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.

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

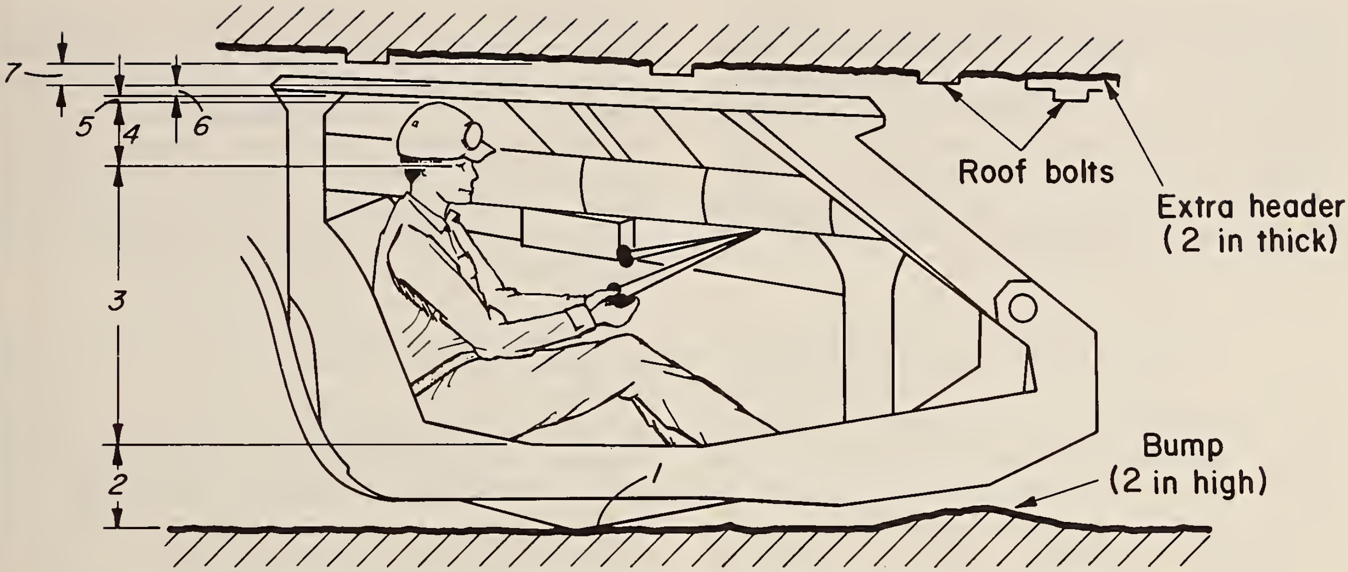

FIGURE 1. - Breakdown of minimum working height with canopies.

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

[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

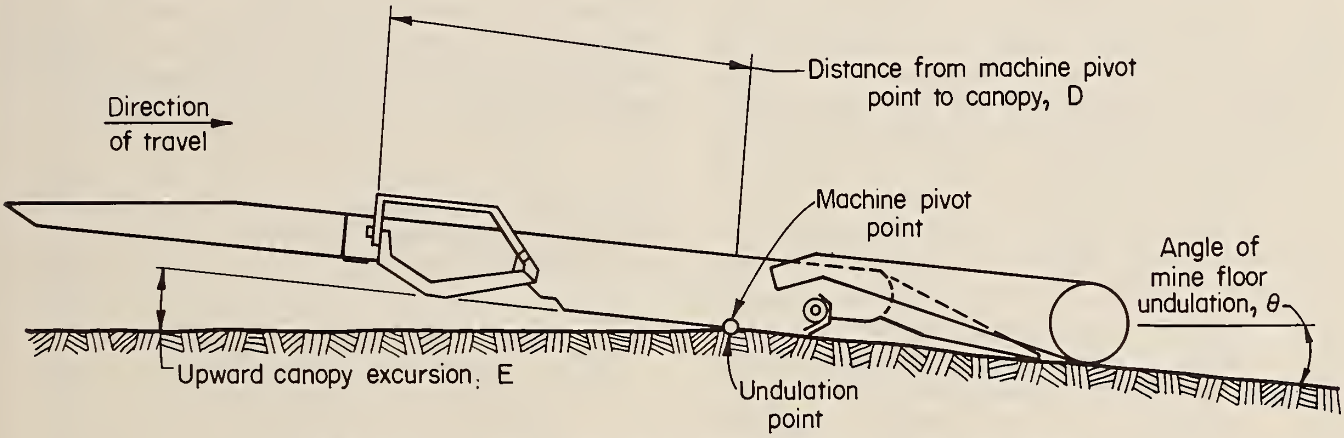

FIGURE 2. - Upward canopy excursion on end-driven equipment.

