATION

The in-mine evaluation was conducted through the cooperation of the Solar Fuel Co. at its mine No. 9 near Somerset, PA. Seam height at this mine generally ranges from 40 to 46 in but frequently pinches down much lower. Entries and crosscuts are 20 ft wide. Moisture, roof, and floor conditions were fair.

The new bridge carrier (Jeffrey model 5010) with operator compartment was substituted on an operating section for a Jeffrey model 506C-5 bridge carrier. The new machine was installed early in October 1981, and the evaluation was planned to last 3 months. This time was extended for various reasons, including unrelated interruptions to the mining operation. The bridge carrier with operator compartment was removed from the mine in October 1982 and was delivered to the Bureau's Pittsburgh Research Center.

In the section area, the mine operator first tried the 35-in canopy setting but settled on 37.5 in soon afterwards. As can be seen in figure 21, there was little clearance between the canopy and the roof when the height was set at 37.5 in. During the in-mine operation, the compartment floated well on the floor through the action of the slides and pivots. As a result, the canopy-to-roof clearance could be nominally as low as 6 in.

Visibility for the operator was fairly good with the canopy at 37.5 in. A protective metal mesh, angled inward, was added to the top of the compartment wall to assure that the operator did not reach beyond that wall and become pinched by the relative movements between the compartment and the discharge conveyor. This mesh did not significantly block visibility toward the opposite side of the machine.

As stated earlier, the discharge conveyor may be raised several inches. Figure 22 is a view from the left front of the machine with the conveyor raised to the roof. While this conveyor would obscure vision directly across the machine, it does not otherwise affect operation. The conveyor would normally be lower when tramming the machine, and the operator would be able to see through the mesh and across the machine.

Four different operators of the double-bridge carrier were observed during the in-mine evaluation. One male operator was in the 50th percentile size range, and two other males were somewhat smaller. The other operator was female and was slightly larger than a 50th percentile female.

Operator indoctrination occurred quickly, although it took the operators some

FIGURE 21. - Clearance under roof with canopy at 37.5 in.

time to get over the restless reaction that resulted from confinement within the compartment. Inability to directly see the inby conveyor carriage was the biggest problem. The movement between stops on the new machine is only 5 ft, which means that the operator must be even more skillful in moving the bridge carrier to avoid banging the carriage against the stops as a result of continuous miner movement. The operator seated in the compartment can only see the top of this carriage.

Each operator had different preferences on positions within the compartment. Repositioning was frequent in order to retain reasonable comfort. There was a tendency toward operator inattention since the workload within the compartment was small. Operator personnel were encouraged to get out of the compartment frequently when not running coal and to do spillage cleanup, machine inspection, etc., in order to overcome boredom.

The attitude of the operators varied as they became more familiar with the new compartment. At first, they did not like the concept and were very uneasy because they could not move around as they did before and because visibility was now restricted. After familiarization for a few weeks, the operators expressed satisfaction with the compartment. However, the satisfaction did not last long as boredom set in and their personal performance tended to deteriorate. The operator workload was subsequently adjusted by having the operators leave the compartment when not running coal and perform duties including spillage cleanup and machine lubrication. Ultimately, the operators accepted the operator compartment as a compromise from the older machine with fender-mounted controls.

Difficult mining conditions, due to incursions of stone into the coal seam, precluded a good measure of the effect that the addition of an operator

FIGURE 22. - Looking at compartment from left side with conveyor raised.

compartment on the double-bridge carrier had on coal production. It appears from data collected that the production rate is unchanged.

CONCLUSIONS

The program objective of investigating the feasibility of providing operator protection on crawler-mounted continuous haulage systems was achieved. These findings are summarized as follows:

1. Adding operator protection requires considerable compromise.

2. An operator compartment is reasonable for seam heights as low as 40 in.

3. Operation in seam heights as low as 36 in is questionable and should be evaluated in-mine.

4. Adding an operator compartment required redesign of the machine.

5. The floating concept using slides and pivots works well.

6. A reclining seat provides the best operating position.

7. Operator repositioning within the compartment occurs frequently.

8. The operators always set the canopy to the highest tolerable setting.

9. Line of sight to the continuous mining machine operator is more frequently obscured.

10. Operators react mostly on the basis of familiarity with running conditions and seldom use signals.

11. Noted shortcomings with the compartment include--

Inattention due to minimal activity.

Limited visibility requires extra care when tramming.

Large operators are not practical at lowest canopy setting.

It is recommended that the double-bridge carrier with operator compartment be further evaluated under in-mine conditions where the mining height is typically 36 in.

ESD LOW-COAL CANOPY TECHNOLOGY

By Jack Mantel[1]

INTRODUCTION

This paper highlights the work performed by ESD Corp. under Bureau of Mines contract H0387026, Development and Assessment of New and Existing Canopy Technology to Lower Coal Seams.

While cab and canopy technology is well established for coal mines with working heights of over 48 in, technological advances are needed for use of cabs and canopies in lower working heights. According to the February 1975 issue of Coal Mining and Processing, many mining fatalities caused by rib and roof failures could be avoided through use of cabs and canopies. Figure 1 shows the effect on reported fatalities of the 1969 Federal Mine Health and Safety Act, which required substantially constructed cabs and canopies on all self-propelled electric face equipment in underground coal mines.[2] These statistics emphasize the importance of improving upon the state of the art in low-coal canopy technology.

Four of the programs conducted by ESD for the Bureau of Mines included development of cabs or canopies:

- Inherently Safe Mining Systems.
- Development of a Dual-Boom, Semiautomated Roof Bolter.
- Fabrication and Evaluation of Optimized Operator Compartments.
- Development and Assessment of New and Existing Technology to Lower Coal Seams.

[1]ESD Corp., San Jose, CA.

[2]Coal Mining and Processing, February 1975.

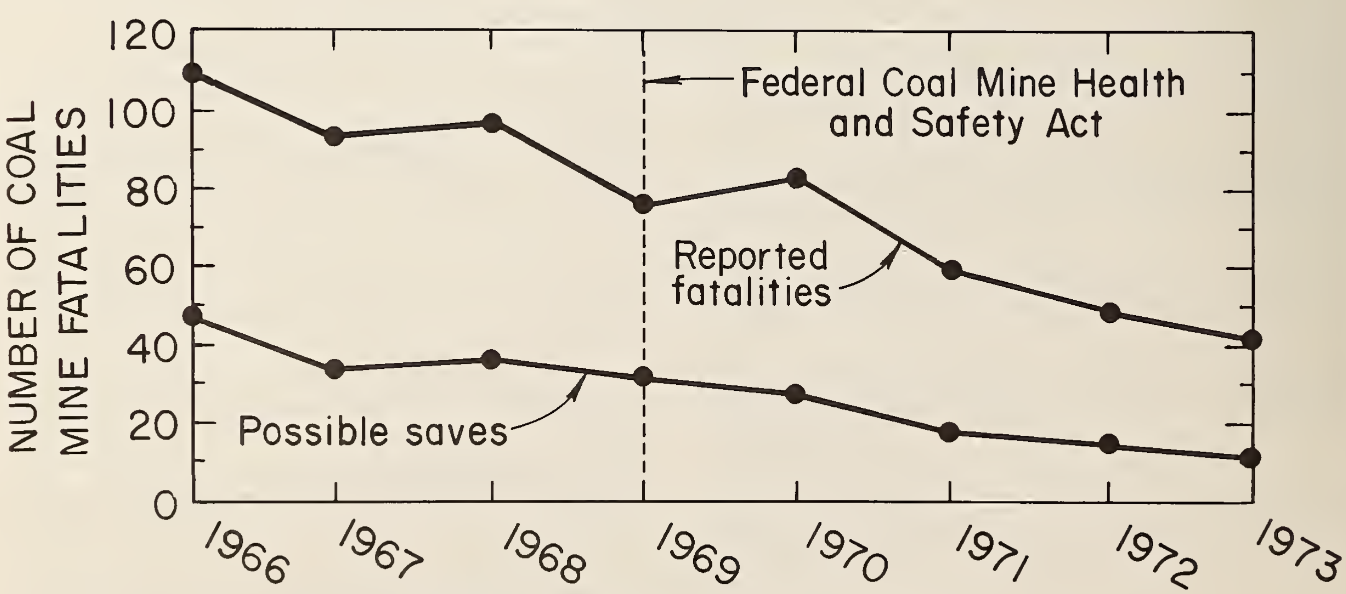

FIGURE 1. - Coal mine fatalities, 1966-74.

The objective of our current program was to develop two transverse-mounted canopies, one to be used on an FMC 6L shuttle car, and one to be used on a Joy 14BU10-11A loader. As shown in figure 2, an operator sitting in a transverse-mounted canopy faces in a direction 90° to the direction of travel. The shuttle car canopy (fig. 3) was to be used in working heights of 42 to 48 in, and the loader canopy (fig. 4) was to be used in working heights as low as 42 in. This paper emphasizes work performed on the shuttle car canopy, because evaluations have been conducted of its performance in an underground mine.

CONCEPT DEVELOPMENT

ESD's initial program work was an investigation of the state of the art in canopy technology to establish design needs. On the basis of this investigation, concept drawings were prepared, and various concepts for shuttle car and loader canopies were compared and evaluated by BCR, the Bureau of Mines, MSHA, and mining equipment manufacturers. Wooden mockups were made of the selected shuttle car and loader canopy concepts:

FIGURE 2. - Mockup of transverse-mounted canopy for shuttle car.

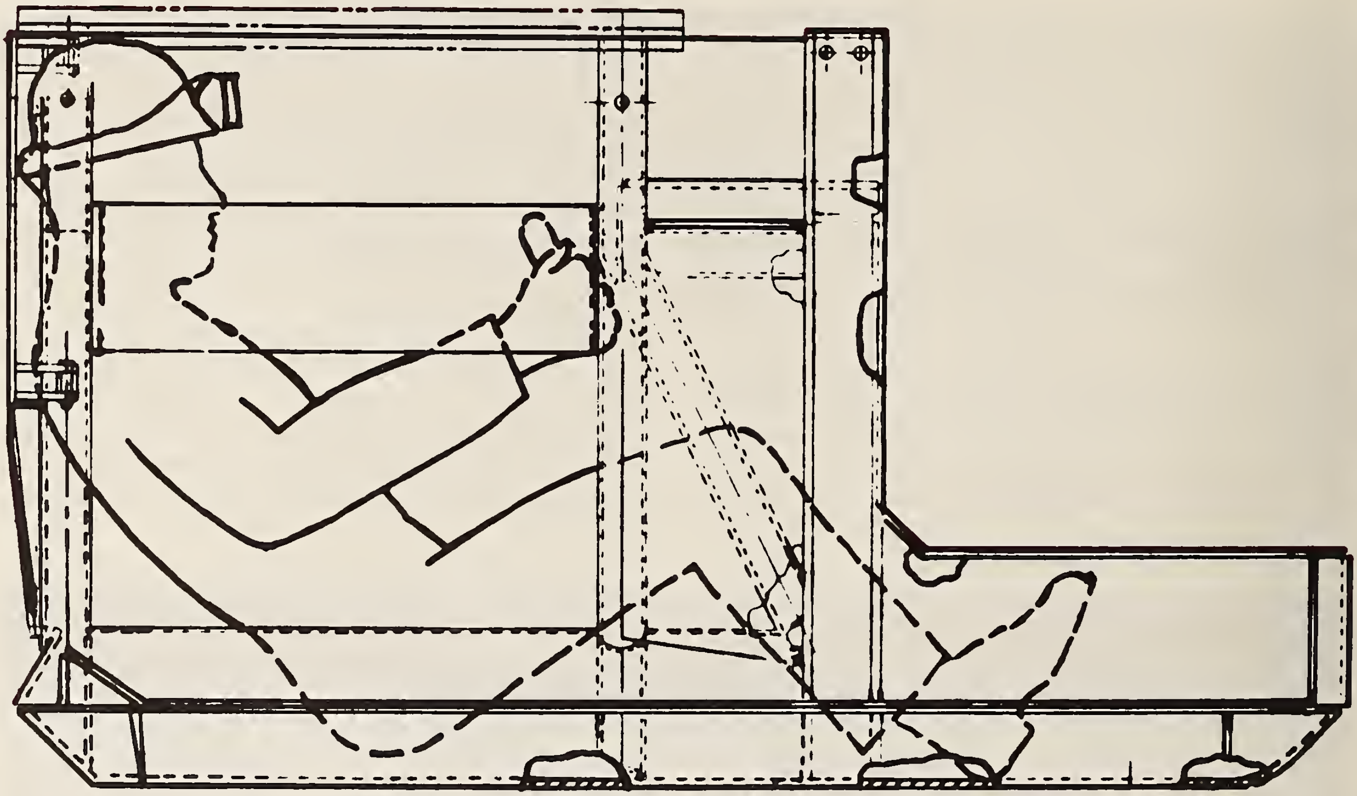

FIGURE 3. - Transverse shuttle car canopy layout.

o A transverse-mounted, floor-riding canopy for an FMC 6L shuttle car.

o A transverse-mounted canopy for a Joy 14BU10-11A loading machine.

Mockups of seats and other equipment were installed in these canopies. Three seating configurations were considered. The first configuration, with the operator seated in a cross-legged position, was considered uncomfortable. The second configuration, which offered a seat which swivelled 35° from side to side, was not considered compatible with the transverse-mounting concept. The third configuration, which had a sling seat which pivoted slightly either forward or backward for adjustment and seated the operator with his legs slightly bent and his feet and lower legs in a tunnel extending below the car body, was considered the most comfortable and responsive to transverse canopy requirements.

The mockups were evaluated on the basis of the following criteria:

o Suitability for operators ranging from a 5th percentile female to a 95th percentile male.

o Maximum inside dimensions.

o Reach envelopes for control placement.

o Seat design.

o Vision.

o Ease of ingress and egress.

o Operator comfort.

Recommendations resulting from this evaluation were incorporated into the canopy design.

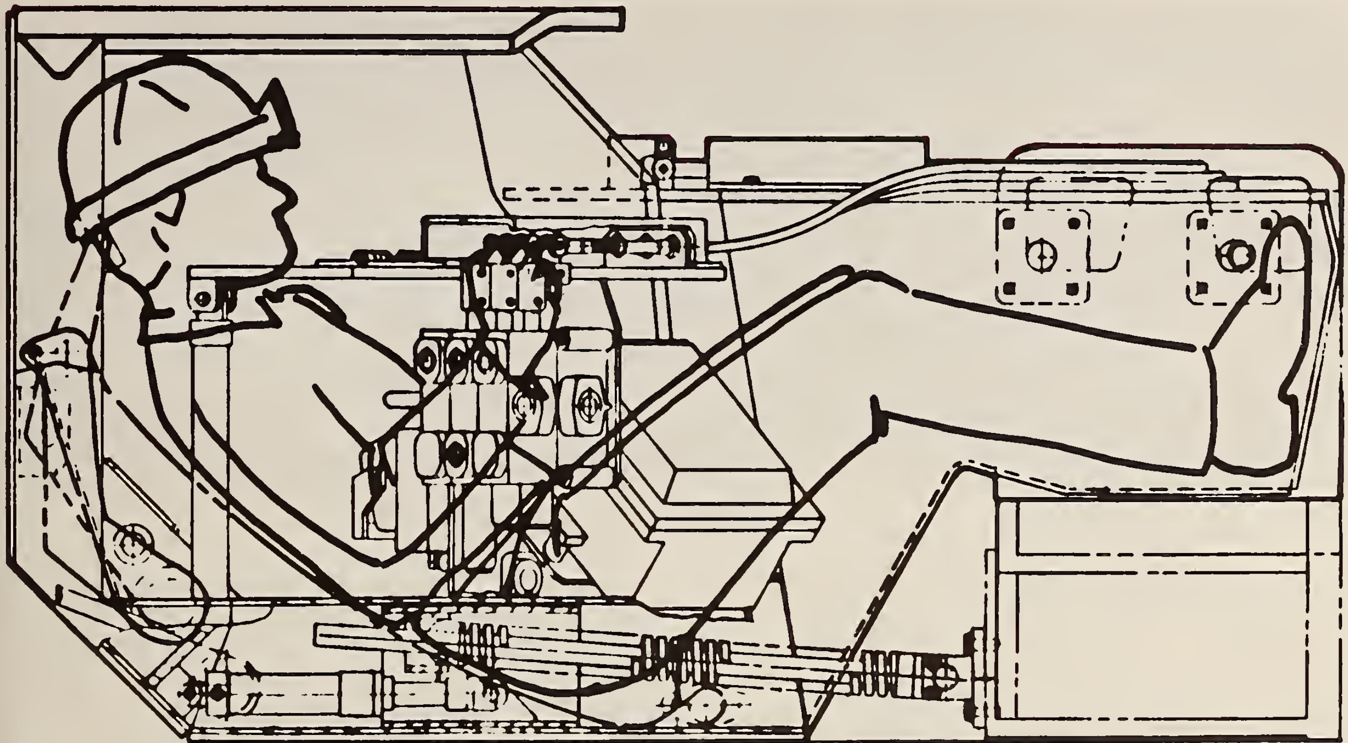

FIGURE 4. - Transverse loader canopy layout.

SHUTTLE CAR CANOPY DESIGN

ESD's shuttle car canopy, shown in figure 5 on FMC 6L shuttle car, has the following design features:

Transverse Mounting.--Seating the operator in a position facing at 90° to the direction of shuttle car travel eliminates the need for the operator to change seats when changing from inby to outby tram and thus leave the protective canopy. Also, the canopy provides better protection from rib bursts or ribbing than conventional canopies.

Floor Riding.--Allowing the canopy to ride on the mine floor reduces the hazard of roofing associated with end mounted canopies. The canopy bottom is flat and curved upward on all four edges, giving it a sled contour to facilitate moving over the mine floor. This sled contour also keeps material on the mine floor from entering the canopy.

