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REMOTE OPERATOR COAL MINE ROOF BOLTER CONCEPTS UTILIZING EXISTING TECHNIQUES AND COMPONENTS

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EVALUATION OF MINE ROOF BOLTER COMPONENTS

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16. Abstract (Limit: 200 words)

A data bank on bolter technology was assembled that included state-of-the-art industrial equipment as well as new equipment currently under development for the Bureau of Mines. This information was augmented by visits to Bureau of Mines contractors, mine operators, and others to obtain a thorough understanding of present coal mine roof bolting safety and productivity problems. Using this background material and information, a series of roof bolter concepts was developed offering improved operator safety with minimum impact on productivity. The concepts developed utilize existing componentry and technology wherever possible. All of the concepts feature a fully protected operator station located 6 to 10 feet outby the active bolt line and the hazardous rotating machinery.

17. Document Analysis a. Descriptors

Mining

Roof bolter	Availability	Reliability
Bolter concept	Existing components	Remote operator
Data bank	Simplicity	

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FOREWORD

This report was prepared by Ingersoll-Rand Research, Inc. under USBM Contract Number HO272028. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of Spokane Mining Research Center with Mr. John Owens acting as Technical Project Officer. Mr. Bill Case was the contract administrator for the Bureau of Mines. This report is a summary of the work completed as a part of this contract during the period October 1977 to September 1978. This report was submitted by the authors on September 1, 1978 and contains no patentable information.

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1.0 FIELD INVESTIGATION

1.1 Introduction

The study of coal mine roof bolter components was to be undertaken by using bolter manufacturers as the primary source of information regarding current, operating roof bolting equipment. Two factors mitigated against this approach. First, manufacturers were reluctant, in general, to cooperate with the study. Even basic sales information was withheld by all manufacturers except Fletcher. Secondly, the information that was available (in the form of sales brochures) was inadequate for a proper component evaluation.

Accordingly, it was determined that the most useful information would be obtained by actually investigating roof bolter usage and production problems in the field, including the observation of selected equipment at the working face of the mine. The field operating groups of the Lee-Norse Company recommended locations for such on-site inspections which were well distributed throughout the major underground coal producing regions of the country. The visits were arranged to make use of this distribution, permitting the review of a broad range of mining conditions that would not otherwise be possible by concentrating on a narrower geographical band.

An important benefit to this field equipment investigation was the direct input received from the mine personnel regarding relative bolter performance and the relative benefits of one component over another. Suggestions for possible improvements to their current, available equipment, both for the short term and the long term, were solicited. The influence of the inputs so received will become apparent in the discussions of the new bolter concepts that follow.

A data bank was established from multiple sources which included 83 mines and well over 300 working sections. The mine personnel interviewed included bolter operators (working at the face), foremen, maintenance personnel, purchasing managers, mine superintendents and vice presidents. Obviously, the opinions and needs of such a variety of skills will not result in the drawing of the same conclusions. However, the body of information presented herein when taken as a whole represents a balance of these sometimes conflicting opinions.

The next section provides a summary of these meetings including our field observations and the input of the mine personnel. For the purposes of assuring consistent background information on those mines visited and not burdening those who were interviewed, the Keystone coal industry manual was used wherever possible. The Lee-Norse Company field personnel, because of their thorough knowledge of the mining conditions and equipment problems of their customers, also provided invaluable assistance in the accumulation of the field input.

1.2 Summary

At the outset of the field investigation phase it was intended to cover as broad a range of mining conditions as possible. Selections were to be based on such variables as geography, seam thickness, ground stability and geology, bolter population, seam pitch and mine size. These factors, along with the individual variations in mining conditions, influence the purchase, overall performance and reliability of a given roof bolter.

Six mines were visited in the Western United States. They were in Utah, Colorado and New Mexico. As a group,they all exhibited thick seams of coal (up to 24 feet) with the tendency (except for one) toward steeply pitching seams. Typically, the ground pressures mandated securing the ribs as well as the roof in seams thicker than 6 feet. Such conditions require a bolter which can bolt the rib, can reach a 10 to 12 feet working height easily (drill string extensions are susceptible to buckling under relatively light loads) and which has good traction during both drilling and tramming in the steep and often wet bottom conditions. The increase in working height allows a fairly liberal use of mast-type drill mechanisms. However, the tendency to fill all of the available entry space with a piece of bolting equipment, simply because the space exists theoretically, should be avoided. Frequently, poor housekeeping in the high seam mine creates difficult maneuvering conditions. Sloughed coal which is left behind to help stabilize the ribs makes entries effectively narrower than the original driven widths. Dips and rolls in the coal seam itself, as well as the variations in cut made by the continuous miner, cause tram interference problems. These problems are intensified with bolters that are very long and have bulky components located too close to the front or rear of the machine. In spite of these problems western mines generally favor the larger bolters, which include additional features such as sumping drills, temporary roof support for more than one bolt site and sometimes angle and rib bolting ability.

The evolution of the bolting machine in the Eastern coalfields has followed very traditional lines. The early bolters incorporated a single Manson-type boom mounted on a very small, sturdy chassis. They were capable of rapid bolt installation due, at least in part, to their inherent high maneuverability. The boom and overall chassis arrangement allowed for a very low collapsed machine height without sacrifice in drill pot feed stroke, making them very adaptable to low seams while maintaining flexibility with respect to seam height.

With the advent of the Coal Mine Health and Safety Act of 1969 and subsequent regulation, several changes began to occur. With two men now required to operate a bolter, the market was open for a twin boom machine. The ensuing upsizing, along with the addition of safety hardware to meet the new requirements, added bulk and complexity to bolting machinery with no increase in productivity. In fact, productive time was reduced because of decreased machine reliability. Productive time, theoretically doubled with two producing operators, was rarely better than 150% of a comparable single boom bolter's production.

Reliability and performance comparisons were provided by mine operators who utilize both twin and single boom machines. They frequently cited similar production capabilities between single and twin boom bolters, with the twin offering a slight advantage in productivity. It should be noted that when a third man is added to a twin boom bolter crew, production can approach twice that of a single boom bolter. The explanation for this improvement is as follows. A roof bolting operation requires more than drill pot operation during the production cycle. Service and supply functions such as maintaining bit, steel and bolt inventories, assembling bolts, changing bits and setting temporary jacks subtract a large fraction of an operator's productive time when a helper is not available.

The conclusion drawn from this review of the evolution of bolting machinery from small, efficient single boom units too bulky, difficult to maneuver, highly accessorized twin boom concepts is that a whole new approach must be taken when designing bolting equipment. Consideration must be given to integrating health and safety features with the necessary performance parameters in such a way as to maximize safety and reliability without sacrificing productivity.

1.3 Background Mine Data

The summary information given in Table 1 documents the range of mining conditions encountered during the field investigation phase. 30 specific mining groups are documented. Each group represents a mining company operating one or more mines. The Table lists the number of mines operated by each mining group and the total number of working sections in the mine group. The numbers tabulated under mining plans and longwall indicate the number of sections using a particular mining method. The seam descriptive entries refer to the total number of working sections in the mining group. Multiple entries at a single matrix mode indicate the data breaks down into two or more significant groups. In mine group 8 under average seam thickness, multiple entries: 15 x 3', 15 x 6', indicate 15 mines have 3 foot seam thickness and 15 mines have 6 foot seam thickness. In mine group 11 under roof stability scale multiple entries: 3 x 5, 1 x 1, indicate 3 mines feature No. 5 roof stability (self supporting roof) and 1 mine has No. 1 roof stability (very bad top). The information on bolter population refers to the actual bolters used in all working sections of the specified mine group. In order to formulate a statistical, but not entirely rigorous, body of results from which to draw conclusions, fundamental descriptive parameters were considered.

Of the readily available information, the total number of working sections in a mine or group of mines was considered to be the most useful piece of data to describe mine size. Although coal production might be a more accurate description of size for many applications, no variable other than number of working section relates as closely to the amount of capital equipment (bolters) to be found in a mine. Therefore, when discussing any type of weighted average, or similar quantity it should be assumed that weight will be given to a dependent parameter by the number of working sections or number of roof bolters associated with that parameter. However, the relatively small sample of mines presented does not always allow the statistical results to be taken at face value. Rather, it is important to consider much of the information within the context from which it was received.

Seam thicknesses for all the working sections visited varied between 2.5 feet and 24 feet with an average thickness about 5.4 feet. The average seam thickness in which single boom bolters were used was 4.8 feet and for twin boom bolters it was 6.8 feet. Most of the 338 working sections utilized a room and pillar mining plan with continuous miners (88.5%). Other methods included conventionally cut-and-blast, room and pillar mining (5%) and longwall mining (6.5%). Most of the room and pillar

TABLE. 1

MINE GROUP DATA BANK[2]

	LOCATION	NO. MINES	NUMBER WORKING SECTIONS	MINING PLAN(S) R&P CM	MINING PLAN(S) R&P CONV.	LONG WALL	SEAM THK. RANGE	SEAM THK. AVERAGE	TYPICAL DRIVEN ENTRY WIDTH	PILLAR ⊄ DISTANCE	ROOF STABILITY 1-5 SCALE	BOLT LENGTH & TYPE MECH.	BOLT LENGTH & TYPE RESIN	SEAM PITCH AVE.	SEAM PITCH MAX.	TRAM DIFFICULTY	WATER PRESENT	BOLTER POPULATION[1] FMC/GALIS 1	FMC/GALIS 2	LEE-NORSE 1	LEE-NORSE 2	FLETCHER 1	FLETCHER 2	ACME 1	ACME 2	OTHER 1	OTHER 2	MINE-BOLTER CAPABILITIES
1	CENTRAL PENNSYLVANIA	4	12	9*		3	3½'-5'	4'	18'	100'	1	6'	6'-7'	2%	8%	1	✓	7				2		3				1
2	CENTRAL PENNSYLVANIA	3	7	4		3	3½'-4½'	4'	16'	100'	1	TRACE	4'		10%	1	✓	10				2	1	5				1
3	CENTRAL PENNSYLVANIA	1	8	7		1	4'-7½'	6'	18'-20'	100'	2	4'-8'	5'	2%	6%	0	✓	2		6	3			1 (STOPER)		1 (LONG AIRDOX)		—
4	NORTHERN WEST VIRGINIA	1	8	7		1	5'-7½'	6'	15½' FULL CUT. WIDTH		4	6'		FLAT		0					8 (MINER BOLTER)							L
5	NORTHERN WEST VIRGINIA	1	6	6			5'-6'	5½'	16'		2	7'-10'	5'	FLAT		2	✓			4	4	5						R, L
6	NORTHERN WEST VIRGINIA	1	8	7		1	7'-8'	7½'	20'	80'	3	6'-8'		3%	10%	1	✓							(STOPER) 8				—
7	NORTHERN WEST VIRGINIA	2	6	6			3½'-6'	5'			3	2½'-6'	5'	FLAT		2	✓											—
8	CENTRAL WEST VIRGINIA	5	30	30			3'-9'	15×3', 15×6'	20'	75'	3	4'-10'	3'-8'	1%		0	✓	21			11							—
9	WESTERN VIRGINIA	2	19	19			3'-8'	4½'	18'	80'	3*	3'-6'	4'	7%	14%	2,1	✓	35	8									—
10	CENTRAL WEST VIRGINIA	9	19	18*		1D	3½'-13'	5'			3	6'	4'	FLAT		0	✓		19✓									1
11	WESTERN VIRGINIA	1	4	4			3'-4'	3½'	20'	60'	3×5, 1×1	2½'	5'	FLAT		2	✓						1	4		3 (WILCOX)		L
12	WESTERN VIRGINIA	1	1	1			4'-7'	5'			5	2½'		FLAT		0										2 (PAUL'S PINNER)		1
13	WESTERN VIRGINIA	1	8	7		1,1D	4'-6½'	5'	18'		3		4'	FLAT		0			8									—
14	WESTERN VIRGINIA	8	30	15	10	4	2½'-8'	3½'			3	3'-6'	4'-5'	3%	6%	3		55	1			1						S (FL. SINGLE)
15	WESTERN VIRGINIA	17	40	40			4'-6'	5'			3	3'-4'	TRACE			2					6	20		24				—
16	EASTERN KENTUCKY	5	14	14			3½'-6'	4½'	20'	60'	4	3'-4'		ROLLS		0	✓	13	3			1	1	1				—
17	NORTHERN ALABAMA	1	3			3D	5'-9'	9'	20'		5*	4'		1%	2%	0				✓						✓ (JOY)		1
18	NORTHERN ALABAMA	8	30	30*			2½'-10'	4'		80'	4	3'	TRACE		5%	0		15✓		10✓				5✓				1
19	WESTERN KENTUCKY	1	2(?PLANNED)	2			5'	5'	20'-22'		5	2'		FLAT		2				27 (CAMP DIV.)								1
20	WESTERN KENTUCKY	1	5		5		5'	5'			2		4'	0%	5%	0		8	1		1							—
21	WESTERN KENTUCKY	1	3	1	2		3½'	3½'			2		3½'-6'	3%	5%	0		3										1
22	SOUTHERN ILLINOIS	1	10	10*			6½'-10'	8'	16'-18'		3*	6'			12%	0				7	3		1					R, L
23	SOUTHERN ILLINOIS	1	16	16*			8'	8'	14'		3	8'		0%	4%	0					16 (MANSON)							—
24	SOUTHERN ILLINOIS	1	9	9°			6'-7'	6½'			3	4'-6'		FLAT		0					6			4				—
25	SOUTHERN COLORADO	1	11	9*		2	6'	6'	16'		2		4'	4%	25%	1,2												L
26	NORTHERN NEW MEXICO	1	8	6*		2	6'-10'	8'			2	5'-6'	4'-8'	FLAT		1,2	✓		9			1	1					R, L, S
27	CENTRAL UTAH	1	4	4*			10'-12'	11'	22'		3*	4'-5'	4'-5'	9%	10%	1	✓				2		2					R, L, S
28	CENTRAL UTAH	1	5	5			18'-24'	20'	18'-22'		4×4*, 1×2		✓	10%	15%	0	✓						3		2	1 (JOY)		R, L, S
29	CENTRAL UTAH	1	6	6			4'-10'	8'	20'		1*	3'-4'	5'-6'	7½%	18%	1				7								1
30	CENTRAL UTAH	1	6	6			5'-11'	9'	20'		3*	3'-5'	4'-6'		12%	3				3								1

1. Reference to specific brands, equipment or trademarks in this report is made to facilitate understanding and does not imply endorsement by the U.S. Bureau of Mines.
2. See next page for key to symbols.

Table 1A

Data Bank Key

Column	Notation	Meaning
Mining Plans	*	With pillar extraction
	D	Under development
Roof Stability	*	With rib bolting
	5	Self supporting roof
	4	Good Top - Short bolts are used
	3	Average Top - Resin bolts frequently used as a control aid
	2	Poor Top - Roof beams and other supplementary support required
	1	Very Bad Top - Continuous miner advance is frequently limited by instability.
Tram Difficulty	0	No difficulty
	1	Tram slips or mires
	2	Insufficient ground clearance
	3	Insufficient tram power
Mine Bolter Capabilities	-	No special capabilities
	R	Drill head rollover for rib drilling
	L	Straight row drilling with no chassis movement of twin boom bolter
	S	Drill head sump capability of 2 rows or more
	1	Single boom bolters only at this mine
Abbreviations	R&P	Room & Pillar
	CM	Continuous Miner
	CONV	Conventional Mining (Drill, Blast, Load)

mining include some removal of pillars upon retreat (88%). It is interesting to note that over one third of the mine groups visited operate at least one longwall section. The room and pillar work done at these mines then, is in part used for longwall development.

Roof pinning rarely varied from a standard bolt pattern of four bolts across an entry with a four foot spacing and with rows separated by four feet. Sometimes, especially in wider entries, a fifth bolt would be installed to comply with local regulations, requiring bolts within two feet of the rib. In this case, the bolt pattern would shift accordingly.

Other bolt patterns were seldom found because they usually required approval by the appropriate state and MSHA regulation authorities. Truss bolting was mentioned rarely although one mine reported that truss installation made one previously unminable section safe for production.

Bolt type and length was found to be a major variable. Mechanical expansion anchor or resin grouted bolts with lengths varying between 2 feet and 10 feet were encountered. The 83 mines continue to use mechanical bolts (90%) although only a small number (21%) use such bolts exclusively. This point is indicative of the growing use of resin bolts because of their improved roof control characteristics. Many mines used resin bolting in their more difficult applications, reverting back to mechanical bolts in better conditions because of the lower cost. For economic reasons only 10% of the mines investigated had roof stability problems sufficient to justify exclusive use of resin bolting.

Rib bolting, necessary for rib stability at certain levels of ground pressure, was performed in 10% of all the mines. No occurrences of rib bolting were observed in seam thicknesses less than 6 feet. However, of those mines with seam thicknesses in excess of 6 feet, more than 30% did secure the ribs.

The most common geolocical roof formations found in the mines was a thin bed (typically 3 feet - 10 feet) of shale underlying a thicker bed of sandstone. The stability of this type of roof varied widely, depending primarily upon the degree of consolidation in the sandstone and shale and upon the uniformity of the laminations in the shale. Typically, bolts were anchored in the sandstone if the shale bed was weak and not excessively thick. Three other formations less commonly observed were: 1.

slate and shale, 2. solid sandstone, and 3. solid limestone (mostly in the Illinois beds). Some mine roofs contained sporadic formations of pyrites and other hard materials (notably the "Dinosaur Tracks" of the West) which required modifications to the drilling apparatus to achieve drill penetration.

About half (54%) of the mines reported roof conditions that could be classified as typical. These mines experienced a small frequency of roof falls, with some sections where roof stability was obviously improved by the use of resin bolts. About 19% reported good roof stability where roof control was typically limited to the use of short mechanical bolts. Only 3% indicated an essentially self-supporting roof requiring bolting only to comply with law. Evidence of this situation was seen in the short length and wide spacing of the bolts used.

Poor roof stability was indicated by 24% of the mines. This condition was demonstrated by the extra roof support that was required to support the opening. Some of the extra support included long resin bolts, wooden or steel beams, wire mesh and cribbing. (Although beams and extra support were seen frequently in places where extended life was expected, e.g., mains, production sections usually kept roof support hardware to a minimum). 11% of the mines indicated that poor roof stability reduced the advance of the continuous miner (Normally 18 to 20 feet) to as little as 4 feet. In these cases the productivity of the section was obviously hampered directly by the roof conditions due to the time lost to extra place changing.

1.4 Equipment Review

Analysis of our data indicates a relationship between the working seam height and the preference for single boom versus dual boom bolters. See Figure 1. Notice the definite trend for low seam mines to favor single boom bolters while high seam mines favor dual boom bolters. The crossover point for our data sample was between 5' and 6'. That is, mines in the 5'-6' range used equal numbers of single and dual bolters. Above 6' there was a mild preference for dual boom bolters over single boom bolters. Below 4' there was a strong bias for single boom bolters. The average bolting height for single boom bolters was 4.7'. The average bolting height for dual boom bolters was 6.9'. The ratio of single to dual boom bolters in the sample was 2.44 to 1.00. On Figure 1 there are various fractions indicating either a ratio

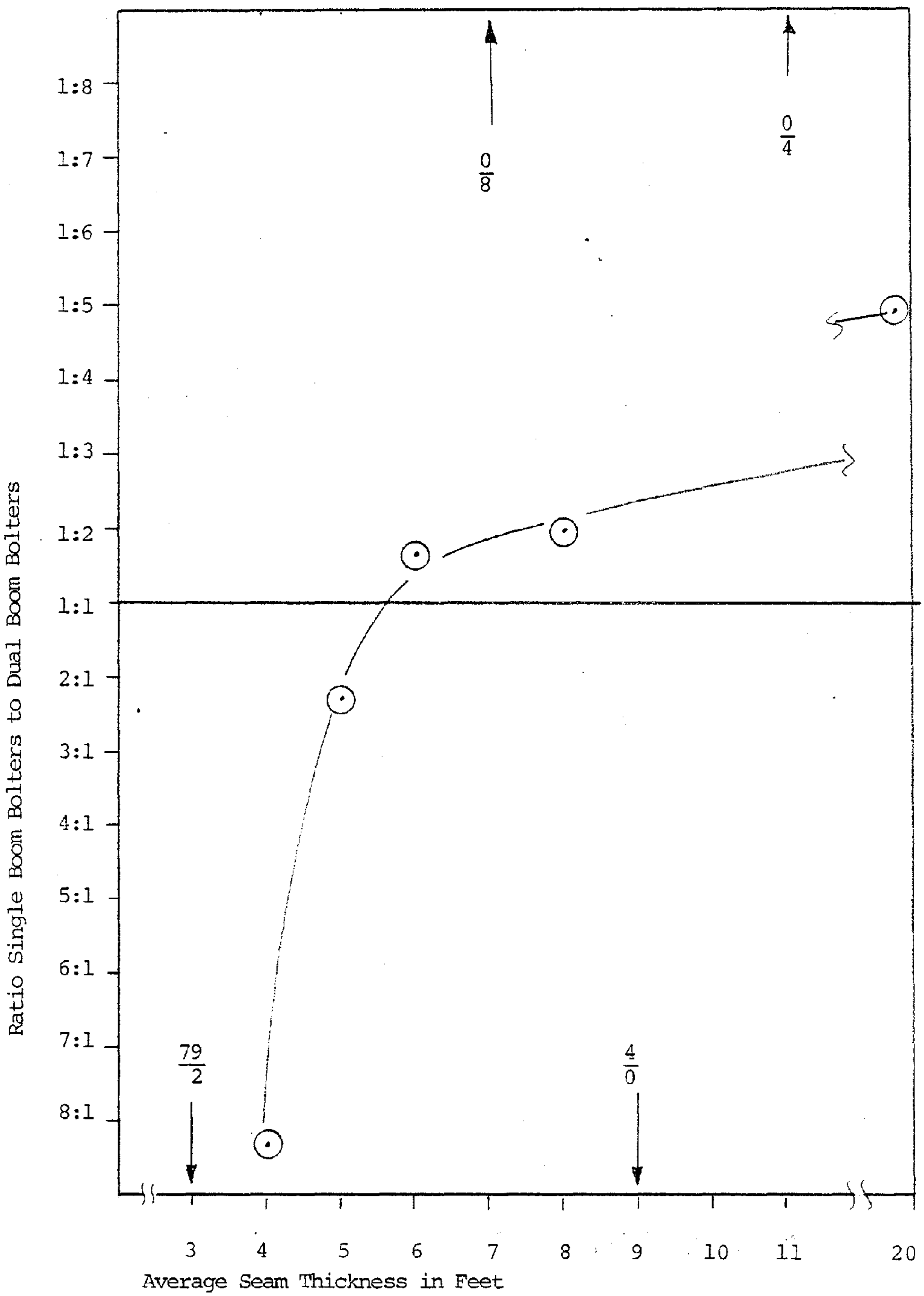

Figure 1: Seam Thickness vs. Single/Dual Boom Bolter Ratio

off the range of the graph or seam heights in which our small sample failed to find use of both single and dual boom bolters.

The fraction 0/8 which occurs at the 7 foot seam thickness indicates our sample included zero (0) single boom bolters and eight (8) dual boom bolters used at 7' average seam height.

These cases are shown on the graph for the sake of complete representation of data. However, we would expect a larger sample to include both dual and single usage and approach the plotted line through data points including both dual and single bolters.

An important performance parameter which is independent of the actual drill and bolt cycle is the ability of a bolter to tram and maneuver efficiently. A reduction in the time required to tram to position will obviously increase the time available for drilling and bolting.

The tramming problems most commonly associated with lost production time were generally confined to poor traction in wet or steeply pitching seams and chassis bottoming out on muck piles and other debris. Very few of the operators expressed a lack of tram power or speed. In most cases, existing torque is more than adequate. However, in the survey approximately 20% of the 83 mines complained of poor traction. All but one of these mines indicated typical seam pitches in excess of 8% or 4-1/2 degrees. All but two mentioned that water was present in quantities that considerably softened the fireclay floor, creating further traction difficulties.

25% indicated that ground clearance and chassis bottoming presented a recurring tram problem. Bottoming frequently can be alleviated by chamfering the chassis extremities. However, ground clearance generally must be sacrificed when designing a low profile bolter. Solutions to this problem can be made in the field by changing tire diameters, however, no good solution exists for easily changing the chassis height in the field. A good solution to this problem would allow the operator to quickly adapt his equipment to seam conditions by increasing (or decreasing) the drill pot reach as well as ground clearance, allowing greater flexibility under varying conditions.

Another performance-related parameter affecting machine availability is downtime. While increased complexity, which exposes more moving parts with closer tolerances to the harsh mine environment, will add to downtime, fundamental drill components are also very susceptible to this environment. Table 2 lists the most commonly cited reliability areas.

TABLE 2

DOWNTIME - Principle Breakdown Areas

Mine Group**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Percentage**
Electric Cable	✓															✓				✓	✓	✓	✓		✓					✓	31%
Drill Heads	✓	✓	✓				✓				✓		✓	✓				✓	✓					✓	✓				✓		46%
Hydraulics					✓			✓		✓							✓	✓	✓				✓	✓				✓	✓		38%
Electric Motors	✓	✓										✓																			12%
Dust Collection	✓	✓						✓			✓			✓												✓					23%
Tram												✓		✓																	8%

* These mine group identification numbers refer to the mine groups listed and described in Table 1.

** Percentages weighted by number of working sections.

Almost half (46%) of the 30 mine group representatives reported short drill-pot life as the most frequent source of downtime. This difficulty is understandable when the drill pot function and location are considered. The high loads from thousands of pounds of thrust and hundreds of pound-feet of torque, coupled with lubricant contamination (particularly rock dust), materially reduce component life. One mine, drilling with a wet head arrangement, reported that drill boxes had to be replaced every three weeks.

Other malfunctions were mentioned as common occurences according to the following weighted percentages of the 30 mine groups:

Hydraulic System -	38%
Electric Trailing Cable -	31%
Dust Collection System -	23%

The hydraulic system of a bolter, necessarily extensive and complicated, will naturally be a source of frequent breakdowns if regular maintenance is not conducted. Unfortunately, this is often the case. Without a regular maintenance schedule, the intervals between filter changes and topping of the reservoirs become excessively long, allowing contaminated oil to circulate through the system. Even the filling of reservoirs introduces contaminants from the mine environment because many manufacturers do not provide filters at the fill ports.

Upon replacement of a given hydraulic component, another problem may arise. The hydraulic-line system, which links the components, is often a complex array of hose bundles. Reconnecting hoses correctly can be a problem (color coding would help). Compounding this problem is the fact that hoses are often rerouted in a manner such as to increase their vulnerability to pinching or snagging on moving parts. This situation further reduces machine reliability. Finally, the hose connections themselves have limited reliability after frequent reassembly operations.

The electric power cable, very vulnerable to breakage when trammed over, must be carefully tensioned at all times to prevent the vehicle from traversing its own power supply cable. Tensioning devices in many cable reels were observed to have no provision for maintaining proper tension when the vehicle is shut down. Accordingly, subsequent start-up would not always remove the slack generated by the shutdown, increasing the likelihood of damage to the cable.

Standard industry dust collection systems were often reported to have difficulty in maintaining the necessary flow through the drill string to prevent clogging of the steels. This problem becomes acute in the presence of water, either present in the roof or generated by a wet head drill system. Frequent maintenance of the dust collection system then becomes necessary.

Other less commonly reported reliability problems centered on such items as electric motors, tram motors and drive trains, electrical switching, tires, heavy duty pin joints (at articulation points) and canopies. It should be noted that many canopy problems were associated with mine retrofit work which resulted in inadequate designs executed merely to comply with the law.

1.5 Equipment Variations and Optional Features

Probing more deeply into the question of equipment preferences by mine personnel, discussions were encouraged on the subject of bolter features; that is, equipment variations which should or should not be included in the overall design. Table 3 documents the opinions of mine personnel regarding the features which their equipment currently offers.

The most commonly reported desirable feature was one which would supplement or replace the normal rotary thrust drilling scheme. 35% of those responding said that in order to economically penetrate their hard roof, either a water cooled bit or percussive drill head was necessary.

Although not component features, the mobility and simplicity of a machine were again emphasized as desirable charactersitics. Bolters which were equipped with a deep chuck drill steel retainer performed well in guiding the drill steel and ensuring perpendicular feed. Bolters equipped with large area, temporary roof support systems were considered to help the production cycle by increasing the safety and, therefore, confidence of the operators.

TABLE 3

DESIRABLE FEATURES

Mine Group*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Percentage**
TRS		√									√			√													√		√		22%
Mast Rollover																											√		√		8.7%
Boom Sump		√									√																√				13%
Simplicity Reliability								√				√		√					√					√			√	√			26%
3-Stage Don-aldson Dust Collector			√					√											√												13%
Mobility/ Small Size	√											√		√					√					√			√	√			30%
Hard Rock Capabilities		√	√			√							√				√	√											√	√	35%
2 Booms Better Than 1 Boom																√	√												√		13%
Deep Chuck			√																√				√				√				22%

* For explanation of Mine Group Numbers refer to Table 1.

** Percentages weighted by number of working sections.

Other desirable features mentioned less frequently included: boom sump, (which allows a bolter to drill a straight row of holes or more than one row without repositioning the chassis), multi-stage cyclone dust collection systems (more dependable especially in wet conditions), twin drill heads and drill head rollover for rib bolting.

Component features which created hazards or reliability problems were generally found to be isolated cases rather than trends throughout the industry. Virtually every mine had some minor recurring problem or required some particular optional feature. However, only two of these problems were causes for widespread equipment dissatisfaction. The first problem was canopies. Almost half of those responding (47%) cited the operator safety canopy as the one item that was not worth the aggravation it generated. Among the causes for this dissatisfaction are the following:

1. The canopy itself requires some space further hindering a bolter operator who already works in a confined space.

2. Many of the canopy designs have been added to existing bolter chassis without consideration of operator comfort, machine balance, or overloading bolter chassis structure.

It was felt that much of the trouble results from canopy retrofitting both in the mine and at the factory. It is vital to move away from the design approach which allows options to be added to a given chassis by retrofitting. Improvements in canopy design, as funded by the Bureau, and integration of those designs into new chassis concepts will alleviate many of these problems.

The second major dissatisfaction, 35% weighted percentage of 30 mine groups was the large size of various bolters, both single boom and twin. This large size adversely affects maneuverability in the narrow mine entries and intersections. Some of the larger machines, when fitted with a temporary roof support suffer an additional loss in maneuverability. Here again, proper component integration will help eliminate these difficulties.

Steering system preferences, vital to machine maneuverability, were investigated as they applied to specific types of equipment. All possible varieties of steering were discussed with the mine operators. However, the positive responses were generally confined to systems with which the operators were already familiar. The results indicated a general preference for squirm steering, especially on the smaller vehicles. One operator with especially soft bottom, however, expressed extreme opposition to this scheme, complaining of the damage done to the mine floor by the lateral motion of the tires. On larger vehicles, orbital (rear wheel) steering seems to hold a good deal of favor because of the reduced lateral slippage. Floor damage can become acute with squirm steering as machine size, weight and track width increase. Other methods which received some interest, although rarely seen on bolting equipment, included a synchronized four wheel steering system and an articulated chassis system. Experience with these methods was limited and conclusions were difficult to draw in the field. Essentially, the desired advantages are increased positioning maneuverability and ability to turn a tight crosscut.

1.6 In-Mine Equipment Modifications

In order to achieve a better matching of a bolter to a given set of mining conditions, mine operators frequently make alterations to their equipment. In fact, the sample indicates that 78% of the mine groups perform at least some of the following significant modifications. The most commonly reported can be found in Table 4. These modifications are frequently made even before the equipment is put into service. Depending upon the nature of a given modification, two explanations can be given for this situation. The first explanation is poor responsiveness on the part of the factory to the needs of the mine. The second explanation is the difficulty which the factory can experience in obtaining government certification for certain modifications.

The most common changes made to a bolter include installing wet drill head systems, altering the chassis height (usually by changing tires) and altering the tram arrangement. The tram arrangement alteration may consist of changing tire tread pattern or profile, modifying the hydraulic circuit to prevent wheel slipping through hydraulic differential action, or adding a remote tram control. The remote tram control allows bolter operator to tram the bolter while he remains at the front of the bolter.

Certain other modifications may be made as the result of efforts to improve reliability. The addition of multi-stage cyclone collectors and staple-type hydraulic fittings are common examples of this effort. The remaining modifications generally

TABLE 4

COMMON IN-MINE EQUIPMENT MODIFICATIONS

Mine Group**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Percentage*
Wet Head Drill Systems										√			√				√	√											√		11%
Alter Chassis Height		√			√			√																						√	15%
Retrofit Canopies	√								√	√		√						√								√					22%
Tram							√		√	√																					11%
Dust Collection					√		√																					√			11%
Pinned or Stapled Fittings								√							√				√												11%

* Percentage of working faces.

** For explanation of Mine Group Numbers refer to Table 2 reflect either the personal preferences of the mine management or the need to improve or strengthen an aging component.

Two important mine modifications to bolting equipment include the now mandatory canopy and lighting installation requirements.

1.7 Potential Improvements

Beyond individual component evaluations, data was compiled to evaluate overall bolting specifications, which relate to machine performance, by defining the operational envelope. A positive response by a mine operator to changing a given parameter indicates that some difficulty occurred in that mine relating to that parameter which hindered the bolter's productivity. The improvement then, would remove that hindrance. The results of these inquiries are recorded in Table 5.

From the standpoint of overall vehicle size, the data indicated that reducing chassis length and width would constitute improvements according to about 40% of the mine management groups. Shortening the vehicle length tends to upgrade maneuverability especially turning ability while narrowing the chassis is useful during tramming and allows easier passage of men, materials and equipment past the bolter in the sometimes crowded mine entries. These responses were more pertinent to twin boom vehicles although some single boom bolters also seem to be too large.

About half of the mine groups indicated a desire for an increase in ground clearance, stemming from tram bottoming difficulties. Less interest (26%) was shown regarding lowering the possible collapsed height of a given vehicle. The lesser interest in lower profile is certainly due to a more careful comparison made between coal seam thickness and vehicle height, rather than other chassis parameters, at the time of bolter selection.

About 40% desired an improvement in the tire footprint which would allow better traction in wet condition. On the other hand, most bolters are geared adequately for torque (only 25% needed more) and speed (only 9% wanted faster tramming bolters). Also, few respondents thought that a lighter weight vehicle would provide any assistance during tram difficulties. 40% felt that a tighter turn radius or cornering capability would be useful.

TABLE 5

BOLTER CAPABILITY IMPROVEMENTS

Mine Group*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Affirmative Response: Weighted %
Tighter Turning Radius	✓	✓	0		0	0		0	0	✓	✓			✓	0	0	0	✓	0	0	0			0	✓	✓		✓	0	0	39%
Shorter Machine	✓	0	0		0	✓	✓	0	0	✓	✓			✓	0	0	0	0	0	✓	0				✓	✓		✓	0	0	38%
Narrower Machine	0	0	✓		✓	✓	✓	0	0	✓	✓				0	0	0	✓	0	0	0			0	✓	✓		✓	0	0	45%
Increase Ground Clearance	0	0	0		✓	✓	✓	✓	✓	0	✓	0		0	0	✓	0	0	✓	0	0			0	✓	✓		✓	✓	0	48%
Lighter Weight	0	0	0		✓			0	0	0	✓				0	✓	0	0	0	0	0			0	0	✓		0	0	0	19%
Increase Tram Torque	0	0	✓		0	0	✓	0	✓	0	0	0		0	0	✓	0	0	0	0	0			0		✓		✓	0	0	25%
Increase Tram Speed	0	0	0		0	0		0	0	0	✓	0		0	0	0	0	0	0	0	0			0	0			✓	0	0	9%
Increase Tram Flotation	0	0	0					0	✓	✓	✓			0		0	0	✓	✓	0	0			0	0	✓		0	✓	0	35%
Increase Tram Traction	0	0	0		✓	0		✓	✓	✓	✓			0	0	✓	0	✓	0	0	0			0	✓	✓		0	✓	0	43%
Increase Drill Thrust	0	0	0		0	N/A		0	0	0	0	0		0	0	0	0	0	0	0	0			0	0	0		0	0	0	0

* For explanation of Mine Group Numbers refer to Table 1

Key

✓ Improvement

0 No Improvement

N/A Not Applicable

Blank Indicates No Response

TABLE 5 (Continued)

BOLTER CAPABILITY IMPROVEMENTS

Mine Group*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Affirmative Response: Weighted %
Increase Drill Torque	0	0	0		0	N/A	0	0	0	0	0	0		0	0	0	0	0	0	0	0			0	0	0		0	0	0	0
Lower Collapsed Height	0	0	✓		0			✓	0	✓	0					0	0	✓	0	0	0			0	0	0		✓	0	0	26%
Higher Drill Reach	0	0	✓		✓			✓	0	0	✓	0			0	0		✓			0			0	✓	✓		0	✓	✓	41%
Greater Reach Drill Heads (Dual Boom)	N/A	N/A	0		0	0		0	0	0	0			0	0	N/A	N/A	N/A	N/A	N/A	N/A			0	0	0		0	N/A		0
(More) Boom Sump w/o Moving Chassis	0	✓	✓		✓			0	✓	✓	✓			0	0	0	0	✓	0	✓	0			0	0	0				✓	45%
Straight Line of Bolts Across Entry	✓	✓	✓					✓		✓				✓	0	0	✓	0	0	0	0			0		✓		✓	✓	✓	61%
Minimum Distance Drill Chuck to Rib	✓	0	0		0	0		✓	✓	0	0	0		✓	0	✓	0	✓	0	✓	0			0	0	✓		✓	0	0	38%

* For explanation of Mine Group Numbers refer to Table 1

Key

✓ Improvement

0 No Improvement

N/A Not Applicable

Blank Indicates No Response

TABLE 5 (Continued)

BOLTER CAPABILITY IMPROVEMENTS

Mine Group*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Affirmative Response: Weighted %
Rib Bolting Capability	0	0	0		0			0	0	0	0			0	0	0	√	0	0	√	√	√		0		0		0	√	√	23%
Truss Bolting Capability	0	0	0		0			√	0	0	0			0	0	0	√	√	0		0			0		0		0	√	0	20%
Shorter Wheel Base	0				0	0		0	0	0	√					0	0	0	0	0	0			0	√	0		0	0	0	11%
Longer Wheel Base	0				0	0		0	0	0	0					0	0	0	0	0	0			0		0		0	√	0	6%

* For explanation of Mine Group Numbers refer to Table 1

Key

√ Improvement N/A Not Applicable

0 No Improvement Blank indicates no response

Regarding the drilling operation, there were no responses indicating the need to increase drill thrust or torque on any make of bolter. In fact, the thrust levels found on many bolters can occasionally cause drill steel buckling when long extensions are used.

Drill head articulation was investigated to determine the most desirable capabilities. The ability to drill a straight line of bolts across an entry without repositioning the bolter chassis was considered to be an advantage by 61% of those responding. Extra drill head reach (minimizing drill steel extensions) was desired by 41%. 45% stated a preference for the boom sumping feature which allowed more than one row of bolts to be installed without moving the chassis although evidence of chassis repositioning difficulties were not found in this study. Boom sumping can be helpful, however, when many temporary jacks are set at a face for support during bolting. The drill head can advance a row of bolts without removing a row of jacks for chassis clearance.

Allowing the drill head to drill closer to the rib would be desirable for 38% of the mines. However, no respondent indicated that total reach between booms on twin boom machines was inadequate. Head rollover capability, mostly needed in those mines where rib drilling is necessary (10% of total, and 30% of those with seams thicker than 6'), was considered to be a useful option by 23% of the data base.

1.8 Conclusions

The above discussion presents the opinions of mine operators regarding bolter improvements which can be accomplished using either available component options or current technology. The question that must be answered next is "what will be the nature of the next generation of bolting equipment?" It is known for instance, that roof bolting is the most hazardous job to be found in underground coal mines. It is also known that roof bolting constitutes a critical production pacemaker in many operations. Even where bolting is not now a pacing operation in certain mining conditions, bolter productivity will have to increase in order to realize the full productivity potential of the advanced coal cutting and haulage systems now under development.

There are several ways of improving overall productivity and bolter productivity in particular. However, some of these methods contribute nothing towards increasing the safety of the bolter operator. More than half of the mine management personnel contacted were interested in improving the safety of the bolter operator by removing him from the two largest sources of injury, namely: unsupported roof and rotating drill steels. The remaining respondents were opposed to the degree of machine automation required to achieve operator remoteness. Their concerns related to decreased productivity arising from the longer cycle times and the poor reliability resulting from the added machine complexity associated with the automation.

Within the parameters defined by the field investigations, an attempt was made to find a middle ground between currently available equipment and fully automated bolters. Prototypes of fully automated bolters have typically been plagued with problems associated with the added complexity. Accordingly, a rational design philosophy should utilize the minimum number of added mechanisms and logic capabilities necessary to accomplish the objectives of increased safety with equivalent (or improved) productivity. This philosophy was employed in defining the bolter concepts presented herein. Further, the strength of those concepts which are not overly ambitious is the heavy reliance on currently available machine components and systems and a close adherence to the guidelines developed by the field investigations. The proposed development timetables for each of the concepts is different favoring the more straight forward concepts which have a better chance of progressing through design and manufacturing phases quickly. Such concepts would accordingly be producing underground sooner and more efficiently than the more sophisticated versions.

2.0 USBM GROUND CONTROL CONTRACTS REVIEW

In conjunction with the sources discussed earlier in the report, selected, current and past USBM contracts were reviewed to obtain background information on roof bolting (as with the Bendix Hazard Analysis Study) and to review the state-of-the-art regarding hardware development. Of primary interest were those programs that demonstrated applicable hardware to achieve the goal of remote bolter operation without excessive complexity. Also of interest were component developments that would be compatible with the overall concept schemes being developed to enhance safe operation. For example, operator station concepts derived from those developed during the FMC Inherently Safe Mining Systems Program were employed on four of the eight chassis configurations presented later in the report.