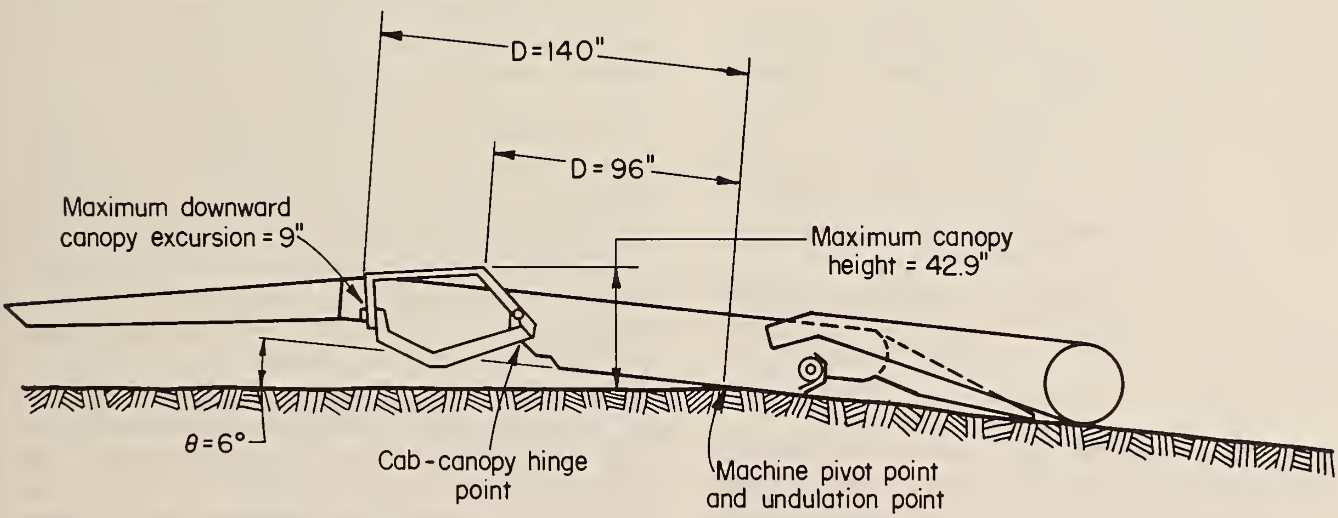

FIGURE 3. - Canopy excursion reduction with floating operator compartment.