Canopy float (floor-riding capability) has been provided by the addition of vertically mounted channels on the inby and outby sides of the canopy, which interface with guide roller assemblies mounted to the car body sides. Two guide roller brackets interface with each channel to guide the canopy as it rides up and down over the floor.

Pivoting Operator Seat.--The operator's seat is composed of heavy canvas fabric 18 in wide and supported by a pivoting strong back. The fabric forms a sling which is adjusted by pivoting the strong back forward, positioning the operator up and forward, or pivoting it backward, positioning the operator down and back. The operator sits with his legs slightly bent and with his feet and approximately 8 to 10 in of his lower leg in the tunnel area (fig. 3). This tunnel extends below the car body and conveyor boom and houses the brake master cylinder and operating pedal and the tram switch and foot actuation pedal. The operator's left foot actuates the brake pedal, and the tram switch is actuated by a pedal that pivots

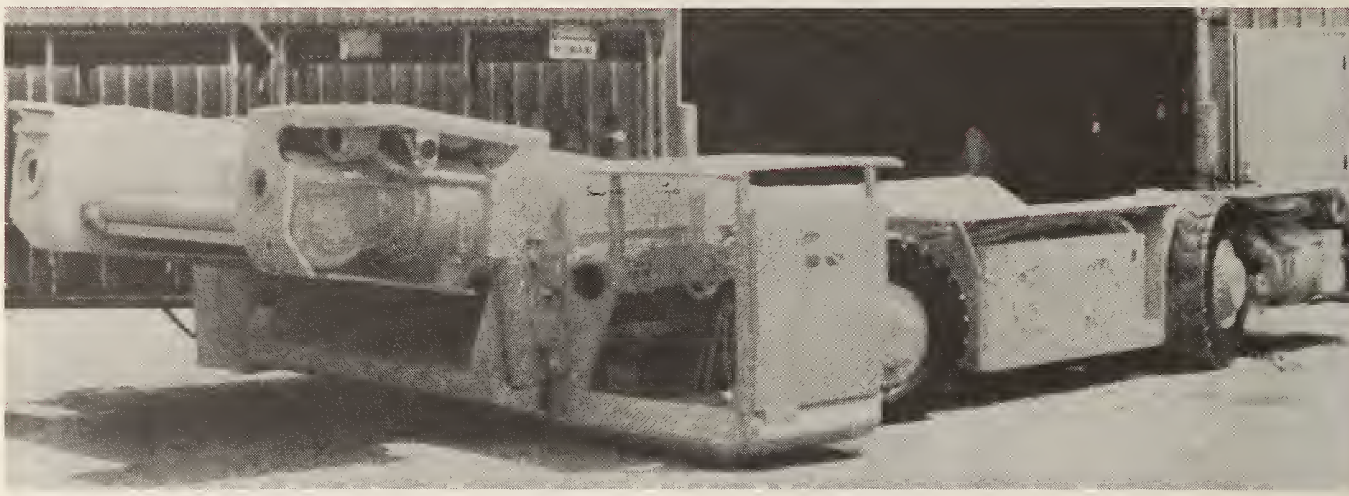

FIGURE 5. - Transverse operator compartment on FMC 6L shuttle car.

about a vertical centerline. The shuttle car moves in the direction of tram pedal rotation.

Easily Reached Controls.--All controls are within easy reach of the operator while in his normal sitting position.

Improved Operator Vision.--Because of the transverse mounting of the canopy, the operator can see both inby and outby without leaving the canopy and changing seats. He also has roof-to-floor vision without extending his head outside the canopy.

SHUTTLE CAR REWORK

To provide room for the canopy tunnel and its upward movement, the following car body rework was performed:

1. The car body was notched to provide clearance for the canopy tunnel and its upward movement.

2. An extension was added to the outby side of the outby fender to keep mud from being thrown into the cab by the wheel.

3. Doubler plates were added to compensate for loss of car body strength due to notching.

Rework was performed on the conveyor boom as follows:

1. The top plate of the conveyor was raised approximately 3 in over that used in the standard FMC 6L design.

2. The conveyor side plate bottom edge was cut out on the canopy mount side to accommodate the canopy tunnel and its upward movement.

3. The space for the conveyor flight return support was reduced by raising the conveyor return guiding side plates.

4. Cable troughs were mounted to the side surfaces of the conveyor vertical plate. These channels doubled as guides for the conveyor flights and were added to clean coal from a valley that was created in the conveyor top plate when it was raised.

UNDERGROUND EVALUATION OF THE SHUTTLE CAR CANOPY

An evaluation of the shuttle car canopy was successfully performed at a Virginia Crews Coal Co. (VCCC) mine. VCCC is a drift entry coal mining operation with seven mines, all located in a 5-square-mile area in West Virginia. VCCC operating personnel and management were extremely cooperative throughout the evaluation process.

The evaluation site was a conventional mining operation with a seam height averaging 52 in. The roof in this mine is bolted, and the floor is relatively dry and pitching at approximately 4 pct. Working height is approximately 48 in. During the evaluation, a Goodman loader was used to retrieve the coal at the face and load either the shuttle car or a scoop. The load was then trammed to the feeder-breaker. Some ribbing of the canopy occurred, especially when tramming at an intersection. Time for a complete cycle was approximately 4 min, with 40 s each utilized in loading and unloading.

Initial reaction to the shuttle car canopy was mostly favorable. The following comments were particularly positive:

- Smooth ride.
- Comfortable seat.
- Roomy canopy.
- Easy ingress and egress.
- Good vision inby and outby.
- Easy orientation to steering.
- No difficulty with pivoted, foot-operated tram switch.
- No change in sitting position required when changing between inby and outby tram.

The following were recommended for improvement:

- Seat sling adjustment.
- Coal entering the canopy at floor level on the entry side when moving into position to unload at the breaker. This problem was corrected by adding 6-in-high plate on the entry side.
- Coal entering by the opening in front of the operator. This problem was corrected by adding an expanded metal shield over the opening.

Figure 6 shows the shuttle car compartment after these improvements were made.

RECOMMENDATIONS FOR FUTURE WORK

Floor-riding canopies offer the most effective use of available head room space, and development of this concept should be continued. For lower working heights, efforts should be made to extend the tunnel farther under the shuttle car body. The operator would then be in a layback position, and more of his legs would protrude into the tunnel. A decrease of 10 in in canopy height could be achieved.

An evaluation site for the loader canopy shown in figure 4 has not yet been located. This loader canopy was designed for use in 39-in headroom. Its suspension system, as designed, consists of captured pivot pins on top, a horizontally mounted adjustable spring suspension on the bottom, and a shock-absorbing radius arm. This suspension system permits upward, downward, or sideways movement of the canopy when roofing or ribbing. This resiliency minimizes damage to the structure and loader attach points and minimizes impact on the operator. This loader canopy offers significant improvements over the state of the art in low-coal canopy technology.

FIGURE 6. - Final configuration of shuttle car compartment.

CABS AND CANOPIES FOR FMC UNDERGROUND COAL MINING EQUIPMENT

By Martin D. Wotring[1]

ABSTRACT

A low-seam canopy has been developed by FMC Corp. to be used on scoops and shuttle rams. It also can be adapted to other equipment. A midseam roof bolter has been developed with built-in canopy protection. This machine features the operator compartment in the center of the machine where tramming and bolting can be done under the protection of the canopy. Cabs and canopies used on other roof bolters and shuttle cars are also discussed.

INTRODUCTION

The 1969 Coal Mine Health and Safety Act required the installation of canopies on face equipment. Initially, many coal miners were opposed to these canopies, which were being retrofitted on existing underground equipment. As more and more lives were saved, most of this opposition vanished. However, operators of equipment used in very low seams still experienced canopy problems, so MSHA subsequently revised the canopy regulations to exclude all machines used in mining heights under 42 in. Equipment manufacturers, rebuild facilities, and coal miners have since tried many different methods of developing protection for the operators.

ROOF BOLTERS

Figure 1 shows the standard cab and canopy configuration on a model 300 roof bolter. The canopy covers a tramming deck on the side of the machine and the drilling station at the front. The original operator's deck was lengthened and widened to allow the operator's position to be lower, and the tram valve was

FIGURE 1. - Standard cab and canopy on model 300 roof bolter.

[1]Lead engineer, roof bolters, FMC Corp., Mining Equipment Division, Fairmont, WV.

placed outside the deck to allow more room for the operator. The canopy in figure 1 was designed to work in seam heights from 34 in up.

Figure 2 shows "floating" operator's deck with a canopy on a model 3000 roof bolter. This deck was located beside the drill boom where the operator can tram the machine as well as install the bolt. The "floating" deck allowed the machine to be built in a lower package. This machine was intended for use in seams 32 in and up.

The cab and canopy configuration on the model 370 roof bolter (fig. 3) positions the operator in the center of the unit. Tramming and bolting are done under the protection of the canopy. This machine is intended for use in coal seams 6 ft and up.

Dual-head roof bolter models are available with canopies over the drill station similar to the canopies on the single-head bolter in figure 1 and the operator's deck (fig. 4). These canopies are basically designed for 42 in and above.

SHUTTLE CARS, SCOOPS, AND SHUTTLE RAMS

The canopy for the center-driven model 5L (fig. 5) has four posts, which can be mechanically or hydraulically operated. The canopy for the end-driven model 10L shuttle car (fig. 6) has only three posts, to provide better operator vision. These machines are intended for use in seams of 42 in and up.

A "low-coal canopy" designed for scoops and shuttle-rams is mounted in a track which allows it to roll from over the operator (fig. 7) to a position over the frame of the machine (fig. 8). By sliding the canopy back over the machine frame, entering and exiting the operator's deck is made easier. This canopy is mechanically adjustable, locks open or closed, and is easily installed on other equipment.

Another protective feature used on scoops and shuttle rams in low coal is a "glancer." When the coal seam is so low that the operator cannot look over the top of the machine, the operator will lean out of the deck and look along the side of the machine. As a form of protection from the ribs, the "glancer" is added to the outer edge of the operator's deck.

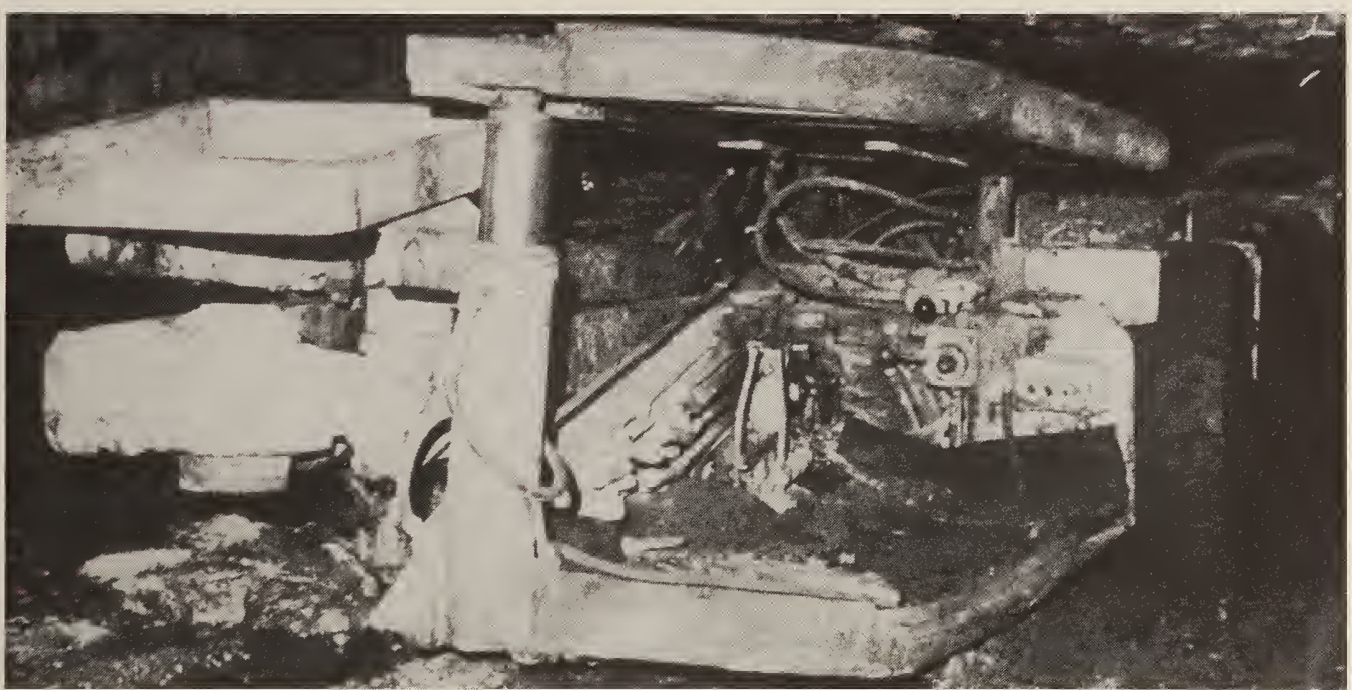

FIGURE 2. - Floating operator compartment on model 3000 roof bolter.

FIGURE 3. - Model 370 roof bolter with central operator platform and canopy.

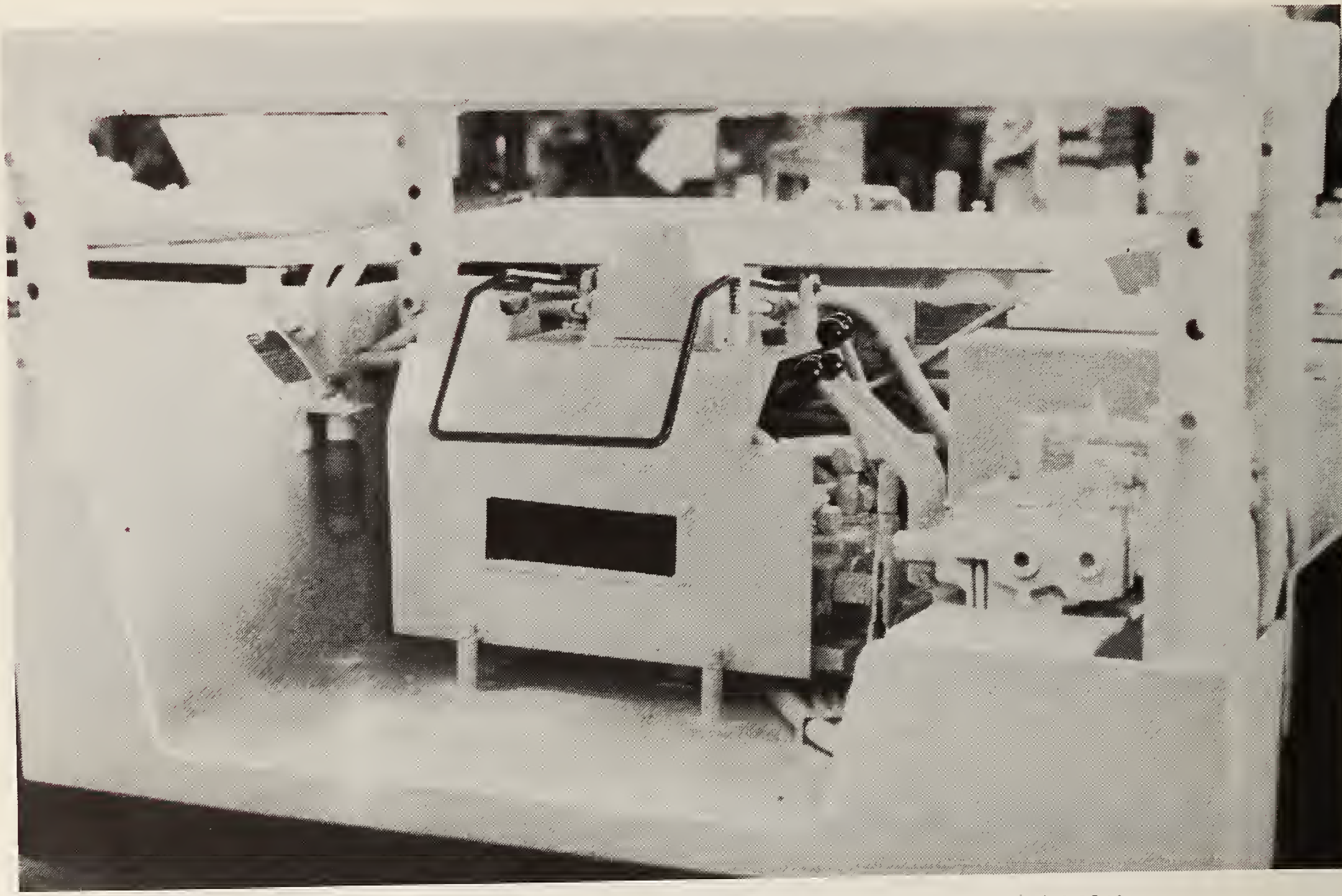

FIGURE 4. - Tram compartment on dual-head roof bolter (model 3510).