Table 6 is a list of the reports that were requested. Table 7 summarizes the USBM contracts that were reviewed. Included in Table 7 are the results of the review of those contract reports which were received as well as a breakdown showing the applicability and quality of the information received and an indication of the status of the prototype hardware. It should be noted that most of the hardware which fell into the category of long-range technology was not specifically utilized in this program, thus reiterating the goals of the forementioned criteria. Such programs as those employing high pressure water jets (for drilling) or sonics (for pin setting) were reviewed with interest, but the major developments contained within these efforts were noted to be not fully developed. As this type of equipment gradually demonstrates its ability to perform competitively with regard to productivity and reliability, it will become increasingly attractive for use on advanced bolter concepts.

Some of the key studies which were funded by the Bureau of Mines and have potentially high applicability to this program are highlighted below:

The Flexible Drill Steel program was investigated thoroughly for useful hardware. The two most promising concepts, previously developed by Bendix and IRRI, comprise fully automatic bolting modules. The Bendix module capable of installing resin bolts and the IRRI module capable of installing mechanical anchor bolts. Either module can be adapted to the automatic bolter module chassis concepts. The larger IRRI module is shown in the concept drawings of this report.

The rod changer-bolt bender bolter concept utilizes components from both the Bendix and IRRI bolter module programs. The IRRI rod changer drill steel storage magazine and the Bendix bolt bender are coupled to create a low coal, remotely operated bolter. Several other concept configurations make use of rod-changer style magazines, extending their usefulness to drill and bolt storage on concepts which install shorter than seam height bolts.

Component mechanisms of interest found in all of the Miner/Bolter programs as well as the FMC automated bolter were studied for possible applicability. The transfer mechanism (on the transfer bolters) was itself inspired by the oval tracked, chain driven drill and bolt storage magazines found on several of the aforementioned programs.

Table 6

USBM SOURCE LIST

Reports Requested:

	Contract	Title
1.	JO265021	Engineering Noise Control Guide-Lines for the Coal Mining Industry -- Handbook
2.	JO265014	Roof Bolting Hazards Analysis Study
3.	HO252091	Fabrication & Evaluation of Optimized Operator Compartments
4.	HO166138	Development of a Dual Boom Semi-Automatic Roof Bolter
5.	JO166051	Performance Requirements of Braking Systems for Rubber Tired Mining Equipment Used in Coal and Non-Coal Mines
6.	HO242054	Development of a Miner/Bolter System
7.	HO242056	Development of a Miner/Bolter System
8.	HO262036	Development of a System for High-Speed Drilling of Small Diameter Roof Bolt Holes
9.	HO262054	Development of a System for High-Speed Drilling of Small Diameter Roof Bolt Holes
10.	JO255038	Feasibility of a Temporary Roof Support System
11.	HO252048	Fabrication and Evaluation of Optimized Operator Compartments
12.	HO262028	Development of a Low Coal, Automated, Remote Controlled Resin Cartridge Inserter, Roof Bolt Bender/Inserter, Roof Bolt Spin/Thrust, Hold Assembly
13.	HO262053	Development of a System for High Speed Drilling of Small Diameter Roof Bolt Holes

Table 6

<u>USBM SOURCE LIST</u> (Continued)

14.	HO262061	Laboratory Investigation to Determine Application and Limits of Sonically Driven Roof Bolts
15.	HO232041	Large Scale Field Test of Pumpable Roof Bolts
16.	HO242062	Flexible Roof Drill for Low Coal
17.	HO155192	Innovative Machine Design Concepts
18.	HO242060	Flexible Roof Drill for Low Coal
19.	HO242027	Flexible Roof Drill for Low Coal
20.	JO265015	Collection of Coal Mining Industry Statistics for Normalization of Accident Data
21.	HO262017	Magnetostrictive Roof Bolt Tension Uniformity
22.	HO262018	Hardened Washers, Roof Bolt Tension Uniformity
23.	HO166096	Roof Bolt Tention Indicating Devices, Field Test
24.	HO242018	Tension Indicating Mine Roof Bolt Development
25.	HO262006	Output Torque Indicator for Bolting Machines
26.	HO262007	Output Torque Indicator for Bolting Machines
27.	SO271014	Full-Scale Roof Bolt Test System
28.	HO166014	Resin Bolt Installations
29.	HO266033	Multiposition Roof Sag Indicator
30.	HO250234	Chemical Injection for Stabilizing Coal Mine Roof

Table 6

USBM SOURCE LIST (Continued)

31.	J0255004	Roof Bolting Using Fully Resin-Grouted Bolts
32.	J0166016	Mobile Roof Shield in an Operating Coal Mine
33.	H0272008	Weathering Protection at the Face
34.	J0155153	Weak Floor Conditions, Stability of Coal Pillars
35.	H0262015	Retreat Mining Support System
36.	H0242063	Flexible Roof Drill for Low Coal - Phase VI
37.	H0242051	Development of a Miner/Bolter System
38.	H0272041	Development of a Mechanical Anchor Bolter Module for Low Coal
39.	H0230021	Standardization of Control for Underground Electric Face Equipment
40.	H0220031	Protective Canopies for Low Coal Electric Face Equipment
41.	S0144087	Logistic Performance of Continuous Miners
42.	H011670	Equipment Modifications for Increased Safety
43.	J0155131	Evaluation of Wet Head Drilling Techniques

Table 6

USBM SOURCE LIST (Continued)

44.	J0155099	Development of a Quiet Rock Drill
45.	J0266014	Development of a Training System for Roof Bolt Equipment Operators
46.	RI7998	Noise Abatement of Pneumatic Rock Drill
47.	G0274009	Application of Water Jet Assisted Drag Bit and Pick Cutter for the Cutting of Coal Measured Rock.
48.	H0252075	Test of Inorganic Replacements for Resins
49.	H0272020	Rapid Excavation of Rock with Small Charges of High Explosives
50.	H0242057	Development of a Miner/Bolter System
51.	J0155133	Evaluation of Wet Head Drilling Techniques
52.	H0177125	Development of 6 Prototype Production of Stoper Drills
53.	J0155099	Development of Other Pneumatic Drills
54.	H0252008	Development of Percussive H_2O Jets
55.	J0166122	Design of a Quiet Roof Drill Using Principles of the Leavell Model D Pavement Breaker Feasibility Study
56.	H0262016	Temporary Face Support System
57.	H0242061	Bendix Resin Bolter Module
58.	H0262058	Temporary Face Support System
59.	H0242020	Survey of Protective Canopy Design

Table 6

USBM SOURCE LIST (Continued)

60.	HO242065	Refined Design of Protective Canopies
61.	*	Operational Effectiveness Improvement Concepts for Mine Machines
62.	RI 8273	Longer than Seam Height Drill Development Program

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* Number Unknown

TABLE 7

USBM SOURCE REVIEW SUMMARY

No.	Contract Number	Contractor	Report Subject	Requested by IRRI	Suggested by BuMines	Contact Made With PI	Report Received	Report Reviewed	Applicable to Program	Best Available Information	Useful Long Range Technology	Available Technology	Utilized by Program
1	J0265021	B.A.H.	Noise Control Guide Lines	x		x							
2	J0265014	Bendix	Roof Bolting Hazards Analysis	x		x	x	x	x	x			x
3	H0252091	FMC	Operator Compartments	x		x							
4	H0166138	FMC	Semi-Automated Roof Bolter	x		x							
5	J0166051	Skelly Loy	Performance of Braking Systems	x		x							
6	H0242054	Joy	Development of a Miner/Bolter	x		x							
7	H0242050	Jeffrey	Development of a Miner/Bolter	x		x	x	x	x	x			
8	H0262030	FRC	High Speed Drilling	x		x	x	x	x		x		
9	H0262054	CSM	High Speed Drilling	x		x	x	x	x		x		
10	J0255038	AEF	Temporary Roof Support System	x		x	x	x					
11	H0252048	Bendix	Operator Compartments	x		x	x	x		x		x	
12	H0262028	Bendix	Automatic Bolter Module	x		x	x	x	x		x		
13	H0262053	Bendix	High Speed Drilling	x		x	x	x	x		x		
14	H0262061	CMU	Sonically Driven Roof Bolts	x		x	x						
15	H0232041	Eimco	Pumpable Roof Bolts	x		x	x	x	x	x			
16	H0242062	Eimco	Flexible Roof Drill for Low Coal	x		x							
17	H0155192	FMC	Innovative Machine Design Concepts	x		x							
18	H0242060	FMA	Flexible Roof Drill for Low Coal	x		x	x	x	x	x	x		
19	H0242027	WSU	Flexible Roof Drill for Low Coal	x		x	x	x	x	x			

TABLE 7 (Continued)

USBM SOURCE REVIEW SUMMARY

No.	Contract Number	Contractor	Report Subject	Requested by IRRI	Suggested by BuMines	Contact Made With PI	Report Received	Report Reviewed	Applicable to Program	Best Available Information	Useful Long Range Technology	Available Technology	Utilized by Program
20	JO265015	Woodward	Coal Mining Industry Statistics	x		x							
21	HO262017	Mech Tech	Bolt Tension Indicator	x									
22	HO262018	Terratek	Bolt Tension Uniformity		x		x	x					
23	HO166096	Eng. Int'l.	Tension Indicating Devices	x									
24	HO242018	Modulus	Tension Indicating Bolt		x								
25	HO262006	Eimco	Output Torque Indicator		x								
26	HO262007	Mech. Tech.	Output Torque Indicator		x								
27	SO271014	MSA Res.	Roof Bolt Test System	x									
28	HO166014	FMA	Resin Bolt Installations	x									
29	HO966032	I. Hawkes	Roof Sag Indicator	x									
30	HO250234	McCarthy	Chemical Stabilizing Mine Roof	x									
31	JO355004	Mich Tech	Resin-Grouted Bolts	x									
32	JO166016	Urbdata	Mobile Roof Shield	x									
33	HO272008	MBA	Weathering Protection at Face	x									
34	JO155153	U. Missouri	Stability of Coal Pillars	x									
35	HO262015	FMC	Retreat Mining Support System	x			x	x					
36	HO242063	IRRI	Flexible Roof Drill for Low Coal				x	x	x	x		x	x
37	HO242051	IRRI	Miner Bolter System				x	x	x	x		x	x
38	HO272041	IRRI	Mechanical Anchor Bolter Module				x	x	x	x	x		x

TABLE 7 (Continued)

USBM SOURCE REVIEW SUMMARY

No.	Contract Number	Contractor	Report Subject	Requested by IRRI	Suggested by BuMines	Contact Made With PI	Report Received	Report Reviewed	Applicable to Program	Best Available Information	Useful Long Range Technology	Available Technology	Utilized by Program
39	HO230021	ASA	Standardization of Control				x	x					
40	HO220031	Bendix	Protective Canopies				x	x	x	x		x	
41	SO144037	Bendix	Performance of Continuous Miners				x	x		x			
42	HO11670	FMC	Equip. Modifications for Safety		x	x	x	x	x	x		x	x
43	JO155131	FMC	Wet Head Drilling Techniques				x	x	x	x		x	
44	JO155099	I. Hawkes	Development of Quiet Rock Drill				x						
45	JO366014	MRI	Training System				x	x	x	x			x
46	RI7998	PMSRC	Noise Abatement Pneumatic Rock Drill				x	x					
47	GO274009	CSM	Water Jet Drag Bit & Pict Cutter		x	x							
48	HO252075	CSM	Inorganic Replacement for Resins		x	x							
49	HO272020	CSM	Excavation of Rock		x	x							
50	HO242057	FMC	Miner/Bolter System		x	x							
51	JO155133	FMC	Wet Head Drilling		x	x							
52	JO177125	I. Hawkes	Stoper Drills		x	x							
53	JO155099	I. Hawkes	Pneumatic Drills		x	x	x	x					
54	HO252008	SC Assoc.	Percussive Water Jets		x								
55	JO166122	VAST	Design of a Quiet Roof Drill		x								
56	HO262016	FMA	Temporary Face Support System		x								
57	HO242061	Bendix	Resin Bolter Module				x	x	x				

TABLE 7 (Continued)

USBM SOURCE REVIEW SUMMARY

No.	Contract Number	Contractor	Report Subject	Requested by IRRI	Suggested by BuMines	Contact Made With PI	Report Received	Report Reviewed	Applicable to Program	Best Available Information	Useful Long Range Technology	Available Technology	Utilized by Program
58	HO262058	ARC	Temporary Face Support System				x	x		x			
59	HO242020	Bendix	Protective Canopy Design				x	x	x	x			x
60	HO242065	Bendix	Design of Protective Canopies				x	x	x	x		x	
61		Bendix	Oper. Effect. Improvement				x						
62	RI 8273	SMRC	Longer Than Seam Height Drill				x	x					

3.0 SAFETY CONSIDERATIONS FOR ALL BOLTER CONCEPTS

The primary goal of all of the concepts presented in this report is to significantly increase operator safety on coal mine roof bolters. The secondary goal is to minimize any adverse effects that increased safety practices or machinery may have on productivity or reliability.

At the outset of the program a review of USBM recent and past programs related to coal mine roof bolting was conducted. Of special interest were all programs relating to the safety of bolter operators, and to advances in equipment and/or machinery techniques which lead to increased safety for the operator or better ground control.

Review of this material led to the conclusion that the bolter operator should be removed from the immediate bolting vicinity. The types of hazards that befall a bolter operator stem from three causes:

1. Injury due to roof fall which most frequently occur in the unbolted area or an area in the process of being bolted.
2. Machinery-associated injury which is proportional to the mechanical activity in the area. An example of this type of hazard would include rotating machinery.
3. Machinery induced injuries which involve the man's position relative to the machinery. For example, a non-riding man may be run over or pinched by the machine.

Many of these problems may be solved with various devices such as centralizers, self centering valves and safety switches which prevent machine operation unless the operator's hands are in safe, preselected locations. However, such devices are susceptible to circumvention. The application of enough individual safety provisions to avoid all or even most of these types of accidents would complicate system design by the introduction of additional, unreliable, often cumbersome devices. Such an approach would appear to be counter-productive to the machine operator and perhaps the mining industry. On the other hand, removal of the operator from this most hazardous and congested area will immediately eliminate a great number of the potential hazards to the operator. He could be relocated to a less congested position that affords him greater comfort and safety onboard the bolting vehicle. This approach places him out of reach of the high speed rotating machinery and unbolted roof in an area where he may be better protected in a more comprehensive canopy.

Another important source of information which impacted the program and the concepts generated came from numerous field visits made with Lee-Norse Company field service personnel. Contacts were made with mine personnel to determine their specific mining roof control and bolter equipment problems in the regions covered by the individual field service representatives. Frequently, these meetings resulted in underground visits to specific mines providing examples of actual bolting equipment usage and an opportunity to determine the level of user satisfaction or dissatisfaction with his current equipment. In general, the mining personnel interviewed expressed a strong desire for reliability, "toughness", maintainability, better maintenance information and field service assistance. The large majority of mines investigated had been able to select standard commercial components suitable to their specific needs. Although the components varied widely from mine to mine, the operators were quite satisfied with them. The mine operators generally concede (about 50%) to a need for a safer bolter and that a remote-operated bolter would achieve this end. However, they caution against excessive displays of technology. They are interested in a minimum amount of additional hardware to achieve sufficient operator remoteness to obtain significantly improved operator safety. They fear that unnecessary complexity will yield a bolter of dubious value with a low availability due to frequent and extensive downtime for repairs to delicate equipment.

Since remote operation requires some handling mechanisms, program interest centered on the various miner bolter programs, the Bendix Automated Bolter Module, and the FMC Twin Arm Remote Bolter. Visits were made to the contractors where hardware was available for inspection. These visits provided program personnel with knowledge of the latest techniques for remote loading of drill steels and bolts.

The evolution of the IRRI bolter concepts was monitored by frequent contacts between IRRI and SMRC.

On August 8, 1978 the IRRI program manager visited MSHA at the Bruceton Research Center where the program concepts for roof bolters were reviewed with Bruceton personnel. Their comments assisted in the selection of the preferred options of several concepts. Preference was expressed for the tapered chassis, dual boom transfer design over the straight chassis version. Specific reference was made at this conference to the disproportionate number of accidents that occur in low seam mines due to the more crowded conditions. Thus, safety advances are especially necessary for low seam equipment.

The information obtained from the investigations described above provided the basis for the Remote Operator Roof Bolter Concepts developed during the program. It is judged that these concepts represent a significant step forward for roof bolter operator safety. These concepts draw heavily upon existing or new bolting equipment components and offer their special advantage primarily because of the relatively unique arrangement of components. Further, these concepts place major emphasis on where the man is located relative to, 1) the primary hazard area and 2) his work. The vehicles have been rearranged to locate the bolter operator in a preferred position approximately 6-10 ft. outby the active bolting position. This positioning is in contrast to the great majority of existing bolter vehicles which fill this prime space with machinery and force the man to stand to either side of the drill or ahead of the drill where he may be pinched or struck by falling debris. Then, as a compromise, existing bolters cantilever a significant canopy structure out over him. The concepts presented herein, on the other hand, attempt to correct historical errors by relocating the bolter operator in the best location for his safety and operation of the bolting equipment.

4.0 ROOF BOLTER CONCEPTS

4.1 Concept Nomenclature

During this program four (4) basic concepts for roof bolter machines were generated which offer the opportunity for improved bolter operator safety without sacrifice in productivity. Several variations on two of these concepts, providing either (1) dual or simple boom bolting and (2) standard or new chassis, provide the total of eight (8) bolting machines that are presented herein. To establish consistent nomenclature for the concepts, thereby assisting the reader in understanding the associated descriptive text, the following summary table of the bolter concepts is presented.

Transfer Bolter

- Dual Boom (New Chassis)
- Dual Boom (Standard Chassis)
- Single Boom (New Chassis)
- Single Boom (Standard Chassis)

Rod Changer - Bolt Bender Bolter

Transverse Rail Rib Bolter

Automatic Bolter (Module Concepts)

- Dual Boom (MABM-DB)
- Single Boom (MABM-SB)

The use of complete bolter titles in the written text has been generally avoided to eliminate repetition and confusion. However, the complete title of each bolter concept, consistent with the above table, has been used on all section headings, figures and tables related to that particular bolter concept.

The following sections describe each of the concepts tabularized above.

4.2 Transfer Bolters

The transfer bolter concepts embodying one (or two) transfer mechanisms provide the most direct and simple method of achieving remote operation. There are no storage magazines in these concepts. The central feature of these concept is a two-way transfer mechanism that allows the operator to be remote from the drill. This transfer mechanism (1) accepts an operator load (drill, bolt or resin bag in inserter tube) and transfers the load to the drill chuck, or (2) accepts a load from the drill chuck and transfers it to the operator. Thus, the transfer mechanism in essence is a mechanical extension of the operator's arm. The transfer feature has been embodied in both dual and single drill head versions. Four (4) versions of bolters embodying the basic transfer mechanism concept are discussed below.

4.2.1 Transfer Bolter - Dual Boom (New Chassis)

This bolter concept, shown in an artist's rendition in Figure 2, features two identical drilling positions. The drill heads are supplied with drills or bolts by (2) chain-driven transfer mechanisms. The remotely located operators, positioned under a substantial protective canopy, manually load the transfer mechanisms which then transports the drill or bolt to the drilling position for use. Drill steels are retrieved in a similar manner by the transfer mechanism. A new chassis design has been provided which efficiently packages the drill heads, transfer mechanisms, operator stations, steering provisions, storage racks and power cable reel into a compact, highly maneuverable vehicle. A preliminary design of this bolter configuration, showing major component layout and basic vehicle envelope dimensions, is given in Figure 3. The detailed design and operating specifications for this bolter vehicle are given in Table 8. The commercial components utilized in this concept are summarized in Table 9.

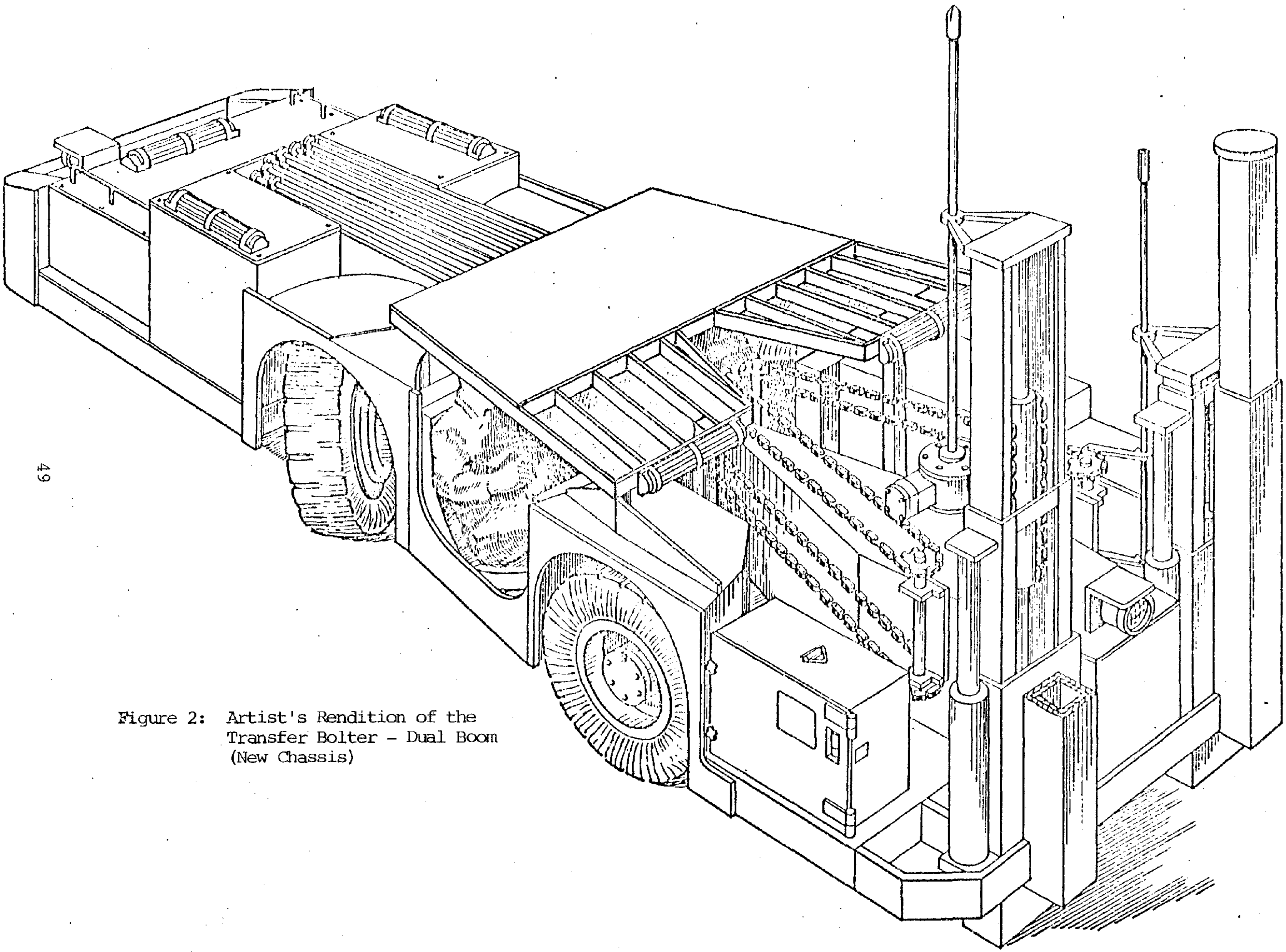


Figure 2: Artist's Rendition of the Transfer Bolter - Dual Boom (New Chassis)

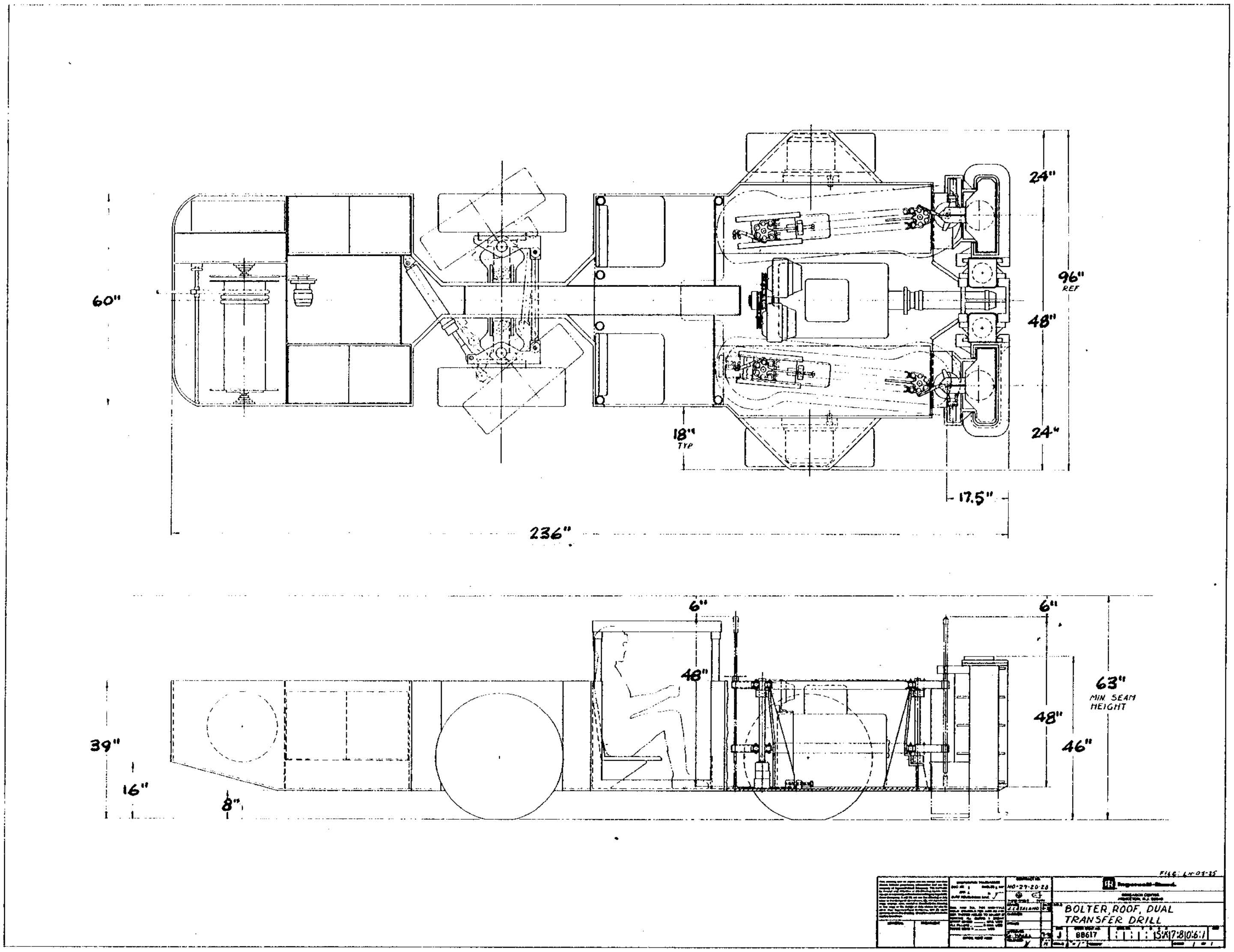


Figure 3: Plan and Elevation Views of the Transfer Bolter - Dual Boom (New Chassis)

Table 8

Design and Operating Specifications for the Transfer Bolter - Dual Boom (New Chassis)

General

A.	Overall Length	19.7 feet
B.	Overall Height	4 feet, 9 inches for 4 foot bolts
C.	Overall Width	8.0 feet
D.	Ground Clearance	8 inches
E.	Maximum Ramp Angle for Clearance	
	Front	9 degrees
	Rear	8 degrees
F.	Operating Seam Range	4 to 9.2 feet
G.	Bolt Length	3 to 8 feet
H.	Turn Capability	
	Single Pass 90° Turn at 17.6 Feet Minimum Entry Width	
I.	Estimated Weight	23,000 pounds

Performance

A.	Tram Speed	120 FPM
		1.4 MPH
B.	Maximum Grade	36% Slope
		20 Degrees
C.	Ground Pressure	72.8 psi

Power

A. Electric Cable 440 VAC 3 Phase

Table 8

Design and Operating Specifications for the Transfer Bolter - Dual Boom (New Chassis) - (Continued)

B. Horizontal Axis Cable Reel - Power Take Up

C. 100 Horsepower Electric Motor

Tram System

A. Tires 10.00-15 35.8 in. dia. x 10.94 in. wide - 79 in. sq. Footprint

B. 4-Wheel Hydraulic Motor Drive

C. Planetary Reduction

D. 3 Point Suspension - Rear Axel Pivot

E. Rear Wheel Steering, Inside Time Turns a Maximum of 45 Degrees

F. Automatic Parking Brake

Hydraulic System

A.	System Pressure	2,000 psi
B.	Pumps	2-35 GPM Gear 2-15 GPM Gear 1-15 GPM Gear Variable Displacement, Pressure regulated, piston pump
C.	Filters	Suction 75 Micron Return 10 Micron

Table 8

Design and Operating Specifications for the
Transfer Bolter - Dual Boom (New Chassis) - (Continued)

Safety Features

A. Full Cover Canopy Protection

B. Remote In-Cab Operation

C. Fire Protection

D. Temporary Roof Support (Local)

E. Tapered Chassis

F. Dual Escape Way - Through Opposite Cab

Special Features

A. Semi-fixed Drill Heads (Plan View)

Table 9

Commercial Components Used
On the Transfer Bolter - Dual
Boom (New Chassis)*

Description

1.0 Electric Power

1.1 Westinghouse Electric Motor

- 100 Horsepower
- 1780 RPM
- 440 VAC, 3 Phase, 60 Hertz
- 113 AMPS
- MESA Certified

1.2 Reel Cable Electric

- Ensign Model No. 5010 2Q08C2B-000
- Penn Approved Reel
- XP 1841-0

1.3 Spooler Cable Electric

- Lee-Norse
- Part No. 4-008200-300

*All quantities listed are one per vehicle unless otherwise noted.

Table 9

Commercial Components Used on the Transfer Bolter - Dual Boom (New Chassis) (Continued)

	1.4	Cable Electric
		- Essex 2-3/C Type G-Gc
		- 600 V P125 MESA
		- or Equivalent
2.0		Hydraulic Power
	2.1	Pumps
		- Commercial Shearing Co.
		- 35-15 GPM Tandem with Output Shaft
		- P25X 178 GI IT17-11 G AB07-1-BO
		- 35-15-15 GPM Triple Tandem
		- P25X 178 GI IP17 -11 C AB07-1 C AB07-1
	2.2	Valves
		- Commercial Shearing Co.
		- Series A20
3.0		Mechanical Power
	3.1	Reel Motor
		- Commercial Shearing Hydraulic Motor

Table 9

Commercial Components Used on the Transfer Bolter - Dual Boom (New Chassis) (Continued)

- M25X 997 BE ER10-30

3.2 Tram Motors - Quantity = 4

- Char-Lynn Hydraulic Motors
- Series 4000
- Model No. 109-1013

3.3 Tram Speed Reducer - Quantity = 4

- Fairfield Torque Hub - Planetary
- Model S3B
- Speed Reduction 25:1

3.4 Hydraulic Cylinders

- Martiner Products
- Steering
- Canopy

4.0 Mast Units

Including Stroke Cylinders,

Drill Pots and Motors

Table 9

Commercial Components Used on the Transfer Bolter - Dual Boom (New Chassis) (Continued)

4.1 Fletcher

Size Optional (Collapsed Ht./Max. Seam)

- 43/63 (inches)
- 49/75 (inches)
- 58/93 (inches)
- 66/110 (inches)

5.0 Tires

5.1 Mining Service Tires, Quantity = 4

- Firestone 10.00-15
- Overall Diameter = 35.8 inches
- Static Load Radius - 16.8 inches
- Footprint Area = 79 sq. in.
- 60 psi Inflation Pressure

5.2 Foam Fill

- Firestone Sup•R•Fil or equivalent

Table 9

<u>Commercial Components Used on the Transfer Bolter - Dual Boom (New Chassis)</u> (Continued)

6.0 <u>Dust Collection</u>

6.1 Air Cleaner

- Donaldson Split Pac™ Quantity = 2
- Model No. XYXOO - 5101
- Large Hopper Option
- 2.5 cu. ft. or
- 100 ft. of 1.38 in. dia. hole or
- 180 ft. of 1.00 in. dia. hole

6.2 Blower - Quantity = 2

- Sutorbilt
- California Series B
- Model No. 3MB
- 42 CFM at 6 psi at 1500 RPM

The simplicity of this transfer mechanism approach specifically addresses the problem of providing operator safety while at the same time assuring good bolter reliability. This concept permits the operators, now comfortably seated under an extensive high strength canopy at a safe distance from the unbolted face and the rotating machinery, to perform at high efficiency, sufficient to offset transfer and coupling times (estimated at 3 to 5 seconds per transfer - with 4 transfers per one mechanical bolt installation) as compared to a manually operated bolter. Resin bolting will require 6 transfers per bolt, a round trip for each of 3 units, a drill, a resin bag, and a bolt. The simplicity of the mechanism and the relatively small number of feedback loops required minimize any downtime caused by the transfer mechanism.

During the development of this concept substantial effort was directed towards simplified maintenance and improved bolter reliability. In order that the operator, boom, transfer mechanism and mast might remain fixed with respect to each other for maximum reliability and good alignment consideration was given to the use of a 4-wheel, 180 degree rotation steering system for this vehicle in addition to the more conventional rear wheel steering. This concept will allow the spread between drill center lines to remain fixed or essentially fixed. A provision could be included for an infrequent mechanical resetting capability to accommodate bolting at other than 4 foot spacing. However,this machine has been designed to perform best using the most common bolting pattern of 4 bolts across an entry on 4 foot centers. Accordingly, it will bolt the 16-18 foot nominal entry width most efficiently. The preferred travel path and bolting sequence for the bolter in such an entry is depicted in Figure 4. The bolter normally starts bolting a fresh cut to the right or left of the entry centerline. In position "A" the first two bolts on one end of a bolt row would be installed simultaneously by the two operators under the protective canopy.

Following the bolt installation, the right hand side bolter operator, whose cab controls include steering and tram, would tram the bolter 8 feet to the opposite side of the entry centerline. For 180 degree, 4-wheel steering all 4 chassis pivot wheels would turn 90 degrees in the direction of travel and the chassis would tram directly along the bolt row 8 feet and stop. If rear wheel steering is used the vehicle will have to back up approximately 2 to 3 vehicle lengths and tram forward, moving 8 feet sideways in the process. The travel path is depicted in Figure 5. It is estimated that this maneuver will be about 30 seconds slower than the sideways maneuver described above. However, it is only required for every other pair of installed bolts. Therefore, the simpler and less expensive rear wheel

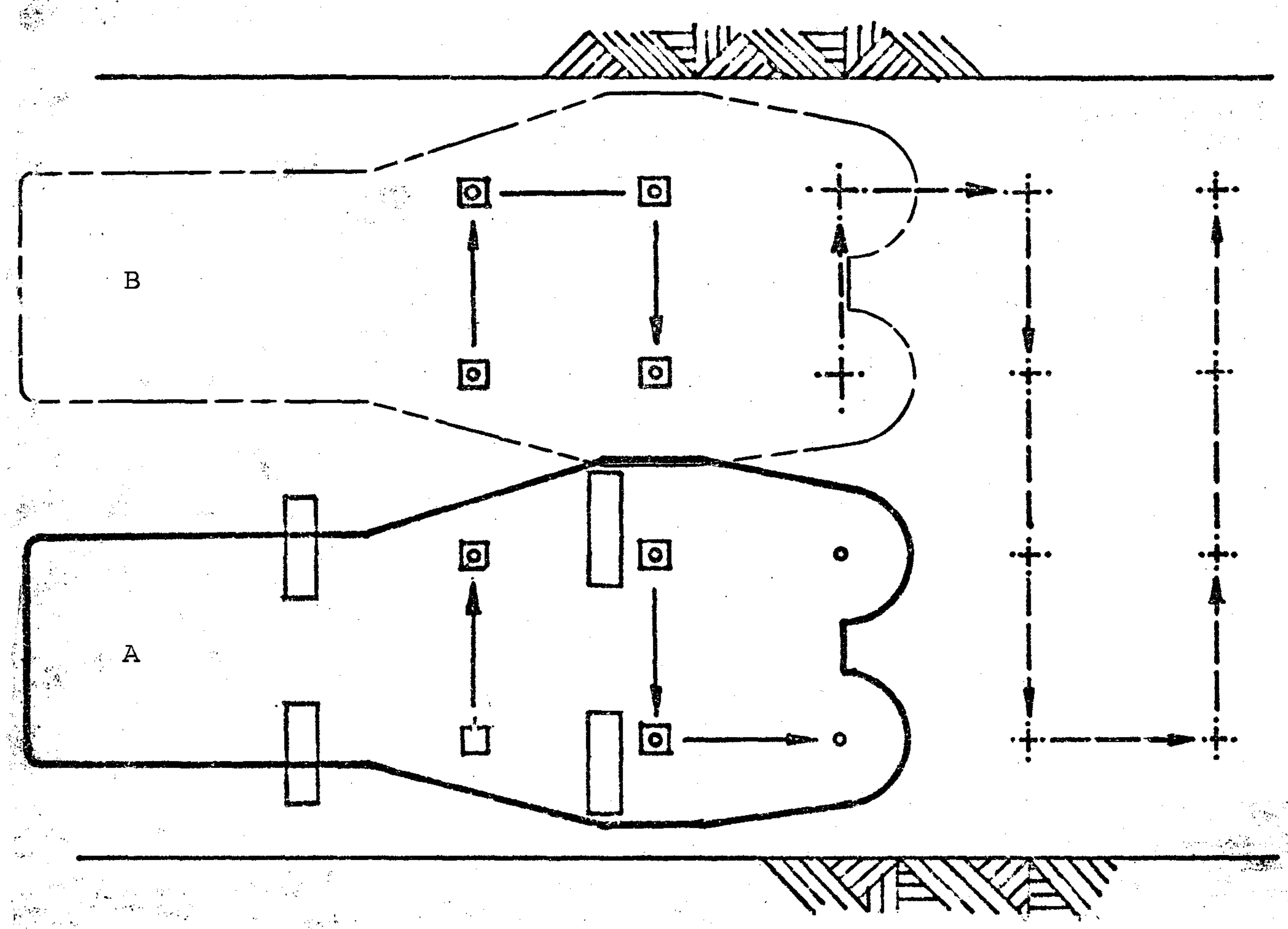


Figure 4: Dual Transfer Crab Travel Path and Bolting Sequence

steering approach would require only 30 seconds more per 4 bolt row, or 2.5 minutes per 20 foot entry bolted. Thus, the total cycle time is increased only 7.5 seconds per bolt. From position "B" (see Figure 4) each operator installs one bolt, completing the first row of bolts. Regardless of tram movement system, the next tram will orient all chassis wheels directly forward and tram the vehicle straight ahead 4 feet to begin a new row of bolts.

Thus, this sequence of operations installs bolts in a progressive square wave pattern. The bolter operators are always under bolted roof and every row of bolts is completed before another row of bolts is begun. Obviously this bolter concept can accommodate certain variations from the nominal bolt pattern to suit local conditions. For example, although bolt spacing is fixed between adjacent bolt pairs across an entry, variations can be made in the direction of bolter advance toward the face. Width variations may be accommodated between the middle bolts in the row and, at the end of the row. End of row distance from rib to bolt may be as close as two feet.

The operation of this vehicle requires a high level of operator utilization at both stations in spite of their remote location because only a minimum amount of control would be automatic. The operators would initiate and hydraulically control all transfers to and from the drill chuck, drill rotations, mast feed, bolt torque and thrust. The only automatic functions would be interlocks required to prevent component interferences during the bolt cycle.

The 180 degree, 4-wheel steering concept would require a wheel suspension steering and drive system unconventional to bolters. Wheel systems of this type have been used on other existing pieces of equipment, such as large lumber carriers, with complete success.