(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

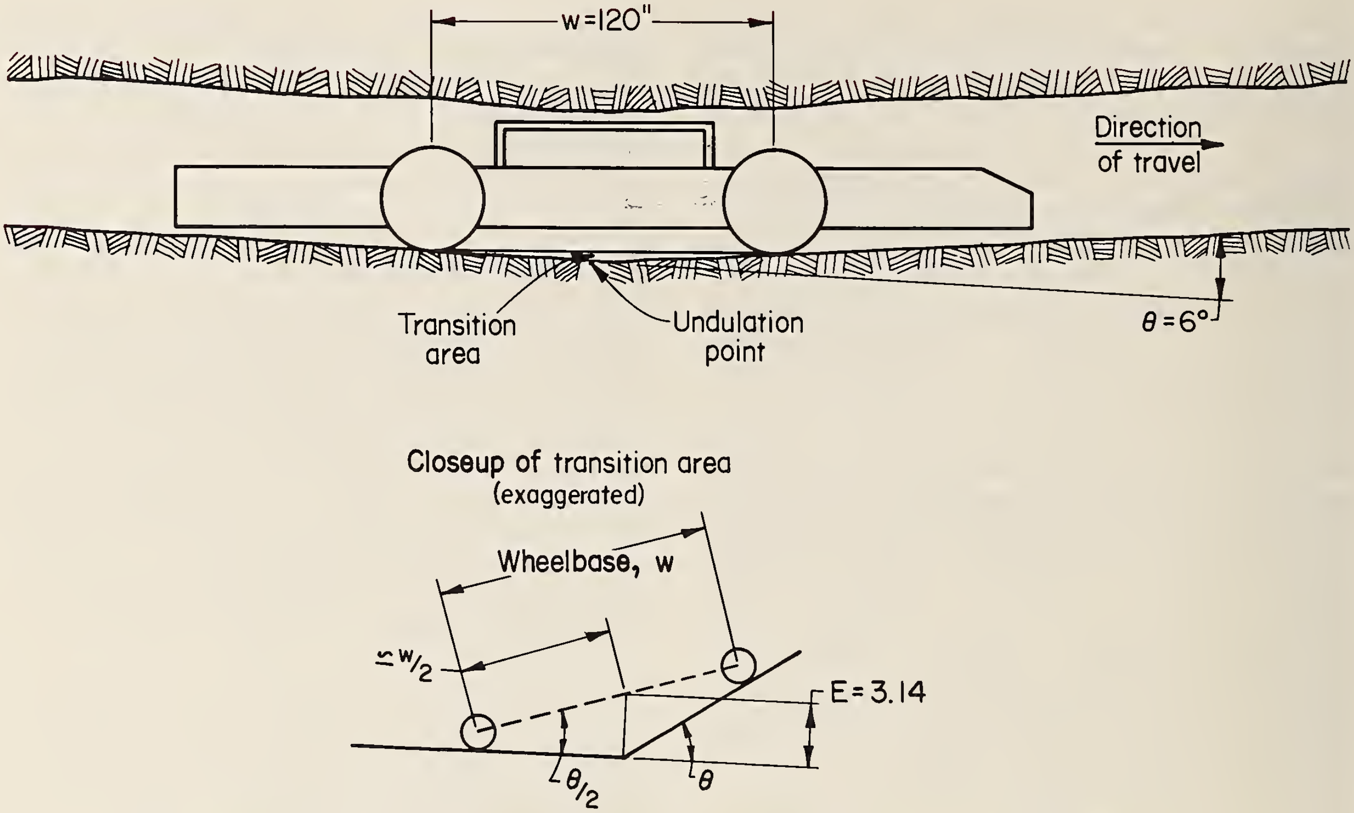

FIGURE 4. - Upward canopy excursion on center-driven equipment (shuttle car).

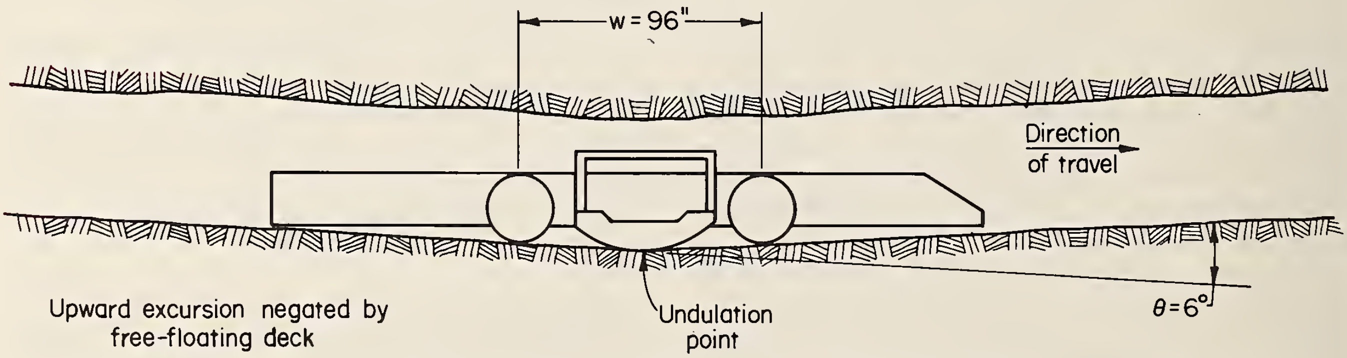

FIGURE 5. - Center-driven shuttle car with floating operator compartment - upward undulation.