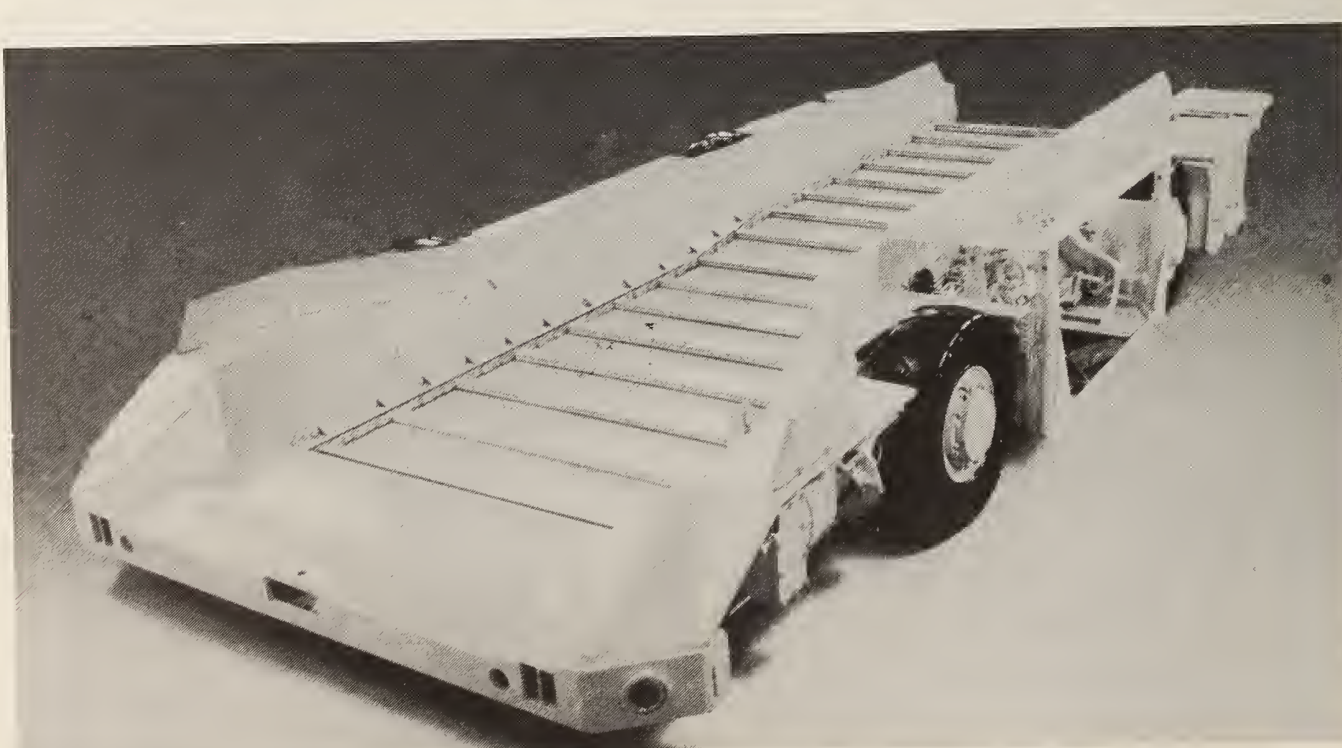

FIGURE 5. - Model 5L shuttle car with center-mounted cab and canopy.

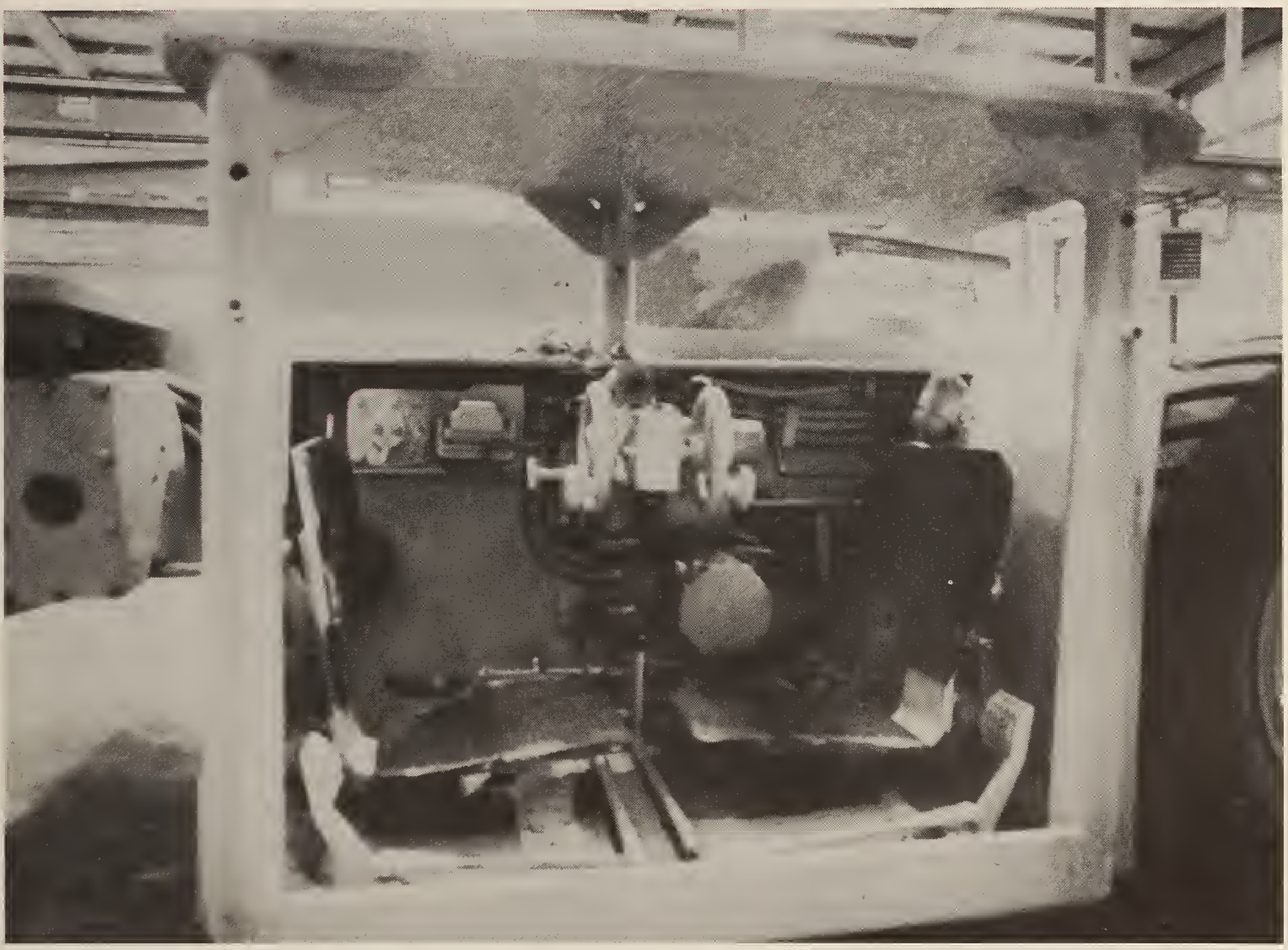

FIGURE 6. - End-driven shuttle car (model 10L) with three-post canopy.

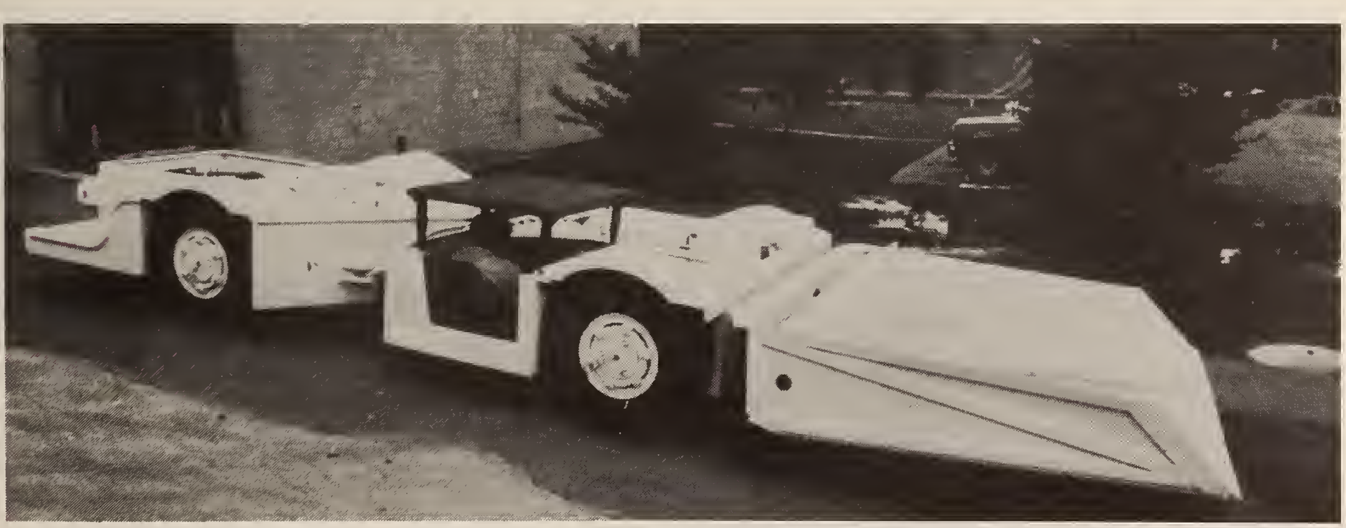

FIGURE 7. - Low-coal scoop with sliding canopy in closed position.

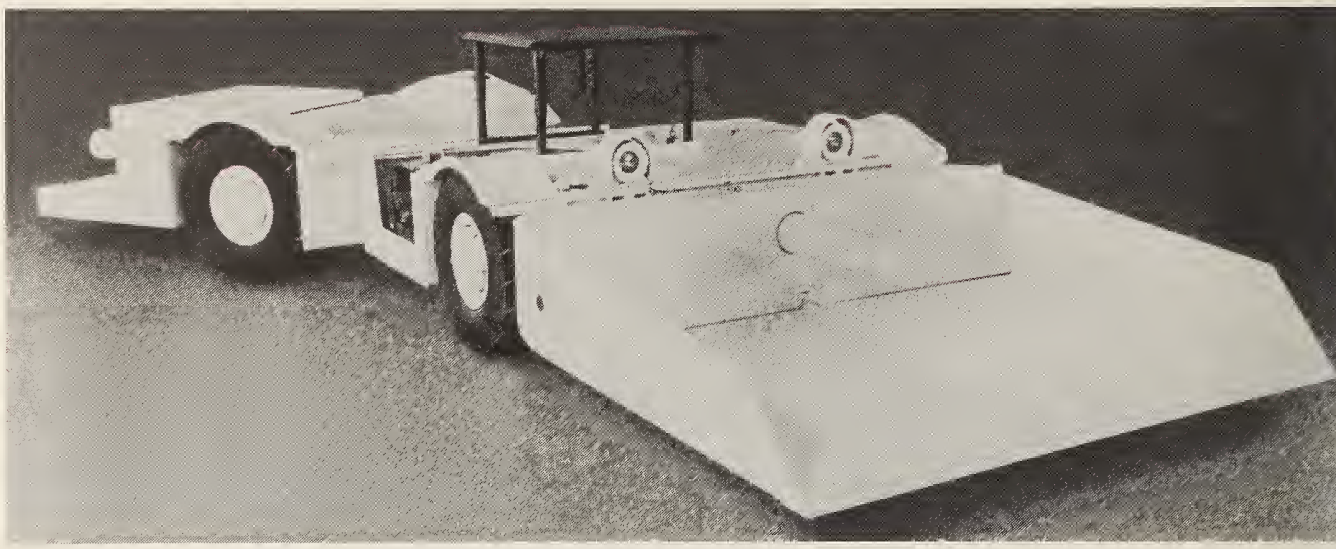

FIGURE 8. - Low-coal scoop with sliding canopy in open position.

CABS AND CANOPIES FOR JOY UNDERGROUND MINING EQUIPMENT

By Gary C. Marshall[1]

INTRODUCTION

In early 1971, the first operator's protective canopies were designed for Joy mining equipment. Since then, more than 370 different cab and canopy designs have been produced. Many more were on the drawing board but never reached production. More than 5,000 cabs and canopies have been shipped to Joy's customers over the past 10 years. This paper shows the evolutionary process in developing cabs and canopies on Joy underground mining machines.

Joy's first protective canopies were fabricated from plate and pipe such that the top structures were reinforced with ribs, making them much deeper than present designs, which use flat plate tops without ribs. The early structures (fig. 1) were very strong, but visibility was adversely affected and extra headspace was used by the pipes or ribs. This is not a serious problem when operating in high seams; however, many machines operating in seam heights of less than 5 ft required lower compartments with thinner canopy sections. Reinforcing ribs were still used, and adjustable height columns became popular.

CONTINUOUS MINERS

It is difficult to predict exactly how much clearance is required between a continuous miner canopy top and the lowest objects on a mine roof. For example, continuous miners tip up and down on their center of gravity when moving over an undulating floor, causing some unexpected problems. A typical miner with a 44-in-high, fixed canopy requires 15 in of clearance to operate on a transition from level ground to a 10° downslope in a 59-in-high seam. However, figure 2 shows that the same miner needs 22 in of vertical clearance to operate on a change from level to a 15° slope, so the seam height must increase to 66 in to keep the canopy from striking the mine roof. Lowering the canopy height does not change the clearance requirements, but it does permit working in a lower seam. If the canopy height in figure 2 is lowered to 33 in, a 10° slope can still be safely traversed if the seam height is 48 in (15-in vertical clearance required). The 15° slope can be negotiated (22-in required clearance) if the minimum seam height is 55 in and the canopy height is 33 in.

Early Joy cabs and canopies for continuous miners were usually rigid box structures surrounding the operators. Sometimes adjustable columns were used to provide easy height changes as the mining conditions varied. When the fixed canopies were "roofed" owing to rolls and bumps in the floor, as in figure 2, designers proposed floating compartments. Joy believes that floating compartments provide the best features for low seams. The canopies on Joy's floating compartments have either three or four adjustable columns and solid plate tops for good visibility and maximum safety. Some operator cabs have side, or rib, protection for high-seam mining applications. Others have MSHA-approved face lighting systems.

In very low-seam heights, a split-level top on a floating compartment provides good visibility on a lower height machine such as the 14CM miner shown in figure 3. The canopy top in figure 3 is vertically adjustable in three different positions. Joy's lowest continuous miner, the 15CM (fig. 4), has a 23-in-high chassis and a 30-in-high operator's compartment (fig. 5). Since most 15CM miners are operated

[1]Joy Manufacturing Co., Franklin, PA.

FIGURE 1. - Rib-reinforced canopy on Joy shuttle car.

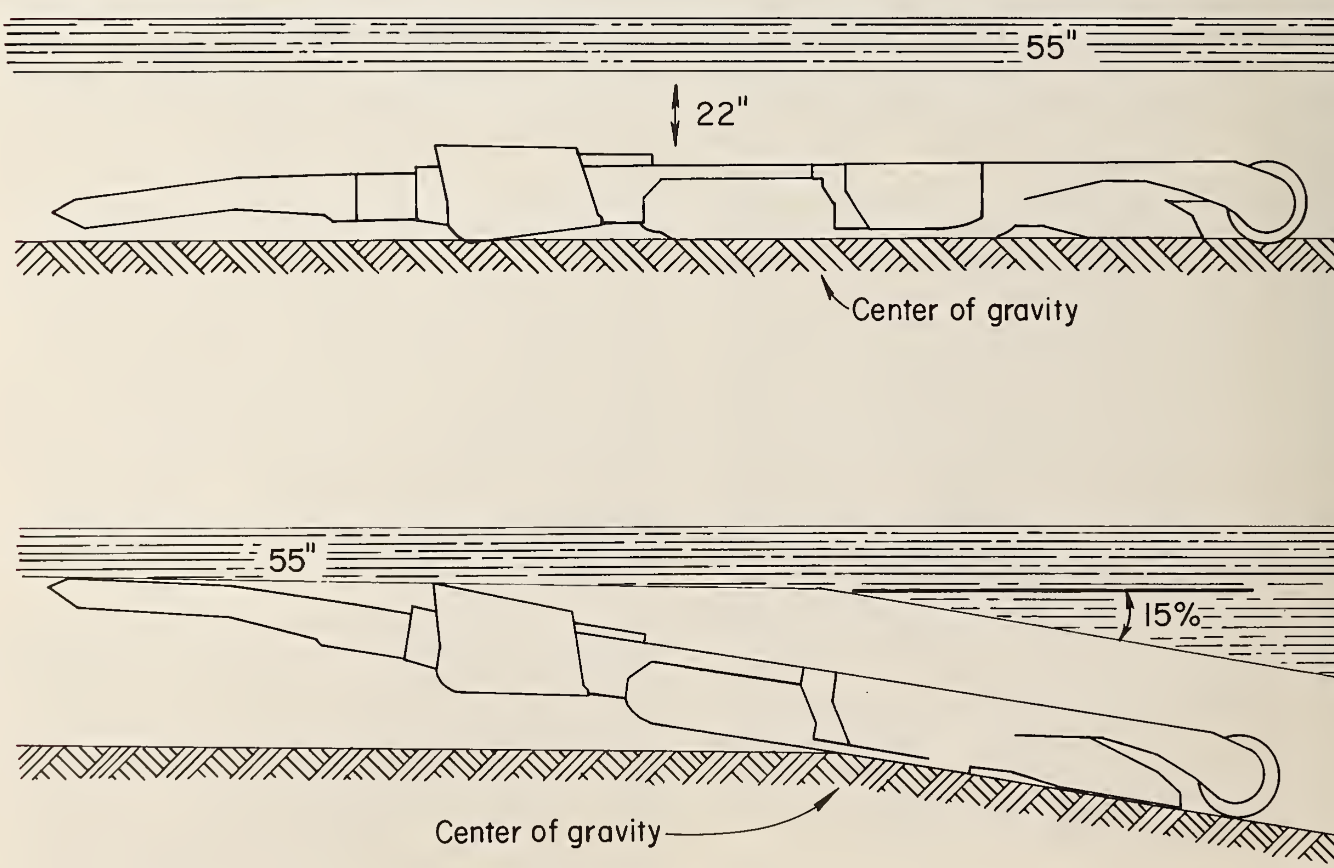

FIGURE 2. - Upward movement of continuous miner canopy in undulating conditions.