The wheel system would consist of 4 identical units of the type shown in Figure 6. Each unit includes one tire and wheel mounted to a hydraulic motor. The hydraulilc motor is mounted to an offset cantilevered frame with a pivot shaft directly over the tire vertical centerline. Thus, these tire units pivot relatively easily even when there is no vehicle motion and would accordingly do a minimum of damage to the floor. They are capable of great angular freedom. For this application, 90 degrees of freedom would be required on either side of the straight-ahead wheel position. Turning effort would be applied at the top of each pivot shaft to turn the the wheel units. Flow

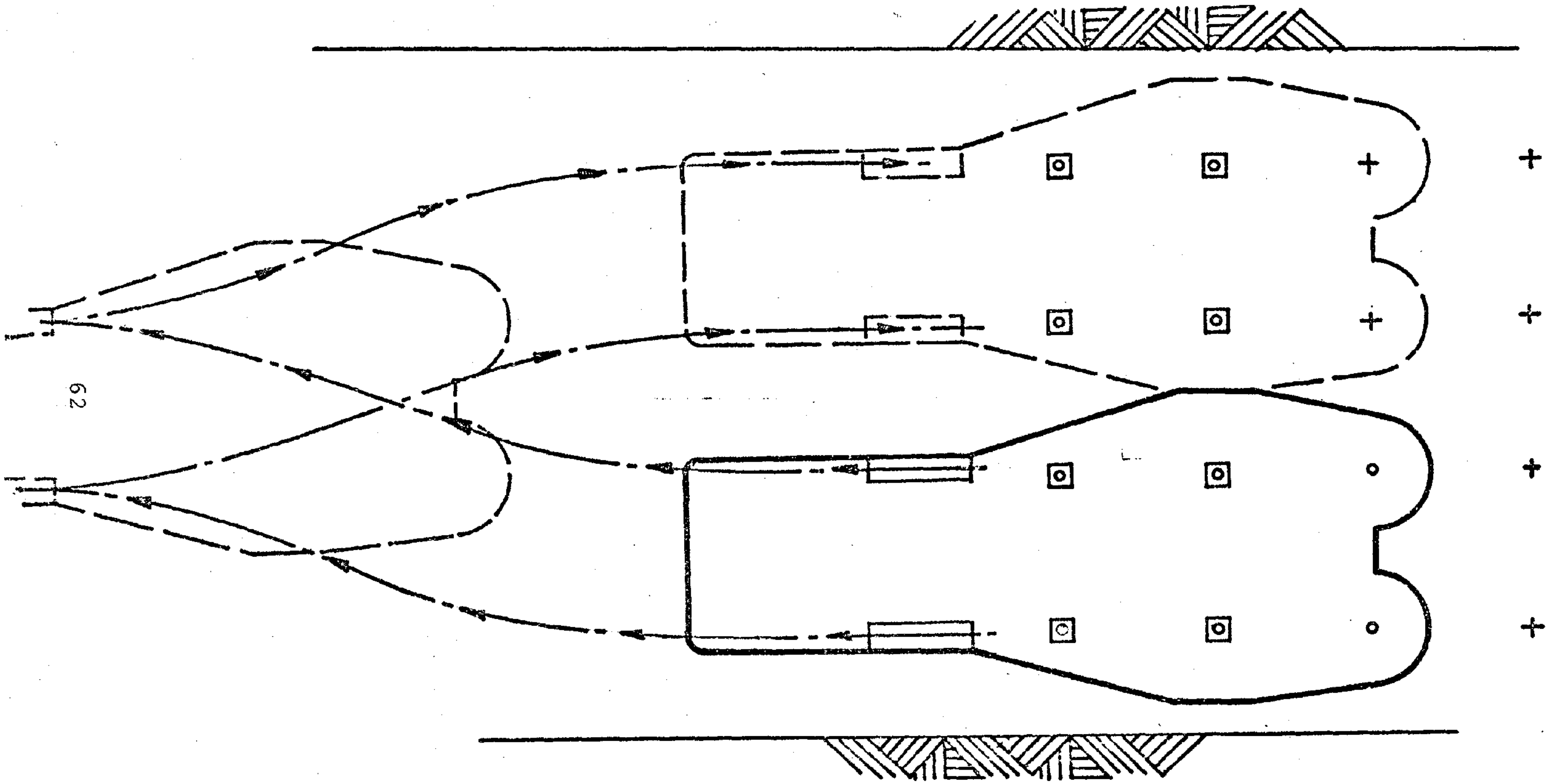


FIGURE 5

Dual Transfer With Orbital Steering Travel Path and Bolting Sequence

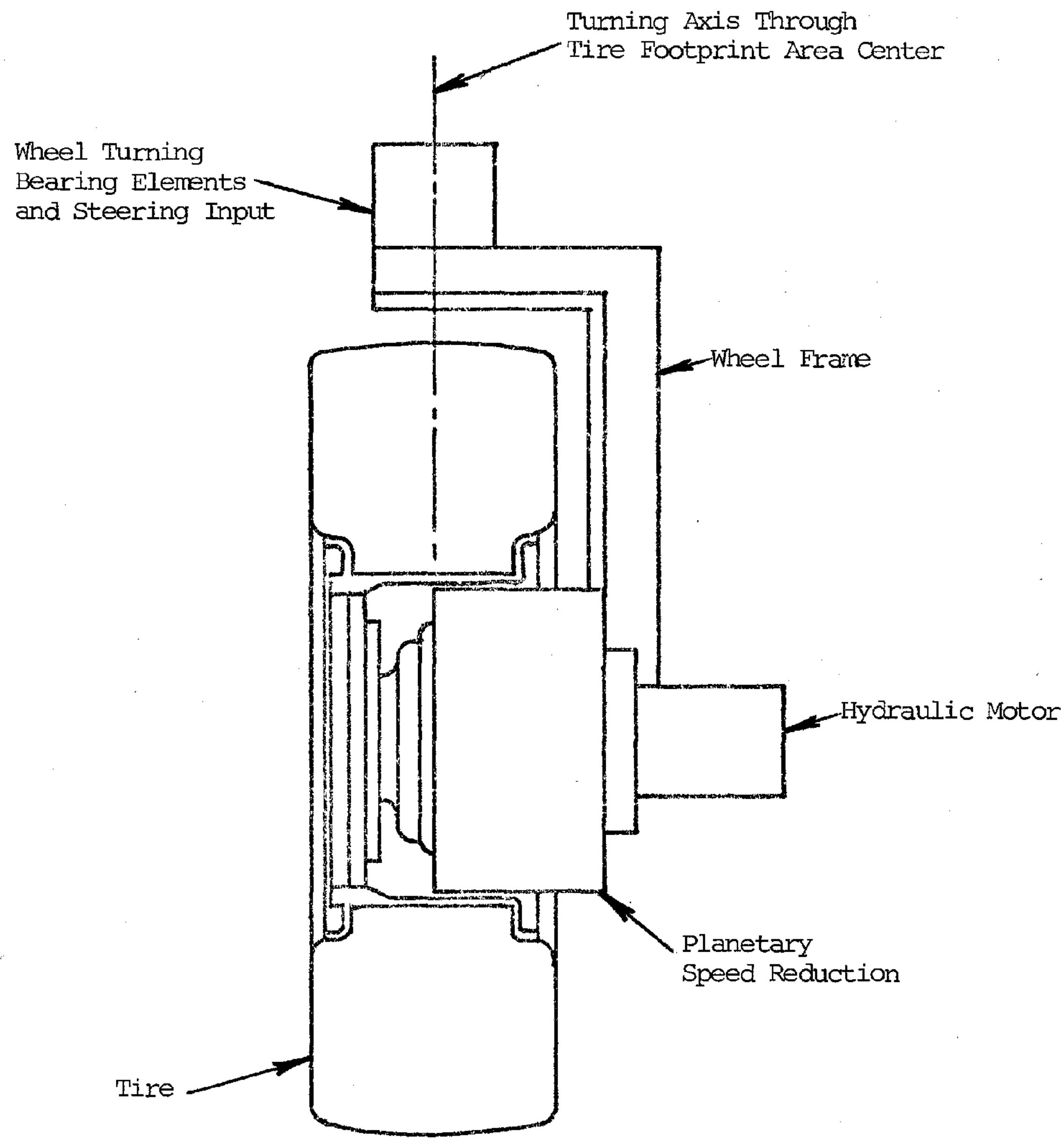


FIGURE 6

180° Steered Wheel Unit For Use
With Transfer Bolter - Dual Boom
(New Chassis)

splitters and/or mechanical drives would synchronize the right hand units with the left hand units. Either a roller chain or hydraulic method would insure synchronous wheel deflections. Front and rear wheel pairs would be controlled individually by separate, concentric steering wheels of the type depicted schematically in Figure 7. Thus, a right hand crab (sideways) maneuver would require both rims to be gripped and both wheels to be turned hard to the right. Steering wheels will turn only 180 degrees corresponding to total wheel travel and would feature an arrow indicating wheel orientation. This system would be very natural for the operator and would provide necessary visual feedback of the current wheel orientation. After the wheel pivot operation, the forward tram control would effect travel to the right in a sideways fashion. Upon completion of the tram maneuver, the operator would release the steering wheels. The inner wheel (connected to the rear wheels) would automatically rotate back to center position and cause the rear wheels to rotate back to the straight ahead position. This reorientation feature was included so that the rear wheels, which protrude beyond the chassis outline when turned right or left, would not hinder passage between the vehicle and rib. In fact, the narrow rear wheel track, self-centering rear wheels and tapered chassis were all developed for this bolter concept to ensure unobstructed passage space for the operator from his work station to the rear of the vehicle between the chassis and the rib. The frontal width of the chassis allows placement of a bolt within 2 feet of the rib and at the same time ensures a minimum of 18" clearance for operator passage. An alternate escape passage for the operator exists through the opposite operator cab.

The separate wheels will allow vehicle heading changes or cornering. In fact, while tramming between cuts, the operator may steer using only the front wheels by leaving the rear wheels in the straight ahead position. This steering mode will afford him the most natural automotive-type steering which would provide the greatest safety and control while the other steering options will maintain maneuvering flexibility.

Because of the narrow chassis profile, the capacity of the hydraulic reservoir was limited to 100 gallons. However, through the use of a pressure compensated, variable displacement pump, one major source of heat buildup can be eliminated. A variable displacement pump replaced the traditional constant flow pump used to preload the temporary roof support. Normally, once roof preloading is achieved, 15 GPM is pumped across a relief valve at roughly 1000 psi. Eliminating this unnecessary oil heating would reduce by nearly half (22,000 BTU) the estimated heat dissipation requirements of the hydraulic tank as follows:

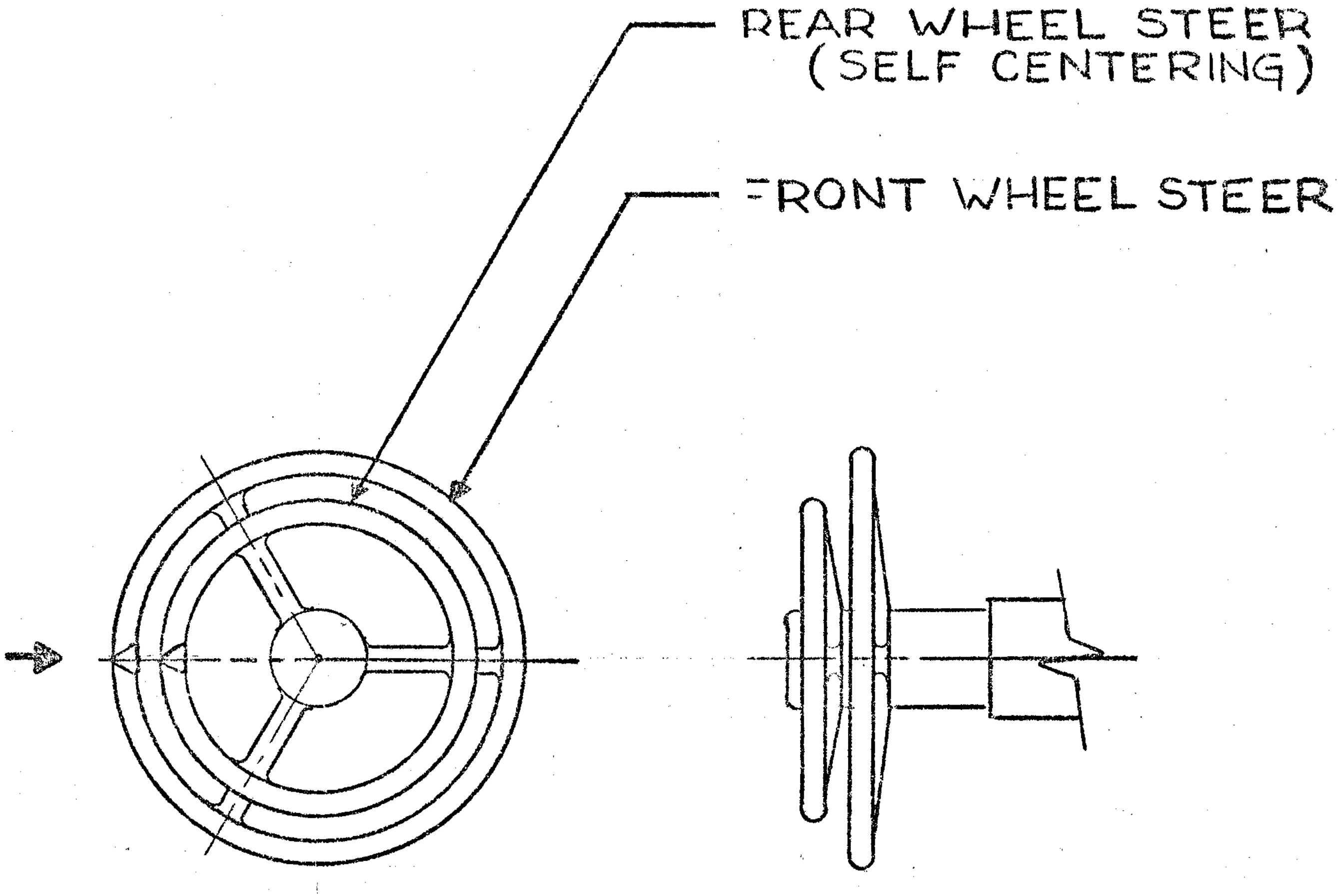


FIGURE 7
Crab Wheel Steering Wheel Arrangement for the Transfer Bolter - Dual Boom (New Chassis)

100% of the power is converted to heat while the temporary roof support remains pressurized against the roof.

$$hp = 1.486 \ \frac{\text{Flow (in. GPM) Pressure (PSI)}}{\text{Efficiency}}$$

Assume a mechanical efficiency = .9

$$\text{Then HP} = \frac{1.486 \times 15 \times 1000}{.9} = 24{,}766 \ \frac{\text{BTU}}{\text{Hour}}$$

Now assume the following duty cycle

TRS Duty Cycle = 4 Min. on 1/2 Min. Off

= 89%

$$\text{Avg. BTU/Hour} = 24{,}766 \times .89 = 22{,}000 \ \frac{\text{BTU}}{\text{Hour}}$$

Assume the remaining pumps are 2-35 GPM and 2-15 GPM pumps. This total flow is 100 GPM. Assume these pumps lose 10% hp to heat and operate at an average pressure of 1500 psi. Then the remaining head load:

$$hp = 1.486 \times \frac{.1 \times 100 \times 1500}{.9} = 24{,}766 \ \frac{\text{BTU}}{\text{Hour}}$$

$$\frac{22{,}000}{22{,}000 + 24{,}766} = \frac{22{,}000}{46{,}766} = 47\%$$

Therefore, use of a pressure compensated variable displacement pump which will destroke to zero displacement at 1000 psi will decrease the heat load on a typical twin boom bolter (which previously put 15 GPM over a relief valve at 1000 psi) by almost 50%.

4.2.2 Transfer Bolter Dual Boom (Standard Chassis)

This bolter concept embodies many of the features of the preceding configuration, but utilizes a standard production chassis.

In this configuration the operator stations, transfer mechanisms and mast drill units would all be incorporated into a substructure which would occupy the area of the manson-type boom on conventional dual boom bolters. Figure 8 provides a general dimensional layout of this bolter concept. Table 10 summarizes the design and operating specifications for this bolter concept. The standard production chassis used here is the Lee-Norse Company TDII-43 and specifications for this unit are also included in Table 11 and are used for comparison purposes only. The new boom members attach at the conventional boom swing pivot location in the conventional manner. This unit could maneuver and operate like conventional equipment, but with the advantage of remote operation.

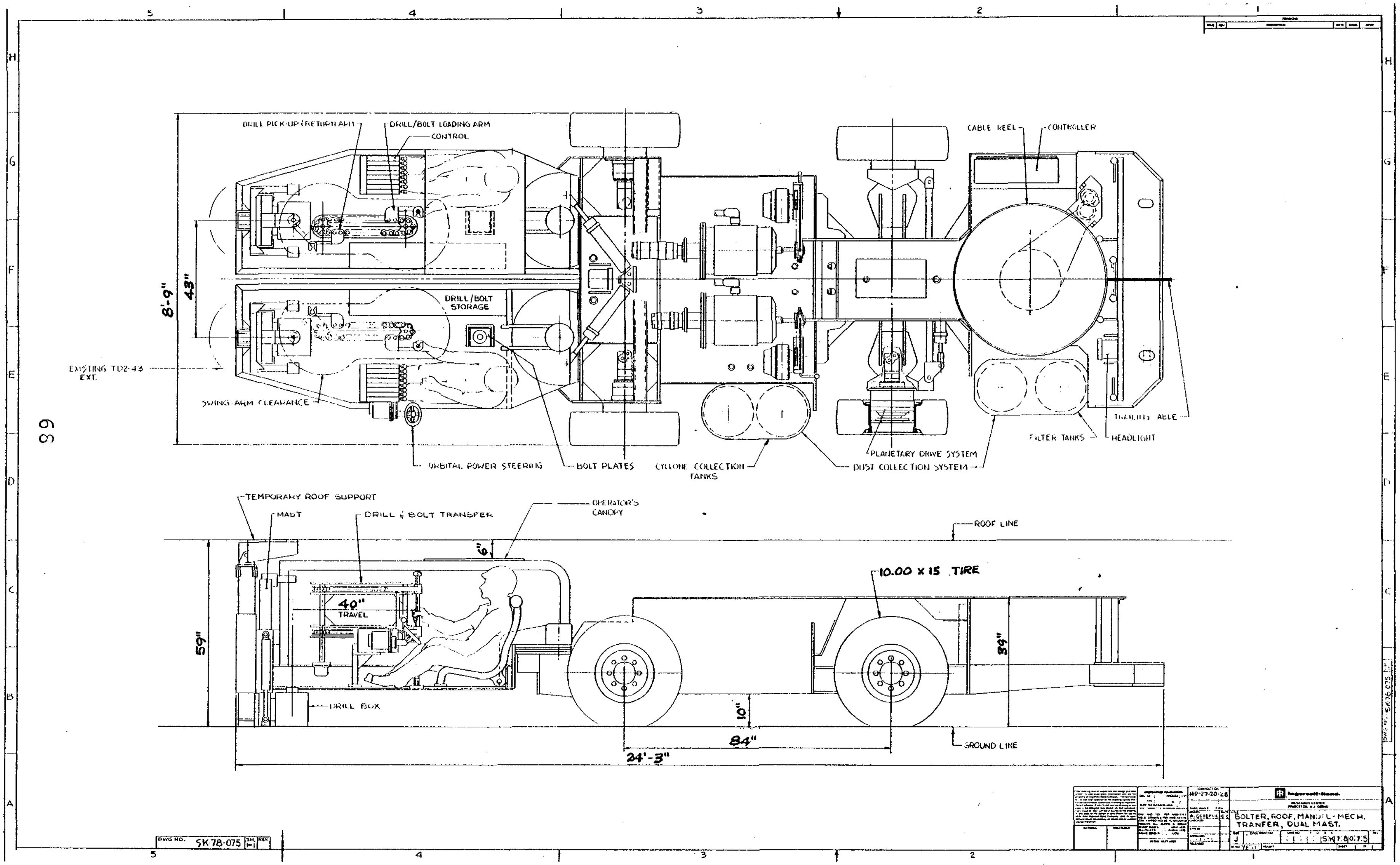


Figure 8: Plan and Elevation Views of the Transfer Bolter - Dual Boom (Standard Chassis)

Table 10

Design and Operating Specifications
for the Transfer Bolter -
Dual Boom (Standard Chassis)

General

A.	Overall Length	24.3 feet
B.	Overall Height	5 feet, 1 inch for 4 foot bolt
C.	Overall Width	8 feet 9 inches
D.	Ground Clearance	8 inches
E.	Maximum Ramp Angle for Clearance	
	Front	5 degrees
	Rear	8 degrees
F.	Operating Seam Range	5.1 to 9.2 feet
G.	Bolt Length	3 to 8 feet
H.	Turn Capability	
	Single Pass 90° Turn at 15.5 feet Minimum Entry Width	
I.	Estimated Weight	23,000 pounds

Performance

A.	Tram Speed	120 FPM
		1.4 MPH
B.	Maximum Grade	35% Slope
		20 degrees
C.	Ground Pressure	72.8 psi

Power

Table 10

Design and Operating Specifications for the Transfer Bolter - Dual Boom (Standard Chassis) (Continued)

A. Electric Cable 440 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

C. 100 Horsepower Electric Motor

Tram System

A. Tires 10.00-15 35.8 in. dia. x 10.94 in. wide - 79 in. sq. Footprint

B. 4-Wheel Hydraulic Motor Drive

C. Planetary Reduction

D. 3-Point Suspension - Rear Axel Pivot

E. Rear Wheel Steering Inside Tire Turn a Maximum of 45 Degrees

Hydraulic System

A.	System Pressure	1,800 psi
B.	Pumps	2-35 GPM Gear
		2-15 GPM Gear
		1-15 GPM Gear
C.	Filters	Suction 75 Micron Return 10 Micron

Safety Features

A. Full Cover Canopy Protection

B. Remote In-Cab Operation

C. Fire Protection

D. Temporary Roof Support (Local)

Table 10

Design and Operating Specifications for the Transfer Bolter - Dual Boom (Standard Chassis) (Continued)

Dust Collectors: Two Units

Donaldson (Split - Pac™)
Model XYXOO-5101
Optional Large Hopper

2.9 $ft.^3$ = 100 ft. of 1-3/8 or 180 ft. of 1.0"

Table 11

Lee-Norse TDII-43 Specifications

General

A.	Overall Length	24.9 feet
B.	Overall Height (CHassis)	43 Inches
C.	Overall Width	8.7 feet
D.	Ground Clearance	10.0 Inches
E.	Maximum Ramp Angle for Clearance	
	Front	10 Degrees
	Rear	9 Degrees
F.	Operating Seam Range	43 - 93 In.
		3.6 - 7.8 Feet
G.	Turn Capability (Orbital)	
	Single Pass 90° Turn at 15.5 Feet Minimum Entry Width	
H.	Weight	30,000 pounds

4.2.3 Transfer Bolter - Single Boom (New Chassis)

The single boom transfer bolter which is shown by an artist's rendition in Figure 9, will operate much the same as the dual unit previously described. It is, however, less complex featuring squirm steering, 4-wheel drive, and dual facing seats in the operator station. Figure 10 presents plan and elevation views of this bolter concept.

The tram motors are high torque, low speed units designed specifically for wheel drive. The motors have sufficient bearing capacity to accept the vehicle ground reaction loads both radially and axially. This bolter will operate as shown in Figure 11. Due to its angular position while bolting near either rib it will not require the tapered chassis featured on the twin version.

The operator is fully protected and comfortably seated near the center of the vehicle with good visibability of the transfer mechanism and drill mast. He enters and exits the operator station from the right hand side of the vehicle between the tires. The cab features a full canopy with height adjustment. The operator is not required to exit the cab during the bolting of a cut. Because the mast features roof and floor stab jacks, the area immediately ahead of the last row of bolts is fully supported. If necessary, an operator could exit the cab and approach the mast area to make an adjustment or correct a minor malfunction under the limited protection of the temporary roof supports. The preferred option would be to collapse the mast and withdraw from the unbolted cut for repair or inspection under previously bolted roof.

In order to maintain operator station access and chassis balance, an asymmetrical wheel pattern was developed for the vehicle. Section 5.0 following the concept discussions, analyzes the effect of this assymetrical wheel pattern on the steering and maneuverability of the bolter. The dual facing seats in the operator station allow maximum tramming visibility when tramming between cuts. Seat bottom hinges will allow the seats to be lifted out of the way when not in use for increased leg-room.

The detailed design and operating specifications for this bolter vehicle are given in Table 12. The commercial components utilized in this concept are summarized in Table 13.

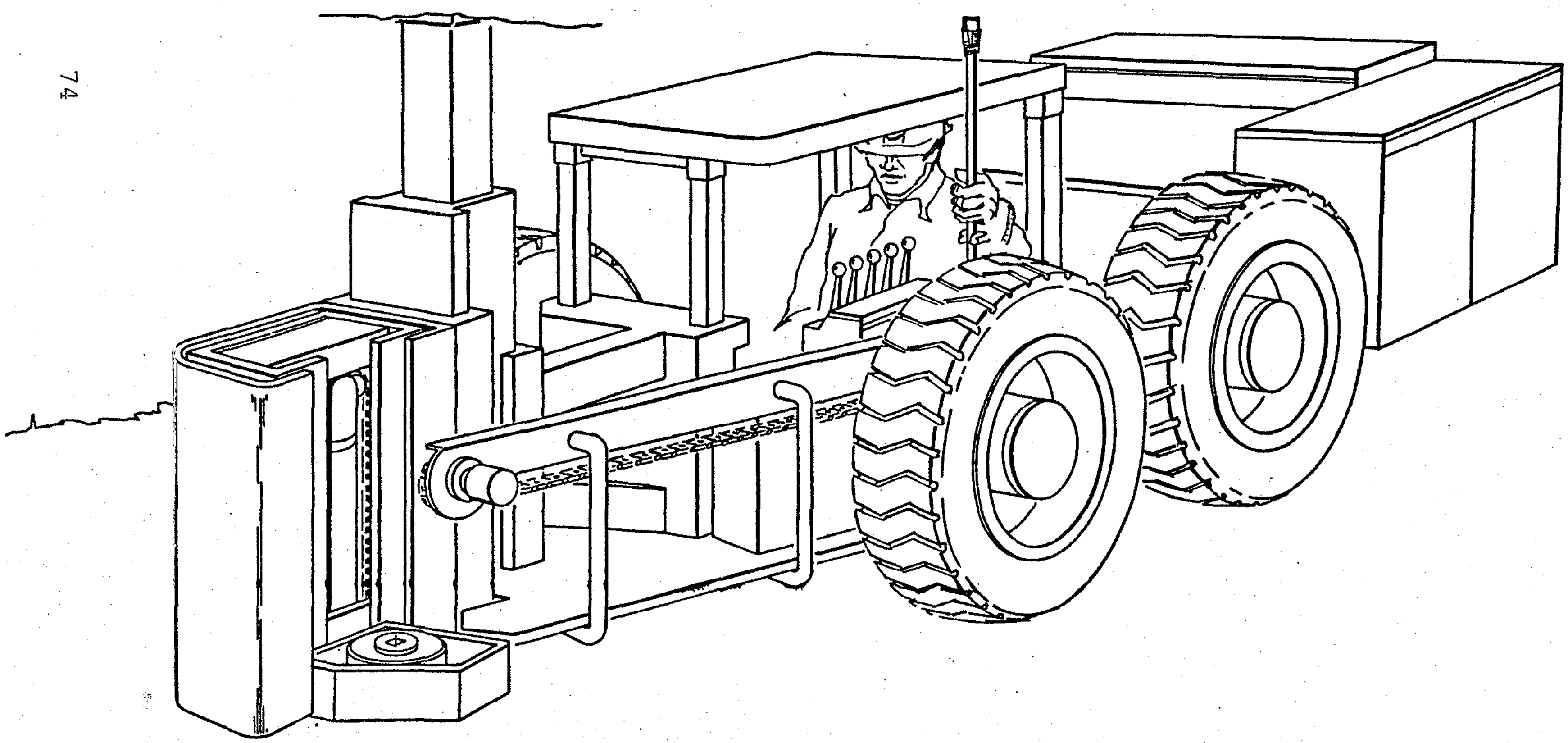


Figure 9: Artist's Rendition of the Transfer Bolter - Single Boom (New Chassis)

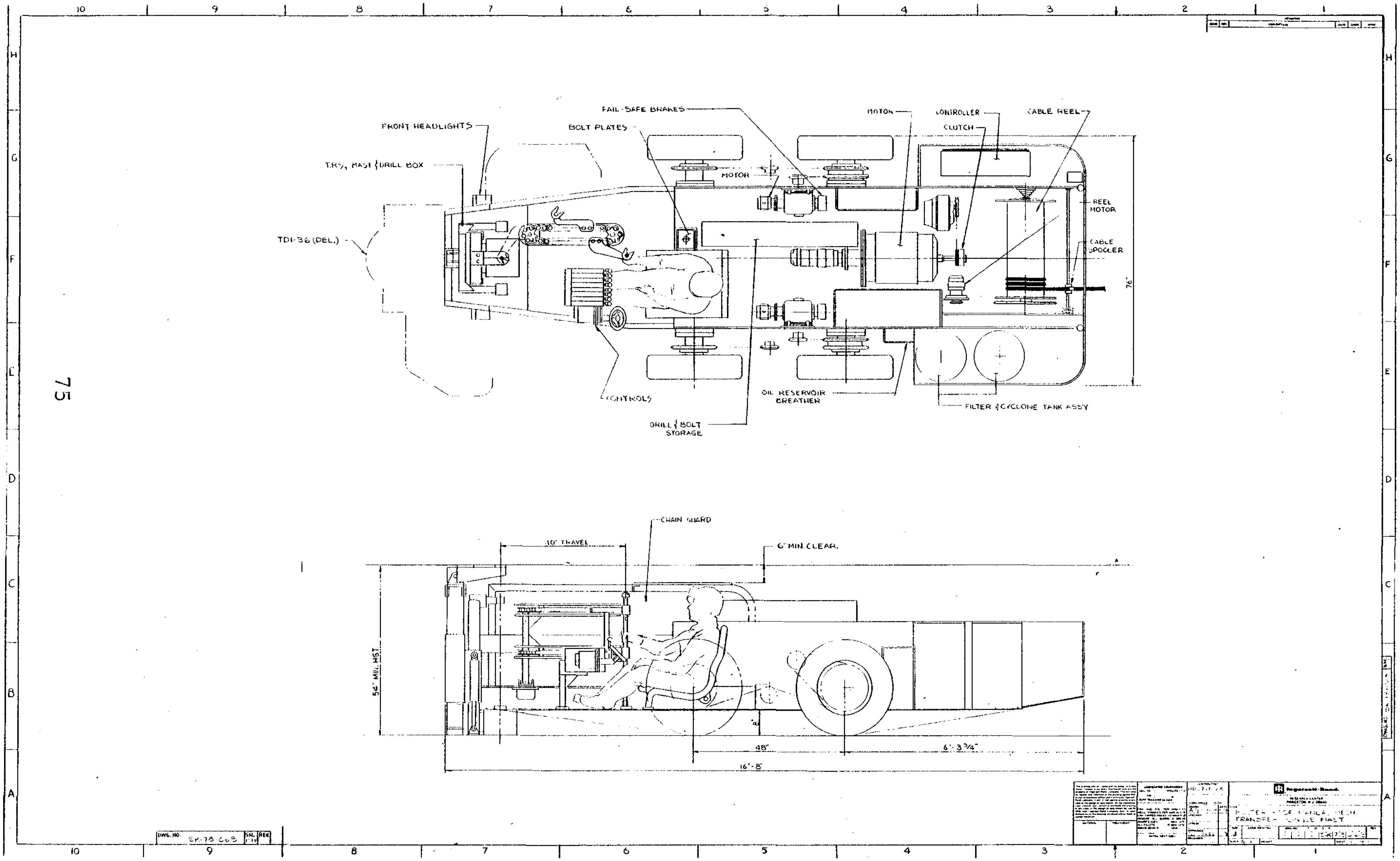


Figure 10: Plan and Elevation Views of the Transfer Bolter - Single Boom (New Chassis)

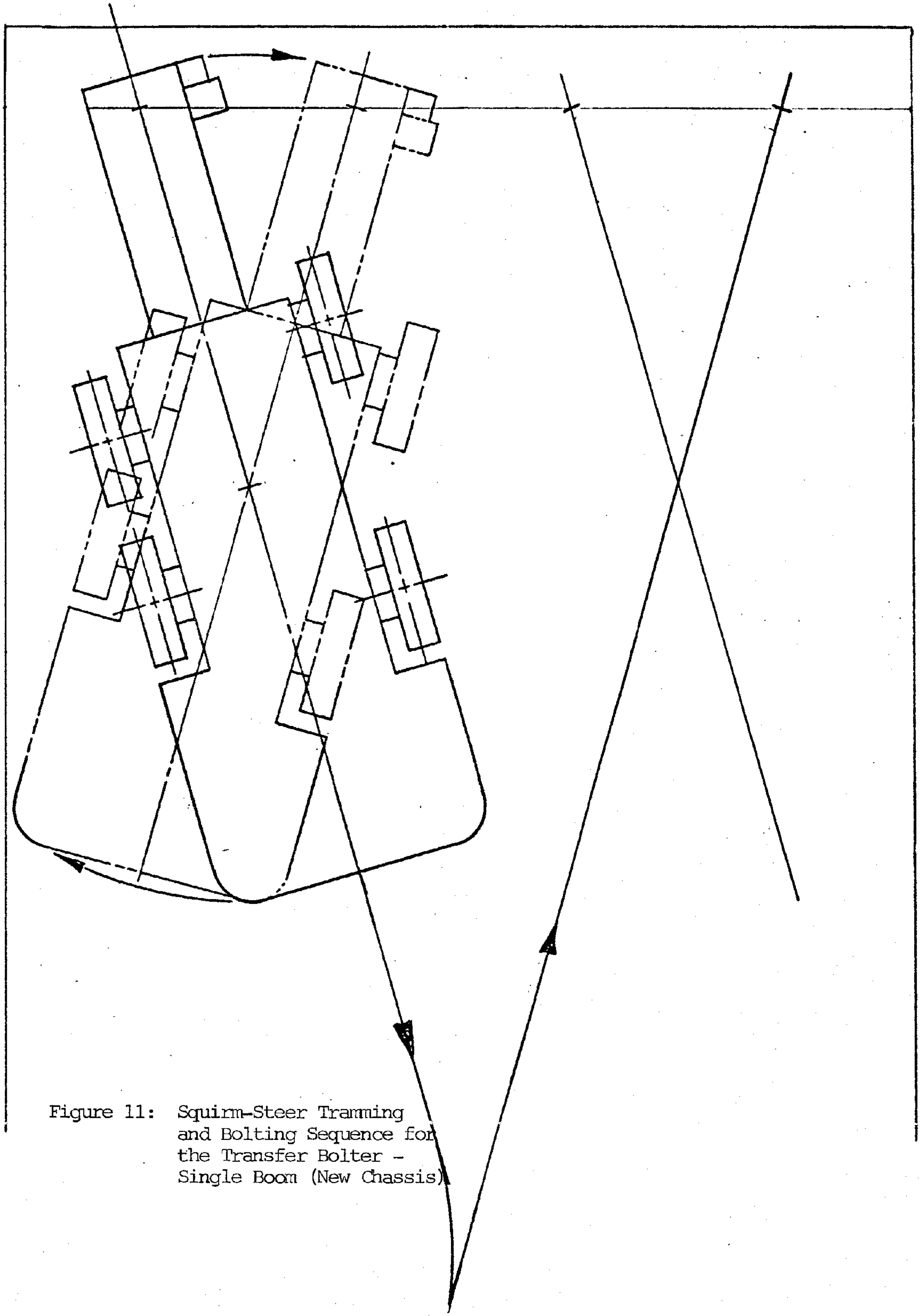


Figure 11: Squirm-Steer Tramming and Bolting Sequence for the Transfer Bolter - Single Boom (New Chassis)

Table 12

Design and Operating Specifications
For the Transfer Bolter -
Single Boom (New Chassis)

General

A.	Overall Length	16.1 feet
B.	Overall Height	4 feet, 2 inches for 3 foot bolt
C.	Overall Width	5.5 feet
D.	Ground Clearance	8 degrees
E.	Maximum Ramp Angle for Clearance	
	Front	11 degrees
	Rear	11 degrees
F.	Operating Seam Range	5.3 to 9.2 feet
G.	Bolt Length	4 to 8 feet
H.	Turn Capability	
	Single Pass 90° Turn at 9.5 feet Minimum Entry Width	
I.	Estimated weight	15,000 pounds

Performance

A.	Tram Speed	120 FPM
		1.4 MPH
B.	Maximum Grade	36% Slope
		20 degrees
C.	Ground Pressure	78.1 psi

Table 12

Design and Operating Specifications for the Transfer Bolter - Single Boom (New Chassis) (Continued)

Power

A. Electrical Cable 440 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

C. 40 Horsepower Electric Motor

Tram System

A. Tires 7.50-15 32.5 in. diameter x 8.52 inches wide - 48 square inch footprint

B. 4-Wheel Hydraulic Motor Drive - Hagglund

C. Squirm Steering Ratio = 1.13

D. Automatic Parking Brake

Hydraulic System

A.	System Pressure	2,000 psi
B.	Pumps	1-35 GPM Gear
		1-15 GPM Gear
		1-10 GPM Gear Variable Displacement, Pressure Regulated Piston Pump
C.	Filters	Suction 75 Micron Return 10 Micron
D.	Oil Reservoir Capacity	80 Gallons

Safety Features

A. Full Cover Canopy Protection

Table 12

Design and Operating Specifications for the Transfer Bolter - Single Boom (New Chassis) (Continued)

B. Remote In-Cab Operation

C. Fire Protection

D. Temporary Roof Support (Local)

Lighting

Shielded Flourescent Tube Fixtures as Required - McJunkin or Equivalent

Table 13

Commercial Components Used on the Transfer Bolter - Single Boom (New Chassis)*

1.0 Electric Power

1.1 Electric Motor

- Reliance ID No. P326928A
- 40 HP
- 1770 RPM
- 440 VAC 3 Phase 60 Hertz
- 52.2 AMPS

1.2 Motor Control Box

- Hubbell Ensign Electric Division
- Class 2010 Starter
- Spec. No. 2210-KSD 40 EX-0002-A
- Schedule 2G XP 1808-0
- 40 HP
- 440 VAC, 3 Phase, 60 Hertz

1.3 Cable Electric

- USS Tigerbrand Lead Cured
- 600 V 3 Conductor 6 AWG

*All quantities listed are one per vehicle unless otherwise specified.

Table 13

Commercial Components Used on the Transfer Bolter - Single Boom (New Chassis) (Continued)

- Type G-GC P109 MESA or equivalent

1.4 Reel, Cable, Electric

- Ensign Model No. 5010 2Q8C2B-000
- Pennsylvania Approved Reel
- Federal Approval XP 1841-0

1.5 Spooler - Cable Electric

- Lee-Norse Part No. 4-009200-300 or equivalent

2.0 Hydraulic Power Supply

2.1 Pumps

- Commercial Shearing
- 35-35-10 GPM Triple Tandem
- P25X 178 GI IT17-11 TL IT17-1 C AB05-1

2.2 Valves

- Commercial Shearing
- Series A20

Table 13

Commercial Components Used on the Transfer Bolter - Single Boom (New Chassis) (Continued)

3.0 Mechanical Power

3.1 Reel Motor

- Commercial Shearing Hydraulic Motor
- M25X 997 BE ER10-30

3.2 Tram Motor

- Hagglund Hydraulic Wheel Motors
- Model No. 1155 with Brake
- (Low Speed, High Torque)

3.3 Transfer Chain Drive

- Lamina Hydraulic Motor
- Model No. A-25
- 32 Tooth Sprocket, 3/8" Pitch Chain

3.4 Hydraulic Cylinders

- Martiner Products
- Canopy, Elevation, Quantity = 4

4.0 Mast Units

4.1 - Including Stroke Cylinders & Drill Pots

Table 13

Commercial Components Used on the Transfer Bolter - Single Boom (New Chassis) (Continued)

4.2 Fletcher

- Size Optional - (Collapsed Ht/Max. Seam)

  43/64 inches

  49/75 inches

  58/93 inches

  66/110 inches

5.0 Tires

5.1 Mining Service Tires, Quantity = 4

- Firestone 7.50-15 or equivalent
- Overall Diameter = 32.5 inches
- Static Load Radius = 15.2 inches
- Footprint Area = 48 square inches
- 65 psi Inflation Pressure

5.2 Foam Fill

- Firestone SUD•R•FIL or equivalent

6.0 Dust Collection

6.1 Air Cleaner

- Donaldson Split-Pac™

Table 13

<u>Commercial Components Used on the Transfer Bolter - Single Boom (New Chassis)</u> (Continued)

- Model No. XYX00-5101
- Larger Hopper Option
- 2.5 cu. ft. or 100 ft. of 1.38 in hole, or 180 ft. of 1.0 inch hole

6.2 Blower

- Sutorbilt Model No. 3MB
- 42 CFM at 6 psi at 1500 RPM

4.2.4 Transfer Bolter - Single Boom (Standard Chassis)

This bolter concept embodies many of the features of the preceding configuration, but utilizes a standard, production chassis.

In this configuration the operator station, transfer mechanism and mast drill unit would all be incorporated into a substructure which would occupy the area of the boom on conventional, single boom bolters. This bolter concept embodies the Lee-Norse Company TDI-36 Standard bolter chassis.

A general dimensional layout of this bolter configuration is shown in Figure 12. The design and operating specifications for this bolter concept are given in Table 14. Included in Table 15 for comparison purposes is information on the TDI-36 conventional bolter chassis.