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

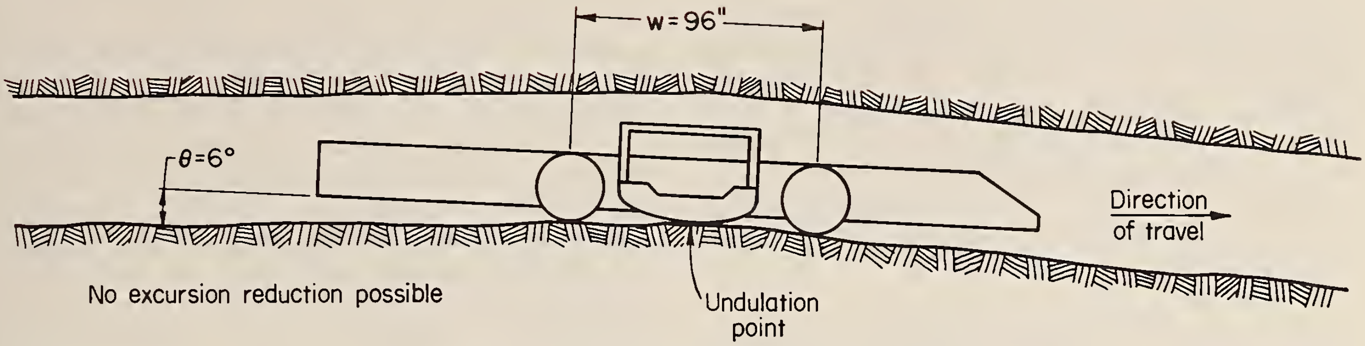

FIGURE 6. - Center-driven shuttle car with floating operator compartment - downward undulation.

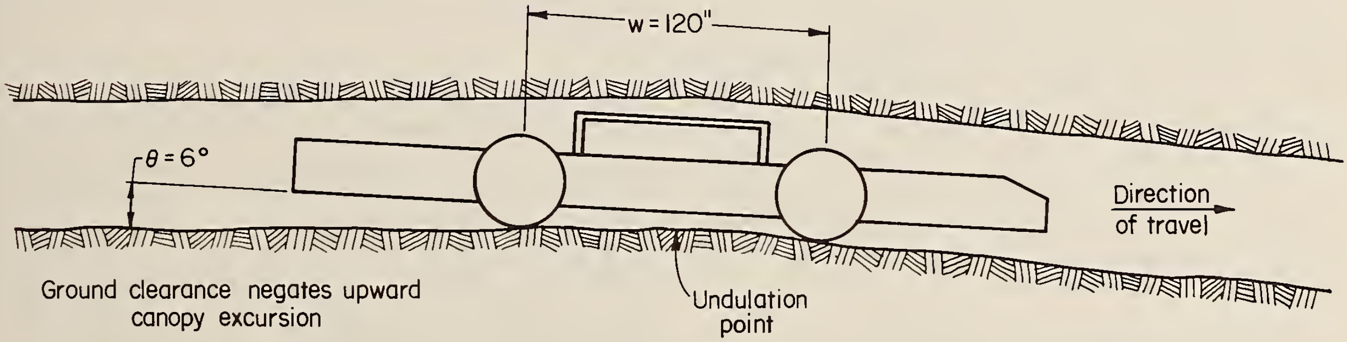

FIGURE 7. - Center-driven shuttle car with fixed operator compartment - downward undulation.

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.

☆U.S. GPO: 1984-505-019/5083

INT.-BU.OF MINES,PGH.,PA. 27751

IC 8996

Bureau of Mines Information Circular/1985

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

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
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Bureau of Mines Technology Transfer Symposium (1983 : Charleston, WV)
Cabs and canopies for underground coal mining equipment.

(Information circular ; 8996)
Includes bibliographical references.
Supt. of Docs. no.: I 28.27:8996.

1. Mining machinery—Safety measures—Congresses. 2. Mine railroads—Cars—Safety measures—Congresses. I. Aljoe, William W. II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 8996.

~~TN295.U4~~ [TN345] 622s [622'.2] 84-600210