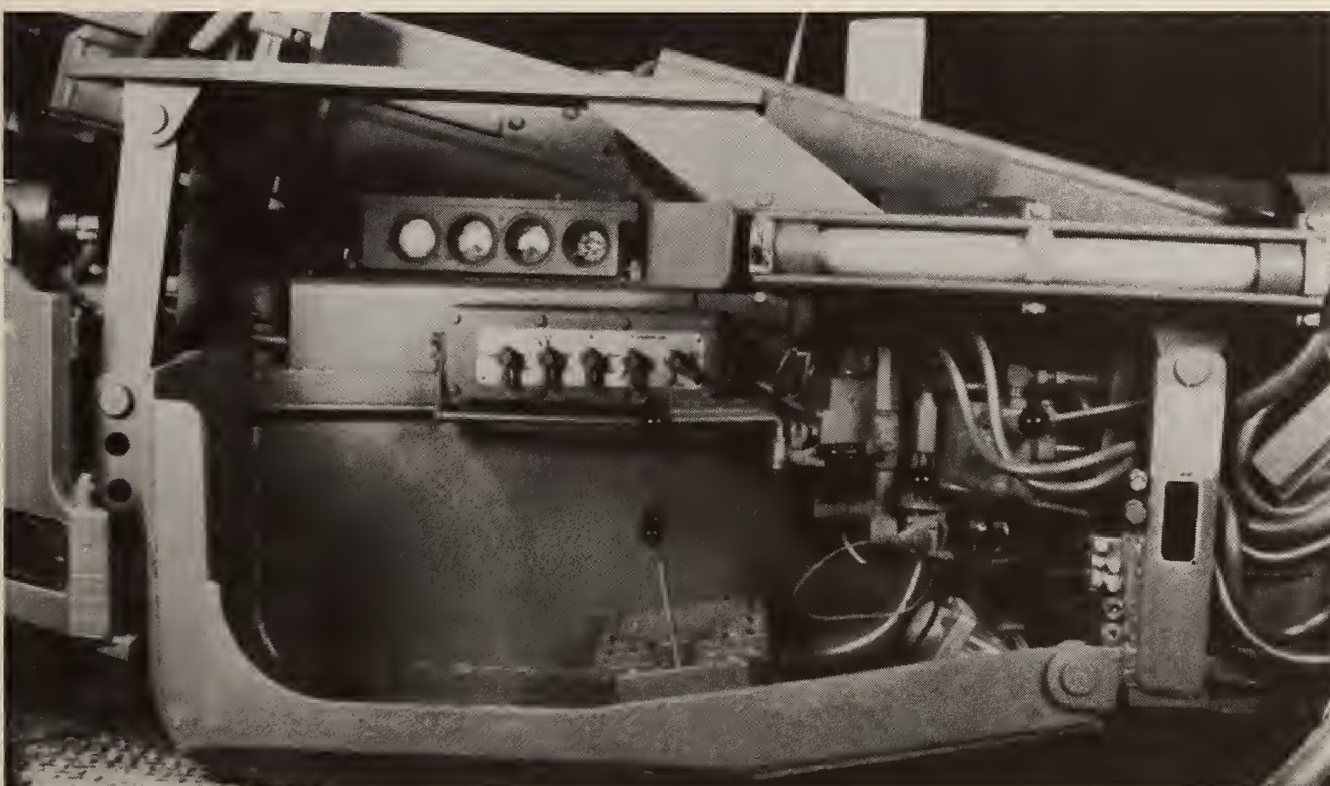

FIGURE 3. - Floating cab and split-level canopy on model 14CM continuous miner.

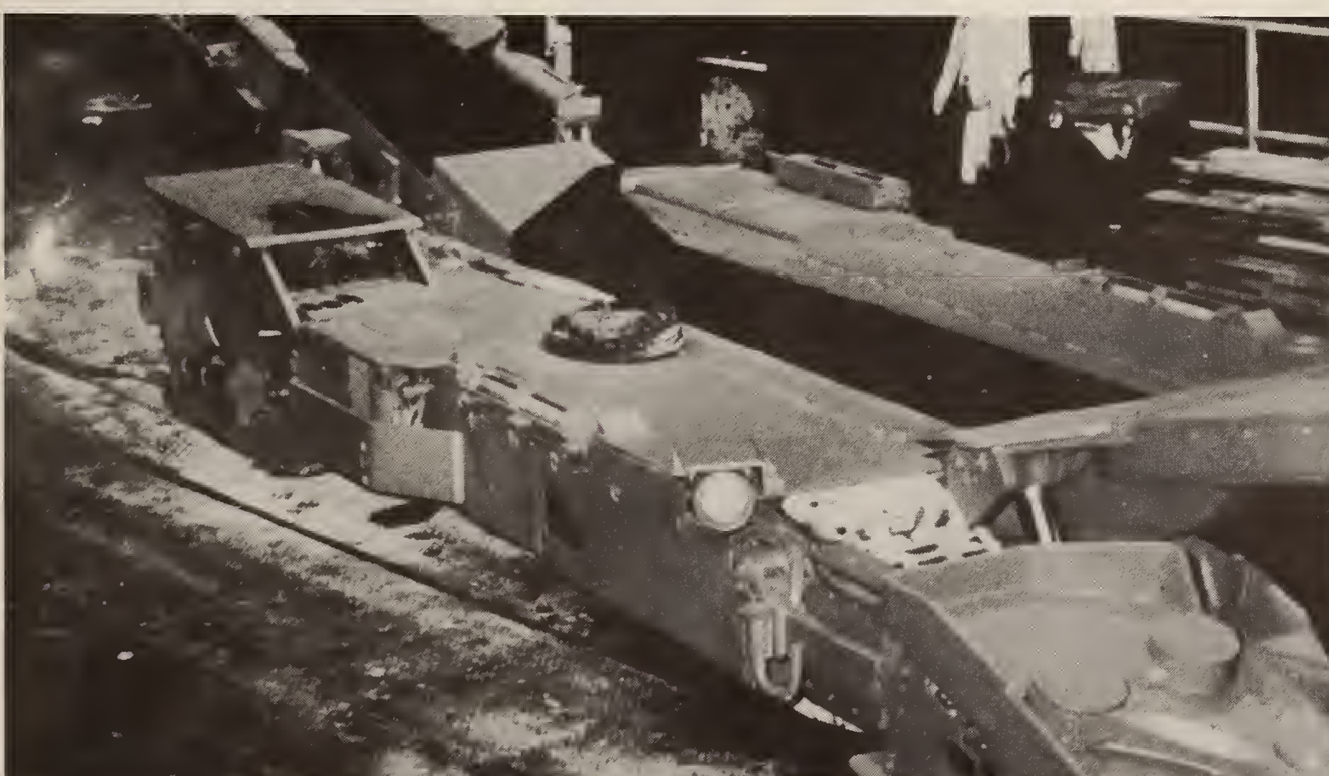

FIGURE 4. - Overall view of model 15CM continuous miner.

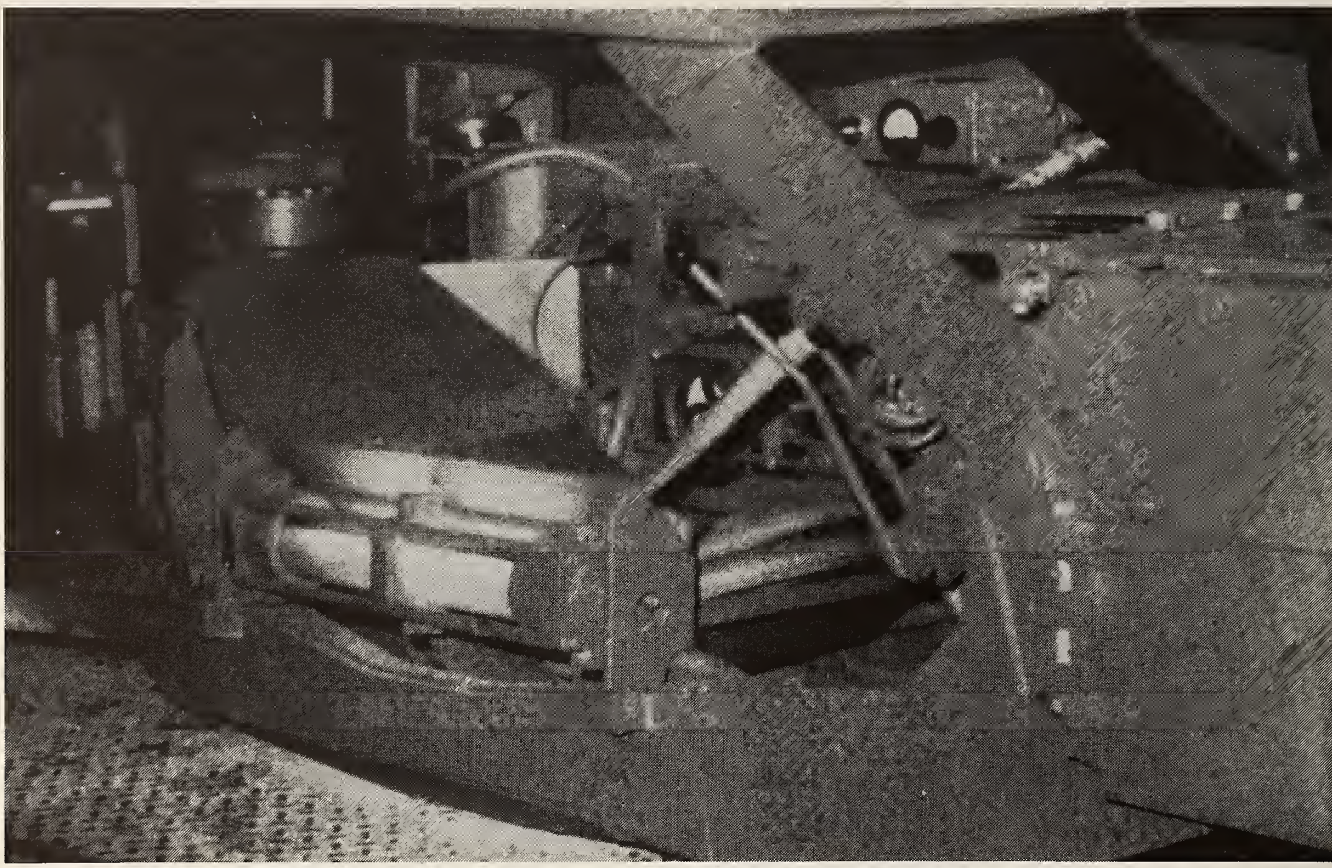

FIGURE 5. - Operator compartment on model 15CM continuous miner.

FIGURE 6. - Wooden mockup used to design continuous miner cabs.

by remote control and do not have operators riding on the miner, Joy developed the compartment in figure 5 specifically for particular customers. Fitting the operator, the controls, and all other necessary items within a 30-in cab height was a very difficult design job.

Full-scale wooden models (fig. 6) are essential to producing successful, innovative cabs and canopies, especially for lower height designs. The wide variety of controls and options require the use of mockups to evaluate the locations for each device. Product managers, designers, field engineers, and customers all have an input into the detailed design process. Many months of work are required before an actual compartment is built, but the result is a sound enclosure with a high chance of success.

Joy also manufactures continuous mining machines with integral roof bolters and temporary roof support (TRS) cylinders. The TRS safety posts are set against the mine roof before a bolter operator proceeds to the drilling-bolting area just in front of the miner operator.

SHUTTLE CARS

Most of Joy's shuttle car cabs and canopies have the unobstructed flat plate tops. Figure 7 shows the cab and canopy on an end-driven shuttle car, and figure 8 shows a center-driven machine. The expanded metal screen next to the conveyor side of the compartment in figure 7 prevents spillage on the operator and keeps the operator from inadvertently squeezing an arm or finger between the elevating conveyor and the canopy top. Over the years, pin-adjustable canopy posts have replaced screw-adjustable and fixed columns because the screws were difficult to operate if the posts were bent or the screws became corroded. Joy's most popular shuttle car canopies today provide for pin adjustments in 2- and 4-in increments.

Floating compartments have been developed for shuttle cars operating in lower seams. Figures 9-11 show recently designed floating compartments on center-driven 21SC shuttle cars. Several of Joy's customers are operating floating units like these, and more cars are on order. The floating decks have well-rounded, beveled bottom edges to prevent plowing of the mine floor while tramming. Smooth, positive cab mounting slides are needed so the compartment floats freely without binding.

SUMMARY

Compared to the last decade, it is doubtful that Joy will produce as many new cab and canopy designs during the next 10 years. However, it is anticipated that improvements in operator's controls, comfort, visibility, and safety will continue.

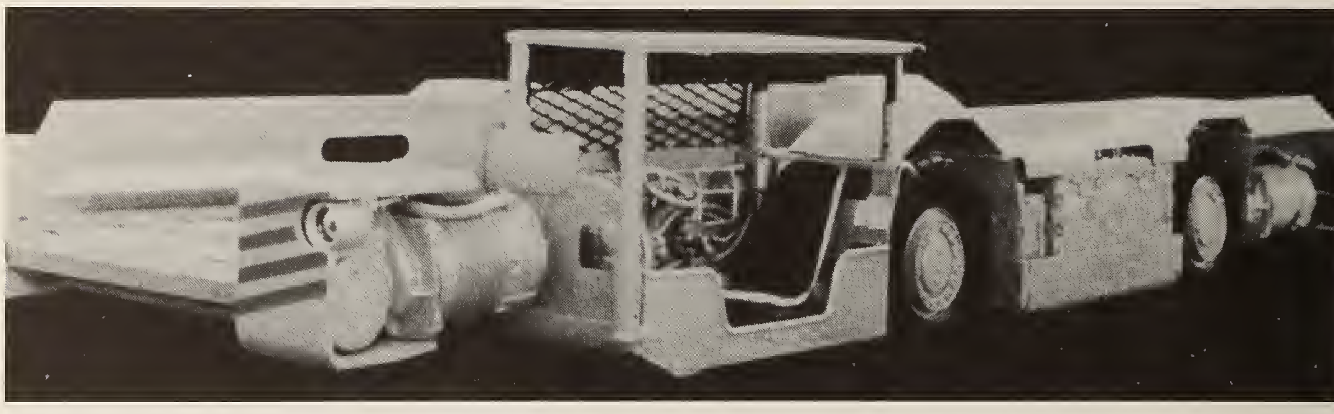

FIGURE 7. - End-mounted cab and canopy on Joy shuttle car.

FIGURE 8. - Center-mounted cab and canopy on Joy shuttle car.

FIGURE 9. - Prototype floating cab on center-driven shuttle car.

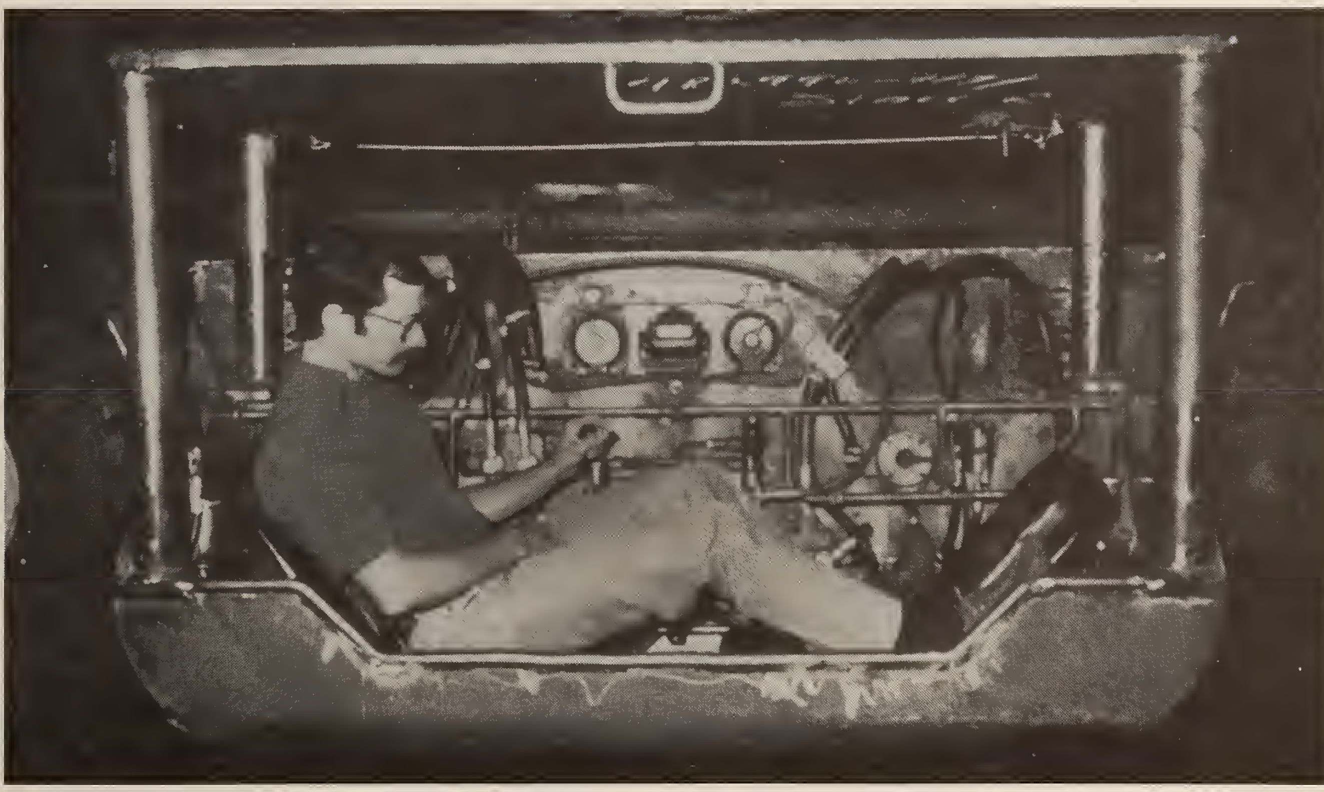

FIGURE 10. - Modified floating cab on center-driven shuttle car (side view).