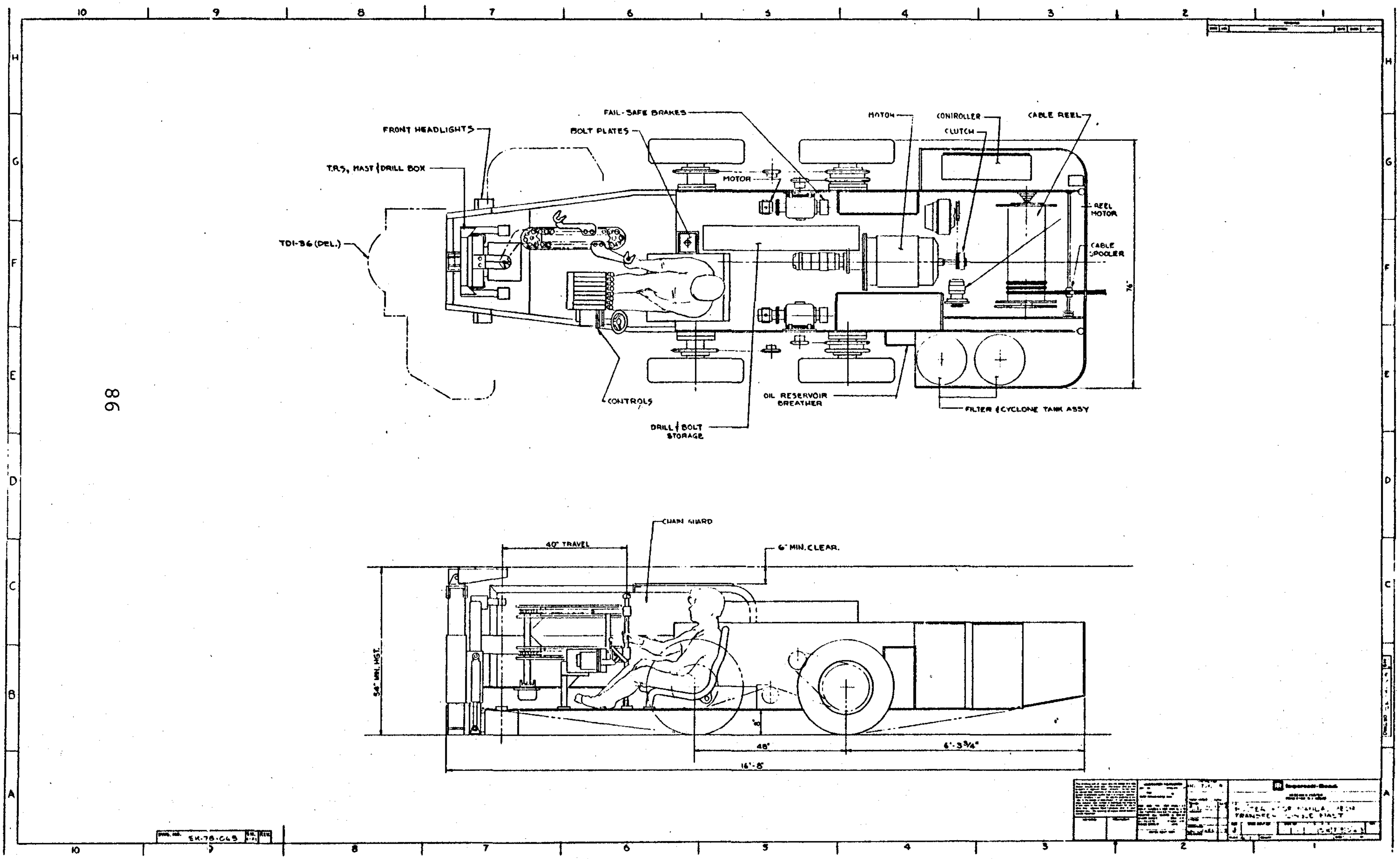


Figure 12: Plan and Elevation Views of the Transfer Bolter - Single Boom (Standard Chassis)

Table 14

Design and Operating Specifications for the Transfer Bolter - Single Boom (Standard Chassis)

General

A.	Overall Length	16.7 feet
B.	Overall Height	4 feet for 3' bolt
C.	Overall Width	6.3 feet
D.	Ground Clearance	8 inches
E.	Maximum Ramp Angle for Clearance	
	Front	7 degrees
	Rear	8 degrees
F.	Operating Seam Range	4 to 9.2 feet
G.	Bolt Length	3 to 8 feet
H.	Turn Capability	
	Single Pass 90° Turn at 10.2 Feet Minimum Entry Width	
I.	Estimated Weight	15,000 pounds
J.	Built From Lee-Norse TDI-36	18,000 pounds

Performance

A.	Tram Speed	120 FPM
		1.4 MPH
B.	Maximum Grade	35% Slope
		20 Degrees
C.	Ground Pressure	78.1 psi

Power

Table 14

Design and Operating Specifications for the Transfer Bolter - Single Boom (Standard Chassis) (Continued)

A. Electric Cable 440 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

C. 40 Horsepower Electric Motor

Tram System

A. Tires 7.50-15, 32.5 in. diameter x 8.52 in. wide - 48 in. square footprint

B. 4-Wheel Hydraulic Motor Drive - Chain

C. Squirm Steering Ratio = 1.45

D. Automatic Parking Brake

Hydraulic System

A. System Pressure	1,800 psi
B. Pumps	1-35 GPM Gear 1-15 GPM Gear 1-10 GPM Gear
C. Filters	Suction 75 Micron Return 10 Micron
Oil Reservoir Capacity	80 Gallons

Safety Features

A. Full Cover Canopy Protection

B. Remote In-Cab Operation

C. Fire Protection

D. Temporary Roof Support (Local)

Lighting

Table 14

Design and Operating Specifications for the Transfer Bolter - Single Boom (Standard Chassis) (Continued)

Shielded Flourescent Tube Fixtures as Required - McJunking or Equivalent

Table 15

Lee-Norse TDI-36 Specifications

(For Reference Only)

General

A.	Overall Length	17.7 Feet
B.	Overall Height (Chassis)	36 Inches
C.	Overall Width	6.3 Feet
D.	Ground Clearance	8 Inches
E.	Maximum Ramp Angle for Clearance	
	Front	10 Degrees
	Rear	8 Degrees
F.	Operating Seam Range	3-6 Feet
G.	Turn Capability (Squirm)	
	Single Pass 90° Turn at 11.5 Feet Minimum Entry Width	
H.	Weight	15,000 pounds

4.3 Rod Changer - Bolt Bender Bolter

This bolter concept is designed for low coal. It is shown in an artist's rendition in Figure 13. It provides the lowest profile of all the concepts presented herein. A general dimensional layout of this bolter, showing plan and elevation views, is given in Figure 14.

This bolter is designed to drill holes and install bolts up to 8 feet long in seam heights from 3 feet to 6 feet with a remote operator. The tram height of 31.5 inches is made possible by using the advanced variation of a Manson-type boom shown isometrically in Figures 15 and 16. The variation produces a straight line locus for the drill chuck center axis and offers improved accessibility to the drill chuck area from one side. Straight line motion improves all alignment conditions relating to the rod changer device while the access to the drill chuck from the right hand side of the bolter is improved by the following changes:

1. The upper right hand parallogram link is removed from the temporary roof support linkage as shown in Figure 15.

2. The drill chuck linkage lower right hand parallelogram link has been removed as shown in Figure 16.

3. The right hand linkage radius link has been eliminated. The function of this link - to move the rear pivot point of the right hand boom forward as the drill chuck raises in synchronism with the left hand side and the appropriate amount of produce a straight vertical drill path - is provided by a modification to the lower boom pivot point.

The left hand side of the linkage is conventional except that the radius link pivot point has been moved forward until it lies in-line with the drill chuck centerline in the side view. This pivot is also at the same elevation with the rear pivot center of the main booms. These changes in addition to making the radius link exactly equal to one half the length of the main boom (pivot center to pivot center) and attaching the radius link to the main boom mid-point provide a straight vertical drill chuck locus.

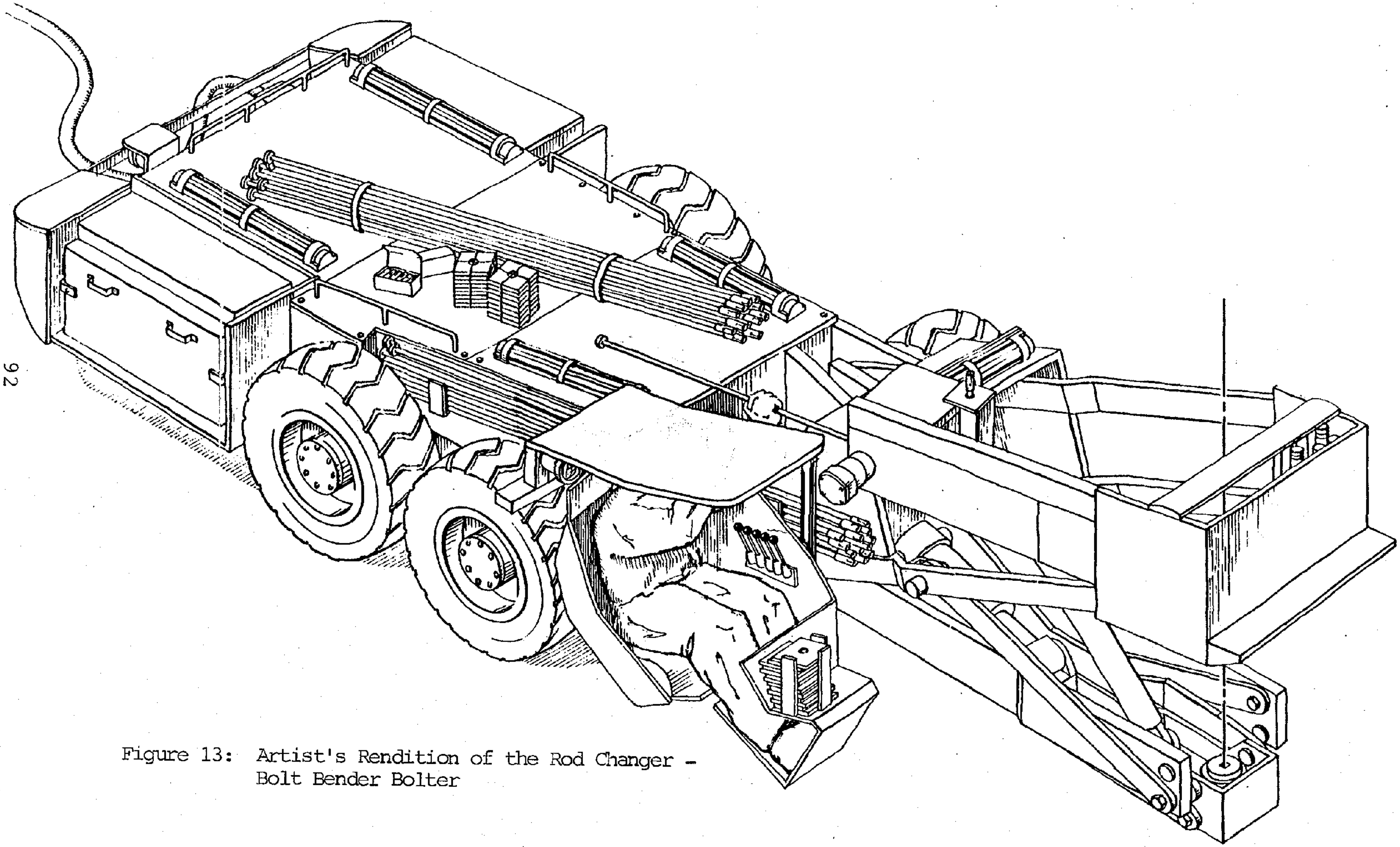


Figure 13: Artist's Rendition of the Rod Changer - Bolt Bender Bolter

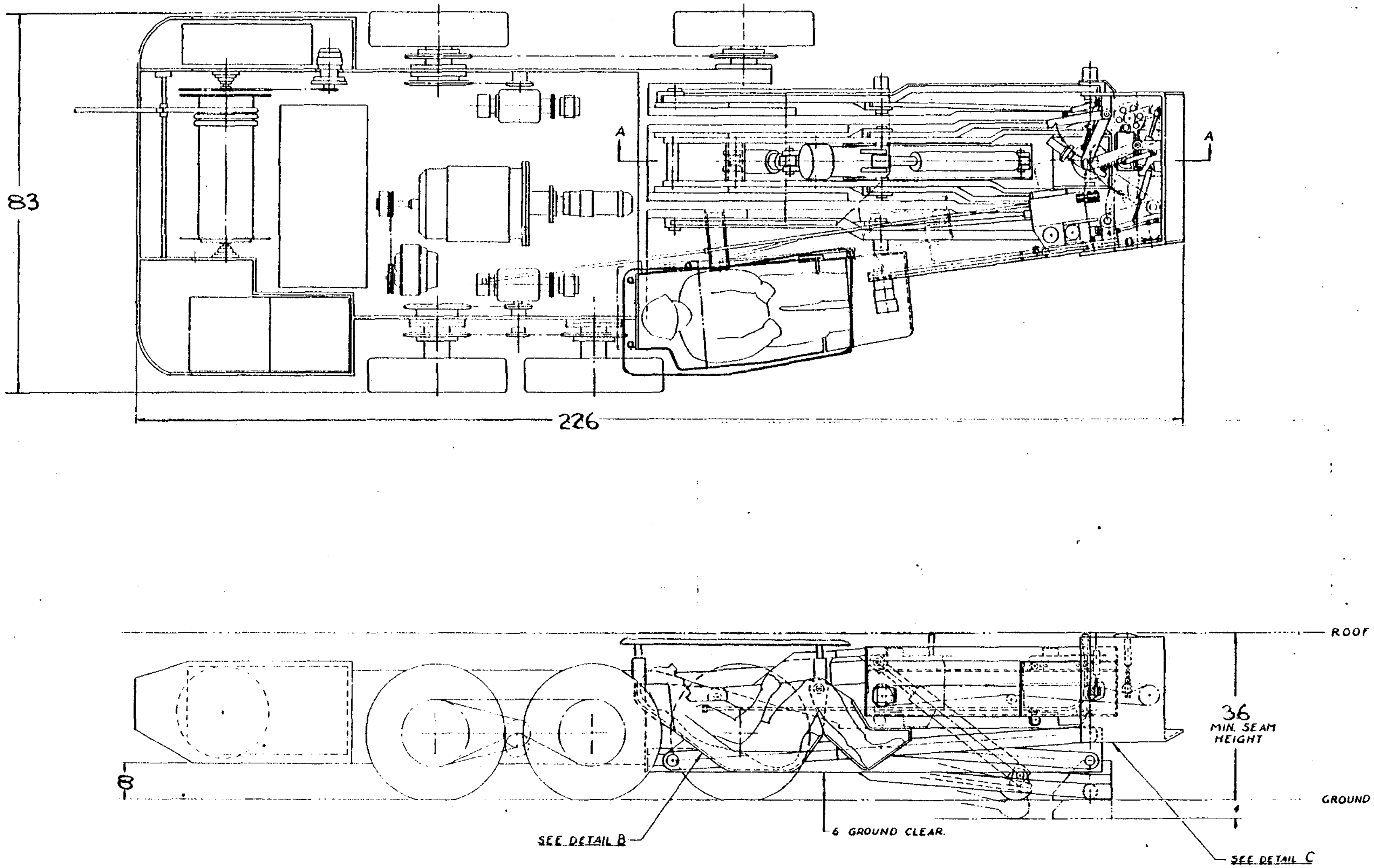


Figure 14: Plan and Elevation Views of the Rod Changer - Bolt Bender Bolter

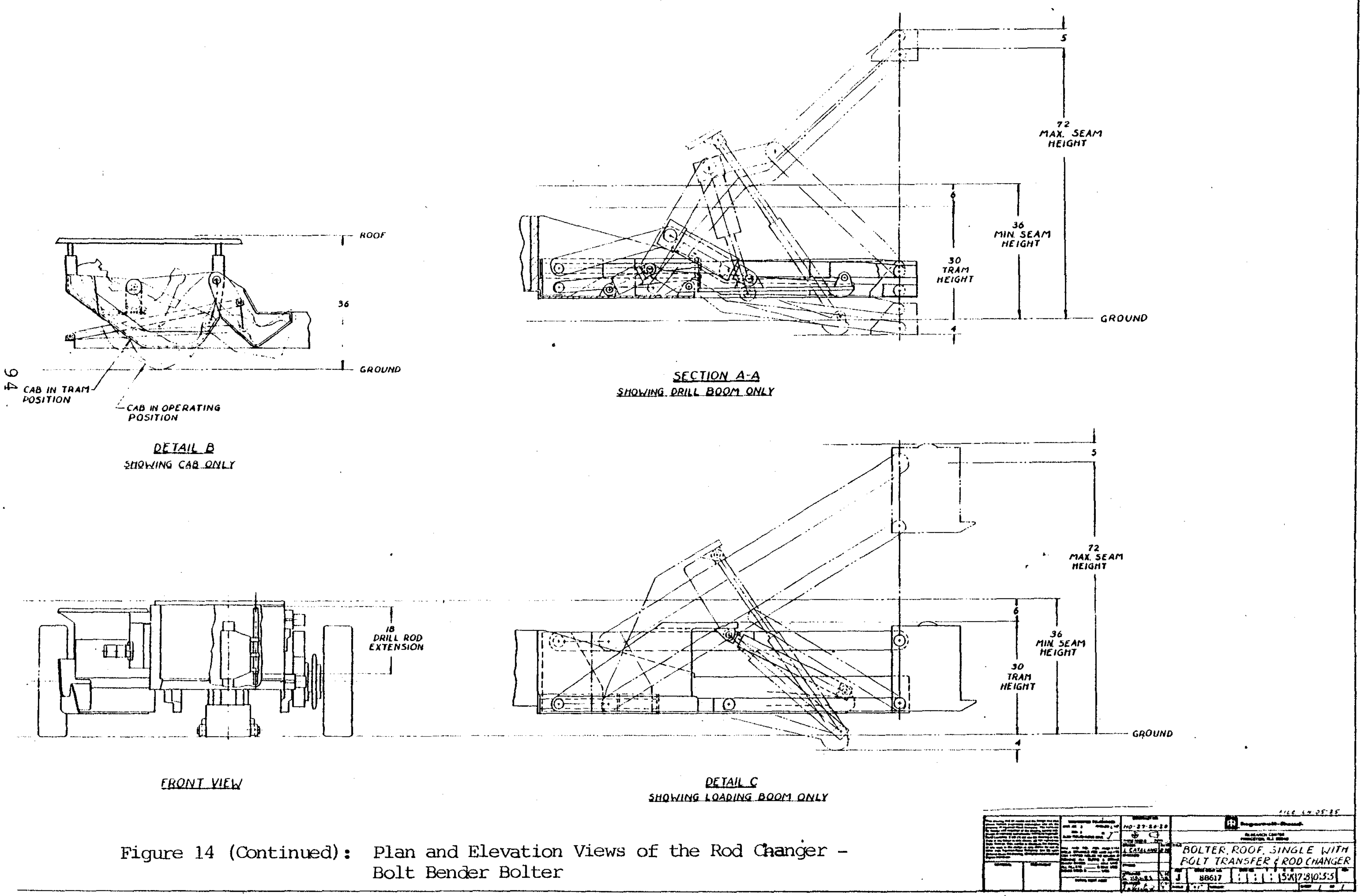


Figure 14 (Continued): Plan and Elevation Views of the Rod Changer - Bolt Bender Bolter

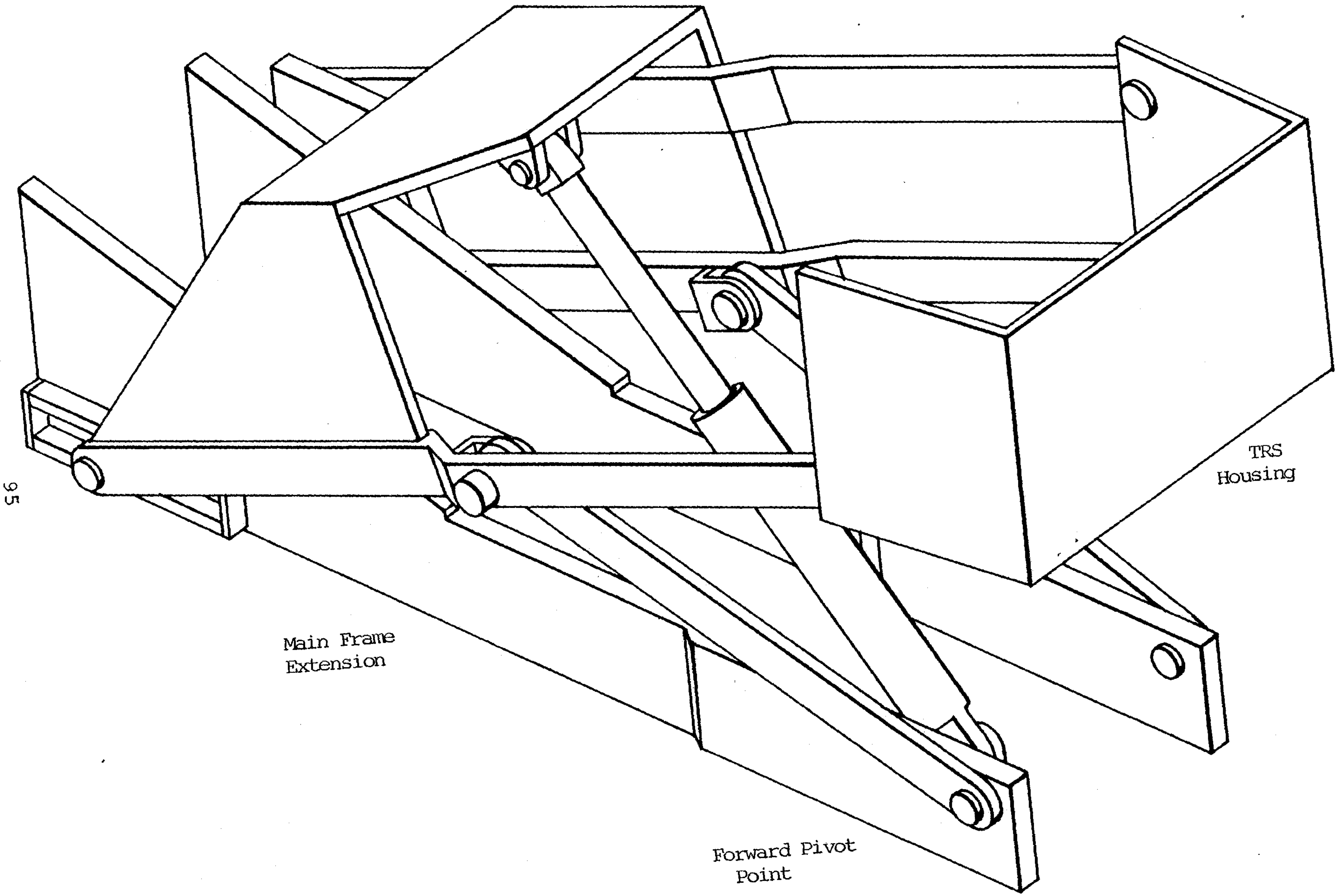


Figure 15: Detail of the Temporary Roof Support for the Rod Changer - Bolt Bender Bolter

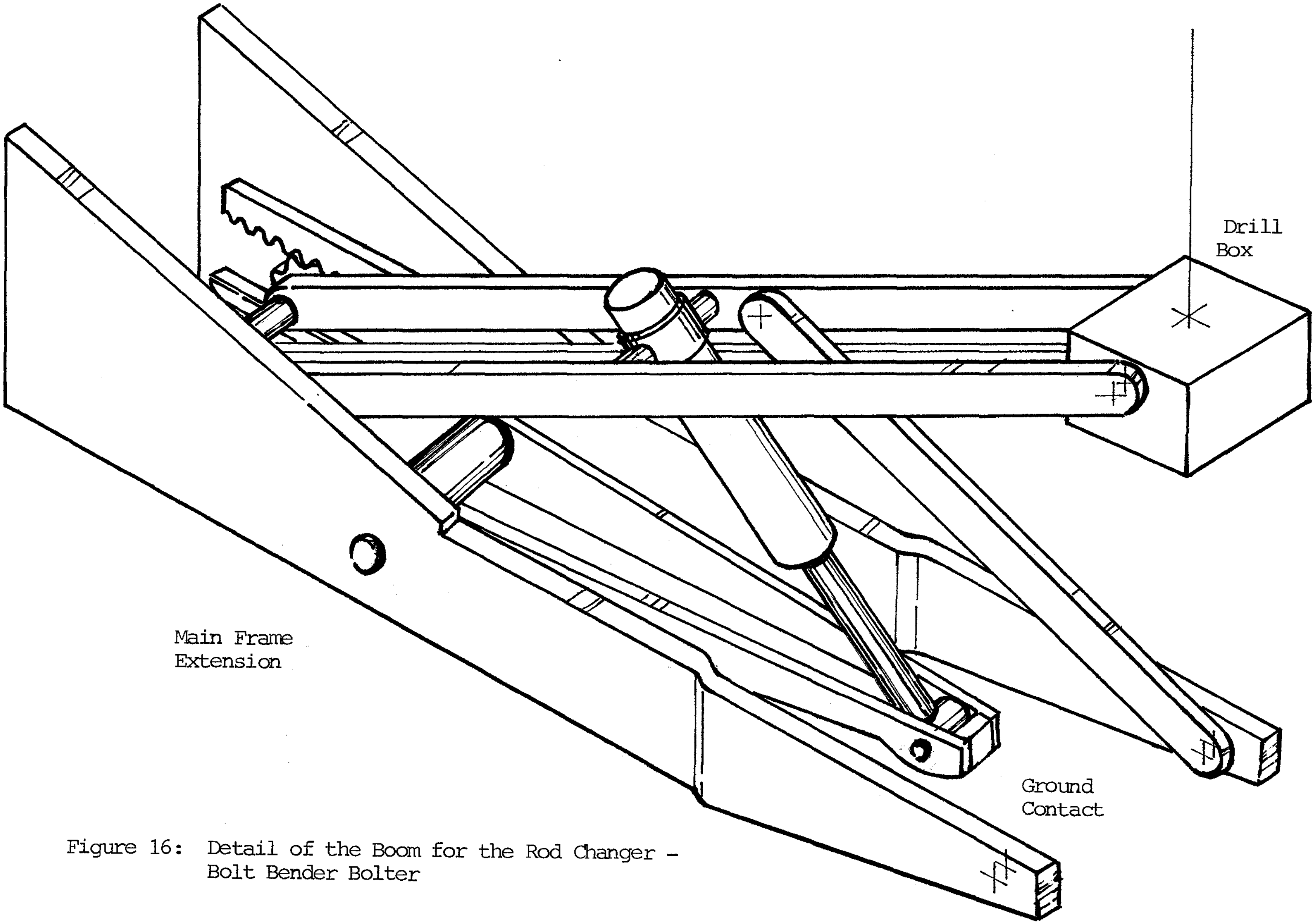


Figure 16: Detail of the Boom for the Rod Changer - Bolt Bender Bolter

Thus, the left hand rear boom pivot is caused to move forward along its track the appropriate amount by the action of left hand radius link. By fitting a rack section above the left hand lower boom pivot in mesh with a spur gear rotary motion proportional to the linear travel of the lower left hand boom pivot can be transmitted to the right hand side. On the right hand side the rotary motion can be converted back to an identical linear motion by use of another spur gear on the same shaft in mesh with an identical rack section. Thus, the right hand rear boom pivot is forced to stay in synchronism with the left hand pivot.

Straight line motion improves alignment conditions relating to the rod changer device while improved access accommodates the traveling bolt bender inserter. The bolt bender inserter is a modified Bendix bolt bender unit similar to the unit previously used by IRRI on the Flex Drill program.

The Bendix roof bolt inserter consists of a power driven grooved roller around the rim of which a roof bolt can be fed. It uses two small diameter fixed axis rollers. One to feed the straight bolt into the bend and one to straighten the bolt as it completes the bend. In addition, there is a jaw which includes two grooved rollers. This jaw can move radially toward the major roller to clamp the bolt against the major roller rim. It can also rotate around the major roller axis for the initial bend in the bolt. See Figure 17 for this sequence of events.

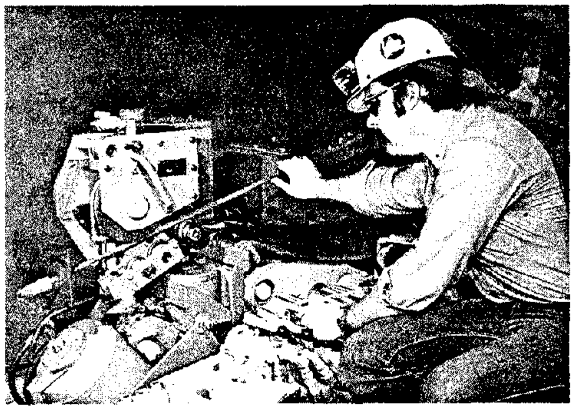
The rod changer mechamism utilized in the design is an upgraded version of the original Flex Drill design. Also, design improvements created for the Mechanical Anchor Bolter Module program (MABM), were incorporated into this design.

This bolt bender inserter has been modified such that the bend angle is adjustable. For use with this concept the maximum bend angle will be 90 degrees. 90 Degrees will be used for the lower seams. In higher seams the operator may at his option select an angle less than 90 degrees. This makes loading the bolt iserter easier for the operator's relatively low position.

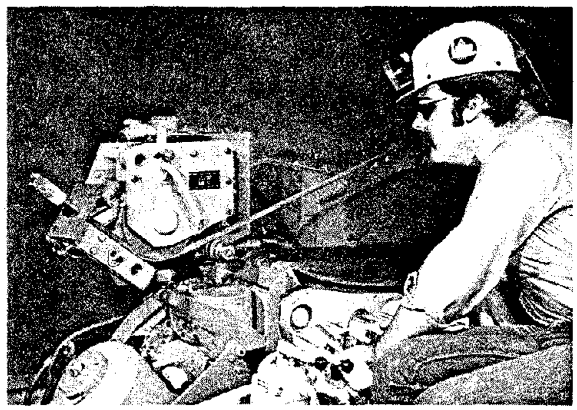
The chassis features squirm steering with staggered wheel locations to allow the operator cab to be placed alongside the boom. This cab position allows the operator to enjoy a remote location with his feet 4-feet behind the active drill-chuck centerline. He is under bolted roof at all times and away from the rotating machinery and yet close enough to the drilling and

Bendix
Roof Bolt Inserter

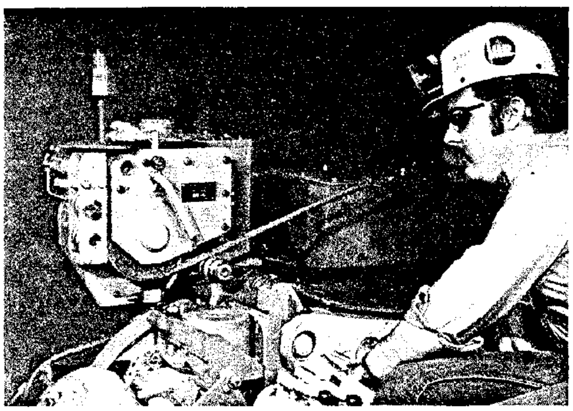
OPERATION



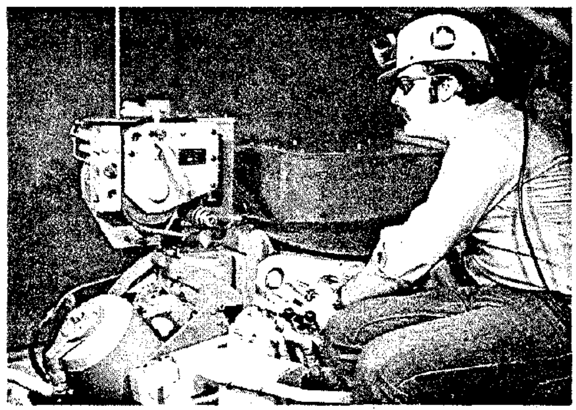
1. Bolt loaded



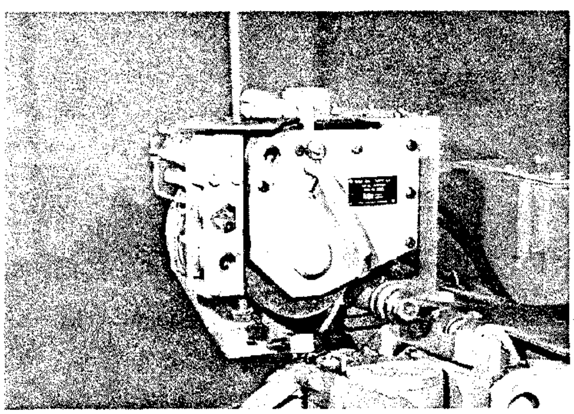
2. Bending started



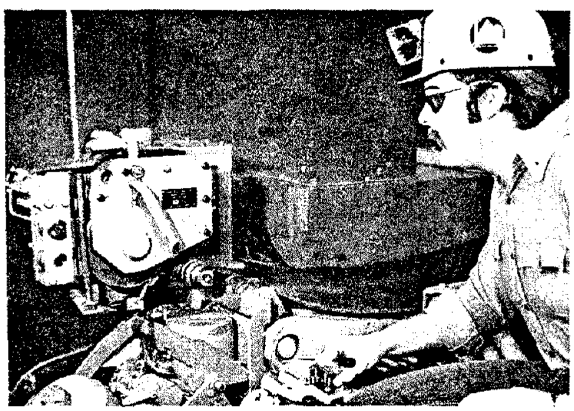
3. Straightening started



4. Bending completed



5. Straightening completed



6. Bolt released

Figure 17

bolting functions to observe the system and perform the remote feeding of the roof bolts.

The cab consists of two sections joined by a hinge and strut. The major portion of the cab supports the operators head, back and seat. This portion of the cab is trunnion mounted and hydraulically positioned. In the tramming position the operator's head clears the minimum seam height (36 inches) by 6 inches and the cab bottom point clears the mine floor by 6 inches. The small forward portion of this cab houses and protects the operator's feet. It is open from the side for easy access and the bottom of the forward portion of the cab is 6 inches above the floor. This, the man occupies only 24 inches of space vertically when in the tram position. Seated in a nearly-horizontal, reclining position, with his knees bent at approximatly 90 degrees, good visibility of the work area over his knees is provided. Further, the controls are readily accessible near his lap to the left hand side. A total coverage canopy is provided directly over his head and body to protect him against falls, dirt and scraping by the mine roof. The chassis operator drives the bolter in this attitude until he is in position to bolt the roof.

He activates the hydraulic cab articulation control causing the cab to rotate about the trunnion wich lowers the cab bottom 6 inches to the mine floor and raises the miner's head rest and canopy 6 inches. In this position, the operator has been reoriented as much as possible for the minimum seam height of this bolter. Now the operator's torso is upright and more comfortable for working, which provides proper visibility of the work area and access to the drill and bolt controls. Kinematically coupled with his back reorientation, the operator's knees have straightened to approximately a 45 degree bend and his heels have been lowered three inches toward the floor. This movement is accomplished by the hinge (at the operator knee location) and strut which attach to the major portion of the operator cab. The tramming and bolting positions of the operator are shown in Figure 14

Hands-off drilling was achieved in the Flexible Drill program at Ingersoll-Rand Research, Inc. by use of the rod changer and an air logic system. Either air logic or a microprocessor system will be used to provide the rod changer with the necessary feedback and logic capabilities. With a short drill coupling system some form of automation or logic system is necessary to achieve rapid and accurate coupling of the several drill sections required to drill one hole. A traveling bolt bender allows the operator to manually and remotely load a bolt and subsequently install the bolt into the roof.

The detailed design and operating specifications for this bolter vehicle are given in Table 16. The commercial components utilized in this concept are summarized in Table 17.

Table 16
Design and Operating Specifications for the Rod Changer - Bolt Bender Bolter

General

A. Overall Length .... 18.8 feet

B. Overall Height .... 30 inches

C. Overall Width .... 6.9 feet

D. Ground Clearance .... 6 inches

E. Ramp Angle

Front .... 4 degrees

Rear .... 10 degrees

F. Operating Seam Range .... 3-6 feet

G. Bolt Length .... 3-8 feet

(Bolt Length Higher Than Seam Height up to 8 foot Bolt in 3 foot Seam)

H. Turn Capability

Single Pass 90° Turn at 13.3 feet Minimum Entry Width

I. Estimated Weight .... 16,000 pounds

Performance

A. Tram Speed .... 120 FPM

1.4 MPH

B. Maximum Grade .... 36% Slope

20 Degrees

C. Ground Pressure .... 83 psi

Table 16

Design and Operating Specifications for the Rod Changer - Bolt Bender Bolter (Continued)

Power

A. Electric Cable 400 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

C. 40 Horsepower Electric Motor

Tram System

A. Tires 750-15, 32.5 diameter x 8.52 wide - 48 sq. in. footprint area

B. 4-Wheel Drive by 2 Hydraulic Drive Motors and Roller Chain

C. Planetary Gear Final Drive Reduction

D. Rigid Frame 4 Point Suspension Rubber Tire Pneumatic or Resiliant Foam Filled

E. Squirm Steering

F. Automatic Parking Brake

Hydraulic System

A.	System Pressure	2,000 psi
B.	Pumps	1-35 GPM Gear 2-15 GPM Gear
C.	Accumulator for Temporary Roof Support	
D.	Filters	Suction 75 Microns Return 10 Microns
E.	Hydraulic Tank	80 Gallons Oil

Safety Features

Table 16

Design and Operating Specifications for the Rod Changer - Bolt Bender Bolter (Continued)

A. Canopy

B. Remote In-Cab Operation

C. Fire Protection

D. Temporary Roof Support (Local)

Special Features

A. Drills Holes and Places Bolts Longer than Seam Height

B. Remote Operation

C. Tilting Cab uses all space available with minimum seam for operator in operating position - Tilts to obtain roof and ground clearance for tram.

D. Rail Mounted Bolt Bender Retracts from Face for Manual Loading

Lighting

Shielded Flourescent Tube Fixtures as Required - McJunkin or equivalent

Table 17

Commercial Components Used on the Rod Changer Bolt Bender Bolter*

1.0 Electric Power

1.1 Electric Motor

- Reliance ID No. P326938A
- 40 HP
- 1770 RPM
- 440 VAC, 3 Phase, 60 Hertz
- 52.2 AMPS

1.2 Motor Control Box

- Hubbell Ensign Electric Division
- Class 2010 Starter
- Spec. No. 2210-KSP 40FX-0002-A
- Schedule 26 XP 1808-0
- 40 HP
- 440 VAC, 3 Phase, 60 Hertz

1.3 Cable Electric

- USS Tigerbrand Lead Cured
- 600 V, 3 Conp, 6 AWG

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*All quantities are one per vehicle unless other wise specified.

Table 17

Commercial Components Used on the Rod Changer Bolr Bender Bolter (Continued)

- Type G-GC, P109 MESA or equivalent

1.4 Reel Cable Electric

- Ensign Mod. No. 5010 2Q08C28-000
- Penn Approved Reel
- XP 1841-0

1.5 Spooler-Cable Electric

- Lee-Norse Part No. 4-009200-300

2.0 Hydraulic Power Supply

2.1 Pumps

- Commercial Shearing
- 35-35-10 GPM Triple Tandem
- P25X 178 BI IT17-11 TL IT17-1 C AB05-1

2.2 Valves

- Commercial Shearing
- Series A20

3.0 Mechanical Power

Table 17

Commercial Components Used on the Rod Changer Bolr Bender Bolter (Continued)

3.1 Reel Motor

- Commercial Shearing - Hydraulic Motor
- M25X 997 BE ER10-30

3.2 Tram Motors, QTY=2

- Char-Lynn Hydraulic Motors
- Series 4000
- Model No. 109 1013

3.3 Tram Speed Reducer, QTY=2

- Fairfield Torque Hub-Planetary
- Model S3B
- Speed Reduction 25:1

3.4 Rotation Motor

- Rineer Hydraulics, Inc.

3.5 Motor Transfer Bolt Bender

- Char-Lynn Hydraulic Motor
- 2000 Series
- 6.1 cu. in/Rev.
- 19 Tooth Sprocket
- 5/8" Pitch Double Strand Chain

Table 17

Commercial Components Used on the Rod Changer Bolr Bender Bolter (Continued)

3.6 Hydraulic Cylinders

- Martiner Products
- Bolt Bender Swing .625 in. bore
- Bolt Bender Detent .625 in. bore
- Bolt Bender Chain Engage .625 in. bore
- Centralizer .625 in. bore
- Drill Bit Handling Arm 1.0 in. bore
- Cable Cylinder 5.5 in. bore
- Boom Lift Cylinder 3.5 in. bore
- Cab Tilt Cylinder 1.0 in. bore
- Canopy

4.0 Tires

4.1 Mining Service Tires, Quantity = 4

- Firestone 7.50-15
- Overall Diameter - 32.5
- Static Load Radius = 15.2
- Footprint Area - 48 in. sq.
- 70 psi Inflation Pressure or Equivalent

Table 17

Commercial Components Used on the Rod Changer Bolr
Bender Bolter (Continued)

4.2 Foam Fill

- Firestone SUP•R•FIL
- to 70 psi or equivalent

5.0 Dust Collection

5.1 Air Cleaner

- Donaldson Split-PacTM
- Model No. XYX00-5101
- Large Hopper Option
- 2.5 cu. ft. or
- 100 ft. or 1.38 in hole, or
- 180 ft. or 1.00 in. hole

5.2 Blower

- Sutorbilt
- Model No. 3MB
- Approvimately 42 CFM at 6 psi at 1500 RPM

6.0 Drill - Developed from IRRI

- Flex Drill Program and
- MABM Program using Microprocessor

Table 17

Commercial Components Used on the Rod Changer Bolr Bender Bolter (Continued)

7.0 Roof Bolt Bender Inserter Developed by Bendix

4.4 Transverse Rail Rib Bolter

The transverse rail rib bolter concept derives its name from the rail across the front of the chassis. An artist's rendition of this bolter configuration is shown in Figure 18 and a general dimensional layout, showing plan and elevation views, is given in Figure 19.

In this concept, two mast drill units travel along the rail to place bolts across the entry width. The mast drill units are also capable of rotation in the frontal plane which allows them to perform rib and angle drilling and bolting. The use of a transverse rail and rotatable drill units is not conceptually new and field experience indicates that commercially available equipment of this type has performed well mechanically. However, such equipment has one important shortcoming in that the drill masts are operated from the front, ahead of the transverse rail. This condition presents a safety hazard since the mast units, when extended to place the drill near the rib or to rib bolt, obstruct the operator's escapeway trapping him at the face.