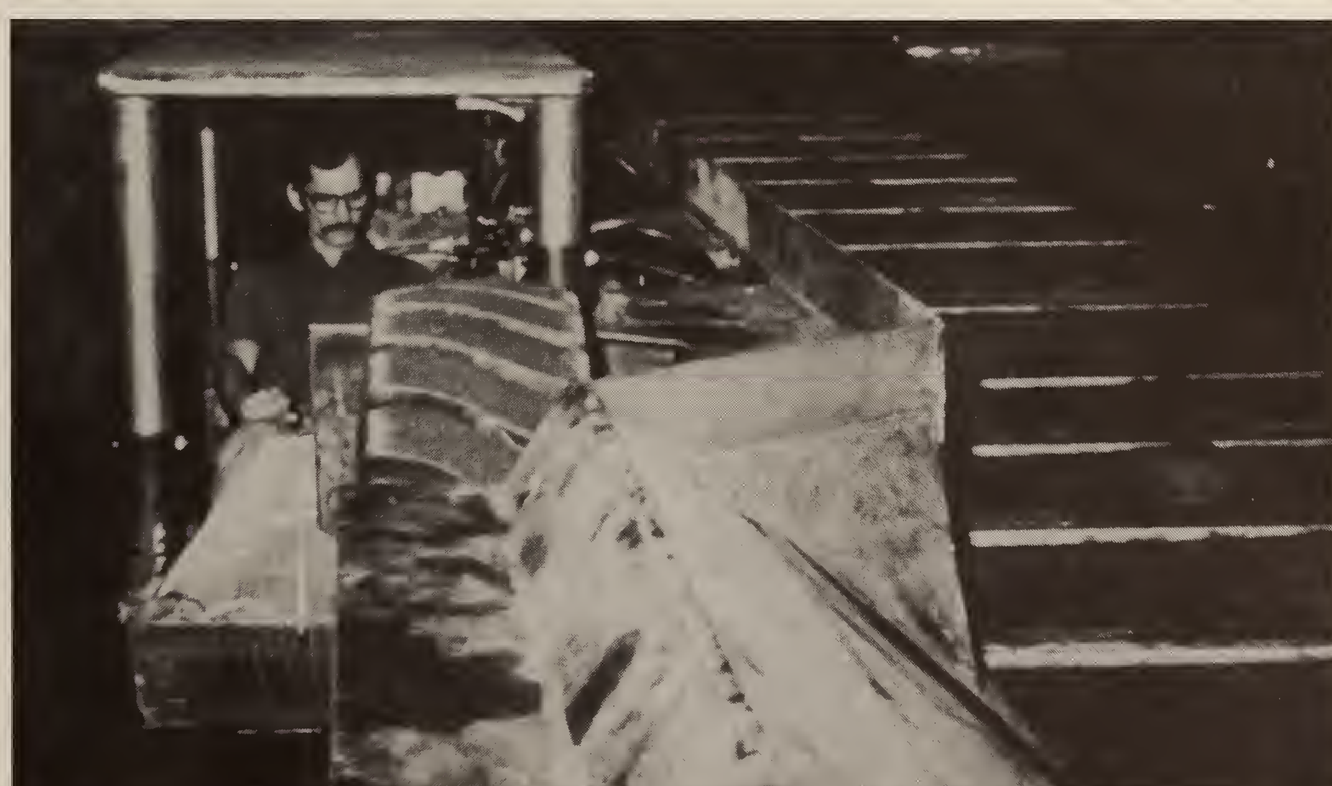

FIGURE 11. - Modified floating cab on center-driven shuttle car (end view).

CABS AND CANOPIES FOR LEE-NORSE CONTINUOUS MINERS

By E. W. Hiltebeitel[1]

INTRODUCTION

The design of a cab or canopy for a continuous miner is subject to many outside influences in addition to the seam height to be considered. In the ideal case, the operator's area is considered from the inception of the machine design. In the case of the Lee-Norse LN 800 continuous miner, it was possible to begin cab design essentially at the beginning of the machine design, starting with consultation of outside sources and human factors specialists. The initial design sketches developed into mockups and later into prototype machines and finally into the production design being sold today. The results of this development have affected many other designs in Lee-Norse continuous miners. This paper reviews the process that was used on the LN 800 and shows how a design can evolve over the course of a long development program. It also discusses some of the cab and canopy developments for low-height miners.

DESIGN PROCESS

The design process of the operator's area for the LN 800 began with the decision to improve the cab early in the machine design process. Such a decision must be accepted by management and shown to offer a true market advantage. The earlier the cab design is started, the more likely that a good design will be developed. One of the factors is choosing space for the operators before it has been allocated to other components or devices on the machine. This space must be determined by considering other machine parameters, including the length of the machine, the width of the machine, height restrictions, and type of machine involved--in this case, a continuous miner (fig. 1). One important factor in a continuous miner is the distance from the operator to the face, or the front of the machine. This effectively determines the safe and legal depth of cut and has a direct effect on productivity and safety since a deeper cut allows more continuous operation before place change. The major consideration, however, is operator size. The cab should be designed to be compatible with the size range from 5th percentile females (smaller individuals) to 95th percentile males. If such considerations are used, the cab should be comfortable for 90 pct of the population using the machine.

The next decision involves the general design approach. For example, the cab could be designed completely in-house, it could be totally subcontracted to outside consultants or specialist organizations, or a combined approach could be used. The combined approach can offer the best of both worlds; however, it requires diplomacy, tact, and careful consideration of the relations between the manufacturer's staff and the consultant's staff. In-house design can be quicker and less costly, if staff is available. Outside design avoids "tunnel vision" or the "not invented here" syndrome, but usually costs more in initial cash outlay. If consultants are to be used, the selection process is extremely important. The contract should be definite about the time frame for the work, the work to be done, and the acceptable form of the final report or design.

For the design of the LN 800 cab, we chose the combined approach. Phillip Stevens Associates of Skaneateles, NY, was chosen since they had a number of

[1] Product design engineer, Lee-Norse Company, Pittsburgh, PA.

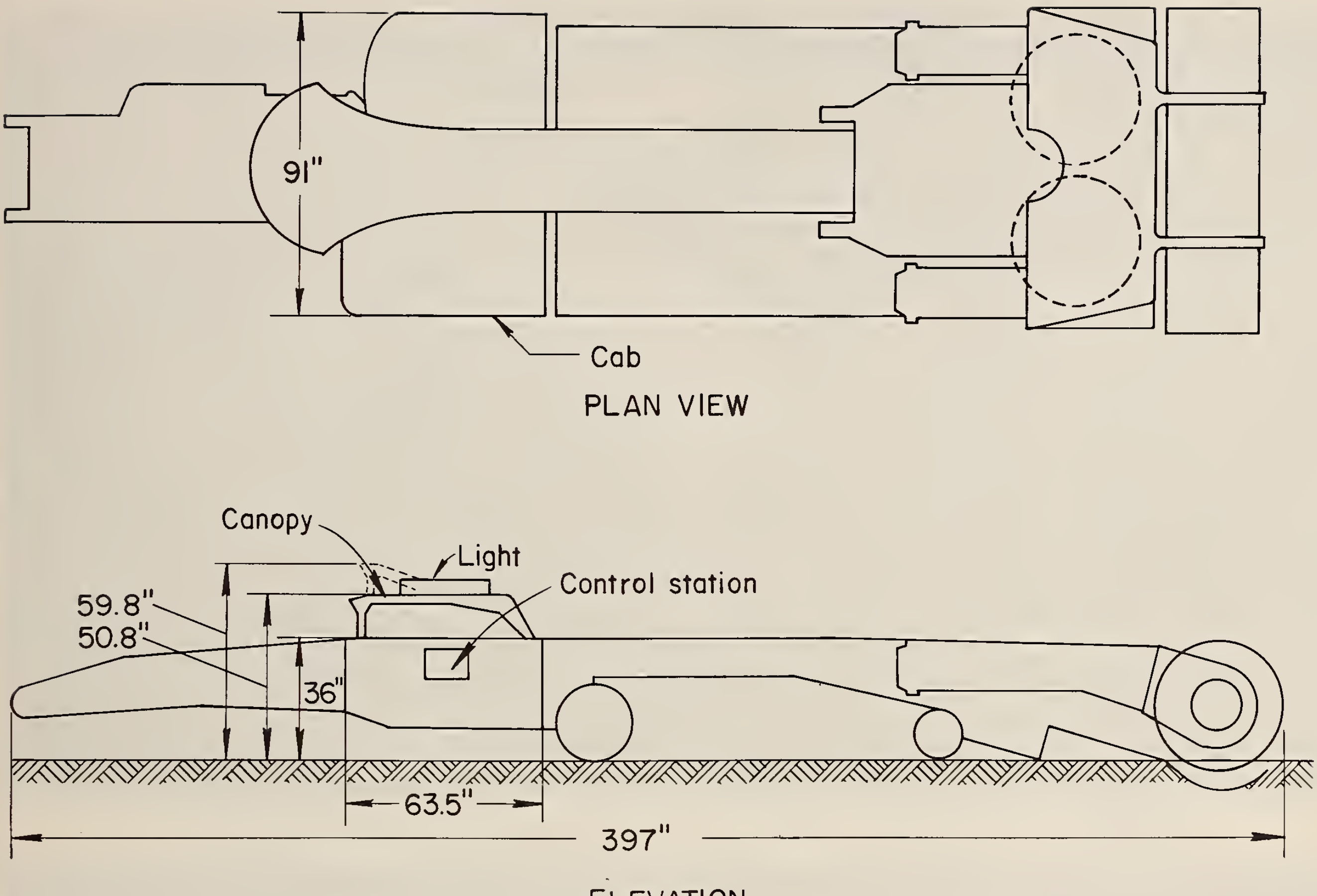

FIGURE 1. - Layout drawing of LN 800 continuous miner.

successful design and human factor projects for Ingersoll-Rand Corp. In the initial meetings with Phillip Stevens Associates, Lee-Norse attempted to define the space available, the specific components that could *not* be changed (and the reasons they could not be changed), the functional controls desired, and the best available machine layout at the time. As the machine and compartment designs progressed, further meetings were held to clarify and combine ideas from both parties. A certain amount of redesign occurred on both sides at this stage.

After a firm paper design was established, a mockup was the next step. Mockups are excellent for design reviews, but they can be expensive and difficult to transport. The mockup was substantially constructed to allow people to "try it on for size." Figures 2 through 5 show how 50th and 95th percentile size male operators fit within the operator's area with the canopy in the low and high positions. The mockup was reworked in the process of design and proved to be an effective way to make good decisions on the prototype design features.

Prototype construction was the next step taken on the LN 800. After final mockup acceptance and completion of detail drawings, two prototype machines were built (fig. 6). During the process of prototype construction, the consultant reviewed the prototype and commented on areas of improvement or difficulties not identified in the mockup stage. The prototype was then field-tested, and comments from the operators on the equipment were noted and evaluated as impartially as possible. The consultants reviewed the underground operation of the prototype after the operators of the machine had a chance to familiarize themselves

FIGURE 2. - Cab mockup - 50th percentile operator with canopy in low position.

FIGURE 3. - Cab mockup - 95th percentile operator with canopy in low position.

FIGURE 4. - Cab mockup - 50th percentile operator with canopy in high position.

FIGURE 5. - Cab mockup - 95th percentile operator with canopy in high position.

FIGURE 6. - Prototype cab and canopy on LN 800 continuous miner.

with the new machine and its operation. These evaluations were followed by rework of the prototype as required. The final stage of the prototype design reflected a value analysis, considering the advantages of the human-engineered design versus its cost.

At this point the design was ready for production. The LN 800 compartment design process also affected other machines in the product line. It was very difficult to measure productivity increases or safety improvements relative to the new design of the LN 800 operator's area; however, the qualitative results showed in positive comments from the owners and operators of the equipment.

PROBLEM AREAS

Potential pitfalls to the design approach described here include human factors data, which are most often taken from samples of the military and therefore represent a younger sample than the general population; this sample is also in above-average physical condition. One must also consider additional width and motion restrictions due to cap lamps, self-rescuers, and other belt-mounted equipment. Hand and foot access must be designed for gloved hands and heavy boots, and simplicity in design is essential. It is particularly difficult to maintain simplicity in low machines and still provide good human factors over a wide range of operator shapes and sizes.

Another area of difficulty is spare controls. Many human factor specialists recommend different-length handles and/or different-shaped knobs to provide tactile sensation of machine operation. This requires the mine to stock more spare parts. Even if the parts are stocked, the wrong spare knob or handle can easily be installed by mine mechanics, creating the potential for serious errors. In addition, electrical enclosure designs must be finalized in the initial machine design stages owing to the time involved in X/P certification by MSHA. Finally, even in long-term programs such as the LN 800, only a limited time is available for review, testing, and redesign.

DESIGN FEATURES

Figure 7 shows a closeup of the LN 800 operator area. One of its advantages is the single control lever for the conveyor; it moves right or left to swing the conveyor tail section and moves up and down to lift or lower the conveyor. The separation of the tram controls from the hydraulic controls is designed to increase safety. There is a logical sequence to the pushbutton station; starting at the trailing cable entry end of the station, the operator proceeds forward on the machine for the normal starting sequence. The start buttons are recessed to prevent accidental tripping. The stop buttons are covered with plates or paddles such that a slap of the hand stops the machine in an emergency. This effectively acts as a backup for the emergency stop and makes the stop mechanism easier to locate. Finally, the entire seat assembly swings out to allow access to control panels, circuit breakers, and the miner water system without major disassembly of the machine. The seat itself is vertically adjustable, has lateral and lumbar support, and includes a self-draining design.

CURRENT LOW-COAL DESIGNS

The operator compartment on the Lee-Norse 285 miner (fig. 8) has a floating cab that doubles as a stabilizer shoe to allow a wider, deeper operator's area than the previous design with a separate stab shoe. The Lee-Norse 245 miner has a similar floating cab. The seating position is more comfortable in the floating

FIGURE 7. - Closeup of LN 800 operator area.

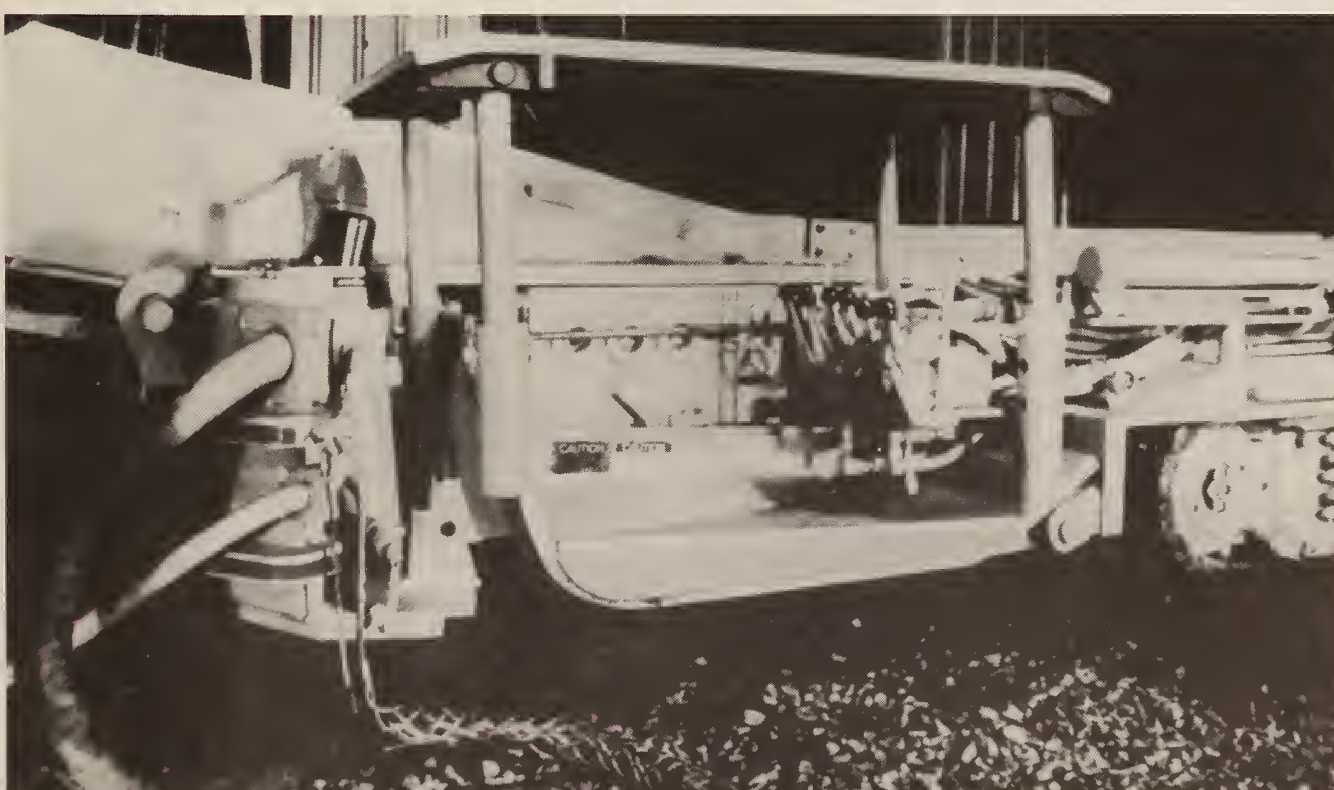

FIGURE 8. - Floating cab and canopy on low-coal continuous miner.

FIGURE 9. - Redesigned controls for low-coal continuous miner.

cab, and the visibility is improved. The floating cab can be mechanically locked in a position clear of the ground, and the canopy height can be adjusted independently in the front and the rear of the compartment. We are currently reviewing this design to move the controls closer to the operator so that they move with the cab, rather than being mounted on the fender and fixed relative to the cab position (fig. 9).

EVALUATION OF "MINIMUM" AND "LOWEST PRACTICAL" WORKING HEIGHTS FOR SAFE USE OF CANOPIES

by William W. Aljoe[1]

ABSTRACT

This paper outlines an analytical approach to determining the "minimum working heights" and "lowest practical working heights" necessary to allow the safe use of canopies on underground coal mining equipment. Each element of the working height (mine floor to nearest overhead obstruction) is discussed in some detail, emphasizing the variability of the numerical values assigned to each element. The effects of machine type, machine frame height, and mine conditions on the working heights attainable with canopies are reviewed. With state-of-the-art cab and canopy technology, these variables will frequently prevent the safe use of canopies in low coal seams without extensive modifications to existing equipment.

INTRODUCTION

Roof falls have historically been one of the most frequent causes of fatalities in underground coal mines. Preventing injuries and deaths from such falls is a difficult technological challenge, but progress is being made through a variety of engineering advancements. For example, the life-saving potential of properly designed and constructed cabs or canopies on self-propelled face equipment has been demonstrated in numerous instances when operators escaped serious injuries from roof falls, some so massive that the machine was buried. Unfortunately, a number of technical problems remain unsolved in the design of functional operator compartments for mining equipment working in low coal seams.

Three principal problems are associated with the use of canopies on low-coal equipment: "roofing" of the canopy during travel over uneven floors, limited vision of the machine operator, and severely cramped operator compartments. Design changes to minimize any of these problems usually worsen the impact of at least one of the other two. If an operator is uncomfortable or has restricted vision, he or she tends to operate the machine in an unsafe manner, such as leaning beyond the protection of his canopy or machine frame. Because many existing cabs and canopies were not designed to compensate for this, numerous injuries to miners have occurred from collisions with the ribs, roofs, or other objects in the mining section.

At present, Federal regulations require protective operator compartments in sections having a minimum mining height of 42 in. However, extensive review of field data indicated that this requirement could have better addressed the uniqueness among mining sections and the seriousness of operational problems with existing canopies in working heights between 42 and 54 in. In numerous cases, low working heights prohibited the consistent use of canopies despite substantial efforts by coal companies to achieve compliance with canopy regulations through innovative cab and canopy design concepts. Often, these designs were unsuccessful because only complete machine redesign or machine replacement would have allowed safe, efficient operation with a canopy.

This paper describes the results of approximately 3 years of research, sponsored principally by the Bureau of Mines,

[1]Mining engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

to document the application of cabs and canopies in low-coal mines. Most of this research was performed by Bituminous Coal Research, Inc., Monroeville, PA, under Bureau contract.[2] This paper describes a procedure that can be used, if the machine, operator's compartment, and canopy have been designed specifically for low coal, to define the "minimum" and "practical" working heights at which canopies could be used without roofing and without restricting operator comfort or vision.

THE MINIMUM WORKING HEIGHT WITH A CANOPY - WHAT DOES IT MEAN?

The working height of the underground mining section is probably the most critical factor governing the successful use of canopies. First, it is very important to note that the term "working height" used here is not the same as the "mining height" contained in MSHA canopy regulations. Mining height as defined by MSHA is the total extracted height, from the mine floor to the unfinished roof; the minimum working height of a mining section is defined as *the distance from the mine floor to the lowest overhead obstruction* on the section, if the obstruction is not the result of poor mining practices. In some cases this obstruction can be the mine roof itself, but it is usually a roof support device, machine trailing cable, or ventilation tubing suspended from the roof. Thus, the minimum working height will always be less than or equal to the minimum mining height, and the mining height at any location is equal to the working height plus the height (thickness) of the overhead obstruction at that point.

Two other clarifications must be made about the meaning of the "minimum working height." First, it must be assumed that the machine frame or objects on top of the machine will *not* interfere prohibitively with operator vision. Second, the mine floor must be fairly level, with no sharp undulations. Because these conditions exist only rarely in actual practice, a "lowest practical working height" with a canopy, usually larger than the minimum working height, must also be defined. Later in this paper, procedures for quantifying the lowest practical working height are given; these take into account the actual machine frame height and degree of mine floor undulation. However, let us first examine how the minimum working height under ideal conditions can be determined.

PRODECURES FOR QUANTIFYING THE MINIMUM WORKING HEIGHT

The first step toward quantifying the minimum working height with a canopy would be to divide the available vertical clearance into seven segments as shown in figure 1. The segments are defined as follows: (*1*) mine floor to bottom of cab deck, (*2*) thickness of deck and operator's seat, (*3*) top of seat to operator's eye level, (*4*) eye level to top of miner's cap, (*5*) cap to underside of canopy, (*6*) canopy thickness, and (*7*) clearance between canopy and lowest overhead obstruction.

Using available anthropometric data and state-of-the-art technology for mining machines, operator's compartments, and canopies, a minimum value can be assigned to each of these segments. Their sum is equal to the minimum working height with the canopy. However, the operator's size, machine type, machine model, and operator compartment design all have very important effects on the values assigned to each segment. In fact, completely new or radically different equipment technology could reduce these values substantially. It may be helpful, therefore, to consider how the minimum working height could be calculated for an existing machine - a continuous miner with a very low frame.

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[2]Bituminous Coal Research, Inc. "Advancement of Cab and Canopy Design and Use in Coal Mines." Ongoing BuMines contract No. J0199055.

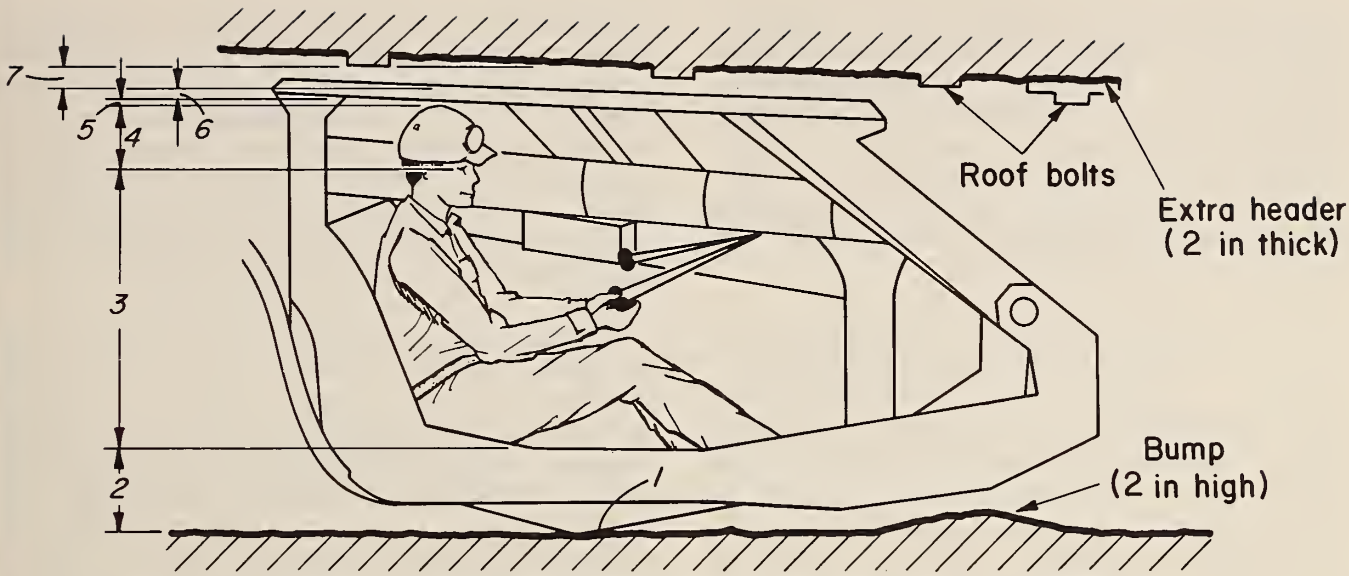

FIGURE 1. - Breakdown of minimum working height with canopies.

Figure 1 was drawn to simulate a continuous miner operator within the compartment (sketch not to scale); let us start at the ground and work upward. Because nearly all models of low-profile continuous miners can be equipped with "floating" cabs which slide along the mine floor in nonundulating conditions, the minimum value of segment *1* of figure 1 would be zero.

Segment *2* of figure 1 consists of two elements--the cab deck and the operator's seat. The floating deck must be strong enough to withstand abrasion from the mine floor. If high-strength, heat-treated steel is used, the deck can be as thin as 1/2 in. However, mild steel is a much more common and inexpensive deck material; for practical purposes, a minimum deck thickness of 1 in (mild steel) is assumed here.

The thickness of a seat or pad, when compressed by the weight of the operator, can also be as small as 1/2 in. In many cases, however, a higher seat is needed. For example, mud and water often spill into floating decks; if the seat were only 1/2 in above the cab deck, the operator would have to spend most of his or her time cleaning out the compartment. Even on a slow-moving machine like a continuous miner, a thicker seat pad is often needed to cushion the operator when tramming over rough mine floors. The minimum seat thickness assumed in this example is 2 in.

A realistic minimum value of segment *2* in figure 1 would thus be 3 in--1 in for the deck, and 2 in for the seat pad. Theoretically, this value could be lower (approximately 1 in); however, as subsequent discussion will show, this reduced deck and seat thickness will not usually result in a substantial reduction of the minimum working height with a canopy.

Segment *3* is perhaps the most critical and controversial component of the minimum working height. The distance from the operator's seat to his or her eyes is governed by the operator's size and the internal configuration of the operator compartment. According to anthropometric data supplied by SAE,[3] the seat-to-eye height would be approximately 23 in for both small (5th percentile female) and large (95th percentile male) machine operators if the operator can recline within the compartment. However, when a "sit-up" position must be utilized to run

[3]Society of Automotive Engineers. "Development of SAE Guidelines for Underground Operator Compartments." Ongoing BuMines contract No. H0308110.

the machine effectively, the required seat-to-eye height can be as much as 29 to 33 in for small and large operators, respectively. Obviously, the minimum working height with a canopy must also increase. To maximize the use of canopies in low coal, the operator's compartment must be designed to minimize the required seat-to-eye height.

Most continuous miners in use today do not have compartments that allow the operator to recline (seat-to-eye height 23 in). However, some presently available models do contain reclining seats, and compartments that provide at least a semireclining operator position can be retrofitted to other models. For the purpose of defining the *minimum* working height attainable with canopies on continuous miners, it will be assumed that segment *3* of figure 1 can be reduced to 23 in.

The distance from the operator's eyes to the top of his or her cap, segment *4* of figure 1, is approximately 6.5 in for both small and large operators. This value agrees with SAE anthropometric data and a survey of high-coal cab and canopy design done by Bendix.[4]

Segment *5* of figure 1 represents the "bounce space" required between the top of the operator's cap and the underside of the canopy. Based on numerous observations of continuous miners in operation, a value of 1.5 in was chosen; this was also the value selected by Bendix in the study mentioned above.

Canopy thickness, segment *6* in figure 1, is governed by its design and the strength of the material used. Solid-plate canopies are thinner than canopies made of structural steel tubing; if high-strength steel plate is used, it can be as thin as 1/2 in. As with cab decks, however, mild steel plate is much more common and inexpensive, so a minimum canopy thickness of 1 in (mild steel plate) is assumed here. Although canopy thickness does not usually have a substantial effect on the minimum working height with the canopy, the overall design of the canopy top can be very important.

Because the minimum working height with a canopy must be chosen so that canopy roofing does not occur, segment *7* of figure 1 must be defined very clearly. This segment represents the minimum vertical clearance required between the canopy top and the nearest overhead obstruction normally present in a flat coal mining section. Although this value is essentially arbitrary, it was chosen to be 4 in on the basis of observations of continuous miners in level seam conditions. This clearance is needed partly to overcome obstructions on the mine floor and partly to account for unexpected overhead obstructions.

Even in flat, nonundulating coal mines where good housekeeping practices are followed, debris or an obstacle of some type will usually be present on the floor of the mining section. When the continuous miner trams over an obstacle, such as a pile of loose coal or a large rock, the machine and canopy will rise temporarily. If this occurs at the same spot in the mining section where an object protrudes below the level normally occupied by the lowest obstruction (e.g., a header board or trailing cable hanging beneath the bottom of required roof bolts), the local vertical clearance could be substantially less than the working height (mine floor to roof bolt) normally present on the section. To prevent the canopy from roofing, the maximum height of the canopy above the mine floor should be at least 4 in less than the working height normally present.

Adding the values assigned to segments *1* through *7* of figure 1 yields the minimum working height needed to allow the

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[4]Farrar, R., R. Champney, and L. Weiner. Survey on Protective Canopy Design. (contract H0242020, Bendix Corp.). BuMines OFR 50-76, 1976, 163 pp.; NTIS PB 251-672/AS.

safe use of canopies on continuous miners:

Segment	in
1--Mine floor to cab deck......	0.0
2--Deck and seat thickness.....	3.0
3--Seat-to-eye height..........	23.0
4--Eye-to-cap height...........	6.5
5--Cap-to-canopy height ("bounce space")...........	1.5
6--Canopy thickness............	1.0
7--Clearance above canopy......	4.0
Total......................	39.0

EFFECT OF MACHINE TYPE AND MINE FLOOR CONDITIONS

Remember that the preceding example dealt with an ideal canopy installation--a slow-moving, low-profile machine with a properly designed operator compartment in a flat, dry, well-kept mining section. However, table 1 shows that the "minimum" working height needed to allow the safe use of canopies is different for different machine types. Also, "imperfect" conditions will increase the minimum working height with the canopy, and the effects of machine type and mining conditions can be quantified by reviewing the seven segments of figure 1.

SEGMENT *1* - MINE FLOOR TO CAB DECK

In the previous example, special care was taken not to use the term "ground clearance" when referring to this distance. The ground clearance of a floating cab deck is zero, while the ground

TABLE 1. - Breakdown of minimum working heights with canopies, inches

Segments of working height (fig. 1)	Machine type						
	Continuous miners	Shuttle cars	Scoops and tractors	Roof bolters, single-head[1]	Roof bolters, dual-head[1]	Cutters and face drills	Loading machines
1--Mine floor to cab deck.	[2]0.0	[2]0.0	[3]6.0	[2]0.0	[2]0.0	[2]0.0	[2]0.0
2--Deck and seat thickness	3.0	3.0	3.0	3.0	3.0	3.0	3.0
3--Seat-to-eye height.....	[4]23.0	[4]23.0	[5]14.0	[4]23.0	[4]23.0	[6]29.0	[6]29.0
4--Eye-to-cap height......	6.5	6.5	6.5	6.5	6.5	6.5	6.5
5--Cap-to-canopy height...	[7]1.5	[8]3.0	[8]3.0	[7]1.5	[7]1.5	[7]1.5	[7]1.5
6--Canopy thickness.......	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7--Clearance above canopy.	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Minimum working height (sum of elements *1* through *7*)...............	39.0	40.5	37.5	39.0	39.0	45.0	45.0

[1]"Tram-only" or "drill-and-tram" compartment.
[2]Floating compartment; if unworkable or unavailable, use ground clearance of operator's compartment.
[3]Floating compartment *not* available; use ground clearance of operator's compartment (6 in normal).
[4]Reclining operator position; add 6 to 10 in for sit-up position.
[5]Lie-down operator position; add 9 in for reclining, 15 to 19 in for sit-up position.
[6]Sit-up operator position; small operator.
[7]Slow-moving machines - tram speed 50 to 200 ft/min.
[8]Fast-moving machines - tram speed 350 to 450 ft/min.

clearance of the frame of the continuous miner is commonly 6 in or more to prevent it from becoming hung up in the mine bottom. In broken, irregular, or muddy bottom conditions, hangup problems often become so severe that the deck must be suspended above the mine floor at all times. The value of segment *1* of figure 1 would not be zero if adverse bottom conditions prevail; it could be as large as the ground clearance of the machine frame.

Although floating operator compartments are available for several models of shuttle cars, they must travel faster, farther, and more often than continuous miners, and they are much more susceptible to hangup problems. As a result, the coal industry has not used floating compartments on shuttle cars nearly as often as on continuous miners. When calculating the minimum working height with a canopy on a shuttle car, the value of segment *1* of figure 1 will often be equal to the ground clearance of its main frame. However, this distance can be as low as zero if very good mine floor conditions exist.

Although conceptual designs of floating cab decks have been developed for conventional equipment--cutters, face drills, and loaders--equipment manufacturers do not usually offer them as either "standard" or "optional" items on new low-profile machines. Substantial modifications or complete machine redesign would be needed to incorporate floating decks on most existing models of conventional equipment. Conceptual designs of floating cab decks have not been developed for scoops, tractors, and ramcars; substantial machine redesign would be needed.

Consequently, the mine-floor-to-cab-deck distance will not usually be zero for scoops, tractors, and ramcars. The ground clearance of the fixed deck need not be as large as the ground clearance of the machine frame, but many manufacturers will make these two clearances equal. A reasonable estimate of the value of segment *1* of figure 1 would, therefore, be the ground clearance of the machine, although new machine technology could lead to the development of mine-worthy floating compartments.

Assigning a minimum mine-floor-to-cab-deck distance to roof bolters is especially difficult because there is really no such thing as a "typical" roof bolting machine. Single-head and dual-head bolters must be treated differently; some models require the operator to walk alongside the bolter when tramming, while others have tram compartments similar to those on the machine types previously mentioned. Also, for the purpose of specifying a minimum working height with a canopy, only the tram function of the roof bolter can be considered. Because the operator must often drill and bolt while sitting or kneeling directly on the mine floor, the operator position shown in figure 1 would not apply to the tasks of drilling and bolting.