The present concept using a transverse rail and rotatable drill masts overcomes this basic shortcoming by adding bolt and drill storage magazines to each mast unit, capable of storing and feeding a sufficient quantity of roof bolts and drills to bolt a 20 foot entry. The operation of these magazines would be remotely controlled by the operators who would be positioned outby the transverse rail. Each operator would occupy a protected cab mounted to the bolter chassis directly behind the front wheels. This location provides a safe position for the operators under bolted roof and beyond the reach of the rotating machinery of the drill chuck and the articulating mast structures. The operator cab would feature a structure meeting canopy strength requirements, providing operator comfort, and providing as much visibility as possible to minimize the need for automatic control of the drill and bolt magazines. This cab would utilize slide-mounting to the chassis and hydraulic elevation control similar to those items developed as part of the Bureau of Mines' Inherently Safe Mining Systems program to improve mast visibility. This type of cab mounting minimizes damage to the cab and occupants in case of a massive roof collapse. Oil contained within the cab cylinder would escape to the reservoir through a relief valve preset to respond to excessive cab loading. The cab and occupants would then descend to the floor, decreasing the cab height relative to the bolter chassis. Thus, the other chassis structures would carry a greater portion of the fall load thereby decreasing the likelihood of severe operator cab deflection and resultant

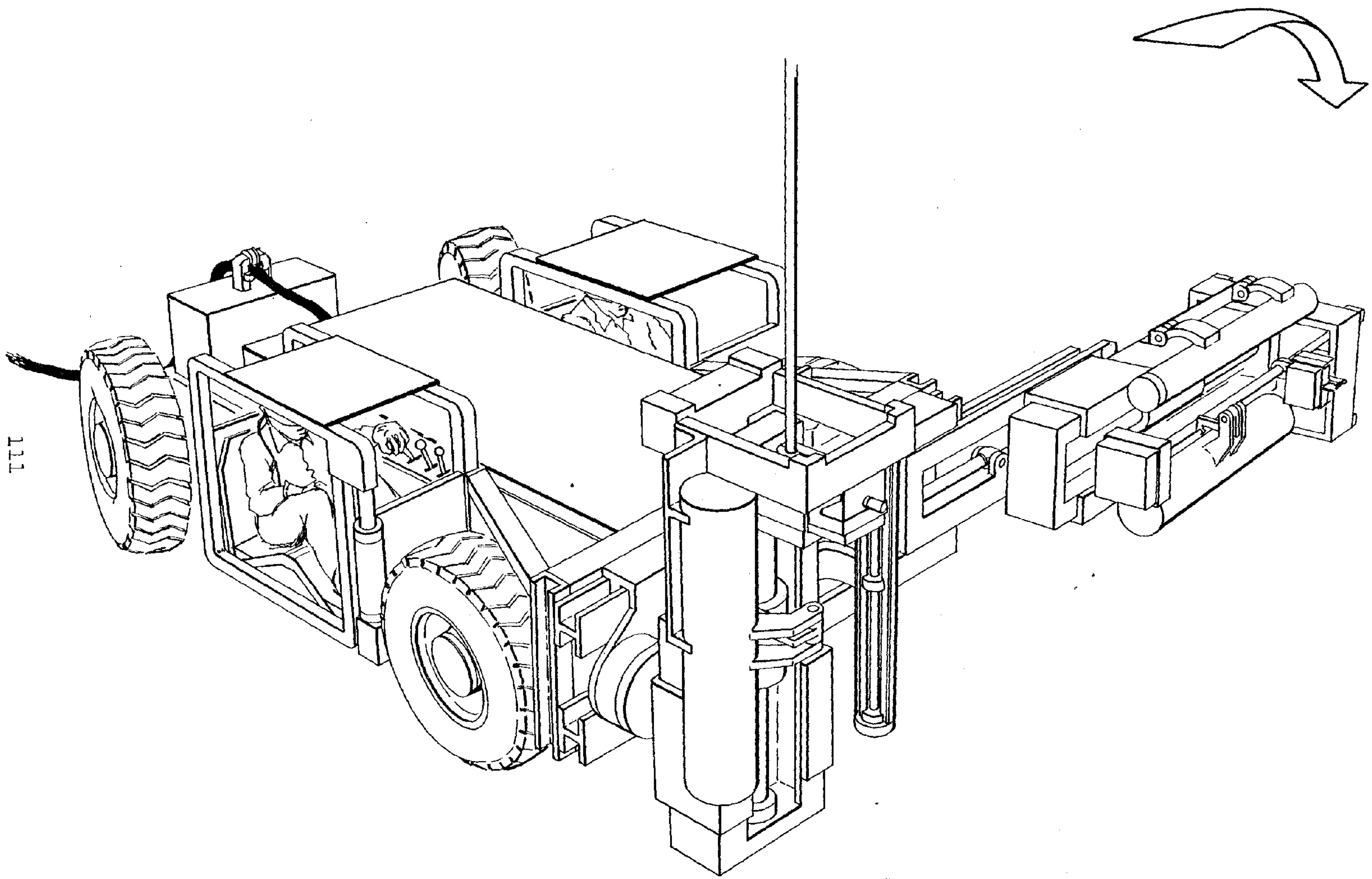

Figure 18: Artist's Rendition of the Transverse Rail Rib Bolter

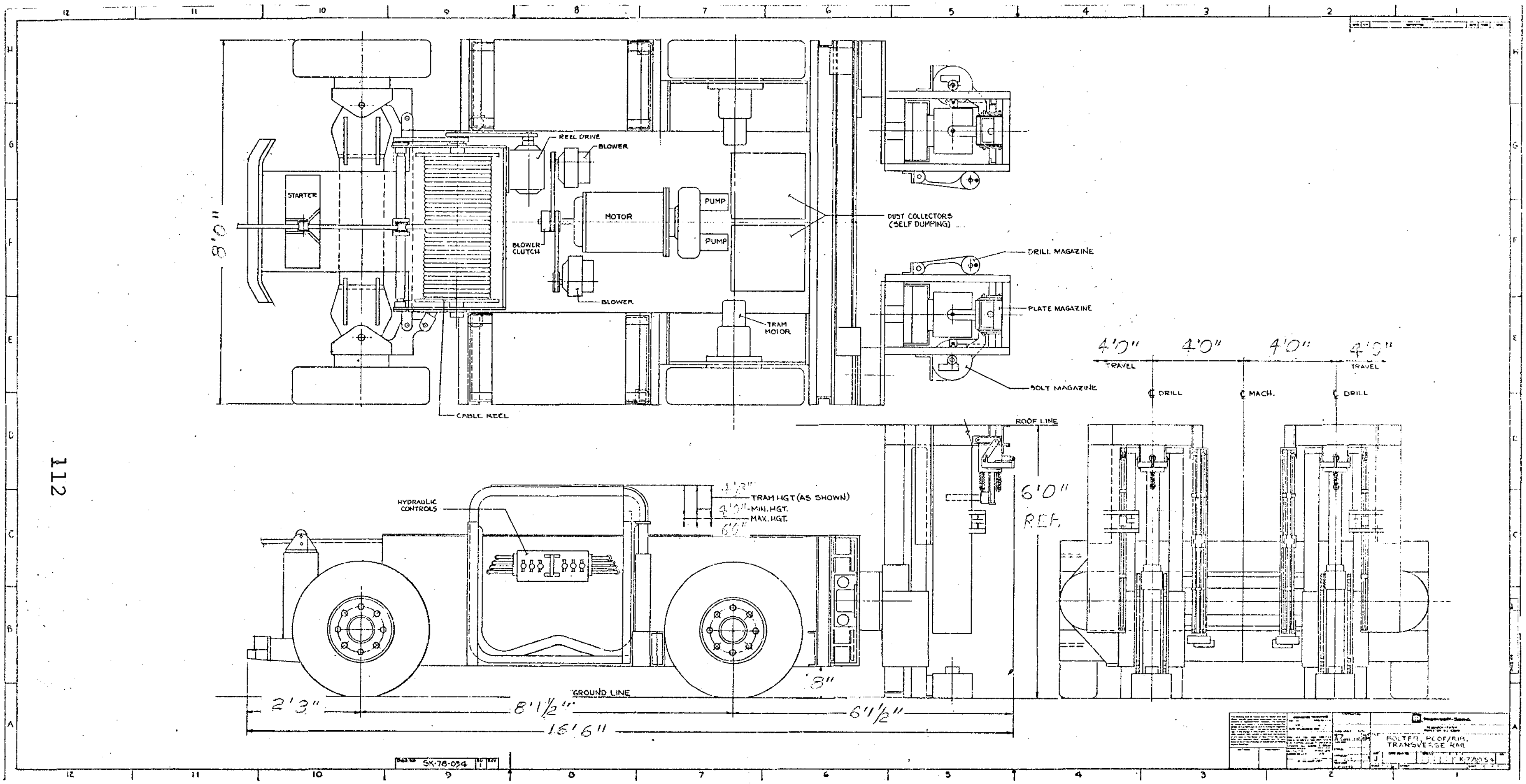

Figure 19: Plan and Elevation Views of the Transverse Rail Rib Bolter

injury. In this case, the vertical members of the operator cabs act as columns directly between the floor and roof debris. Short, heavy columns are very effective at handling compressive loads.

A large portion of the structure could be acquired for this concept from existing production equipment. For example, the entire front end from a Fletcher model DOH could be used which would include the transverse rail structure with its associated drives and twin masts, drill chucks and motor package complete with their rollover structures.

Two areas of it would require rework or alteration. The mast roll over drive would be utilized with or modified for a 90 degree rotation capability and the forward control area would be relocated to the two, mid-chassis operator stations. This change would decrease mast overhang approximately 12-18 inches improving structural strength. The mast units would be fitted with rod-changer style, full length drill and bolt storage carousels which would remotely feed the drill steels and bolts to the drill chuck. Full length drill steels and bolts allow bolts to be installed with lengths up to about 1 foot shorter than seam height. A logic system similar to that used on the current Flexible Drill program would be required. However, because of the use of full length steels and bolts, the logic required will be simpler and bolt time will be faster.

It can be noted from the vehicle layout (Figure 19) that the efficient use of space on the chassis and the elmination of long booms makes the bolter very short in overall length. This condition improves maneuverability, machine balance, clearance-related problems and chassis loading.

The detailed design and operating specifications for this bolter concept are given in Table 18, while the commercial components utilized are summarized in Table 19.

Table 18

Design and Operating Specifications for the Transverse Rail Rib Bolter

General

A.	Overall Length	16.5 feet
B.	Overall Height	5.5 feet
C.	Overall Width	8 feet
D.	Ground Clearance	8 inches
E.	Ramp Angle	
	Front	10 degrees
	Rear	20 degrees
F.	Operating Seam Range	6 feet to 9.2 feet
G.	Bolt Length	4.5 feet
H.	Turn Capability	
	Single Pass 90° Turn at 12.35 foot entry width	
I.	Estimated Weight	23,000 pounds

Performance

A.	Tram Speed	123 FPM 1.4 MPH
B.	Maximum Grade	20 Degrees
C.	Ground Pressure	73 psi

Power

A. Cable 440 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

C. 100 Horsepower Electric Motor

Table 18

Design and Operating Specifications for the Transverse Rail Rib Bolter (Continued)

Tram System

A. Tires 10.00 - 15 (35.8" ø x 10.94")

B. 4-Wheel Hydraulic Motor Drive Char-Lynn 4000 Series 12 in^3/rev.

C. Planetary Reduction Fairfield S3B

D. Three Point Suspension - Rear Axel Pivot

E. Rear Wheel Steering

F. Automatic Parking Brake

Hydraulic System

A.	System Pressure	2,000 psi
B.	Pumps	2-35 GPM Gear 2-15 GOM Gear 1-15 GPM Gear Variable Displacement Piston Pressure Controlled
C.	Filters	Suction 75 Micron Return 10 Micron

Safety Features

A. Canopy Protected Slide Mounted Dual Cabs with Elevation Control

B. Remote-In-Cab Operation

C. Donaldson Auto Dump Dust Collection System

D. Fire Protection

E. Temporary Roof Support (Local)

Table 18

Design and Operating Specifications for the Transverse Rail Rib Bolter (Continued)

Special Features

A. Fletcher Dual Masts Slide Transversely

B. Roof Angle and Rib Bolt Capability

C. Compactness

D. Front and Rear Facing Cab Seating

E. Drill Pattern - Along a Transverse Straight Line up to at least 12 feet.

F. Rib Bolts Approximately 36 inches off Floor if Installed Horizontally

Drill Box

A.	Fletcher	Thrust:	1,000 lbs.
		Torque:	300 ft-lbs.
		Speed:	580 RPM

Lighting

Shielded Flourescent Light Fixtures as Required - McJunkin or Equivalent.

Table 19

<u>Commercial Components Used on the Transverse Rail Rib Bolter*</u>

1.0 Electric Power

1.1 Electric Motor

- Westinghouse
- 100 HP
- 1780 RPM
- 440 VAC, 3 Phase, 60 Hertz
- 113 AMPS
- MESA Certified

1.2 Reel Cable Electric

- Ensign Model No. 5010 2008C2B-000
- Penn. Approved Reel
- XP 1841-0

1.3 Spooler Cable Electric

- Lee-Norse
- Part No. 4-008200-300

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*All quantities are one per vehicle unless otherwise specified.

Table 19

Commercial Components Used on the Transverse Rail Rib Bolter (Continued)

1.4 Cable Electric

- Essex 2-3/C Type G-GC
- 600 V, P 125, MESA or equivalent

2.0 Hydraulic Power

2.1 Pumps

- commercial Shearing
- 25-15 GPM Tandem with Output Shaft
- P25X 178 GI IT17-11 G AB07-1

2.2 Valves

- Commercial Shearing
- Series A20

3.0 Mechanical Power

3.1 Reel Motor

- Commercial Shearing - Hydraulic Motor
- M25X 995 BE ER20 - 25

3.2 Tram Motors, Quantity = 4

Table 19

Commercial Components Used on the Transverse Rail Rib Bolter (Continued)

- Char-Lynn Hydraulic Motors
- Series 4000
- Model No. 109 1013

3.3 Tram Speed Reducer, Quantity = 4

- Fairfield Torque Hub-Planetary
- Model S3B
- Speed Reduction 25:1

3.4 Hydraulic Cylinders

- Martiner Products
- Cab Elevaon Quantity = 4
- Steering

Table 19

Commercial Components Used on the Transverse Rail Rib Bolter (Continued)

4.0 Mast Units

4.1 Fletcher Masts, Quantity = 2

- Including DDJ Hydroslide
- Transverse Rail System
- Optional Heights Collapsed/Max
  - 43/63 inches
  - 49/75 inches
  - 58/93 inches
  - 66/110 inches

5.0 Tires

5.1 Mining Service Tires, Quantity = 4

- Firestone 10.00-15
- Overall Diameter - 35.8 inches
- Static Load Radius - 16.8 in.
- Footprint Area - 79 sq. in.
- 60 psi Inflation Pressure or Equivalent

Table 19

Commercial Components Used on the Transverse Rail Rib Bolter (Continued)

5.2 Foam Fill

- Firestone Sup•R•FIL

  to 60 psi or equivalent

6.0 Dust Collection

6.1 Air Cleaner

- Donaldson Self Dumping Dust Collector

6.2 Blower, Quantity = 2

- Sutorbilt
- Model No. 3MB
- Approximately 42 CFM at 6 psi at 1500 RPM

4.5 Automatic Bolter (Module Concepts)

These bolter concepts use a self contained, fully automatic pin setting unit that is adapted to a conventional type bolter chassis. Two such units are currently being developed by Bendix and IRRI under contracts to the United States Department of Energy. The two major differences between their modules are the type of bolt which can be installed, and their overall package dimensions, Bendix's module can install resin bolts while IRRI's module can install mechanical anchor type bolts. Due to the availability of the layout drawings for the IRRI module, it was chosen over the Bendix version. Since IRRI's module proper name is Mechanical Anchor Bolter Module, the acronym MABM is used in its place. Conceivably, the bolters could be designed to permit fast interchanging of bolt modules to allow either resin or mechanical bolt installation. Unfortunately, the cost of the modules would prohibit such a scheme.

For the purposes of this discussion, the IRRI bolter module is depicted as a black box with certain physical dimensions and external capabilities. A general outline covering the essential operating features of both systems is presented here to promote understanding of the following concepts. See Figures 20 and 21 for overall dimensions.

The IRRI MABM system uses segmented drill steel and an automatic feeder mechanism to drill holes longer than seam height. It can drill holes 2, 4, 6 or 8 feet deep in the roof of a coal seam down to a 42 inch seam height. It collapses to 30 inches high for tramming allowing 6 inch clearance at roof and floor.

The Bendix system utilizes a flexible drill string fed through the drill chuck to accomplish longer-than-seam-height drilling. It can drill roof bolt holes up to 8 feet in length in seams down to 34 inches in height.

Both of these systems utilize plate magazines and horizontal bolt magazines to store and automatically feed plates and bolts to the bolting area. Also, both systems utilize modifications of the Bendix Bolt Bender to feed bolts up to 8 feet long around a radius and into a roof bolt hole in the previously mentioned low seams. On both systems the entire bolting cycle is fully automatic.

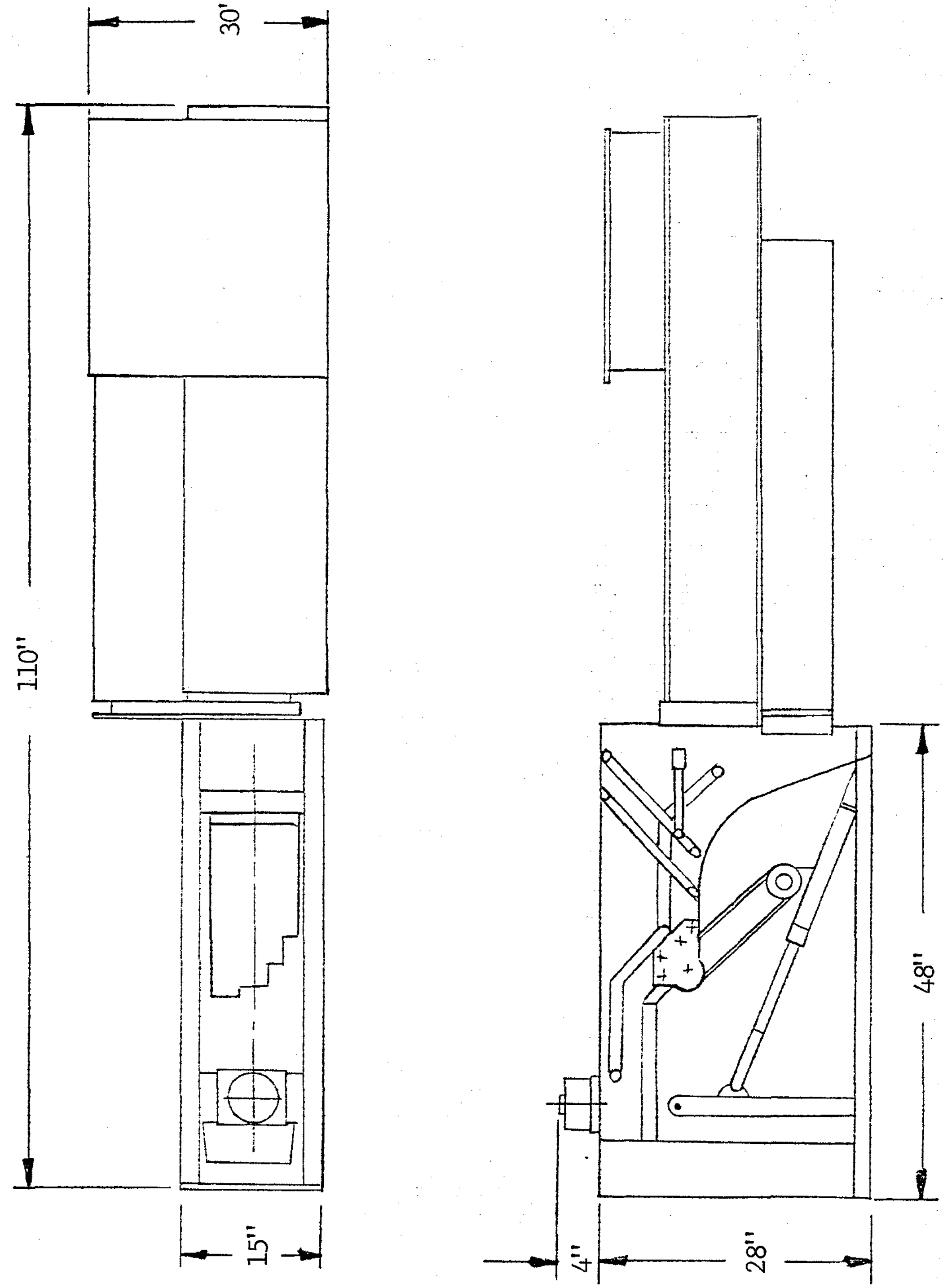


Figure 20: Bendix Automatic Resin Bolter Module

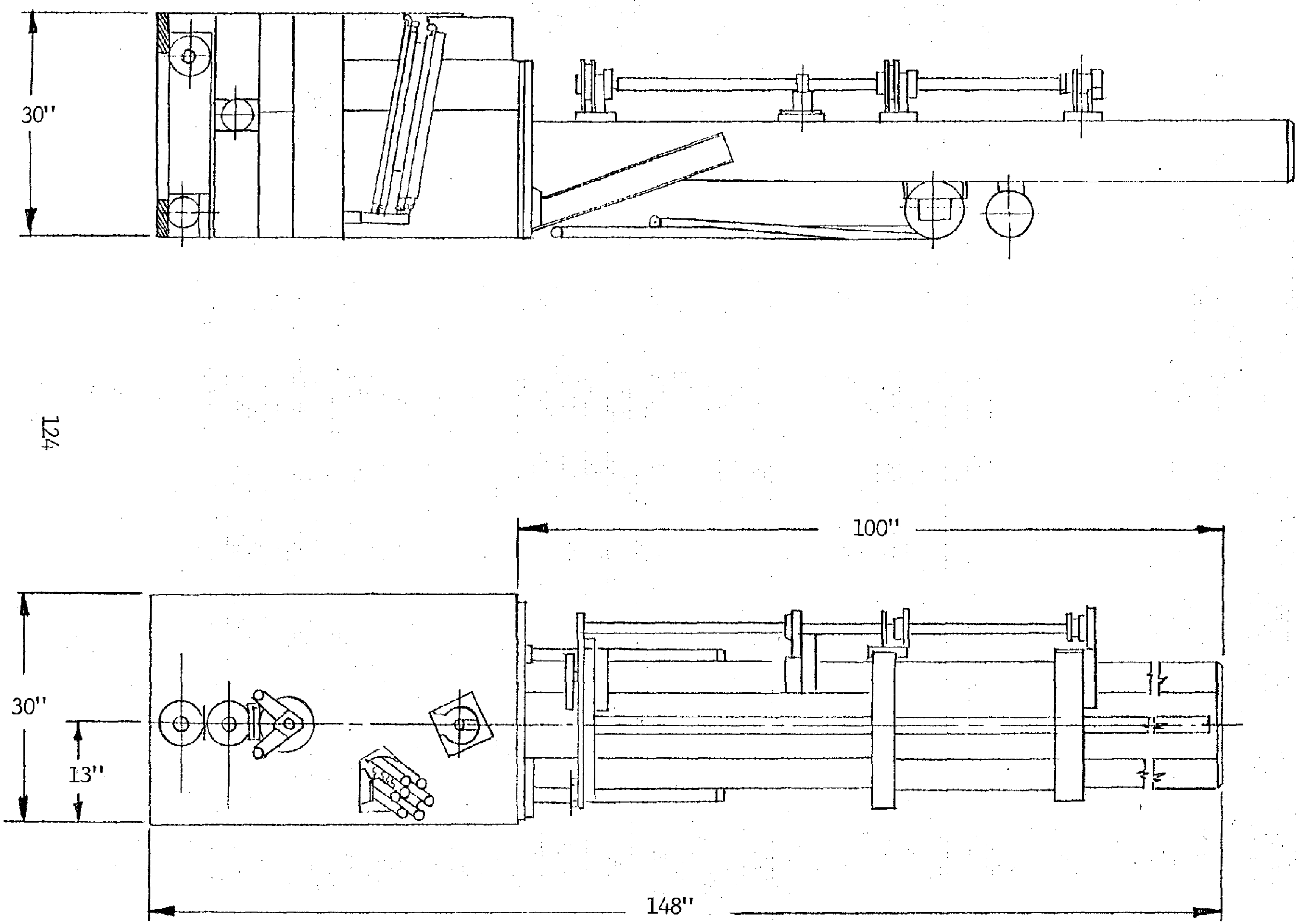


Figure 21: IRRI Mechanical Anchor Bolt Module (MABM)

In view of the low profile of the IRRI module (30 inches) every attempt was made to utilize the module on a low profile chassis. Assuming that 6 inches will be required for ground clearance and that 6 inches will be necessary for roof clearance, the bolter was designed to operate in a minimum seam thickness of 42 inches. The upper limit of seam height capability is determined by the module's mast extension to 72 inches.

Drawing on the floating cab designs which have been developed under Bureau funding, a floating cab design was developed for use with these concepts. The advantages of this type of cab include the maximization of operator comfort for a given seam thickness and the ability of the operator to instantly reposition the cab for optimum visibility where the seam thickness allows. Thus, the operator station need not be 30 inches high (thirty inches plus six inches of ground clearance plus six inches of top clearance equals 42 inch seam) for a 42 inch seam, but rather in the worst case where the cab must slide along the ground, a 36 inch high floatng cab would still have 6 inches of top clearance in that seam. The automatic features of the module will allow the operator to remain in the cab for both the tramming and bolting functions.

4.5.1 Automatic Bolter - Dual Boom (MABM - DB)

The MABM - DB concept, shown in an artist's rendition in Figure 22, features a crawler-type chassis mounting with dual, pivotable booms supporting and positioning the bolter modules. Two remotely located operator stations, mounted in floating cabs, are provided. Of special note is the capability of the machine to bolt a full row of bolts without chassis repositioning. A general dimensional layout of the MABM - DB bolter concept, showing plan and elevation views is given in Figure 23.

The drill and bolt cycle is expected to require 4.5 minutes which is somewhat long compared to existing bolters. Despite this long cycle time, it is expected that twin drill heads will effect a significant increase in production because the fully automated drill cycle allows one operator to operate both drill heads which frees the helper to perform supply functions full time.

The drill heads and bolt storage units are mounted on booms which swing outboard from the chassis, allowing a full row of

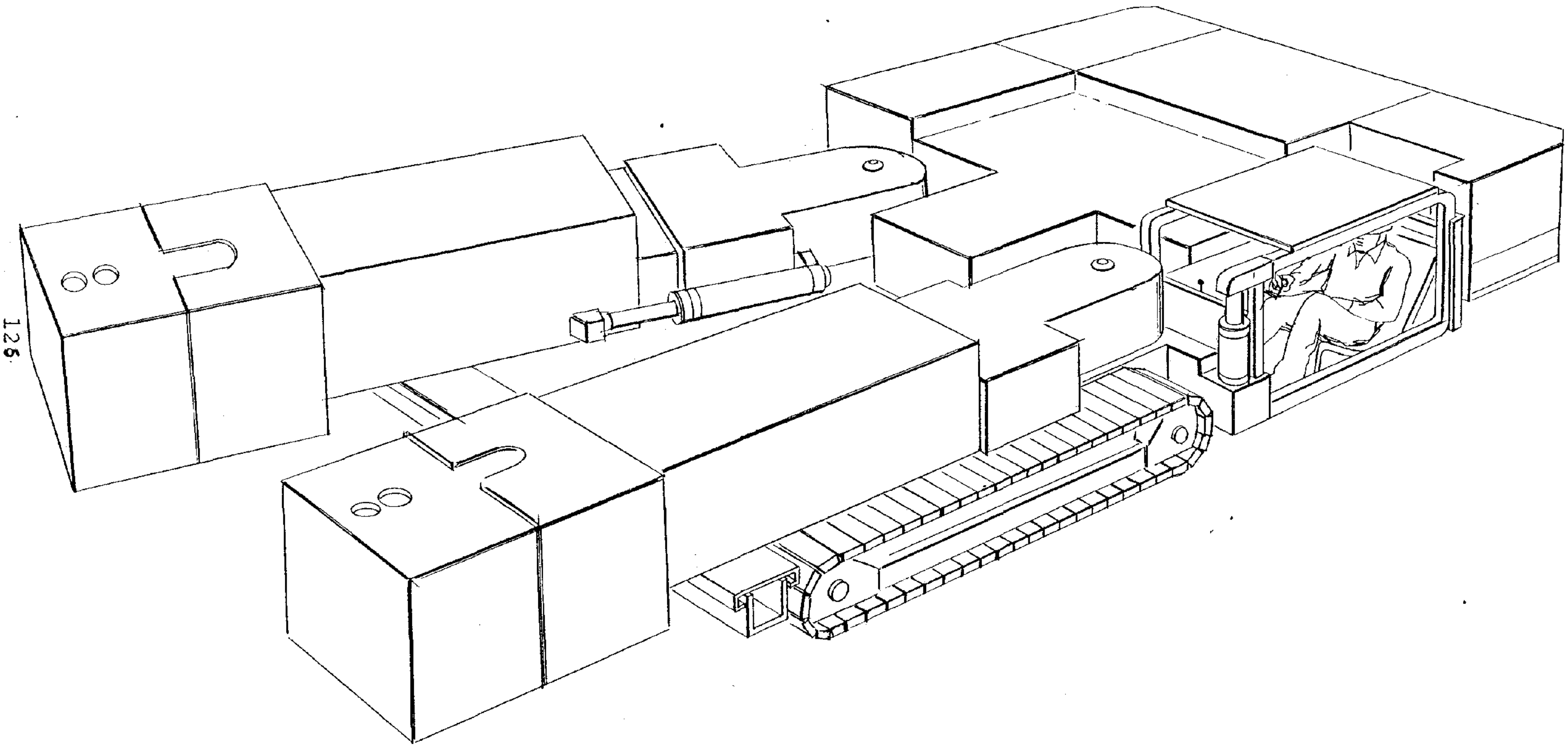


FIGURE 22

Artist's Rendition of the Automatic Bolter Dual Bocm (MABM - DB)

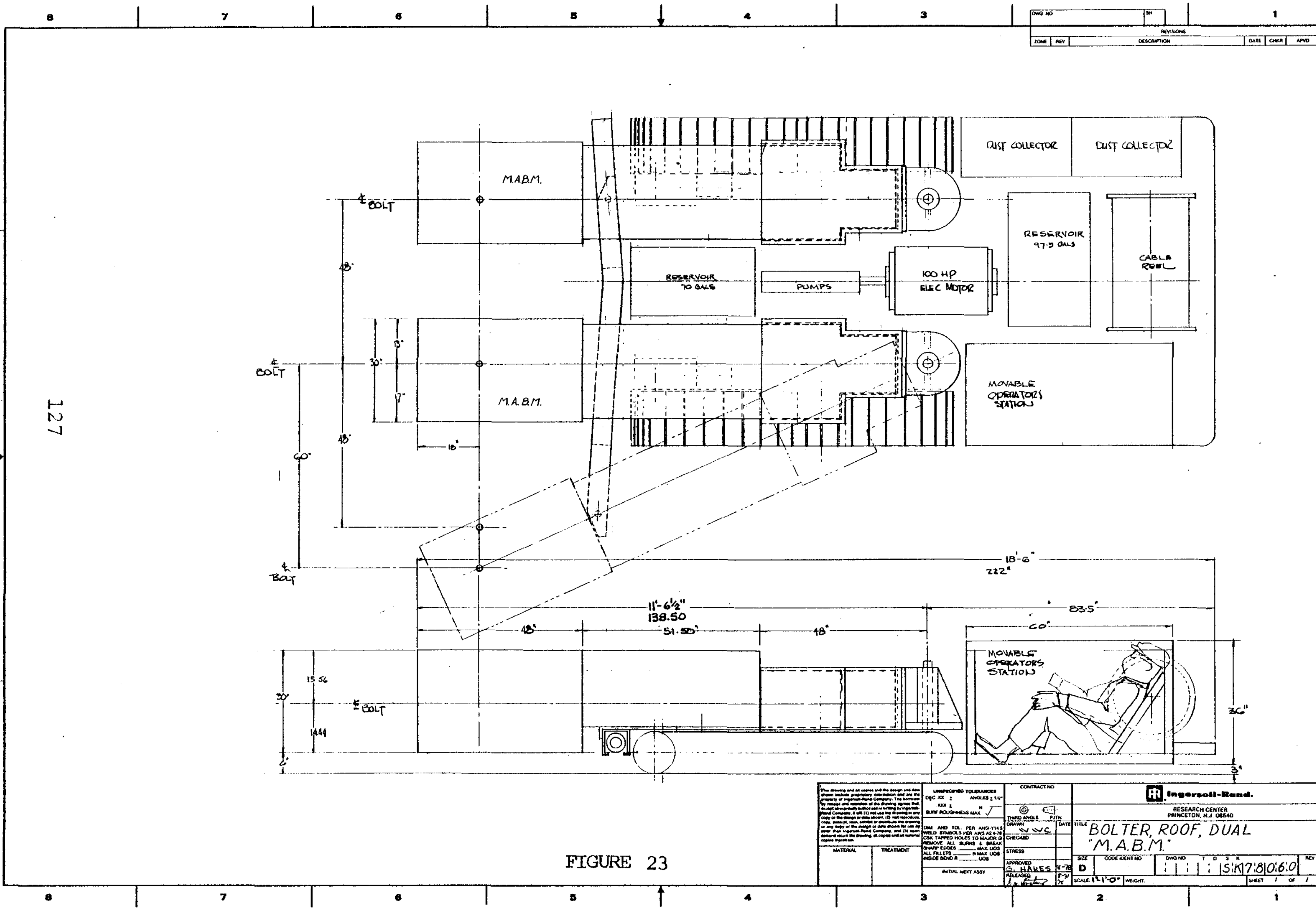


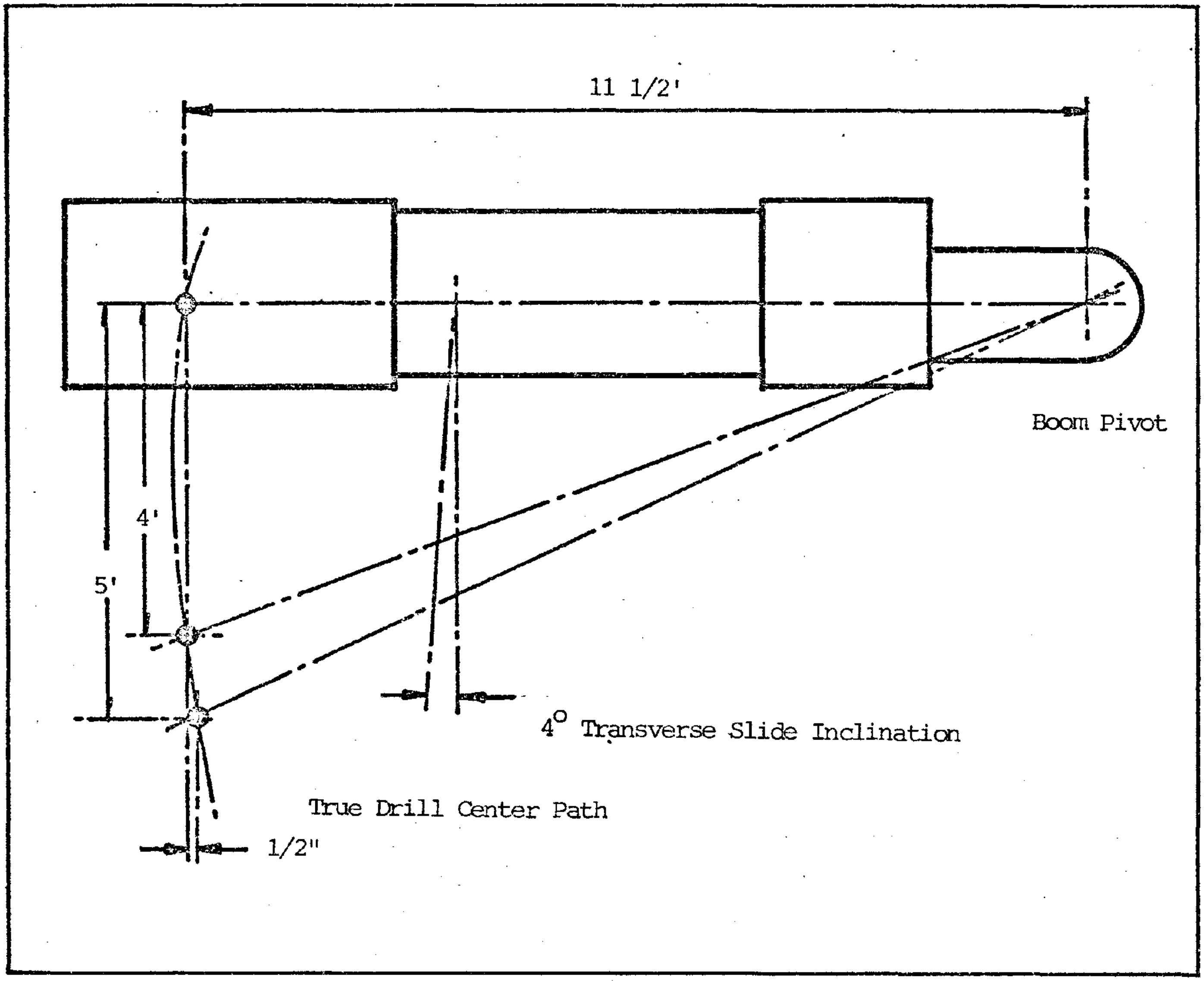
FIGURE 23

Plan & Elevation Views Automatic Bolter - Dual Boom bolts to be installed without moving the chassis. Boom motion is kinematically determined by a pair of slides, one at the pivot point providing sump and one oriented transversely near the drill head. The geometry of the slides allows the path of the drill centerline to approximate straight line motion perpendicular to the chassis centerline. Maximum deviation from straight line motion does not exceed ± 0.75 inch over 5 feet of swing. When bolts are to be drilled on four foot centers, a true straight pattern is achieved. The boom articulation scheme is shown graphically in Figure 24.

One major departure from traditional bolter design was necessitated by allowing the booms to swing. Because of the length (8 feet) and depth (22.5 inches) of the bolt storage unit, it was necessary to tram the vehicle on crawlers rather than foam filled tires in order to maintain the low profile capability of the modules. Thus, the booms swing out over the crawlers and the bolter center of gravity is kept within the limits of the crawlers.

Each IRRI module stores 18 to 25 bolts and 18 plates with lengths up to 8 feet. Thus, the MABM - DB bolter concept could theoretically bolt 36 feet of entry placing 4 bolts per row in rows 4 feet apart. The MABM - SB concept, described in the next section, would have to be altered to accomodate at least 20 plates in the plate magazine in order to fully bolt the conventional 20 foot cut most common today.

The design and operating specifications for the MABM - DB bolter vehicle are presented in Table 20, while the commercial components utilized are summarized in Table 21.



Automatic Bolter Module Boom Articulation Scheme

FIGURE 24

Table 20

Design and Operating Specifications
for the Automatic Bolter - Dual Boom
(MABM - DB)

General

A.	Overall Length	18.5 feet
B.	Overall Height	41 inches
C.	Overall Width	8 feet
D.	Ground Clearance	6 inches
E.	Ramp Angle	
	Front	5 degrees
	Rear	5 degrees
F.	Operating Seam Range	41 inches - 72 inches
G.	Bolt Length	4 feet - 8 feet
H.	Turn Capability	
	Single Pass 90° Turn at 14.3 foot Entry Width	
I.	Estimated Weight	36,000 pounds

Performance

A.	Tram Speed	75 FPM .38 MPH
B.	Maximum Grade	20 Degrees
C.	Ground Pressure	15.6 psi

Power

A. Cable 440 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

Table 20

Design and Operating Specifications for the Automatic Bolter - Dual Boom (MABM - DB) (Continued)

C. 100 Horsepower Electric Motor

Tram System

A. Crawlers - 16" wide x 12" high x 72 " cc

B. 4-Wheel Hydraulic Motor Drive Char-Lynn 4000 Series 12 in^3/rev.

C. Planetary Reduction Fairfield S3B

D. 3 Point Suspension - Rear Axel Pivot

E. Rear Wheel Steering

F. Automatic Parking Brake

Hydraulic System

A.	System Pressure	2,000 psi
B.	Pumps	2-35 GPM Gear 2-9 GPM Gear 1-15 GPM Variable Displacement Piston Pressure Controlled for Floating Cab
C.	Filters	Suction 75 Micron Return 10 Micron
D.	Reservoir Capacity	150 Gallons

Safety Features

A. Canopy Protected Slide Mounted Cab with Elevation Control

B. Fully Remote and Automatic In-Cab Operation

Table 20

Design and Operating Specifications for the Automatic Bolter - Dual Boom (MABM - DB) (Continued)

C. Auto Dump Dust Collection Donaldson

D. Fire Protection

E. Temporary Roof Support (Local)

Special Features

A. Dual Masts Slide for Straight Line Bolting on 4-foot Centers.

B. Low Seam Capability (41 inches)

C. Floating Operator Station

D. Bolt Inventory Capable of Securing 2 20' deep by 8' wide entries

Drill Box

A. IRRI .... Thrust 8,000 lb.
Torque 350 ft-lb.
Speed 300 RPM

Lighting

Use Shielded Floursecent Tube Fixtures as Required - McJunckin or Equivalent.

Table 21

Commercial Components Utilized on the Automatic Bolter - Dual Boom (MABM - DB)*

Item No.

1.0 Electric Power

1.1 Electric Motor

- Westinghouse
- 100 HP
- 1780 RPM
- 440 VAC, 3 Phase, 60 Hertz
- 113 AMPS
- MESA Certified

1.2 Reel Cable Electric

- Ensing Model No. 50102Q08C2B-000
- Penn Approved
- XP 1841-0

1.3 Spooler Cable Electric

- Lee-Norse
- Part No. 4-008200-300

*All quantities are one per vehicle unless otherwise specified.

Table 21

Commercial Components Utilized on the Automatic Bolter - Dual Boom (MABM - DB) (Continued)

1.4 Cable Electric

- Essex 2-3/C Type G-Gc
- 600 V P125 MESA or equivalent

2.0 Hydraulic Power

2.1 Pumps

- Commercial Shearing
- 35-15 GPM Tandem with Output Shaft
- P25X 178 GI IT17-11 G AB07-1-BO
- 35-15-15 GPM Triple Tandem
- P25X 178 GI IP17-11 C AB07-1
  C AB07-1

2.2 Valves

- Commercial Shearing
- Series A20

3.0 Mechanical Power

3.1 Reel Motor

- Commercial Shearing - Hydraulic Motor
- M25X 995 BE ER20-25

Table 21

Commercial Components Utilized on the Automatic Bolter - Dual Boom (MABM - DB) (Continued)

3.2 Hydraulic Cylinders

- Martiner PRoducts
- Boom Swing Quantity = 2
- Cab Elevation Quantity = 2

4.0 Dust Collection

4.1 Air Cleaner Quantity = 2

- Donaldson XYX00-4032
- 2.4 cu. ft. Capacity

4.2 Blower Quantity = 2

- Sutorbilt
- Model 3MB
- Approximately 42 CFM at 6 psi at 1500 RPM

4.5.2 Automatic Bolter - Single Boom (MABM - SB)

One major disadvantage with the twin module bolter concept is its cost. The module itself, because of its mechanical complexity and degree of automatic control, will be expensive to manufacturer and maintain. In addition, the crawlers required for tramming the twin module concept are more expensive than a wheeled vehicle concept.

As a result, a more economical single module version was developed. Boom articulation was eliminated, simplifying the module supports and allowing the chassis to be squirm steered by a traditional fixed four wheel system. Functionally, the bolter would tram and bolt in virtually the same manner as current small bolters except for the time savings developed by eliminating operator movement between tram and bolt stations. Bolt storage capabilities will be adequate to secure one full 20 foot 4 x 4 pattern cut. An artist's rendition of the MABM - SB bolter concept is shown in Figure 25. A general dimensional layout of this bolter concept, showing plan and elevation views, is given in Figure 26. The detailed design and operating specifications for this bolter concept are given in Table 22, while the commercial components utilized are given in Table 23.

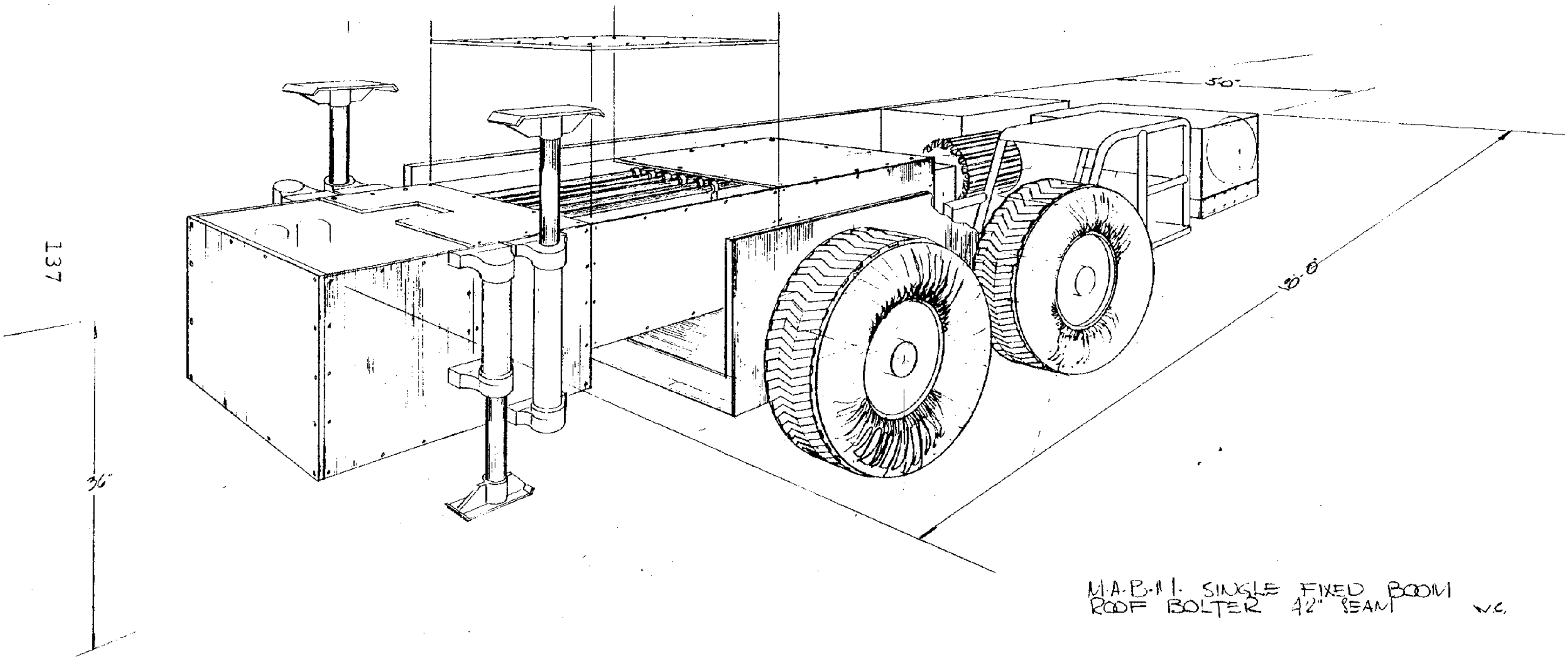


FIGURE 25

Automatic Bolter Single Boom (MABM - SB)

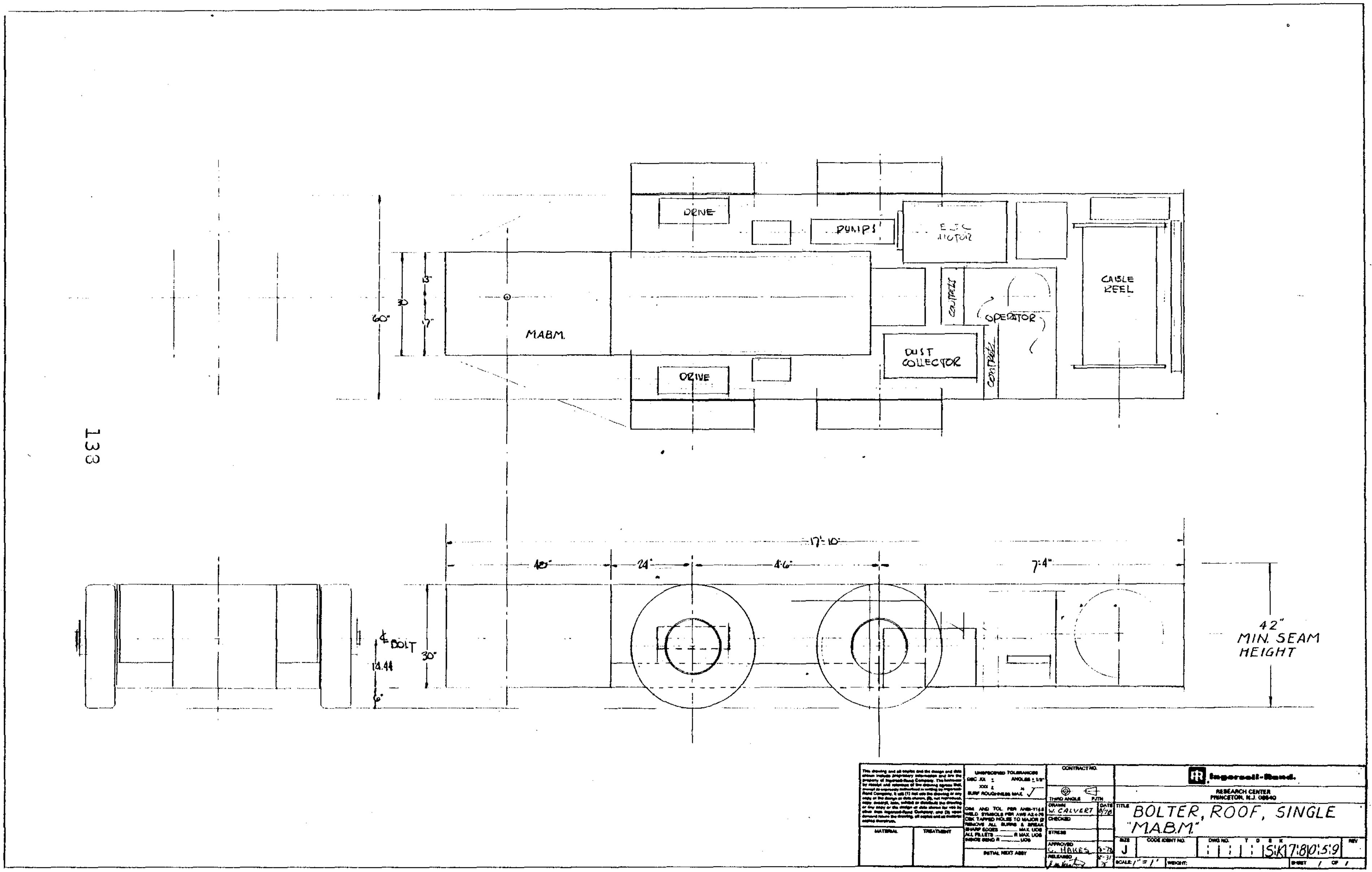


FIGURE 26

Automatic Bolter Single Boom (MABM - SB)

Table 22

Design and Operating Specifications for the Automatic Bolter - Single Boom (MABM - SB)

General

A.	Overall Length	17.8 feet
B.	Overall Height	41 inches
C.	Overall Width	6.5 feet
D.	Ground Clearance	6 inches
E.	Ramp Angle	
	Front	5 degrees
	Rear	5 degrees
F.	Operating Seam Range	41 to 72 inches
G.	Bolt Length	4 to 8 feet
H.	Turn Capability Single Pass 90° Turn at 11.4 foot Entry Width	
I.	Estimated Weight	18,000 pounds

Performance

A.	Tram Speed	123 FPM 1.4 MPH
B.	Maximum Grade	20 degrees
C.	Ground Pressure	78.9 psi

Power

A. Cable 440 VAC 3 Phase

B. Horizontal Axis Cable Reel - Power Take Up

C. 40 Horsepower Electric Motor

Table 22

Design and Operating Specifications for the Automatic Bolter - Single Boom (MABM - SB) (Continued)

Tram System

A. Tires 8.25-15, 33.6" x 9.25"

B. Four-Wheel Hydraulic Motor Drive Chary-Lynn 4000 Series 12 in^3/Rev.

C. Planetary Reduction Fairfield S3B

D. Squirm Steering

E. Automatic Parking Brake

Hydraulic System

A.	System Pressure	2,000 psi
B.	Pumps	1-35 GPM Gear 1-10 GPM Variable Displacement Piston Pressure Controlled
C.	Filters	Suction 75 Micron Return 10 Micron
D.	Reservoir Capacity	80 Gallons

Safety Features

A. Canopy Protected Slide Mounted Cab with Elevation Control

B. Fully Automatic and Remote In-Can Operation

C. Donaldson Auto Dump Dust Collection System

D. Fire Protection

E. Temporary Roof Support (Local)

Table 22

Design and Operating Specifications for the Automatic Bolter - Single Boom (MABM - SB) (Continued)

Special Features

A. Compactness - Narrow and Highly Maneuverable Squirm Steering

B. Floating Operator Station

C. Bolt Inventory Capable of Securing 20' Deep by 18' Wide Entry

Drill Box

A. IRRI .... Thrust = 8,000 lbs.
Torque = 350 ft-lbs.
Speed = 300 RPM

Lighting

Use shielded Flourescent Tube Fixtures as Required - McJunkin or Equivalent

Table 23

Commercial Components Utilized on the Automatic Bolter - Single Boom (MABM - SB)*

1.0 Electric Power

1.1 Electric Motor

- Reliance ID No. P326938A
- 40 HP
- 1770 RPM
- 440 VAC, 3 Phase, 60 Hertz
- 52.2 AMPS

1.2 Motor Control Box

- Hubbell Ensign Electric Division
- Class 2010 Starter
- Spec. No. 2210-KSD40FX-0002-A
- Schedule 26 XP 1808-0
- 40 HP
- 440 VAC, 3 Phase, 60 Hertz

1.3 Cable Electric

- USS Tigerbrand Lead Cured
- 600 V, 3 Cond, 6 AWG

*All quantities are one per vehicle unless otherwise specified.

Table 23

Commercial Components Uitlized on the Automatic Bolter - Single Boom (MABM - SB) (Continued)

- Type G-GC, P109 MSHA or equivalent

1.4 Reel, Cable Electric

- Ensign Model No. 50102Q08C2B-000
- Penn Approved Reel
- XP 1841-0

1.5 Spooler, Cable Electric

- Lee-Norse Part No. 4-008200-300 or equivalent

2.0 Hydraulic Power Supply

2.1 Pumps

- Commercial Shearing
- 35-35-10 GPM Triple Tandem
- P25X 178 GI IT17-11 TL IT17-1 C AB05-1

2.2 Valves

- Commercial Shearing
- Series A20

Table 23

Commercial Components Uitlized on the Automatic Bolter - Single Boom (MABM - SB) (Continued)

3.0 Mechanical Power

3.1 Reel Motor

- Commercial Shearing Hydraulic Motor
- M25X 997 BE ER10-30

3.2 Tram Motors, Quantity = 2

- Char-Lynn Hydraulic Motors
- Series 4000
- Model No. 109 1013

3.3 Tram Speed Reducer Quantity = 2

- Fairfield Torque Hub-Planetary
- Model S3B
- Speed Reduction 25:1

3.4 Hydraulic Cylinders

- Martiner Products
- Roofa and Floor Jacks

4.0 Tires

4.1 Mining Service Tires Quantity = 4

Table 23

Commercial Components Uitlized on the Automatic Bolter - Single Boom (MABM - SB) (Continued)

- Firestone - .25-15
- Overall Diameter = 33.6 in.
- Static Load Radius - 15.7 in.
- Footprint Area = 57 sq. in.
- 65 psi Inflation Pressure or equivalent

4.2 Foam Fill

- Firestone Sup•R•Fil
  to 65 psi or equivalent

5.0 Dust Collection

5.1 Air Cleaner

- Donaldson Self Dumping
- Model No. XYX 005109

5.2 Blower

- Sutorbilt Calif. Series B
- Model 3 MB
- Approximately 42 CFM at 6 psi
  at 1500 RPM

5.0 SCHEDULE AND COST ESTIMATES

The design cost and schedule of each concept is based on the engineering effort required to develop each concept. The design effort would include; 1) a complete package of detailed drawings sufficient to build parts, standard components and assemble the prototype unit, and 2) Design calculations, assumptions, stress calculations on all areas of the prototype vehicle where calculations are deemed necessary to predict or insure performance. This body of information will provide a reference for "how and why" the prototype design evolved, construction materials selection, and function. It will assist materials selection and prevent arbitrary changes to the design when such changes are inconsistent with some factor of the prototype design.

Since the prototypes fall into three different levels of development effort, there are 3 different time schedules and labor costs in the detail design phase.

Group I Concepts, which require significant engineering effort to optimize the chassis for space and location considerations, result in an estimated design cost of $264,000 and a nine month design schedule.

Group II Concepts, which require significant engineering effort to adapt and modify bolt, steel, and plate magazines or other major mechanisms, result in an estimated design cost of $294,000 and a ten month design schedule.

Group III Concepts which utilize standard, existing chassis configurations require a $151,000 dollar design effort and an eight month design schedule.

The procurement, assembly, and test phase estimate includes the effort of a program manager and a project engineer to select qualified suppliers and place purchase orders for all material. An assembly crew of four is required to assemble and conduct preliminary testing on the first prototype build. A test crew of two will be required during the extensive, above ground test of the prototype. Any problems revealed during this period will be corrected.

The program manager and project engineer will perform all liaison with the Bureau of Mines and prepare a final report incorporating the entire development history of the prototype bolter. This labor effort is the same for all three groups of concepts.

Procurement Assembly and Test Tasks:

	Cost	Time
Group I Concepts	$190,000	19 Months
Group II Concepts	$198,000	20 Months
Group III Concepts	$174,000	17 Months

Prototype cost estimates are based primarily on the individual features of each concept and this naturally varies with each concept. The selling price of standard components was used whenever applicable, but primarily on the standard chassis concepts in Group III. Where the chassis are different, but similar in construction details and size to standard equipment standard costs were multiplied by a "factor" to predict prototype costs. For the more complex systems utilizing magazines, handling arms, logic systems, etc. the cost estimates are based on current prototype costs for other programs which include hardware of a similar nature, but projecting the decrease in cost for quantity production.

These three estimates were then summed to produce the total development cost and schedule for each concept. The results are presented in Table 24.

The total development cost for the two concepts using standard chassis is $396,000 for the transfer bolter - single boom and $453,000 for the transfer bolter - dual boom. The development cost for the transfer bolter - single boom (standard chassis) is 72% of the transfer bolter - single boom (new chassis), but its estimated selling price is 119% of the transfer bolter - single boom (new chassis) unit. This situation is

Table 24: Cost and Schedule Estimates

Group	No. of Booms	Concept Title	Fig. Nos.	Design, Detail, Check Labor Cost $x1000	Design, Detail, Check Labor Time Months	Procure Assemble Test Labor Cost $x1000	Procure Assemble Test Labor Time Months	Prototype Cost $x1000	Total Development Cost $x1000	Total Development Time Months	Sales Price x Std. Bolter Price	50 Unit Prod. Sales Price $x1000/Unit
I	1	Transfer Bolter - Single Boom (New Chassis)	8	264	9	190	19	98	552	28	1.09	49
II	1	Rod Changer - Bolt Bender	12,13	294	10	198	20	186	678	30	2.07	93
I	1	Automatic Bolter - Single Boom (MABM-SB)	20,21	264	9	190	19	218	672	28*	2.42	109
III	1	Transfer Bolter - Single Boom (Standard Chassis)	11	151	8	174	17	71	396	25	1.29	58
I	2	Transfer Bolts - Dual Boom (New Chassis)	1,2	264	9	190	19	166	620	28	.95	83
II	2	Transverse Rail Rib Bolter	15,16	294	10	198	20	364	856	30	2.07	182
I	2	Automatic Bolter - Dual Boom (MABM-DB)	17,18	264	9	190	19	468	922	28**	2.67	234
III	2	Transfer Bolter - Dual Boom (Standard Chassis)		151	8	174	17	128	453	25	1.23	108

* Single Boom Bolters Compared to Lee-Norse Co. TD-I 36" Sales Price.

** Dual Boom Bolters Compared to Lee-Norse Co. TD-II 43" Sales Price.

indicative of the optimization achieved by redesigning the entire chassis for a specific purpose, but utilizing standard, off-the-shelf componentry.

The Transfer Bolter - Dual Boom (standard chassis) development program cost is 73% of the Transfer Bolter - Dual Boom (New Chassis) development cost, but its estimated selling price is 130% of the latter unit. This situation is due to the less complex construction of the non-swinging transfer bolter - dual boom machine. The fixed mast chassis feature is very rugged and compact with high structural integrity. This results in an inexpensive, but rugged bolter. However, a fixed-boom configuration might not be as readily accepted by operators used to the more conventional and versatile transfer bolter - dual boom (standard chassis).

In general, the other optimized chassis designs are more expensive than the transfer mechanism bolter concepts because of increased complexity. Notice that for the single boom concepts the MABM - SB has the third lowest development cost (3 of 4) while MABM - DB was the highest (6 of 6). This result is due to the track mounted feature, the sump, and swing of the MABM - DB all of which do not exist on the single boom MABM - SB.

The final item on the cost and time estimate chart is the estimated selling price. This cost evolved by comparing all single boom machines against the Lee-Norse TDI-36 selling price and all dual machines against a TDII-43. Since all of these bolter concepts feature "remote operator control", they will sell for more than the conventional units. Some of the concepts also exhibit considerable degrees of automation, adding significantly to their costs. This is especially true of the MABM concepts which are fully automatic.

An interesting fact is that one unit is actually priced less than the standard model; the transfer dual bolter - dual boom (new chassis) is only 95% of the standard TDII-43. This result is again due to the structural and spatial efficiency of the non-swinging, dual bolter chassis of the transfer bolter - dual doom (new chassis) concept. In general all of the transfer concepts cost from 1 to 1.3 times the conventional vehicle.

The remaining vehicles, in the order of ascending prices, would include the rod changer-bolt bender at 2.07, the transverse rail rib bolter at 2.07, the MABM - SB at 2.42 and finally the MABM - DB at 2.67 times the TDII-43 price.

Obviously then, the transfer bolters could be considered cost competitive. The other bolters incorporate increasing degrees of complexity and provide special features (longer than seam height bolts, low seam operation, fully automatic bolter). These features will require additional testing to assure the mine operators a high degree of reliability.

6.0 Maneuverability Discussion

6.1 Tire Size Evaluation

A segment of the roof bolter mobility study was devoted to the selection of tire size - both width and diameter. The tire selection is often dictated by design such as space encroachment thus a tire may not exceed a specific width or diameter because of the wheel clearance.

Low seam roof bolters will select the lowest profile tire to minimize tram height.

The most important factors in the selection of tires are based upon performance, i.e., ground pressure, tire diameter, ability to transmit drive train torque. Ground pressure can be adjusted by both tire width and diameter to achieve the desired results.

The tire diameter provides the means of transmitting the vehicle power to the ground and in addition impacts the ability of the vehicle to "roll over" obstacles. The tire diameter has an effect on the probability of a tire slipping while trying to roll over an obstacle.

Generally 3 conditions result in a vehicle becoming immobile.

1. The vehicle chassis becomes "grounded" on some portion of the roadway.
2. The vehicle tires slip - the coefficient of traction is inadequate to supply the force the vehicle requires.
3. The vehicle tram system cannot provide adequate torque to overcome the tram resistance.

For purposes of this evaluation it will be assumed that cases 1 and 3 are unaffected by tire size due to:

1. Selection of tires with equal footprint areas, and

2. Selection of different final drive gear ratios to provide equal drawbar pull with either size tire.

Case No. 2 cannot be so easily compensated for. On smooth surfaces level or inclined the tire diameters perform equally well. However, on undulating terrain irregularities such as potholes, ridges, strips and pieces of debris the larger diameter does have an advantage. This advantage results when we consider the effective ramp angle produced as a tire encounters a step in its roadway.

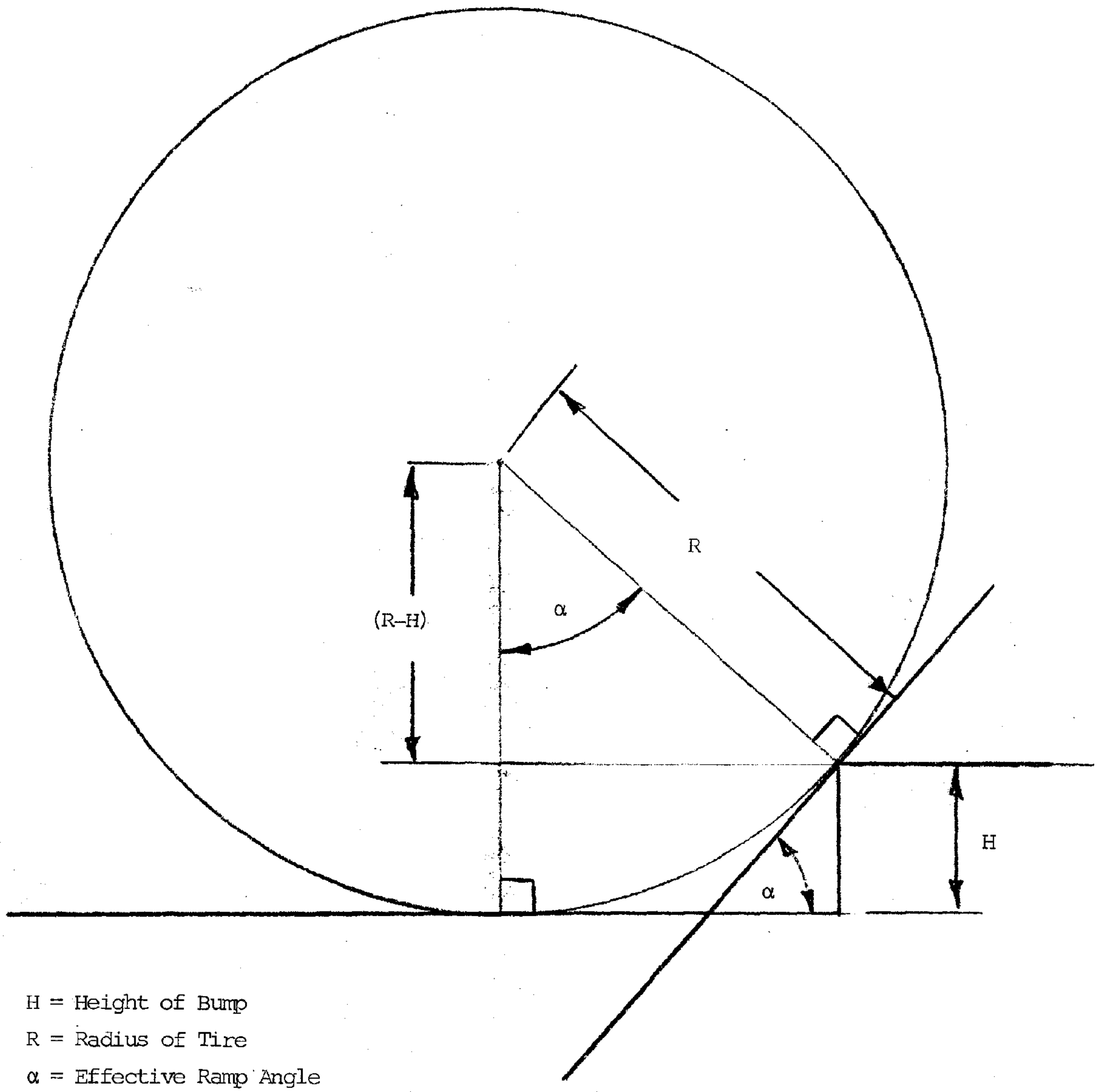
Figure 27 depicts the relationship between a tire diameter and the effective ramp angle created by a given step height. In this discussion, deformations of the tire from the unloaded toroidal shape will be disregarded for simplicity. Consider the effective ramp angle generated when tires of different diameters encounter a discontinuity of a fixed height. The smaller diameter tires generate a larger effective ramp angle for a given step height. The greater the ramp angle the greater the resistance to negotiate the step. The effective ramp angle a tire can climb is limited by stall torque and its coefficient of traction. Assuming 1. Equal stall torques for both tire sizes (which can be accomplished by appropriate gearing), and 2. Equal coefficients of traction for both ties, the large diameter tire has an advantage. The larger diameter tire can climb a higher step height without slipping. Figure 29 plots the variation in effective ramp angles with step height for 3 tire diameters.

Figure 28 shows how the ability to climb a ramp angle is limited by the coefficient of traction.

Figure 30 indicates the maximum step heights that 3 tire diameters could climb for different coefficients of traction.

Notice that at $\mu T = 0.3$ the 36" diameter tire can climb a 0.76 inch step while the 24 inch diameter tire can climb a 0.51 inch step. This is a 50% greater step height. $\mu T = 0.3$ is a condition approximating loose wet clay which is the ground condition found in many mines where tire slip occurs frequently.

The apparently low values of step height may require some explanation. They relate to one tire only. Thus, when applied



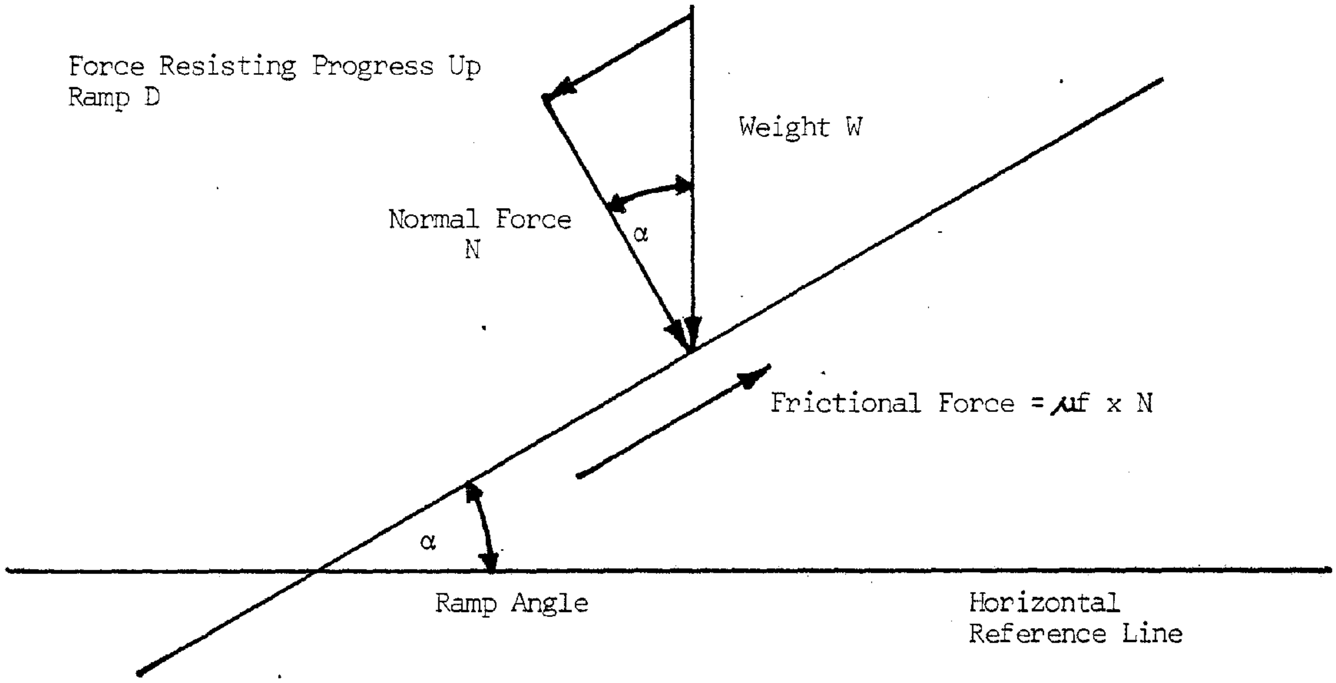
H = Height of Bump

R = Radius of Tire

α = Effective Ramp Angle

$\alpha = \text{acos}\ \frac{(R-H)}{R}$

Figure 27: Tire Diameter vs. Bump Height Schematic



Wheel Slips Down Ramp When

$D \geq \mu f\ N$

$\mu f = \frac{D}{N} = \tan \alpha$

μf	α Degrees	% Grade
.1	5.72	10
.2	11.32	20
.3	16.70	30
.4	21.8	40
.5	26.57	50
.6	30.97	60
.7	34.98	70
.8	38.67	80
.9	41.98	90

Figure 28

Coefficient of Friction vs.
Maximum Climbable Ramp Angle

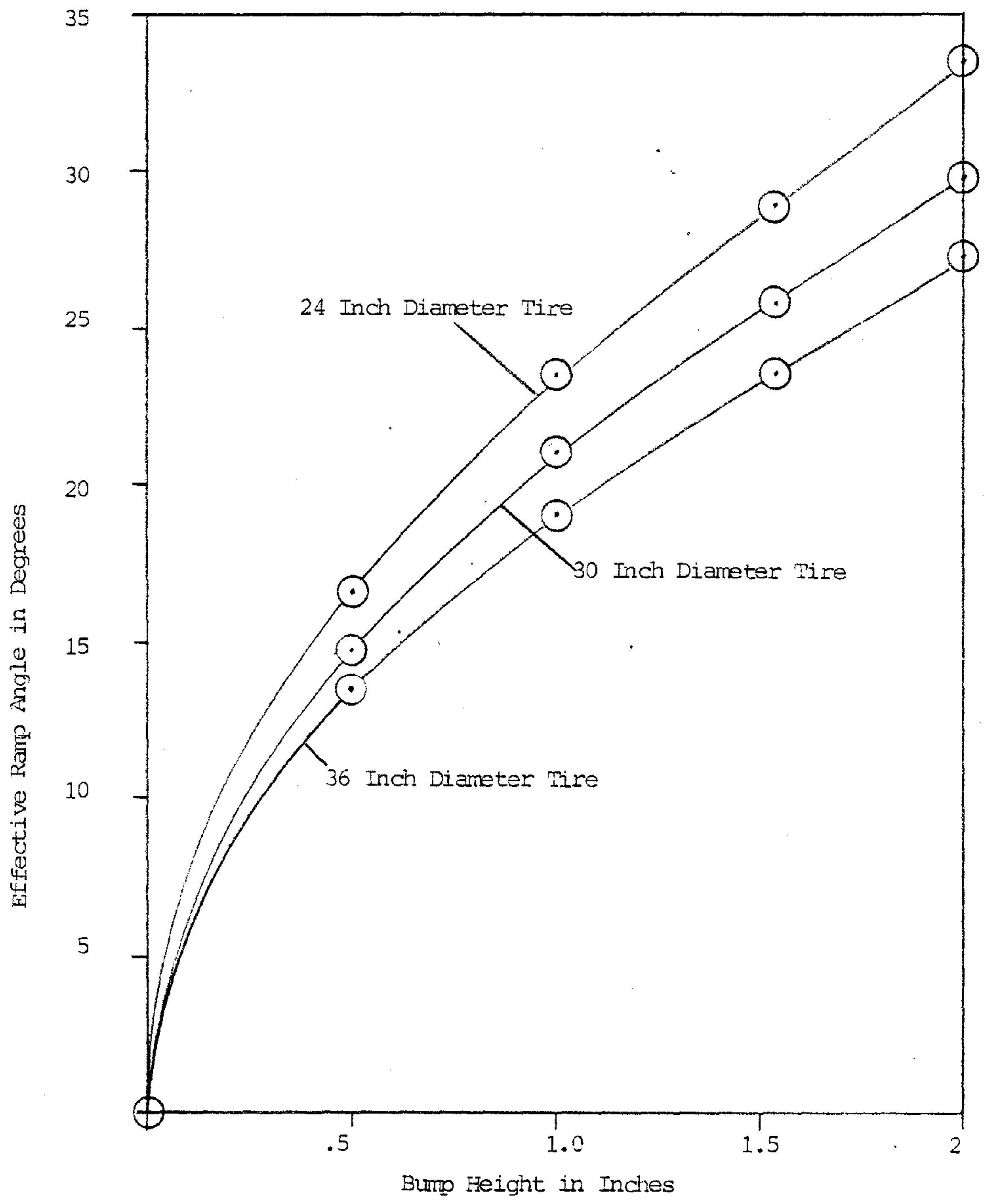


Figure 29: Bump Height vs. Effective Ramp Angle for Various Tire Diameters

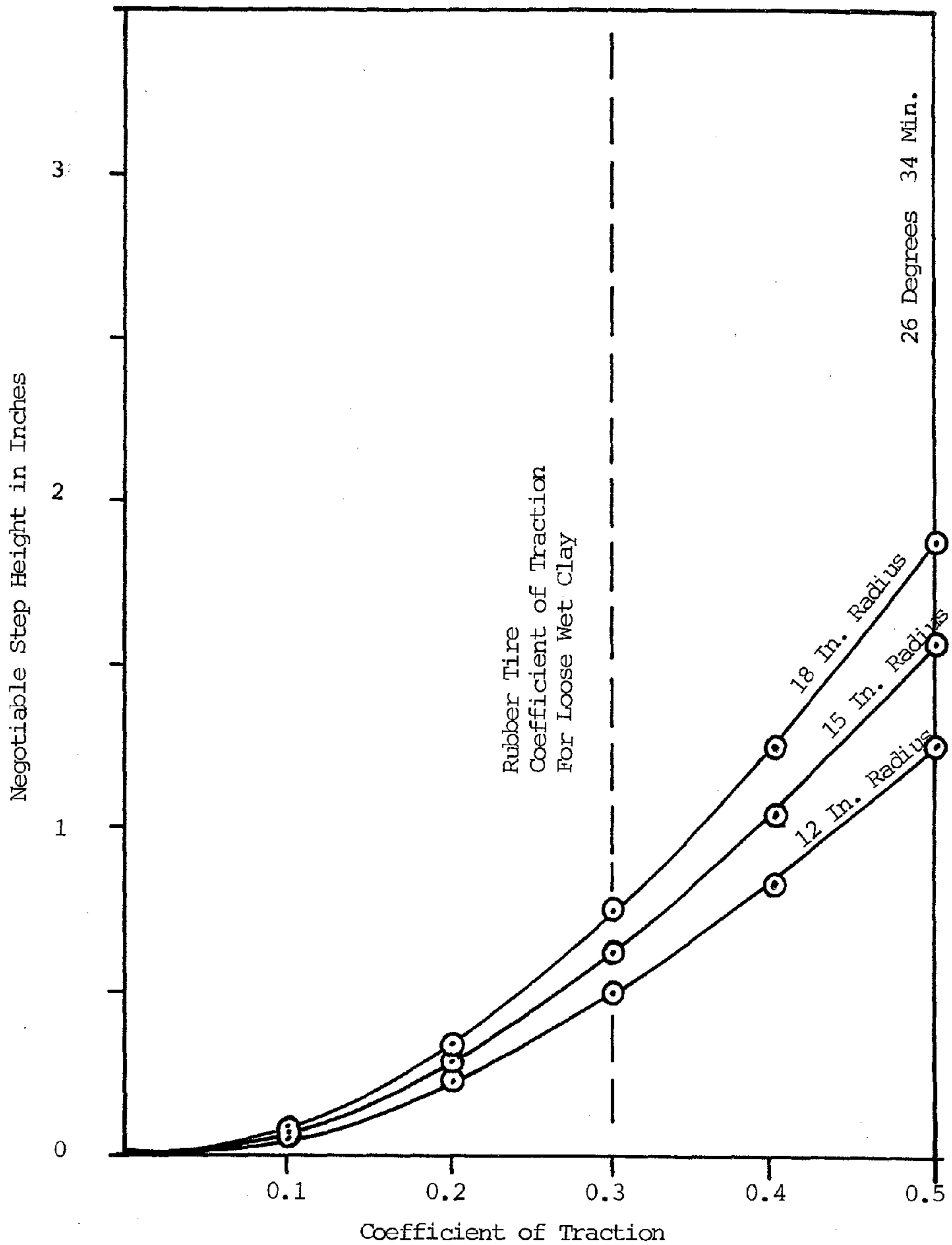


Figure 30: Negotiable Bump Height vs. Coefficient of Traction For Specific Tire Radii

to a four wheel machine all four tires would have to simultaneously encounter this step height before the vehicle would be stalled. Thus, in the general 4-wheel drive vehicle case sufficient step to cause one wheel slip might have to be almost 4 times as high as this one wheel step indicated. In addition, the effect of vehicle momentum has been discounted in this example.

For these reasons it was decided to use the largest tire diameters compatable with the minimum operating seam height of the bolter, on each concept. This decision was of course tempered with cost, availability and other space considerations.

6.2 Turning Studies

During the field studies many field personnel expressed the opinion that mining equipment is getting much too large. The major source of concern is the difficulty in maneuvering the equipment through the low narrow mine passages. While reviewing equipment specifications, it was noted that equipment manufacturers do not provide meaningful turning specifications. Some provide a turn radius for steered wheel vehicles. Most squirm machines provide no turning information. Layout studies of how various vehicles can turn a corner have led us to develop a useful performance specification which relates simply to the ability of a vehicle to turn a 90° angle in a narrow passage. This turn must be accomplished in one pass - without a change of direction. The parameter quoted is the "one pass 90° turn entry width". It assumes equal widths for entry and crosscut. It also assumes square corners and that the corner is not yet a 3 or 4 way intersection. This is the turning performance parameter we have quoted on the performance specifications in this report.

It should be noted that:

1. Many vehicles can perform a single pass 90° turn in smaller entries at a 4-way intersection and

2. In general, vehicles can turn in even narrower entries by using several changes of direction. This maneuver is time consuming and does additional damage to the mine floor. The absolute minimum width will also demand considerable operator skill and patience. As such, the

absolute minimum mine entry turn width is not a good parameter for the nominal turn specification.

Consider an example case, the transfer bolter-dual boom (new Chassis). See Figure 31 for reference. Figure 31 shows that an inside wheel pivot angle of 40° was selected for this concept. This selection results in a turn radius of 9.6 feet and a one pass 90° turn entry width of 12.8 feet. It can be ovserved from Figure 31 that a much smaller turning radius will result if the inside wheel pivot angle is increased. In fact, it appears that the turn radius could be as small as half the front wheel track. Figure 32 has been constructed to show this condition. Notice the inside wheel pivot angle is now 80 degrees. The turn radius has decreased from 8.5' to 2.9'. However, the one pass 90° turn entry width has increased from 12.8 to 14.6 feet.

Figure 33 plots the variations of turn radius and "one pass 90° turn entry width" versus inside wheel turn angle in degrees. Note that a "one pass 90° turn entry width" reaches a minimum at a turn radius of about 9.6 feet which occurs at 40° inside wheel angle.

Figures 34 and 35 show similar turn studies for squirm steer 4 wheel vehicles and track mounted vehicles.

Comparison turn studies were made for all of the concept bolters and several commercial bolters. This information is summarized in Figure 36 and Table 25.

6.3 Ground Clearance

Figure 37 and Table 26 compare ground clearances for various vehicles in addition to the concept vehicles.