Floating tram compartments are presently available for some models of single-head bolters whose drilling, bolting, and tramming functions are performed from the same compartment at the front of the machine, near the drill head. For these machines the minimum mine-floor-to-cab-deck distance would be zero. Some models of dual-head roof bolters also have floating compartments. However, many models of single-head bolters and almost all models of dual-head bolters have separate tram compartments, whose ground clearance is usually equal to the ground clearance of the machine. For these machines, the ground clearance of the frame of the roof bolter would often be a reasonable estimate of the value of segment *1* of figure 1.

In summary, the minimum distance required between the mine floor and the bottom of the tram deck can range from zero to the ground clearance of the machine frame, depending on machine type, model, and mine floor conditions. Each individual mine-machine combination must be examined carefully to determine how large this distance must be.

SEGMENT *2* - DECK AND SEAT THICKNESS

As explained in the previous example of the continuous miner, machine design and mine floor conditions can affect the minimum thickness of the deck and seat. However, the 3-in combined thickness assumed in that example represents a reasonable tradeoff between the best and worst deck material, floor conditions, and riding comfort. For practical purposes, a nominal 3-in deck and seat thickness can be used when calculating the minimum working height with a canopy.

SEGMENT *3* - SEAT-TO-EYE-HEIGHT

The variable nature of this distance on a continuous miner was discussed in the previous example. Theoretically, the 23-in seat-to-eye height also represents the minimum height attainable on other types of electric face equipment. However, compartments on most existing low-profile machines were designed for sit-up operation; these must be modified to provide the minimum possible (23-in) seat-to-eye height. In many cases such modifications would be difficult or unfeasible because of original machine design, and the minimum seat-to-eye height would be 29 in, even for the smallest operators. Almost all cutters, face drills, and loaders presently require operators to sit upright at all times.

Some models of scoops and tractors, however, can be modified to allow machine operation from a "lie-down" position. SAE anthropometric data[5] indicate the minimum operator seat-to-eye height in the lie-down position would be approximately 14 in for both small and large persons. In the transverse or "side-saddle" compartments characteristic of scoops and tractors, the long axis of the operator's body (head to toe) is perpendicular to the direction of machine travel, and the operator needs only to rotate his or her head to see alongside the machine in the forward and reverse directions. On almost all other machine types, the long axis of the operator's body is parallel to the travel direction, and the attempt to look forward from the lie-down position would result in excessive head and neck strain. Changing seats or turning around to face the opposite tram direction would also be extremely difficult. Therefore, the lie-down operator position and 14-in seat-to-eye height are applicable only to scoops and tractors with transverse compartments.

Unfortunately, only a few models of scoops and tractors have been designed to accommodate operators in the lie-down position. Substantial modifications would be needed on most models to provide adequate leg room while allowing the operator to remain protected by the compartment. Even if such modifications are made, the resulting compartment configuration could place the operator's eyes far below the top of the machine frame, prohibiting vision to the opposite side of the entry.

SEGMENT *4* - EYE-TO-CAP HEIGHT

No significant type-to-type or model-to-model variations exist for this distance; a minimum value of 6.5 in can be used in all cases.

SEGMENT *5* - CAP-TO-CANOPY "BOUNCE SPACE"

When traveling over mine floors of equal roughness, the operators of fast-moving machines--shuttle cars, scoops, and tractors--will need approximately twice as much "bounce space" as operators of slow-moving machines--continuous miners, cutters, face drills, loaders, and roof bolters. Therefore, the values assigned to segment *5* of figure 1 would be 3.0 and 1.5 in, respectively.

SEGMENT *6* - CANOPY THICKNESS

The same statements made about deck thickness apply to canopy thickness; most existing low-coal canopies are made of 1-in-thick mild steel rather than 1/2-in-thick high-strength steel. For practical

[5]Work cited in footnote 3.

purposes, 1 in should be allowed for canopy thickness when calculating the minimum working height with a canopy on existing equipment.

SEGMENT *7* - CLEARANCE ABOVE CANOPY

The value of this dimension on continuous miners--4 in--applies equally to all machine types and models as long as large-scale mine floor undulations are not present. As will be shown later in this paper, machine type and model do have significant effects on the clearance required above the canopy when mine floor undulations occur.

SUMMARY

Table 1 summarizes the values to be assigned to segments *1* through *7* of figure 1 when calculating the minimum working heights attainable with canopies on existing equipment. As noted in table 1, many of these values can be either higher or lower because--

1. Floating cab decks may or may not be available or feasible on existing machines. If a floating deck is not commercially available for a particular equipment type, a nominal compartment ground clearance of 6 in is listed in table 1. However, the actual ground clearance of the fixed deck can be lower than 6 in, and it could be reduced to zero if mineworthy floating decks can be developed.

2. The deck and seat thickness of 3 in can be reduced to about 1 in if high-strength steel and minimal seat padding are used. Conversely, some machine operators may insist upon higher seats if mud and water spillage are excessive, and more seat padding or suspension may be needed to cushion the operator against rough rides.

3. The required seat-to-eye height is governed by the control configuration and interior dimensions of the operator's compartment. Substantial type-to-type and model-to-model variations exist.

4. "Bounce space" between the operator's cap and the canopy depends on machine tram speed.

5. Canopy thickness can be reduced if stronger steel is used; however, if steel tubing is used for the canopy, its thickness will be greater than 1 in.

6. Required clearance above the canopy in a flat coal seam depends on the number and height of unexpected obstructions on the mine roof and floor; these will vary greatly from mine to mine, from section to section in a mine, and within the same mining section.

LOWEST PRACTICAL WORKING HEIGHTS WITH CANOPIES

The ideal conditions needed to achieve the minimum working heights with canopies listed in table 1--flat, nonundulating seams and equipment that does not obstruct operator vision--will not be present on most mining sections in operation today. Therefore, we should define the "lowest practical working height" with canopies, again using state-of-the-art technology, to take into account the adverse effects of mine floor undulations and visual obstructions caused by the canopy and machine frame.

EFFECTS OF MACHINE FRAME HEIGHT

The machine frame almost always obstructs vision in low coal. Operators frequently lean outward to see alongside their machines because this is the only vision available when clearance between the frame and the mine roof is limited, even when a canopy is not present. The canopy introduces yet another visual obstruction, one that many machine operators consider "unnecessary" and "dangerous." The following paragraphs describe a simple procedure for calculating the lowest practical working height with a canopy from the machine frame height.

When defining a relationship between the machine frame height and the lowest practical working height at which a canopy can be used, one critical factor must be specified--the vertical distance between the top of the machine frame and the operator's eye level. A wide range of opinions was received regarding the distance needed to assure "adequate" operator vision. For example, in the Bendix canopy survey[6] equipment manufacturers recommended that the operator's eyes be placed 3 to 8 in above the machine frame. Conversely, the fact that low-coal equipment operators can often run their machines using solely "down-the-side" vision has been used as evidence that their eyes can be at any level below the top of the main frame. Considerable disagreement will continue to exist no matter what frame-to-eye level distance is chosen; however, for simplicity, it is assumed here that the operator's eyes must be at the *same* level as the top of the machine frame to assure adequate vision. Using this assumption and the procedures described earlier in this article, the "lowest practical working height" with canopies can be determined directly from the machine frame height.

Referring again to figure and table 1, segments *1* through *3* define the minimum distance between the mine floor and the operator's eye level. Since it is assumed the machine frame will not obstruct operator vision if it is below eye level, the lowest practical working height with a canopy will *not* be governed by the machine frame height if it is less than the sum of segments *1* through *3*. For such low-frame machines, the lowest practical working height in a flat coal seam will be equal to the minimum working height listed in table 1; operator headroom rather than vision will be the limiting factor.

[6]Work cited in footnote 4.

The first four columns of table 2 show how the machine type, compartment ground clearance, and operator seating position combine to determine the minimum machine frame height to be considered in the analysis of the lowest practical working height with a canopy. For example, if the operator compartment on a continuous miner forces a 95th percentile size male to assume an upright position (33 in from seat to eyes), the minimum frame height to be considered will be 36 in (33 in + 3 in deck and seat thickness) despite the compartment's ability to float on the mine floor. On the other hand, scoops and tractors with frames as low as 23 in can be considered because the operator's ability to lie down (if modifications to the compartment are made) places his or her eyes at this height despite the nominal 6-in compartment ground clearance. If the actual machine frame height is greater than the minimum applicable height given by table 2, it is assumed that segment *1*, *2*, or *3* of table 1 would be increased to place the operator's eyes at the same level as the frame.

The fifth column of table 2 shows how the lowest practical working height with a canopy in a flat coal seam is calculated from the machine frame height. The sum of segments *4* through *7* in figure 1 and table 1 is the required vertical clearance between the machine frame (eye level) and the nearest overhead obstruction. This clearance is 14.5 in for fast-moving machines and 13.0 in for slow-moving machines because the need for operator headroom increases with tram speed. Thus, in level seams, one of the two formulas listed in the fifth column of table 2 can be used to calculate the lowest practical working height.

Note that if the lowest practical working height were calculated with the requirement that the operator's eyes be placed at a certain level *above* the top of the machine frame, for example, 3 in, the result would be the same as if the formulas listed in table 2 were used.

TABLE 2. - Formulas for calculating "lowest practical work heights" with canopies in flat coal seams

Machine type	Compartment ground clearance, in	Operator seating position[1] and size	Minimum applicable frame height, ground clearance plus--	Formula for lowest practical working height, frame height plus--
Continuous miners...	0-6	Reclining - 5th pct female and 95th pct male.	26 in	13 in
		Sitting - 5th pct female	32 in	
		Sitting -95th pct male..	36 in	
Shuttle cars........	0-6	Reclining - 5th pct female and 95th pct male.	26 in	14.5 in
		Sitting - 5th pct female	32 in	
		Sitting -95th pct male..	36 in	
Roof bolters,[2] cutters, face drills, and loading machines.	0-6	Reclining - 5th pct female and 95th pct male.	26 in	13 in
		Sitting - 5th pct female	32 in	
		Sitting -95th pct male..	36 in	
Scoops and tractors.	6[3]	Lying - 5th pct female and 95th pct male.	17 in	14.5 in
		Reclining - 5th pct female and 95th pct male.	26 in	
		Sitting - 5th pct female	32 in	
		Sitting -95th pct male..	36 in	

[1]Modifications to operator compartments may be necessary to allow reclining and lying-down positions. "Pct" indicates percentile in entries in this column.
[2]Tram canopy only.
[3]Floating operator compartments unavailable; actual ground clearance may be more or less than 6 in.

Although the minimum applicable frame height would be 3 in lower than listed in table 2, the numerical value added to the frame height to obtain the lowest practical working height would be 3 in greater (16.0 in or 17.5 in versus 13.0 in or 14.5 in). On the other hand, if the operator's eyes are allowed to remain below the level of the machine frame, the lowest practical working height with a canopy would be equal to the minimum working height listed in table 1. The minimum applicable frame height in this case would be equal to the minimum working height minus 4 in to allow for rough bottom conditions which may cause the frame itself to hit the roof.

EFFECTS OF MINE FLOOR UNDULATIONS

Until this point, it was assumed that mine floor undulations (abrupt changes in coalbed elevation) were not prevalent. However, all mine floors undulate to some degree, and both the machine frame and the canopy will experience some amount of upward or downward movement, or excursion, when tramming through the undulation. The amount of canopy excursion must be added to either the minimum working height (table 1) or the lowest practical working height in a flat coal seam (table 2) to obtain the lowest practical working height with a canopy in undulating conditions.

Overall canopy excursion can be calculated geometrically and depends on three major factors: (1) the location of the operator's compartment and canopy on the machine, (2) the degree of change in the slope of the coalbed floor (degree of undulation), and (3) the design of the cab and canopy. Floating operator compartments can reduce canopy excursion somewhat but cannot always eliminate it. Figures 2 through 7 illustrate canopy excursion and show how it can be calculated.

Canopy Excursion on End-Driven Equipment

Figures 2 and 3 are scale drawings of a typical continuous miner tramming over a "severe" undulation--an abrupt 6° change in the slope of the mine floor. When the miner is in the position shown in figure 2, the maximum amount of vertical canopy excursion is taking place because its center of gravity (pivot point) has just crossed the undulation point. The maximum possible excursion E is equal to D

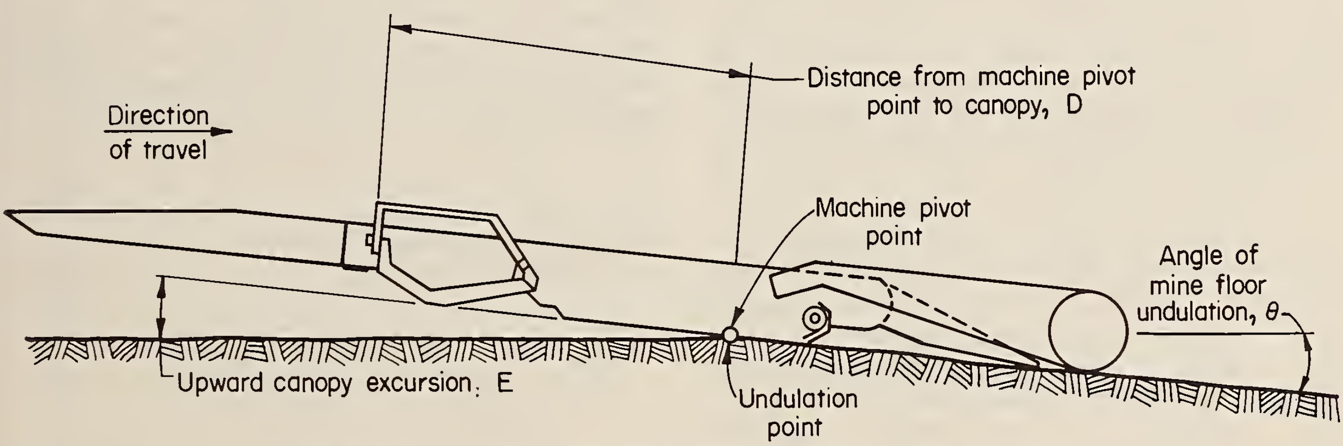

FIGURE 2. - Upward canopy excursion on end-driven equipment.

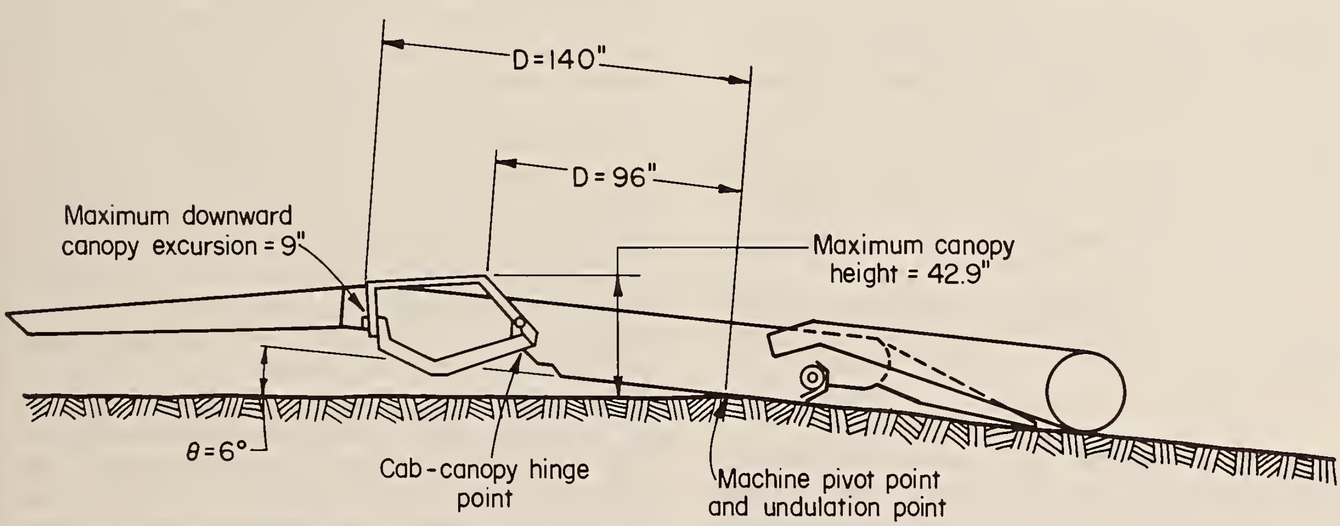

FIGURE 3. - Canopy excursion reduction with floating operator compartment.

(sin Θ), where D is the distance from the machine's center of gravity to the point on the canopy being considered, in this case the rear edge, and Θ is the degree of mine floor undulation. In figure 2, D equals 140 in and Θ is 6°, so E equals 14.6 in.

If the operator's compartment and canopy cannot float downward below the original level of the crawlers of the miner, as in figure 2, the lowest practical working height with a canopy would be 14.6 in greater than indicated in table 1 or 2, and the rear end of the canopy would "roof out" first. However, as shown in figure 3, floating operator compartments on continuous miners are usually hinged at the end closest to the cutting heads, with the rear end free to float downward until stopped mechanically, in this case by the rear bumper of the miner. The amount of downward canopy movement depends on (1) the location of the front and rear ends of the canopy with respect to the hinge point and (2) the distance below the crawler at which the deck is downstopped. To show how this downward movement can be calculated, let us examine figure 3.

Figure 3 shows the full-down position of the operator's compartment--note that the deck is *not* resting on the mine floor. The distance between the downstop block and the rear bumper of the miner when the deck is in the level position (fig. 2) represents the maximum downward excursion of the rear end of the canopy, in this case 9 in. Subtracting this value from the 14.6 in of initial upward canopy excursion yields an overall upward excursion of 5.6 in at the rear end of the canopy.