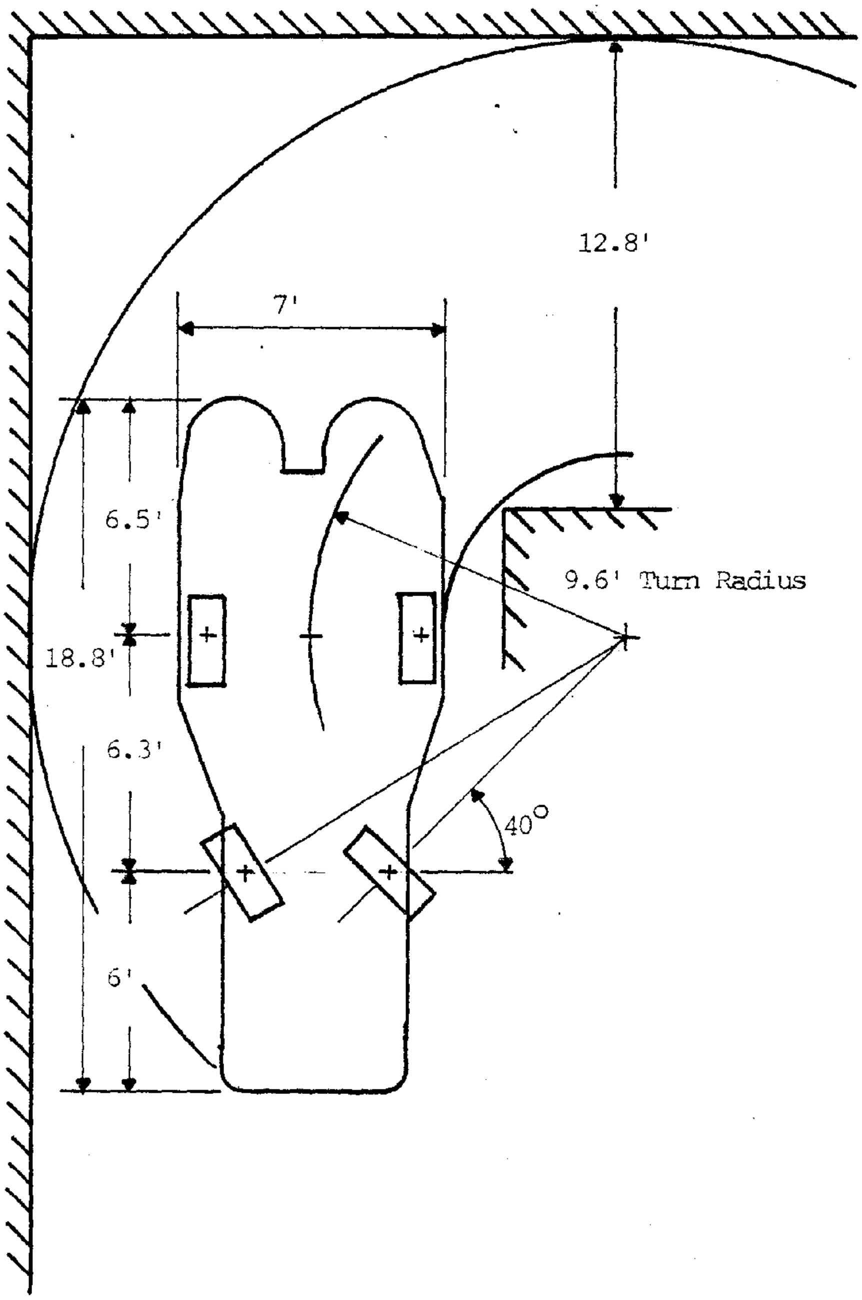


Figure 31: Turning Study #1 of the Transfer Bolter - Dual Boom (New Chassis)

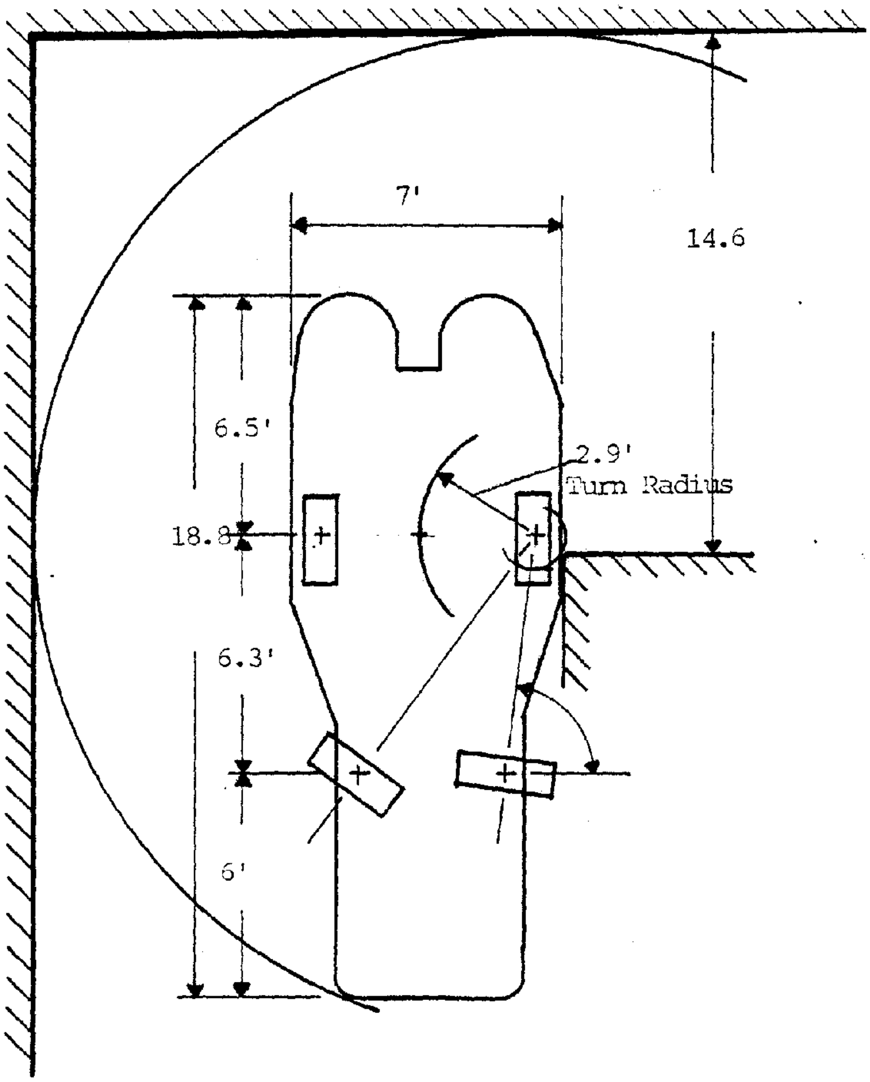
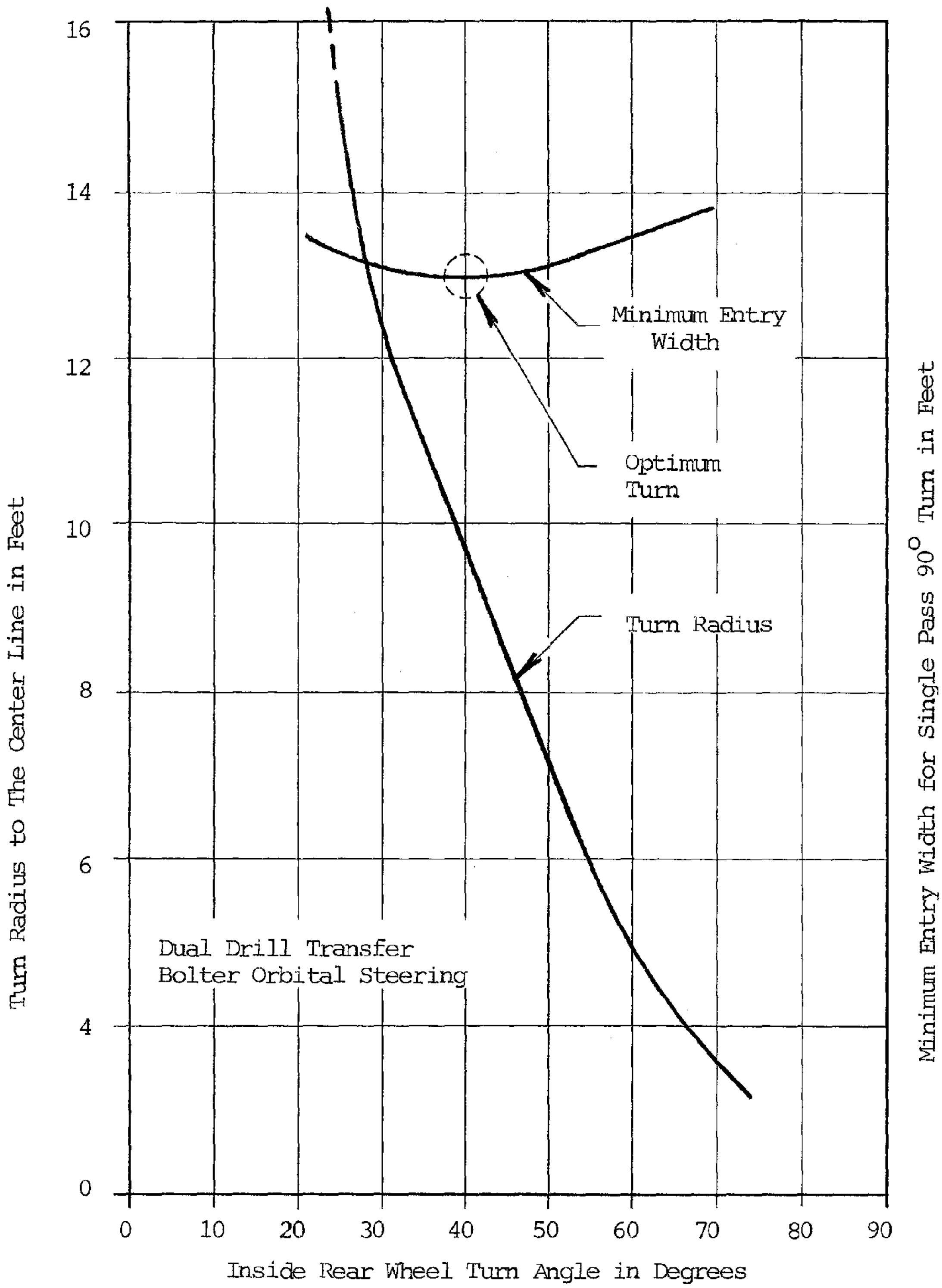


Figure 32: Smallest Turn Radius for Transfer Bolter - Dual Boom (New Chassis)

Figure 33:

Variation of Turn Ardius and Minimum Entry Width for Single Pass 90° Turn as a Function of Inside Rear Wheel Turn Angle in Degrees



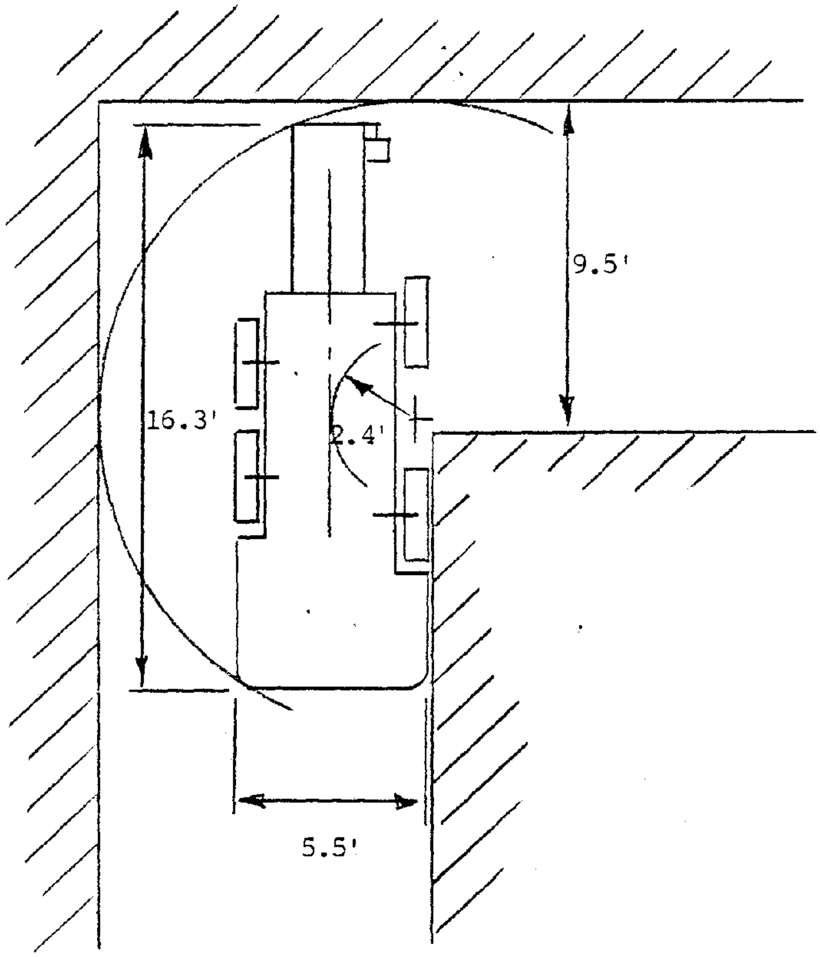


Figure 34: Minimum Entry Width for 90° Single Pass Turn Transfer Bolter Single Boom (New Chassis)

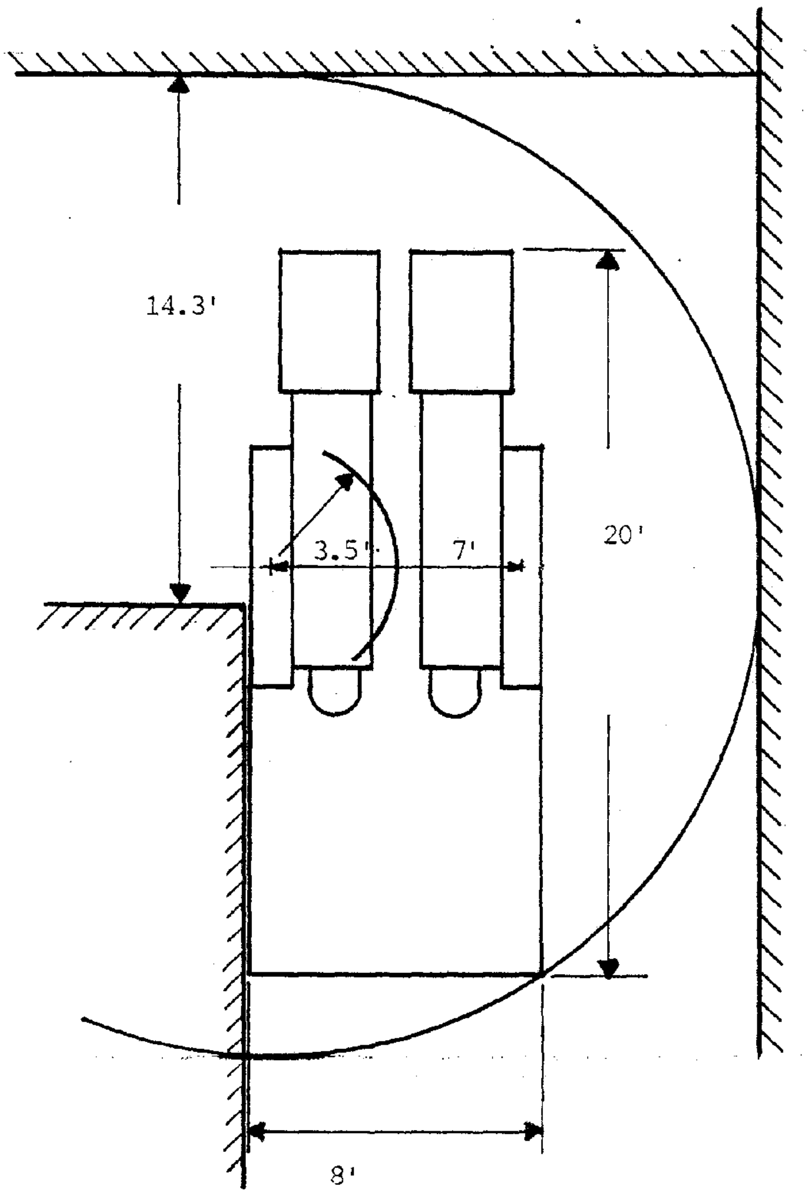
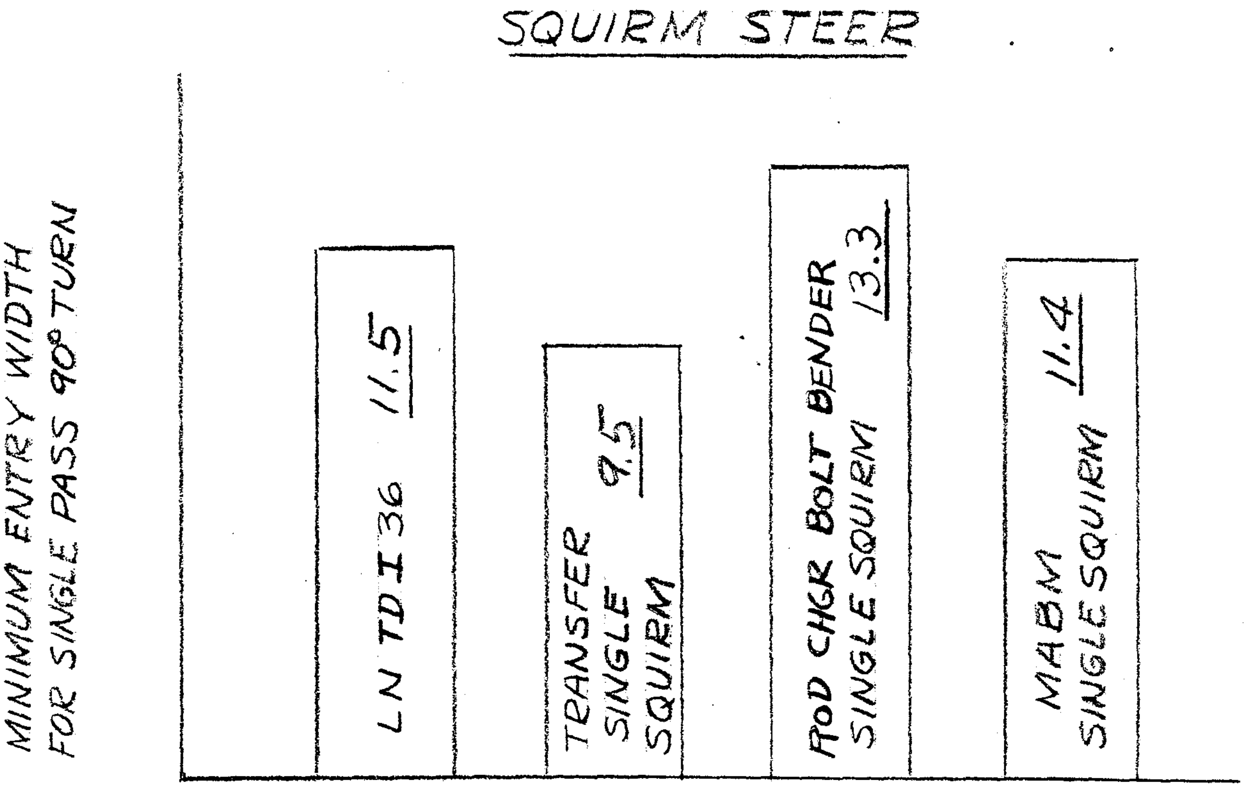


Figure 35: Turn Study for the Transfer Bolter -
Single Boom, Optimum Turn



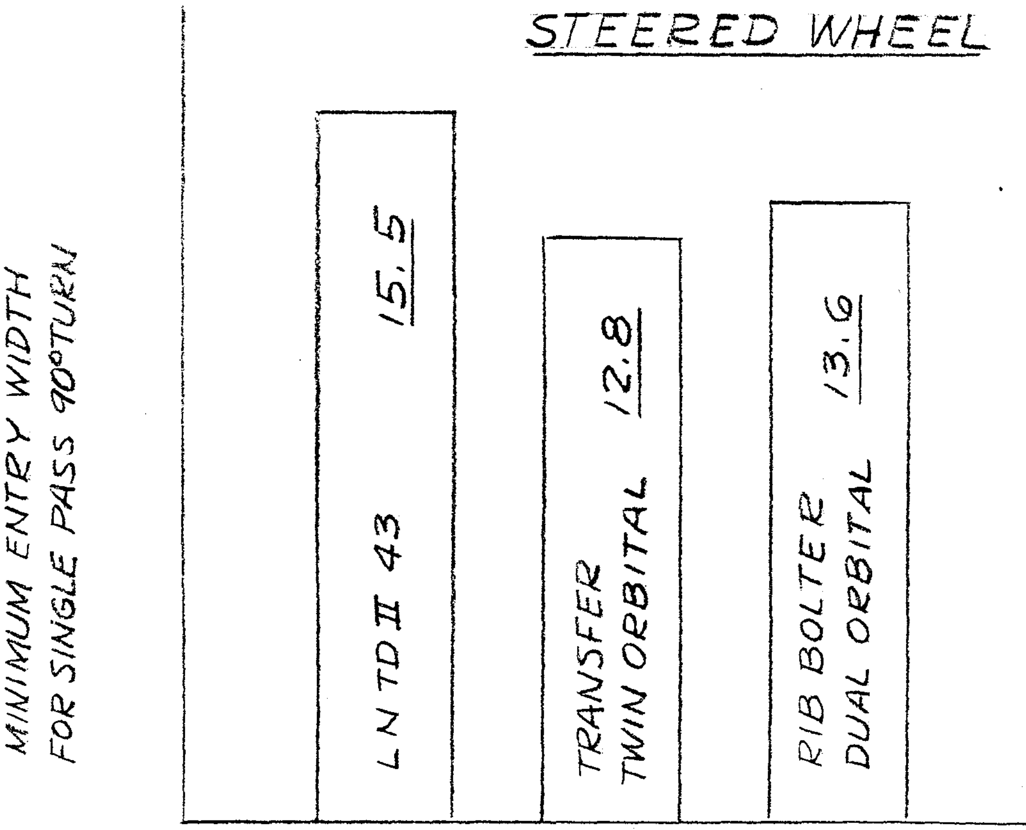


FIGURE 36:
Squirm Steering vs. Orbital Steering

TABLE 25

BOLTER VEHICLE TURNING STUDIES

ITEM	MACHINE	INSIDE WHEEL TURN ANGLE		TURN RADIUS TO VEHICLE CENTERLINE	MINIMUM ENTRY WIDTH FOR ONE PASS 90° TURN	MINIMUM ENTRY HYPOTHETICAL OPTIMUM SQUIRM SAME VEHICLE	OPT/ACT %
		REAR	FRONT				
A	LN TD II 43	26	0	17.2	15.5	15	97
B	LN TD I 36	0	0	2.6	11.5	--	100
1	Transfer Twin	45	0	8.5	12.8	11.3	88
2	Transfer Single	0	0	2.4	9.5	--	100
3	Rod Changer Bolt Bender	0	0	3.0	13.3	--	100
4	Rib Bolter Twin	45	0	11.0	13.6	11.4	84
5	MABM Single	0	0	2.9	11.4	10.6	93
6	MABM Twin	Track	Mounted	3.5	14.3	12.9	90

GROUND CLEARANCE DIAGRAM

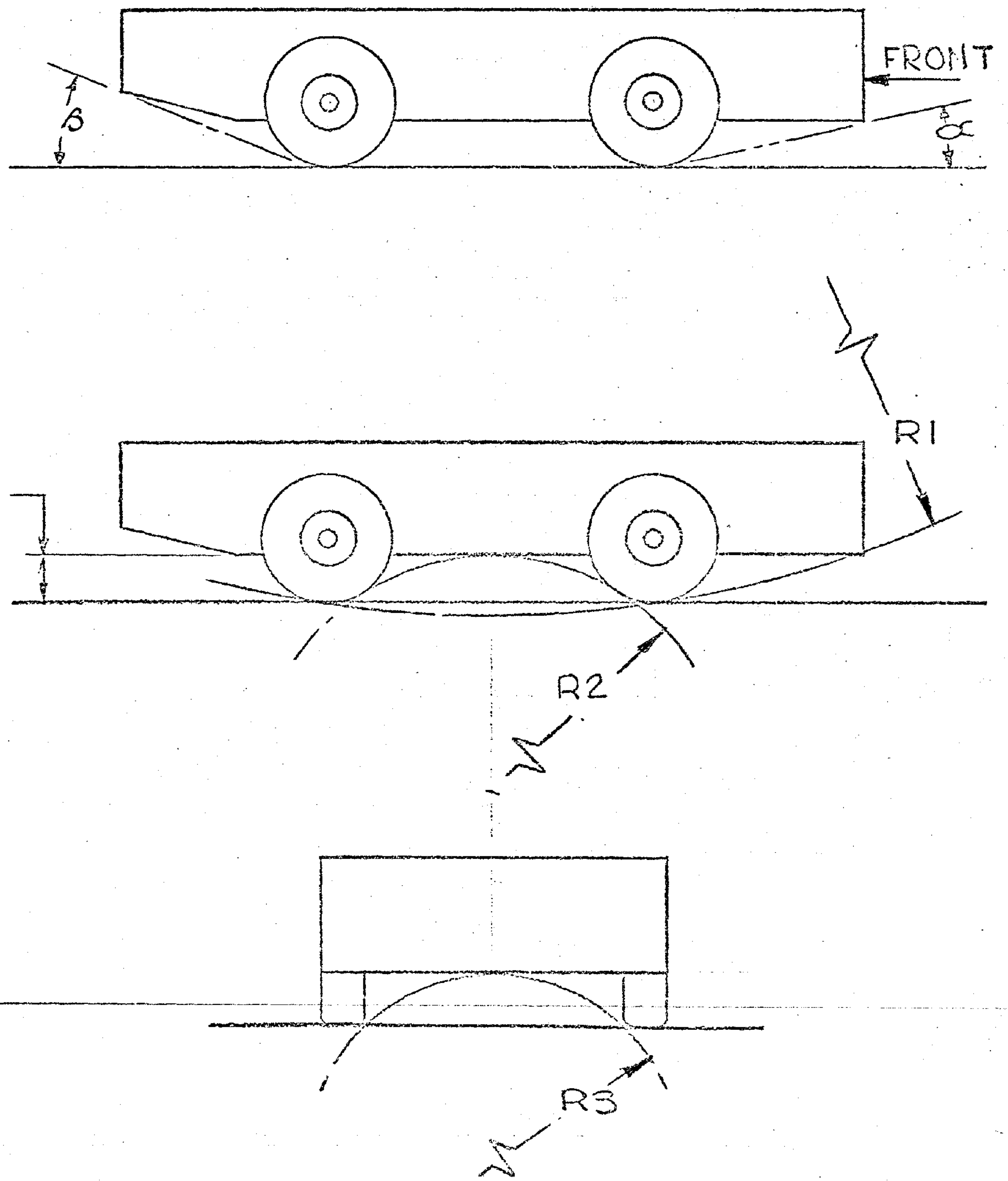


Figure 37: Ground Clearance Diagram (See Following Table)

VEHICLE	Front A	Rear B	R1	R2	R3	GC
LN TDI-36	10°	8°	48'-0"	6'-0"	7'-10"	10"
LN TDII-43	20°	9°	32'-0"	1'-4"	6'-10"	8"
MABM-5	5°	5°	54'-0"	3'-10"	7'-0"	6"
Rod Changer/ Bolt Bender	3½°	9°	80'-7"	2'-2"	6'-6"	8"
Bolter, Single Transfer, Mast	10°	11°	20'-9"	2'-3"	3'-8"	8"
Bolter, Double Transfer, Mast	6°	6°	48'-10"	6'-9"	3'-2"	8"
MABM-D	5°	5 (2½°)	102'-10"	N/A	12'-1"	6 (3")
Bolter-Roof Rib	10°	20°	24'-10"	10'-7"	7'-0"	8"

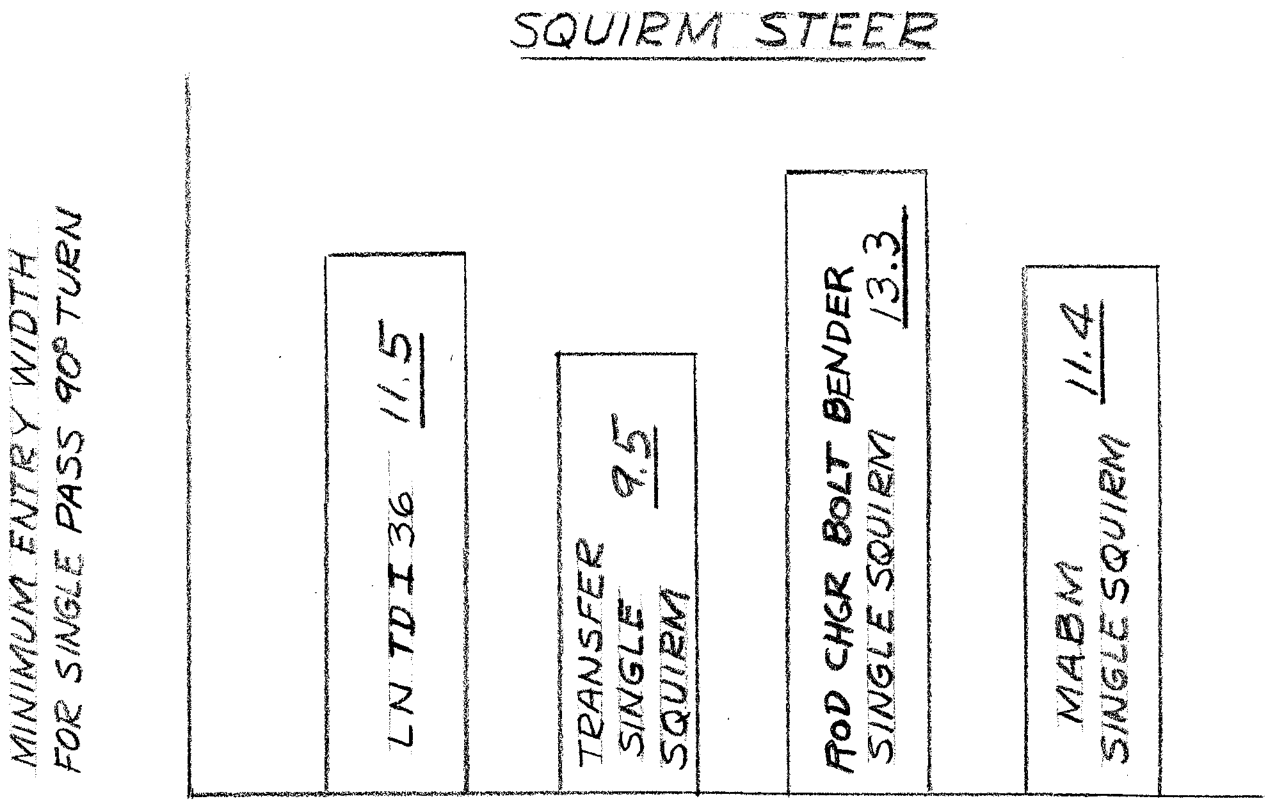
TABLE 26

Ground Clearance

	Front	Rear				
VEHICLE	A	B	R1	R2	R3	GC
LN TDI-36	10°	8°	48'-0"	6'-0"	7'-10"	10"
LN TDII-43	20°	9°	32'-0"	1'-4"	6'-10"	8"
MABM-5	5°	5°	54'-0"	3'-10"	7'-0"	6"
Rod Changer/ Bolt Bender	$3\frac{1}{2}^{\circ}$	9°	80'-7"	2'-2"	6'-6"	8"
Bolter, Single Transfer, Mast	10°	11°	20'-9"	2'-3"	3'-8"	8"
Bolter, Double Transfer, Mast	6°	6°	48'-10"	6'-9"	3'-2"	8"
MABM-D	5°	5 ($2\frac{1}{2}^{\circ}$)	102'-10"	N/A	12'-1"	6 (3")
Bolter-Roof Rib	10°	20°	24'-10"	10'-7"	7'-0"	8"

TABLE 26

Ground Clearance



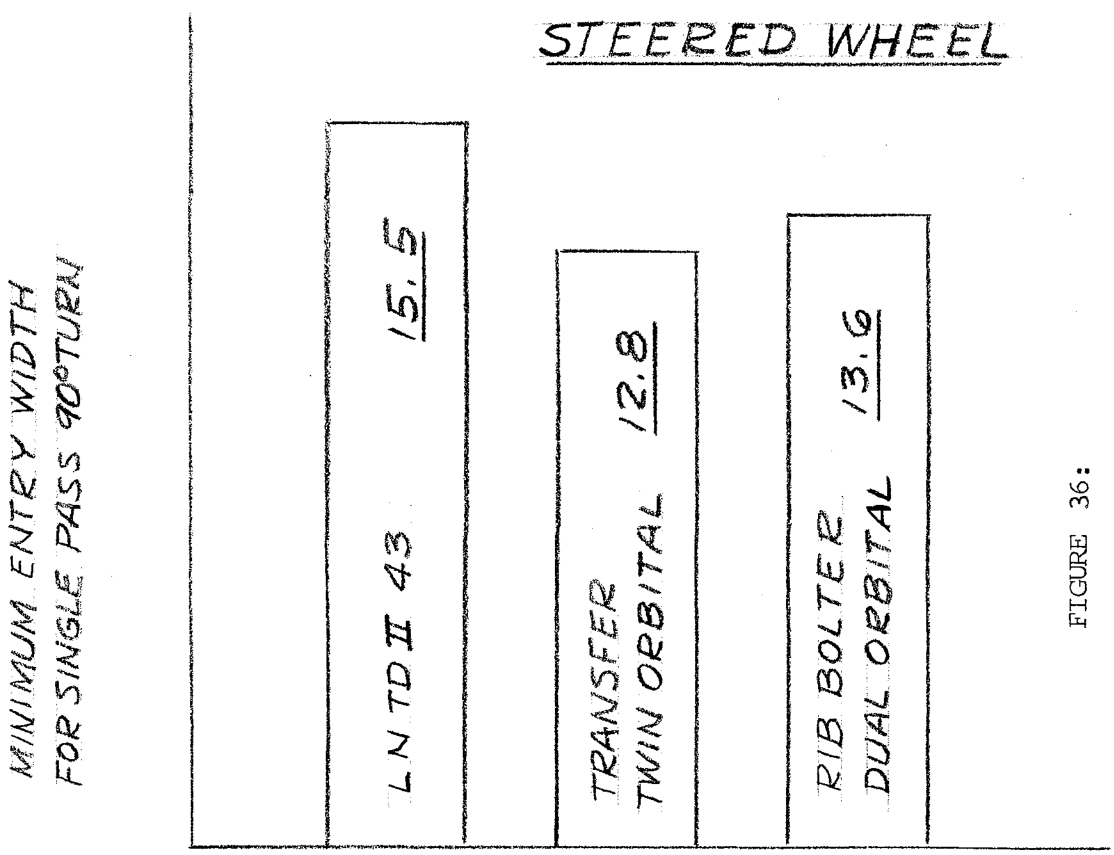


FIGURE 36: Squirm Steering vs. Orbital Steering

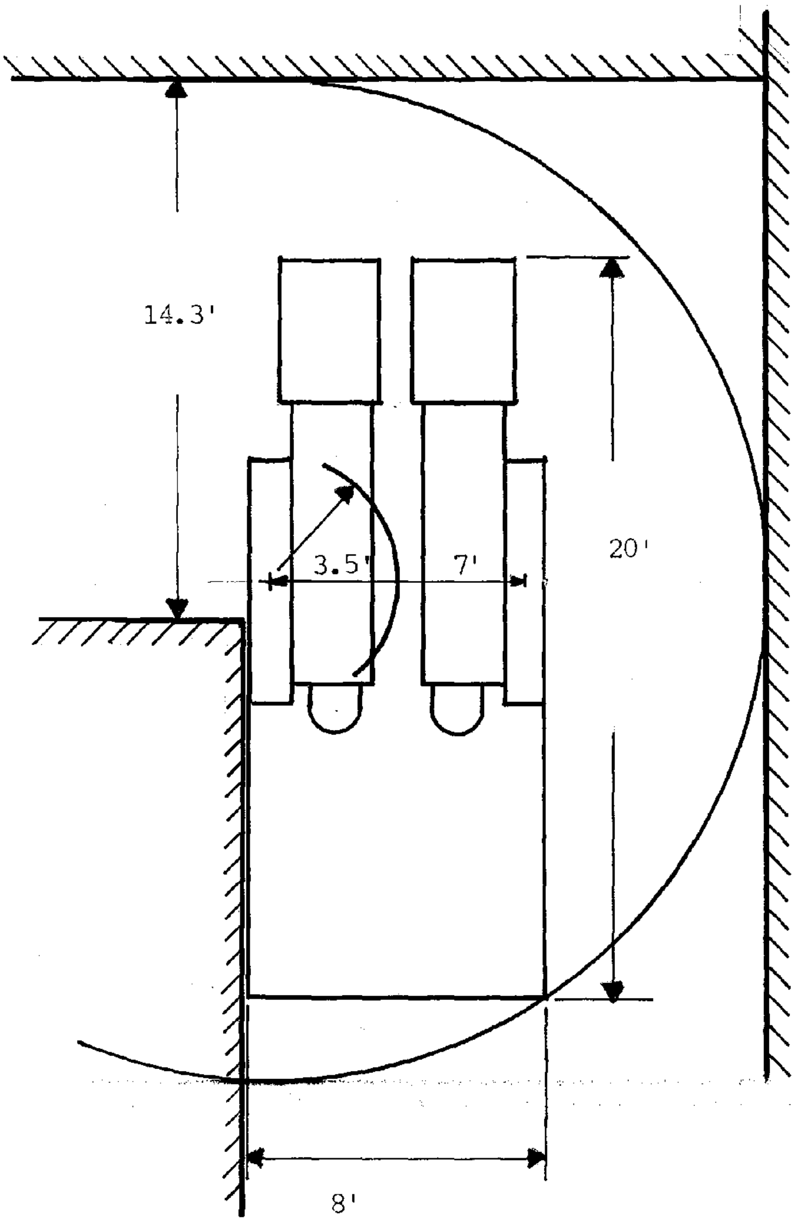


Figure 35: Turn Study for the Transfer Bolter - Single Boom, Optimum Turn

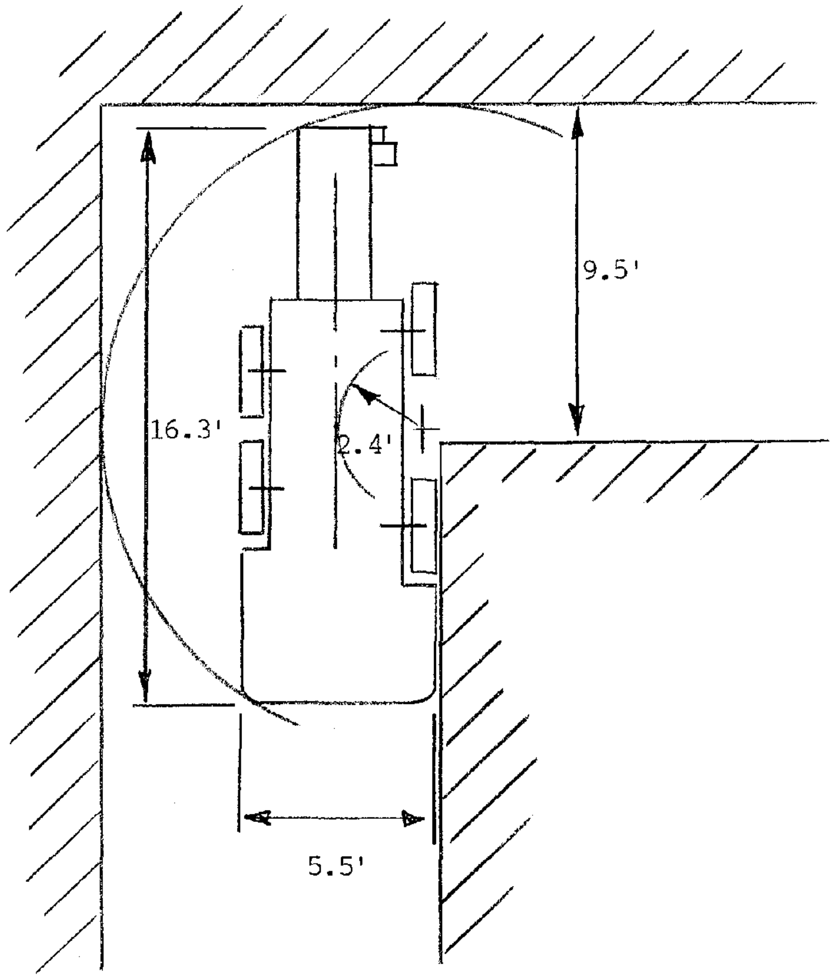


Figure 34: Minimum Entry Width for 90° Single Pass Turn Transfer Bolter Single Boom (New Chassis)

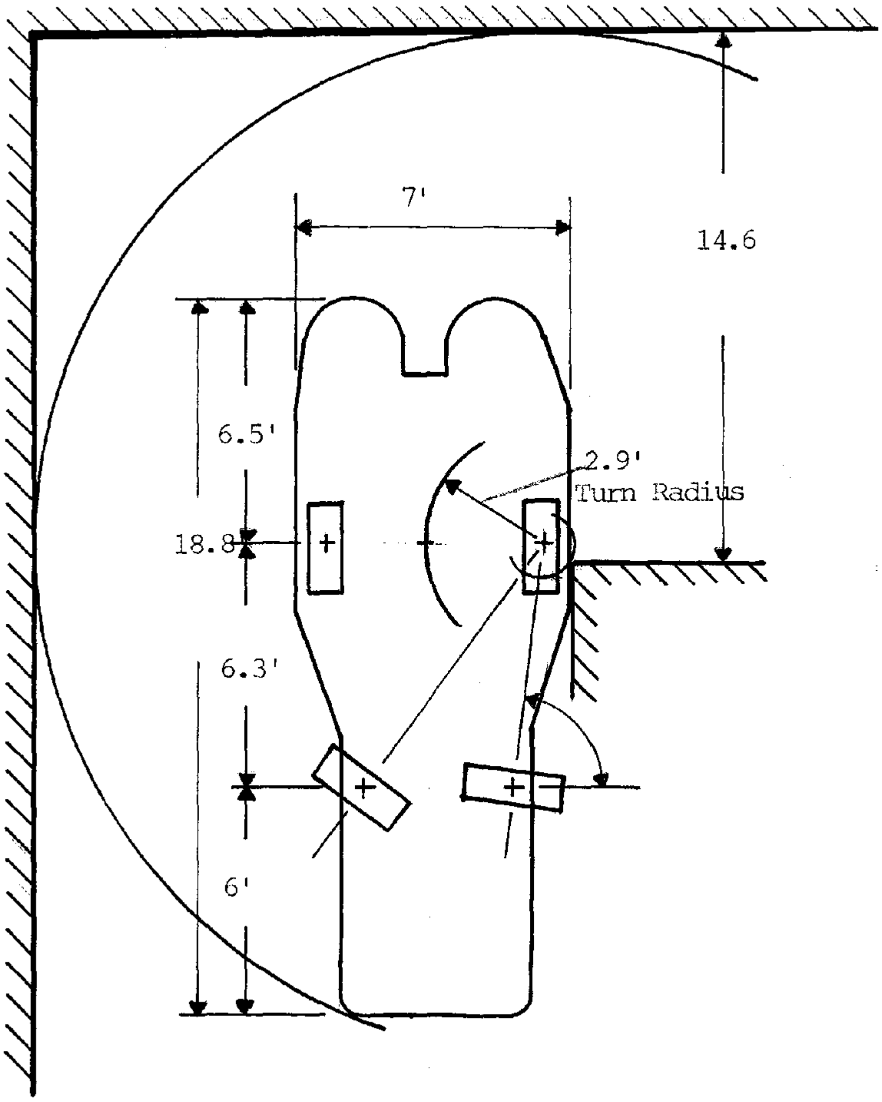


Figure 32: Smallest Turn Radius for Transfer Bolter - Dual Boom (New Chassis)