Now the excursion of the front end of the canopy must be examined. The angle through which the canopy rotates when it floats downward is the same at both its front and rear ends, and the amount of downward movement at the front end depends on its horizontal distance from the hinge. From geometry, the downward excursion was found to be 2.1 in, using compartment dimensions provided by the manufacturer. Subtracting this downward movement from the 10-in upward excursion of the front end [from the formula E = (D) (sin Θ) at D = 96 in] yields a total canopy excursion of 7.9 in. Thus, if the front and rear ends of the canopy were at the same level before the 6° undulation was encountered, the *front* end would strike the roof or roof supports first (7.9 in versus 5.6 in overall excursion).

Note in table 1 that the minimum working height for canopy-equipped continuous miners in level conditions was found to be 39.0 in. The lowest practical working height with the canopy on the miner in figures 2 and 3 can now be calculated:

	in
Minimum working height in level conditions (table 1)..........	39.0
Maximum upward canopy excursion (fig. 3)......................	7.9
Total.....................	46.9

Although figures 2 and 3 show a crawler-driven continuous miner, the procedure used to calculate canopy excursion would be the same for any wheel-driven machine whose operator's compartment is at the front or rear end. Several models of shuttle cars, roof bolters, scoops, and tractors fall into this category. Because the maximum canopy excursion will take place when the axle closest to the operator's compartment crosses the undulation point, the distance D depicted in figures 2 and 3 would be the distance from the end of the canopy to the axle of the nearest wheel. Also, if the operator's compartment can float downward at *both* ends, instead of being hinged, the amount of downward movement would be the same at both ends of the operator's compartment, and the end of the canopy farthest from the axle would roof out first.

In general, the procedure for determining the lowest practical working height with canopies on end-driven equipment can be summarized as follows:

1. Find the potential upward excursion from the formula E = (D) (sin Θ) for the actual slope change angle and pivot-point-to-canopy distance.

2. Use actual compartment geometry to calculate the maximum excursion reduction possible, as in figure 3.

3. Add the difference of items 1 and 2 to the height obtained from table 1 or table 2 for the machine under consideration.

The resultant distance is the working height that must be provided to keep the canopy from roofing when undulating mine floor conditions prevail. The same procedure can be used to calculate the "lowest practical working height" with the machine itself, simply by adding the maximum upward excursion of the machine frame (usually near its rear end) to the original machine frame height.

Canopy Excursion on Center-Driven Equipment

Figures 4 through 7 illustrate canopy excursion as it would occur on a shuttle car whose operator's compartment is located between the tramming wheels. Most low-profile shuttle cars fall into this category, along with cutters, face drills, and many models of roof bolters.

Canopy excursion on center-driven equipment is different from that on end-driven equipment in three important ways. First, the *center* portion of the canopy on a center-driven machine will experience greater upward excursion than either the front or rear end. Second, the wheelbase of a center-driven vehicle is the critical dimension governing the overall canopy excursion. Finally, both upward *and* downward mine floor slope changes can cause upward canopy excursion on center-driven machines. Therefore, four individual mine-machine-canopy configurations are shown in figures 4 through 7 to describe all situations where canopy roofing can occur.

Figure 4 shows a center-driven shuttle car whose deck is fixed at 6 in above the mine floor, tramming over an upward undulation. This situation represents the maximum upward excursion possible with a center-mounted canopy and illustrates most clearly the geometrical relationship between the cab, canopy, machine, and mine floor. Note first the enlarged sketch of the transition area around the point of coalbed slope change (undulation point). The maximum canopy excursion (E) occurs when the wheels of the shuttle car straddle the undulation point and the upward projection of the undulation point bisects the wheelbase. From geometry, it can be seen that E = (w/2) sin (Θ/2), where E is the upward canopy excursion, w is the wheelbase of the machine, and Θ is the angle of mine floor undulation.

Applying this formula to the shuttle car in figure 4 (w = 120 in, Θ = 6°) yields a canopy excursion of 3.14 in. Note also that the center portion of the canopy is closest to the mine roof, which has been drawn parallel to the mine floor in figure 4.

The lowest practical working height with a canopy on this shuttle car can now be calculated (the minimum working height is 46.5 in because 6 in of compartment ground clearance is added to the sum of segments *2* through *7* of table 1):

	in
Minimum working height.........	46.5
Overall canopy excursion (fig. 4).....................	3.1
Total.....................	49.6

Figure 5 shows a slightly different shuttle car, this one with a floating compartment, as it trams over an upward mine floor undulation. The formula for calculating the potential upward canopy excursion is the same as in figure 4, E = (w/2) sin (Θ/2). However, the overall canopy excursion would be equal to

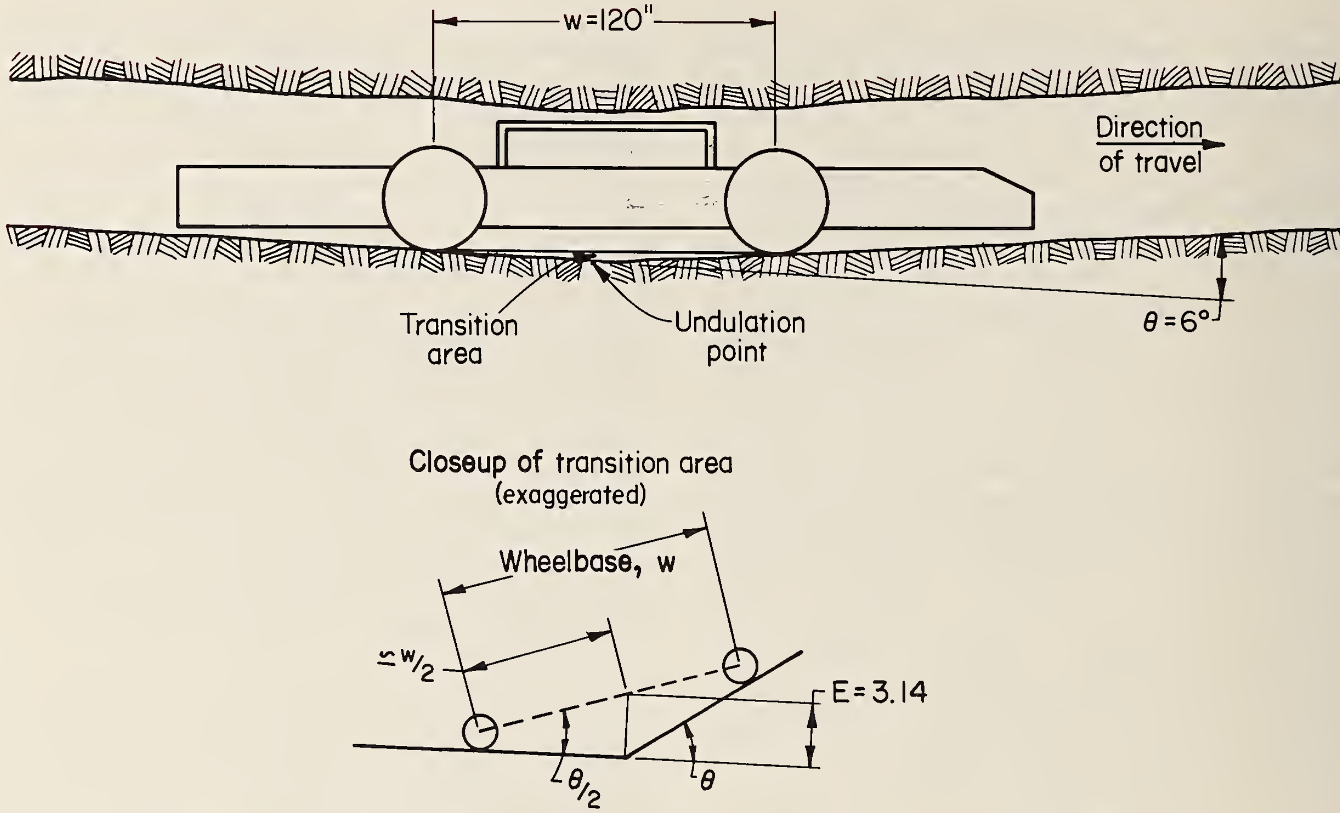

FIGURE 4. - Upward canopy excursion on center-driven equipment (shuttle car).

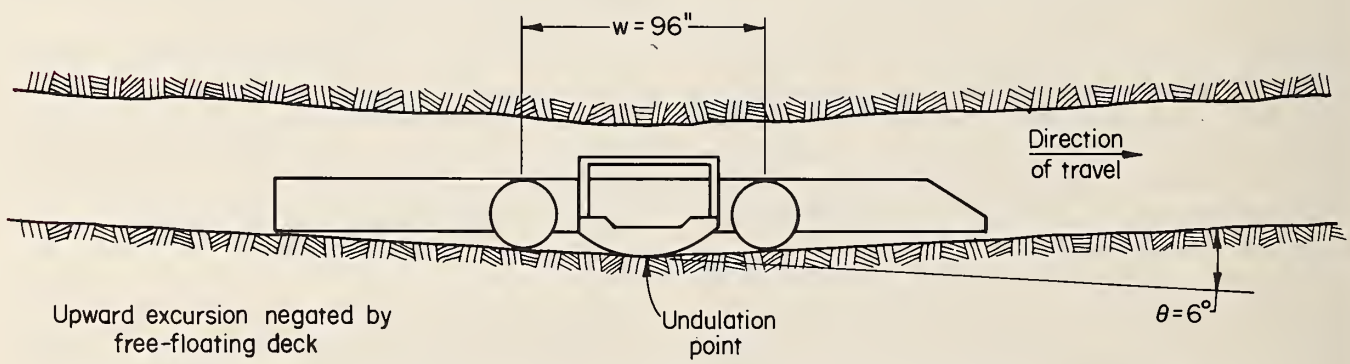

FIGURE 5. - Center-driven shuttle car with floating operator compartment - upward undulation.

zero if the cab deck were allowed to float downward far enough to negate the upward movement. Then the lowest practical working height with a canopy would be 40.5 in, the same as in table 1.

Figure 6 shows the same shuttle car as in figure 5, this time tramming across a downward mine floor undulation. However, instead of floating downward into open space, as in figure 5, the compartment in figure 6 will be pushed upward by the mine floor as the shuttle car crosses the undulation point. The maximum canopy excursion occurs when the undulation point contacts the midpoint of the deck and is calculated from the formula $E = (w/2) \sin (\Theta/2)$.

Figure 7 shows a shuttle car whose operator's compartment is fixed at 6 in above the mine floor, tramming across a downward mine floor undulation. The compartment ground clearance enables it to pass over the undulation point as though the floor were level. The canopy

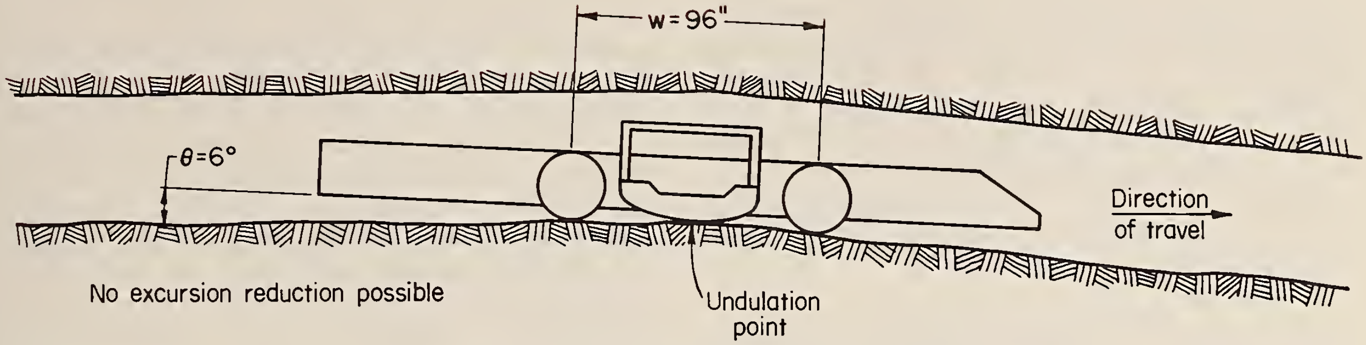

FIGURE 6. - Center-driven shuttle car with floating operator compartment - downward undulation.

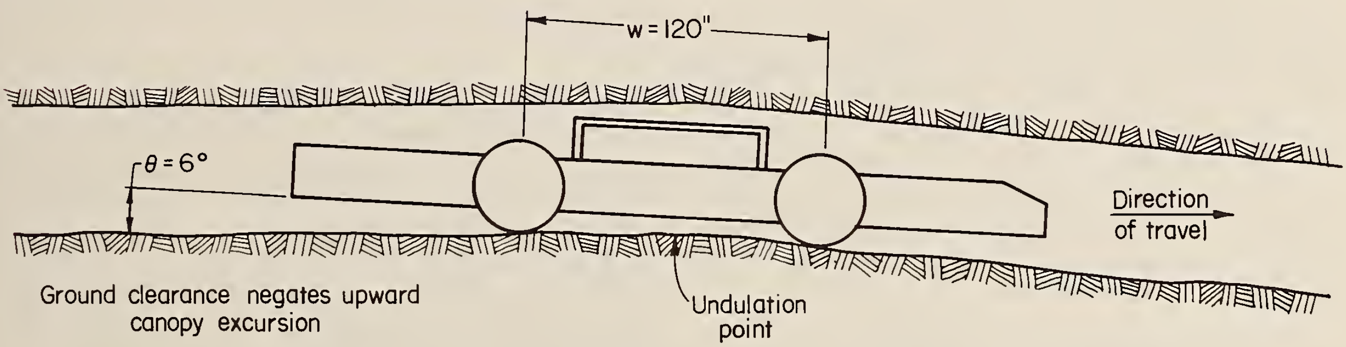

FIGURE 7. - Center-driven shuttle car with fixed operator compartment - downward undulation.

excursion in this situation would be negligible, and the lowest practical working height with a canopy would be the same as the height found in table 1 or 2.

Summary

Table 3 lists the range of canopy excursions that can be expected when "severe" mine floor undulations of 6° are encountered. The values in the right-hand column of table 3 were obtained from the formulas (D) (sin Θ) and (w/2) sin (Θ/2), for end-driven and center-driven equipment, respectively. Obviously, end-mounted canopies will almost always experience more excursion than center-mounted canopies because the undulation angle is halved in the latter calculation.

A wide range of potential canopy excursions exists for continuous miners for two reasons: (1) Different models

TABLE 3. - Typical values of canopy excursion[1]

Machine type	Canopy excursion,[2] in
Continuous miners, all end-driven.................	6-15
Shuttle cars, center-driven.	3- 4
Shuttle cars, end-driven....	6- 8
Scoops and tractors, center-driven.....................	2- 3
Scoops and tractors, end-driven.....................	6- 8
Roof bolters - single- and dual-head, center-driven...	2- 3
Roof bolters - single- and dual-head, end-driven......	6- 8
Cutters, face drills, and loaders, all center-driven.	2- 3

[1]Severe mine floor undulations assumed; slope change = 6°.

[2]Excursion determined by machine model, compartment location, and design of cab and canopy.

of continuous miners can have significantly different pivot-point-to-canopy distances, and (2) the design of the hinged, floating cab and canopy has an important effect on the amount of excursion reduction attainable. Cab and canopy design is also very important when calculating canopy excursion on any end-driven machine.

Excursions of center-mounted canopies do not vary greatly from machine to machine because wheelbases do not vary as much as pivot-point-to-canopy distances. Also, figures 6 and 7 show that floating compartments experience *more* canopy excursion than fixed compartments when downward mine floor undulations are encountered. Therefore, the *only* advantage of using floating operator compartments on center-driven machines is that they eliminate the initial compartment ground clearance, segment *1* of figure 1 and table 1.

COMPLIANCE WITH MSHA CANOPY REGULATIONS

As stated earlier, present MSHA regulations require the use of canopies on all face equipment when the minimum mining height on the section is 42 in or greater. However, even though the minimum working heights with canopies listed in table 1 are less than 42 in for some equipment types, there are several reasons why compliance may be difficult or impossible in low-coal situations:

1. The thickness of required roof supports or other roof-mounted obstructions must be added to the minimum working height to obtain the minimum mining height. In mines where planks, crossbars, or rails are needed for extra roof support, the minimum mining height (mine floor to unfinished roof) needed to allow the safe use of a canopy will almost always be greater than 42 in.

2. Floating operator compartments are not presently available for all equipment types and models. Minimization of compartment ground clearance is essential to the increased used of canopies in mining heights close to 42 in.

3. The need for equipment operators to assume upright positions makes it physically impossible for them to remain beneath a canopy without discomfort when the mining height is limited to 42 in. This problem cannot be resolved until compartments are designed to allow protected machine operation from a reclining or lying down position.

4. Canopy excursion due to mine floor undulations can cause roofing to occur in mining heights much greater than 42 in.

5. The heights listed in tables 1 and 2 were based mostly on static human body and equipment dimensions rather than dynamic work procedures. The effects of the machine frame, the canopy, and machine-mounted obstructions as the machine is operated will be very different from machine to machine. Each operator's willingness to tolerate constraints to his comfort and vision will also be different.

6. In many mines, the mining height fluctuates above and below 42 in very frequently. When the mining height is below 42 in, canopies are not required, so machine operators usually remove them to improve comfort and vision. However, these machines would be "out of compliance" when the mining height rises above 42 in. Canopies are often very heavy, cumbersome, and time-consuming to install and remove, especially in the confined quarters of low coal seams. Therefore, both the mine operator and the workers on the mining section tend to be reluctant to reinstall canopies that have just been removed, if they know that in the near future the mining height will again fall below 42 in.

In conclusion, it is obvious that low-coal canopy problems are very complex and can be resolved only if the exact machine, mine conditions, and equipment operator involved with the problem are defined.

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