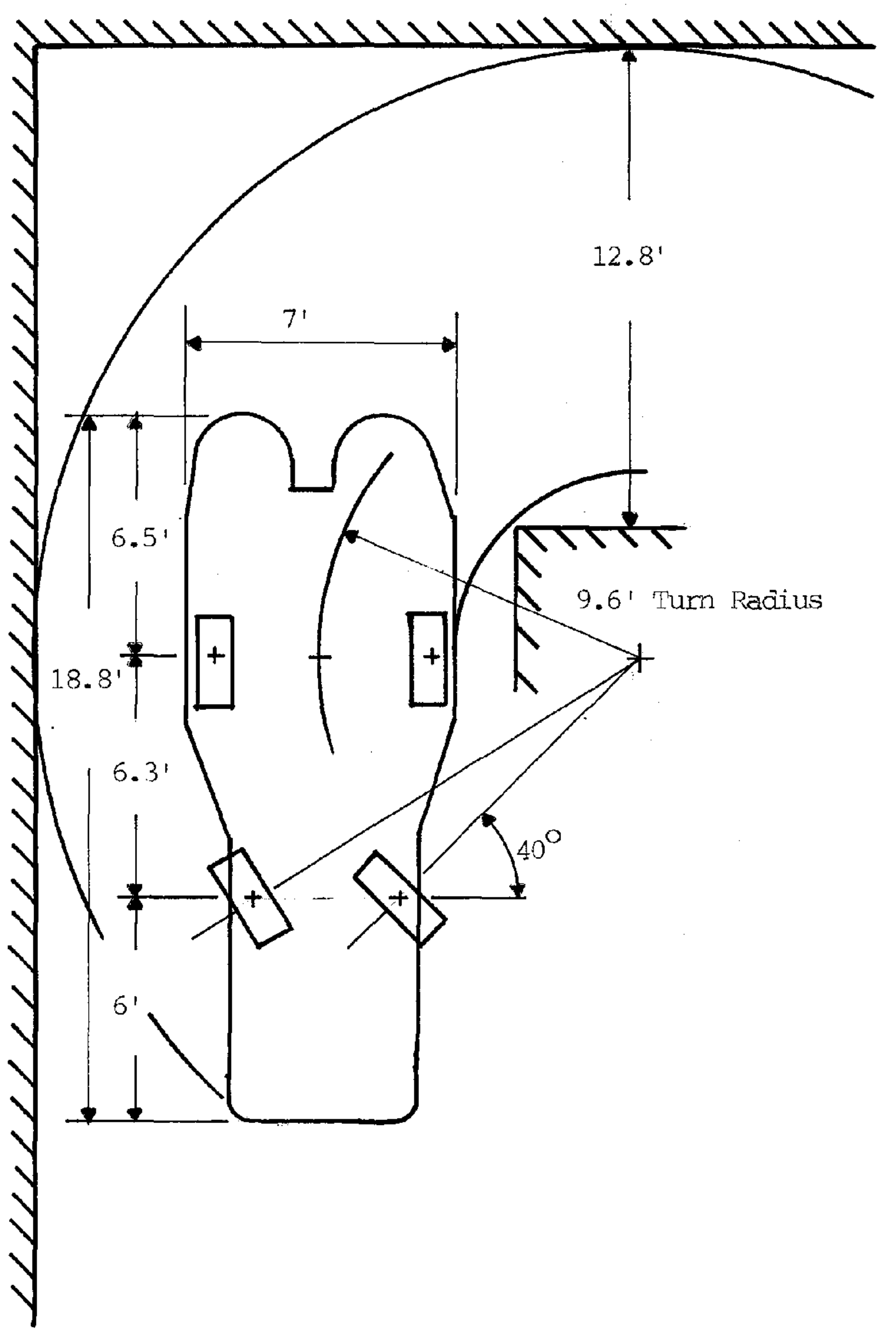


Figure 31: Turning Study #1 of the Transfer Bolter - Dual Boom (New Chassis)

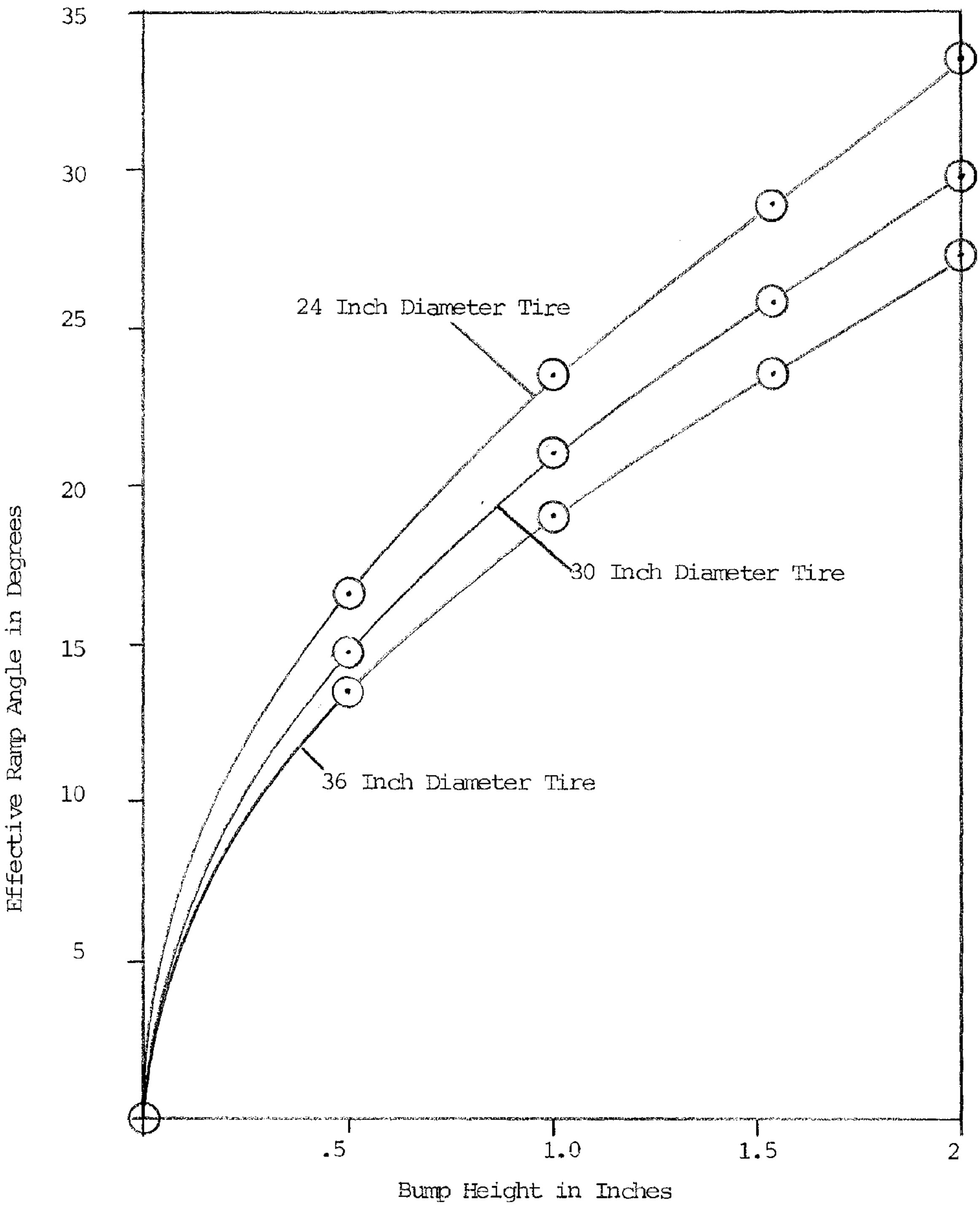
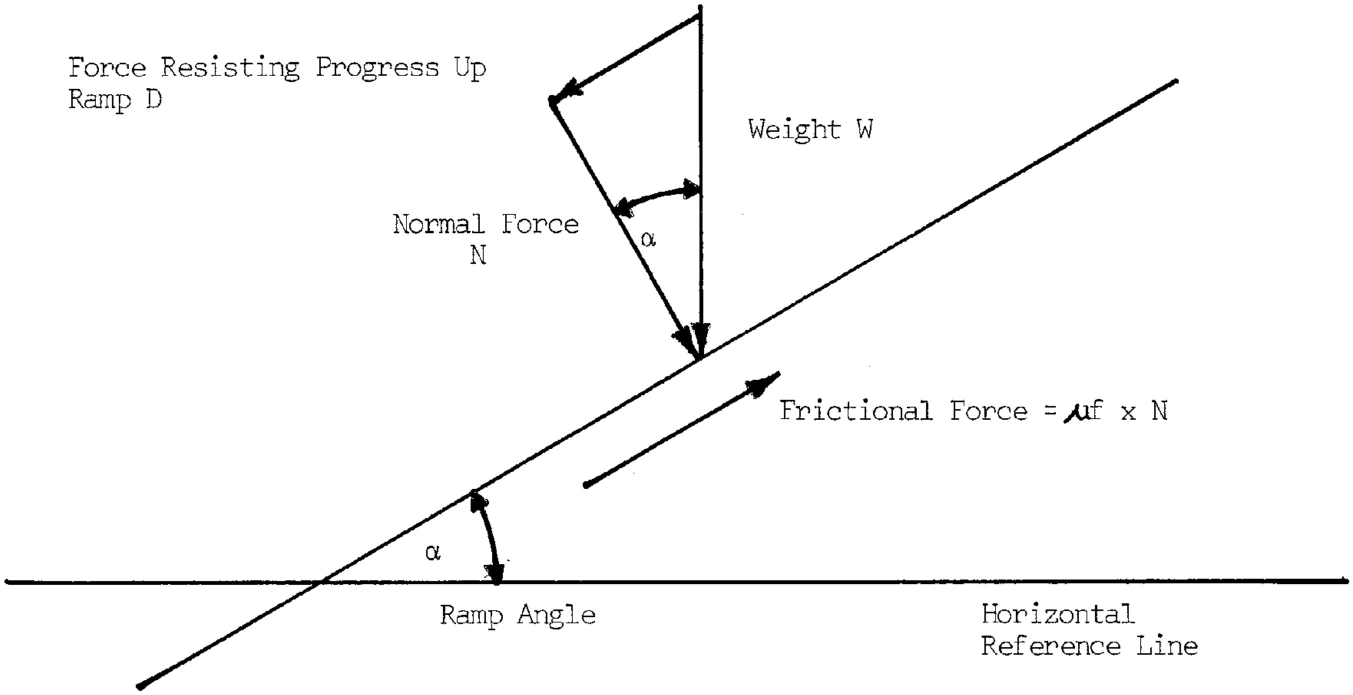


Figure 29: Bump Height vs. Effective Ramp Angle for Various Tire Diameters



Wheel Slips Down Ramp When

$D \geq \mu f\ N$

$\mu f = \frac{D}{N} = \tan \alpha$

μf	α Degrees	% Grade
.1	5.72	10
.2	11.32	20
.3	16.70	30
.4	21.8	40
.5	26.57	50
.6	30.97	60
.7	34.98	70
.8	38.67	80
.9	41.98	90

Figure 28

Coefficient of Friction vs. Maximum Climbable Ramp Angle

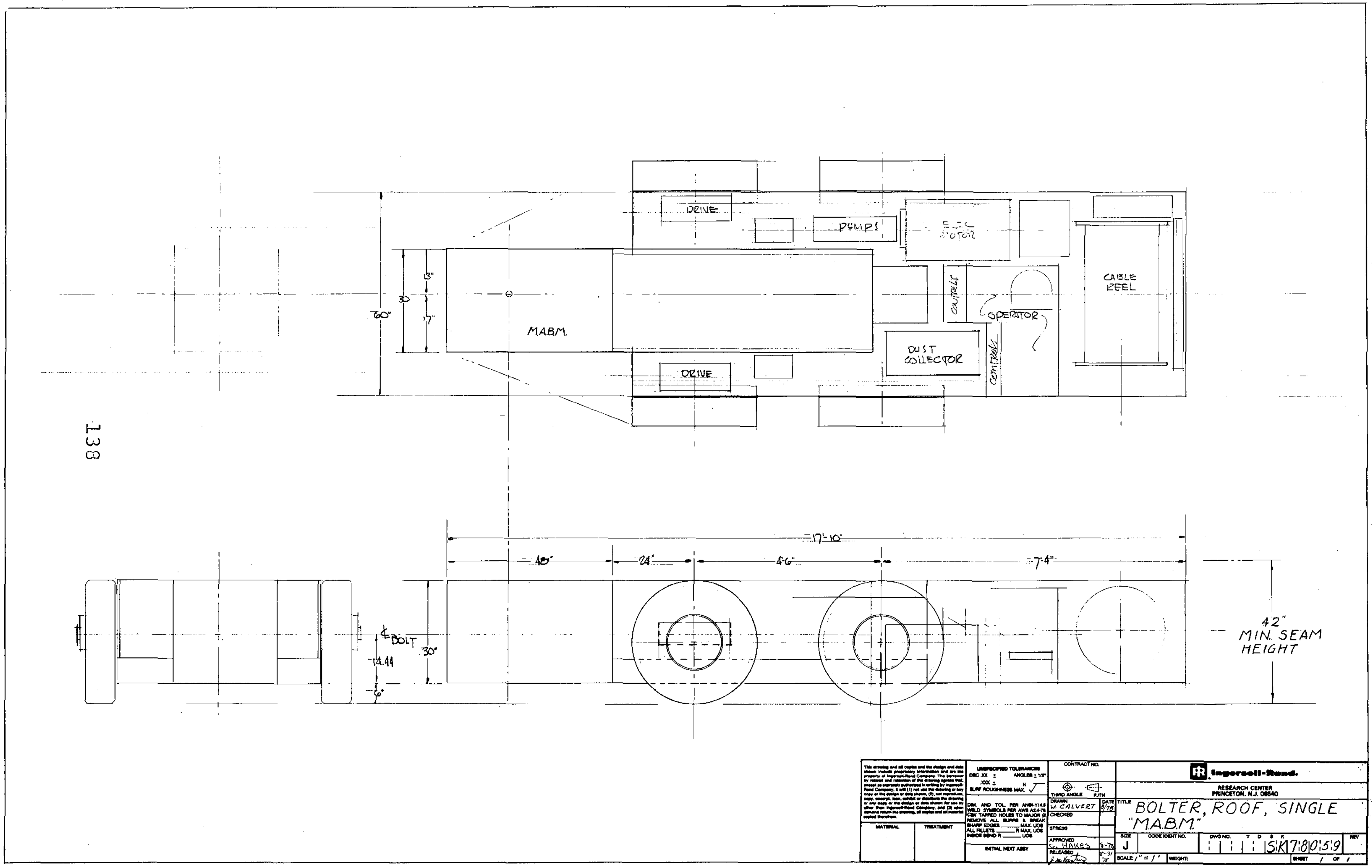


FIGURE 26

Automatic Bolter Single Boom (MABM - SB)

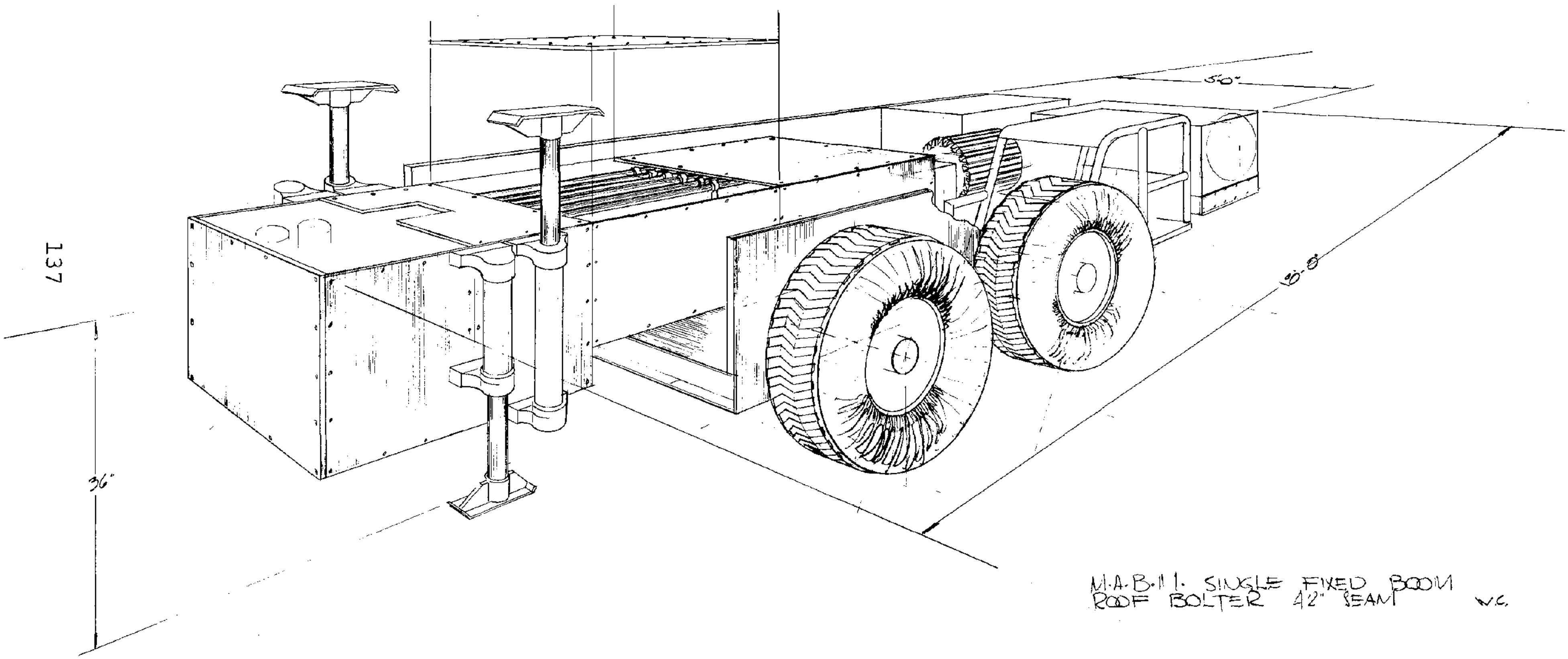


FIGURE 25

Automatic Bolter Single Boom (MABM - SB)

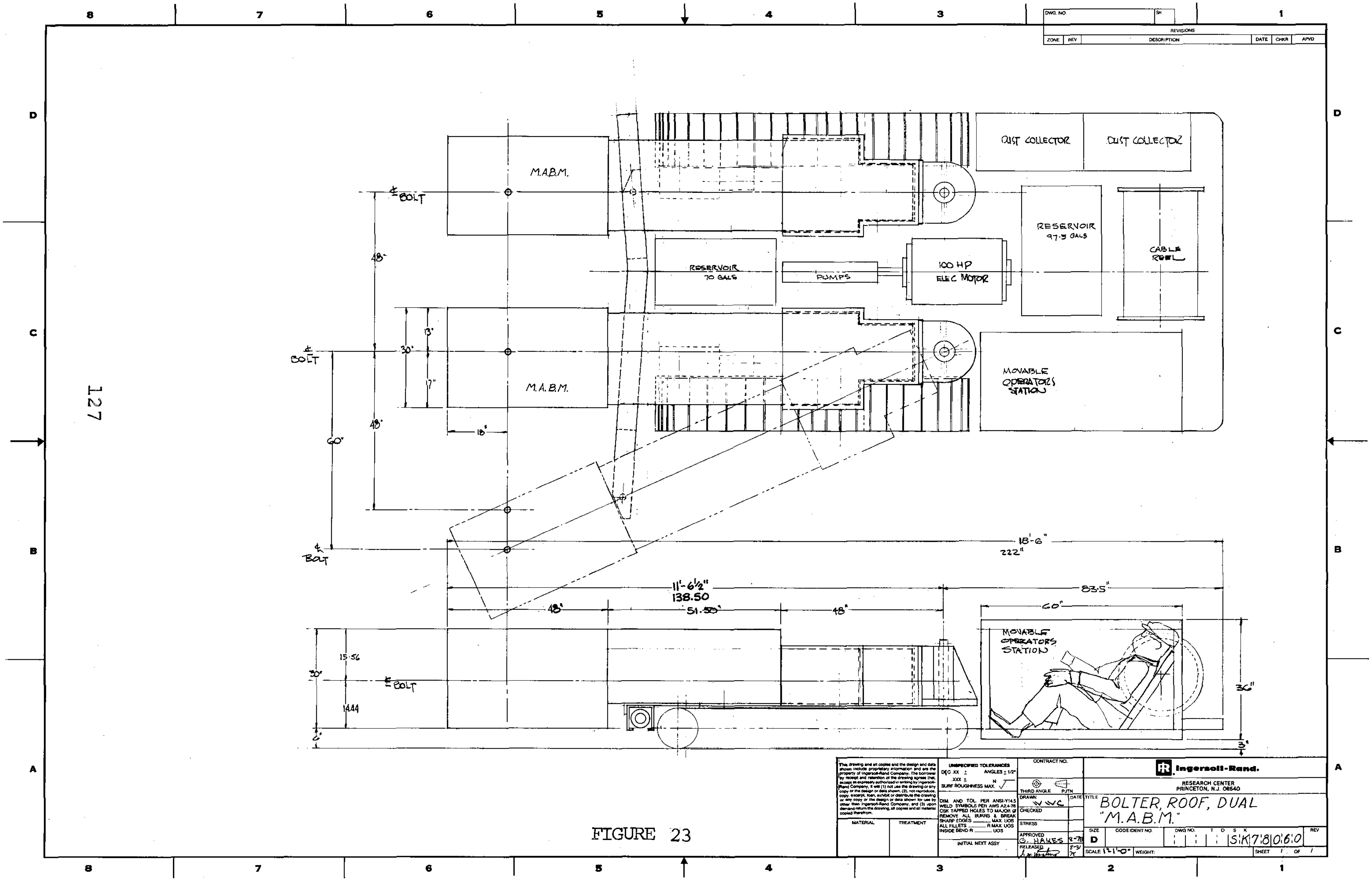


FIGURE 23

Plan & Elevation Views Automatic Bolter – Dual Boom

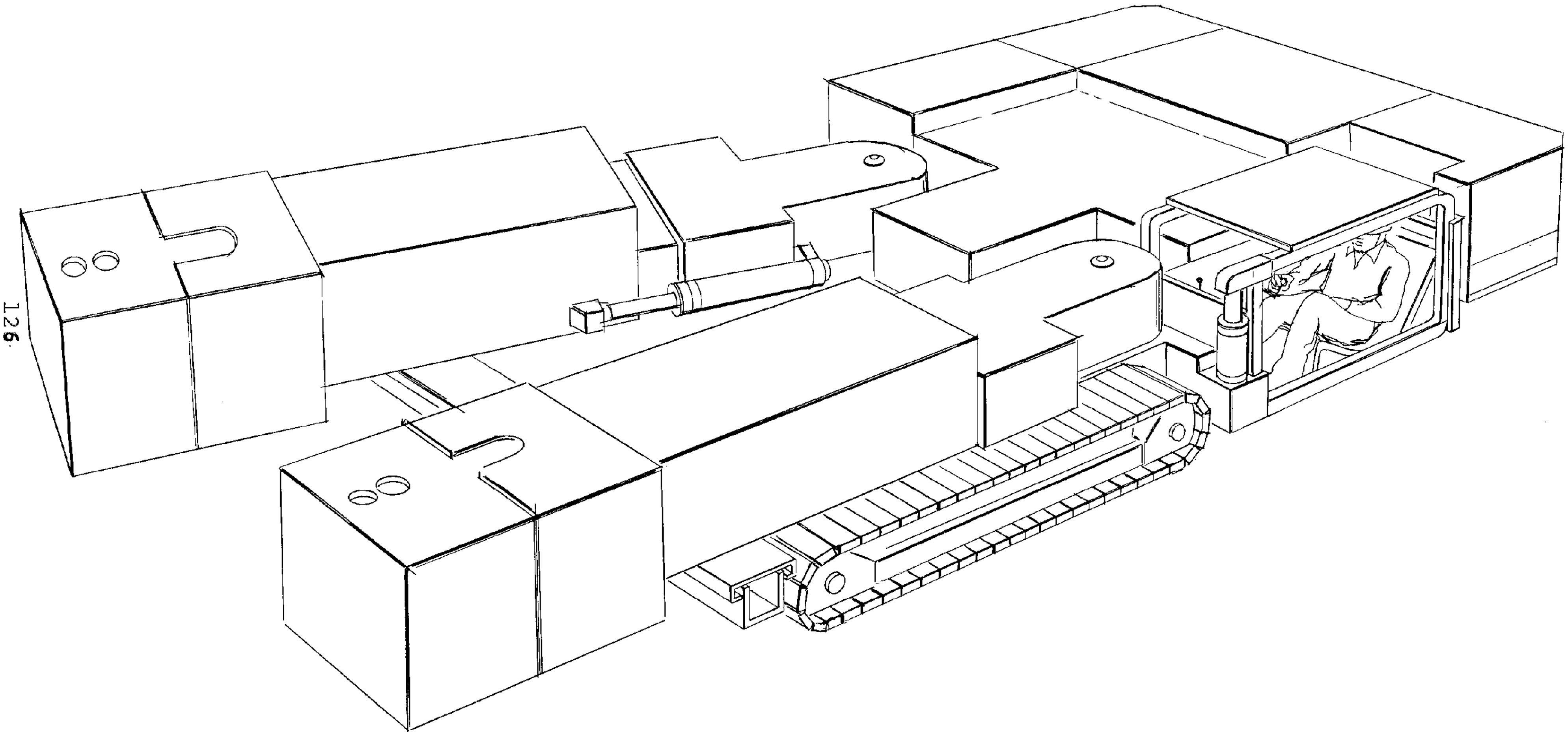


FIGURE 22

Artist's Rendition of the Automatic Bolter Dual Bocm (MABM - DB)

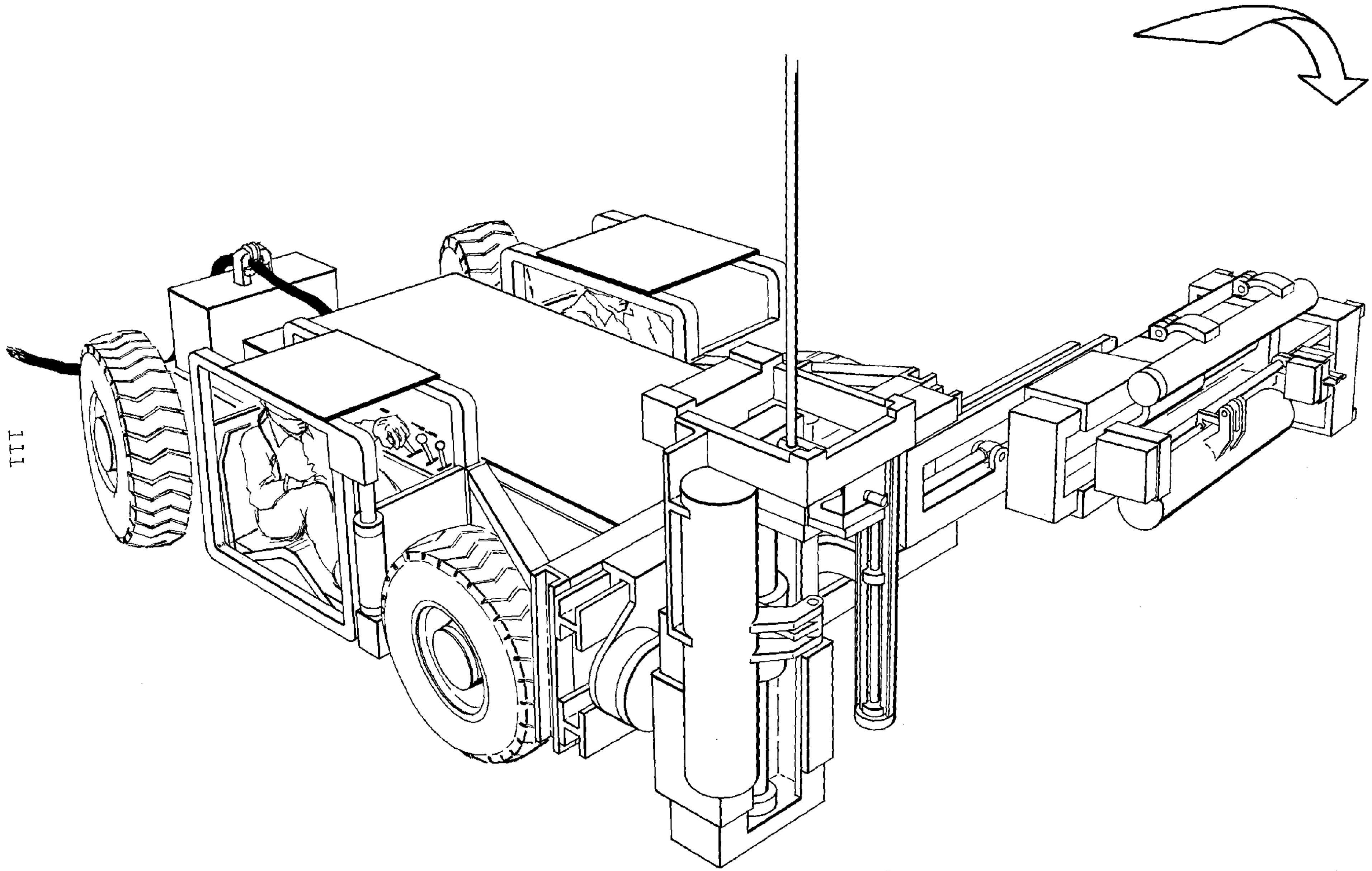
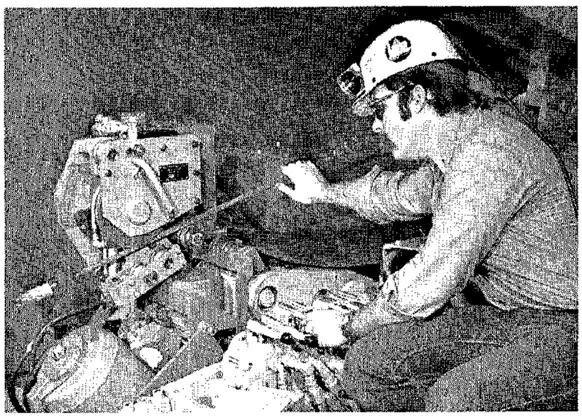


Figure 18: Artist's Rendition of the Transverse Rail Rib Bolter

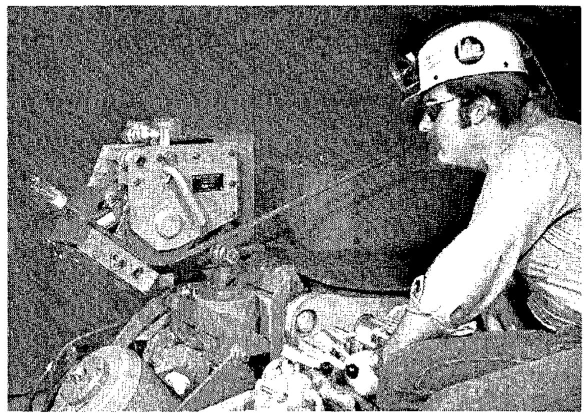
Bendix
Roof Bolt Inserter

Roof Bolt Inserter

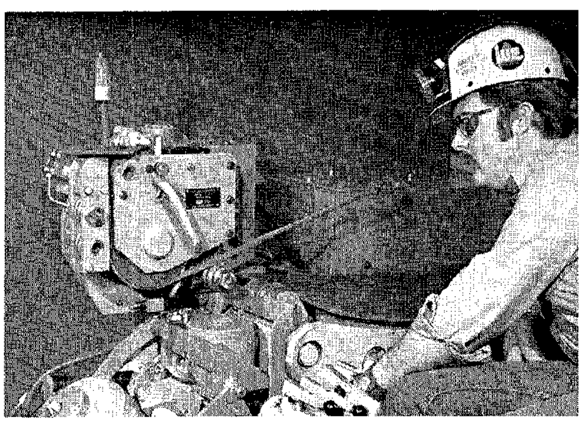
OPERATION



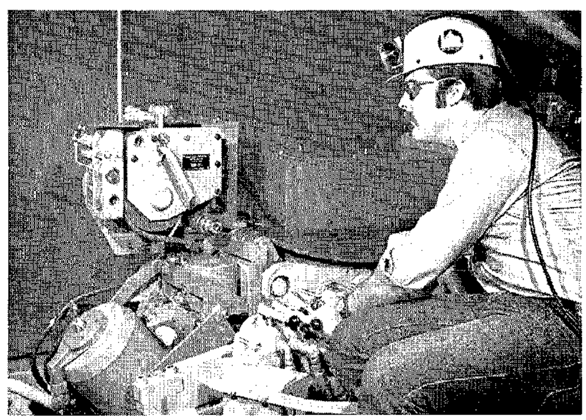
1. Bolt loaded



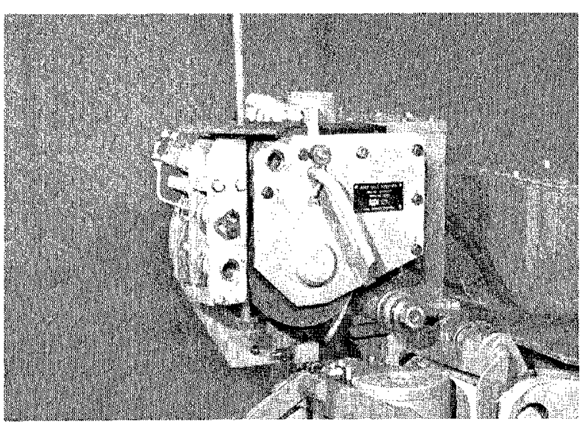
2. Bending started



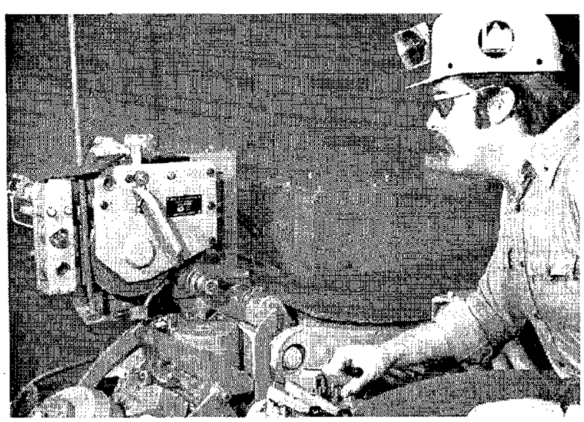
3. Straightening started



4. Bending completed



5. Straightening completed



6. Bolt released

Figure 17

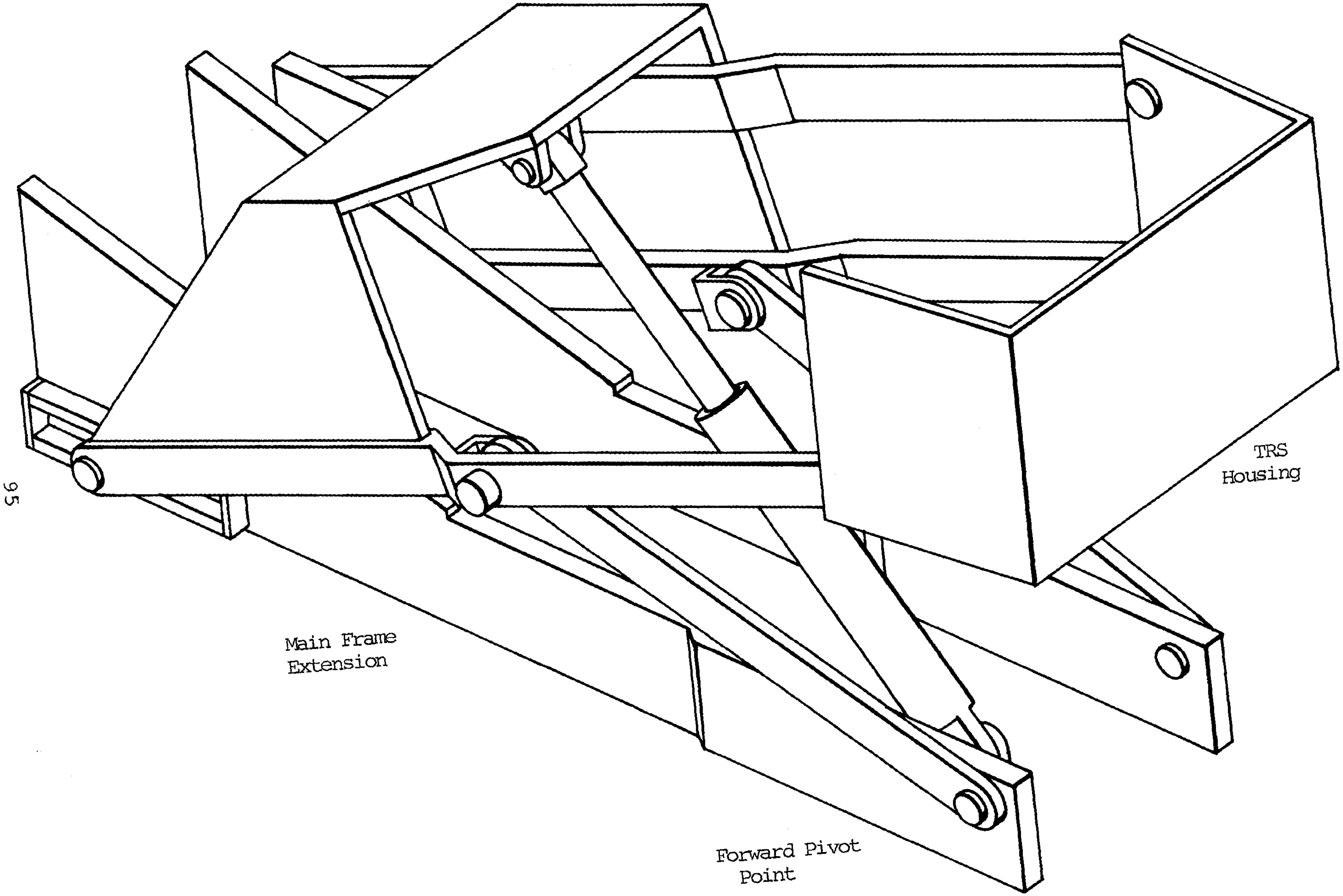


Figure 15: Detail of the Temporary Roof Support for the Rod Changer - Bolt Bender Bolter

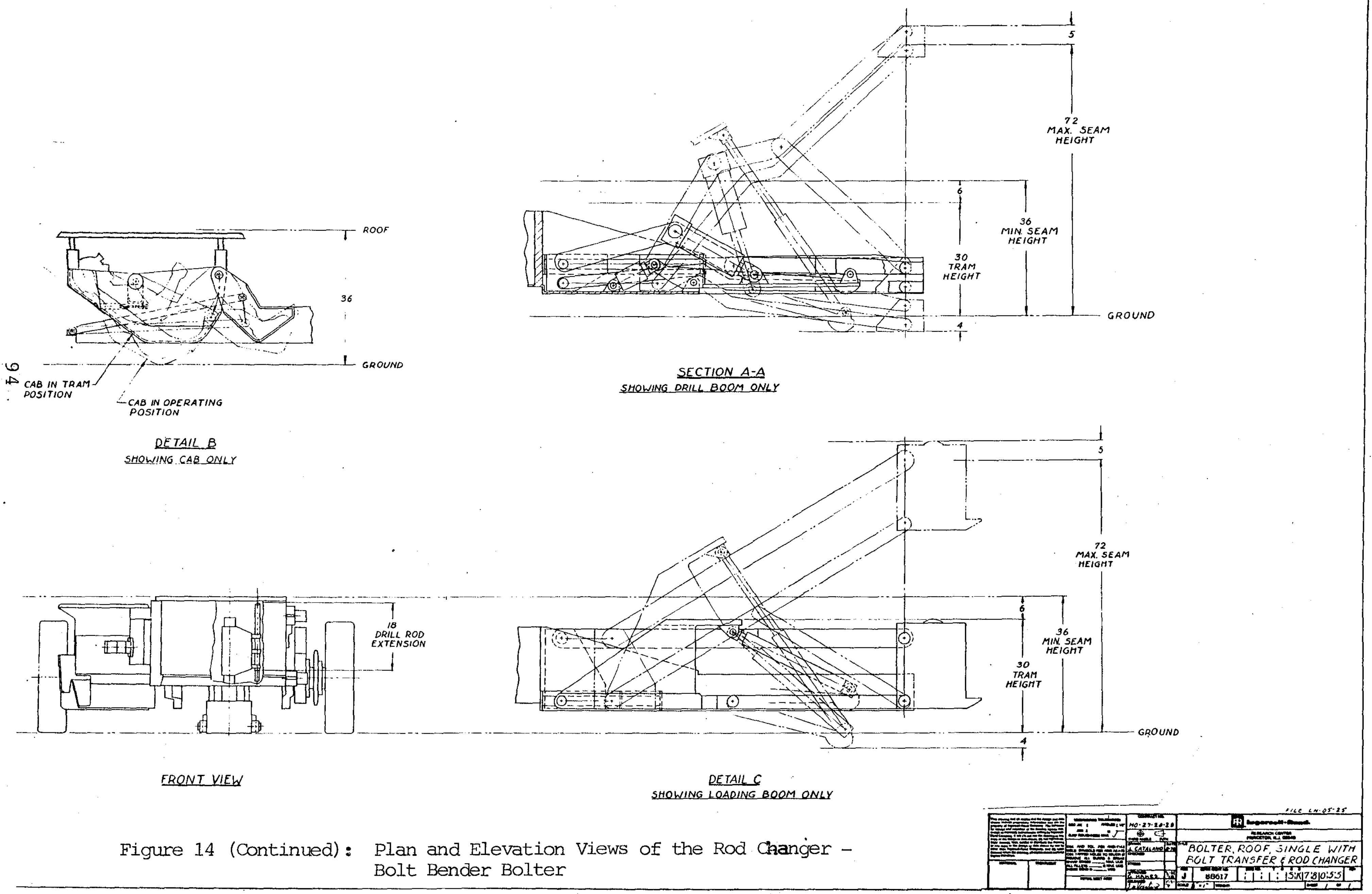


Figure 14 (Continued): Plan and Elevation Views of the Rod Changer - Bolt Bender Bolter

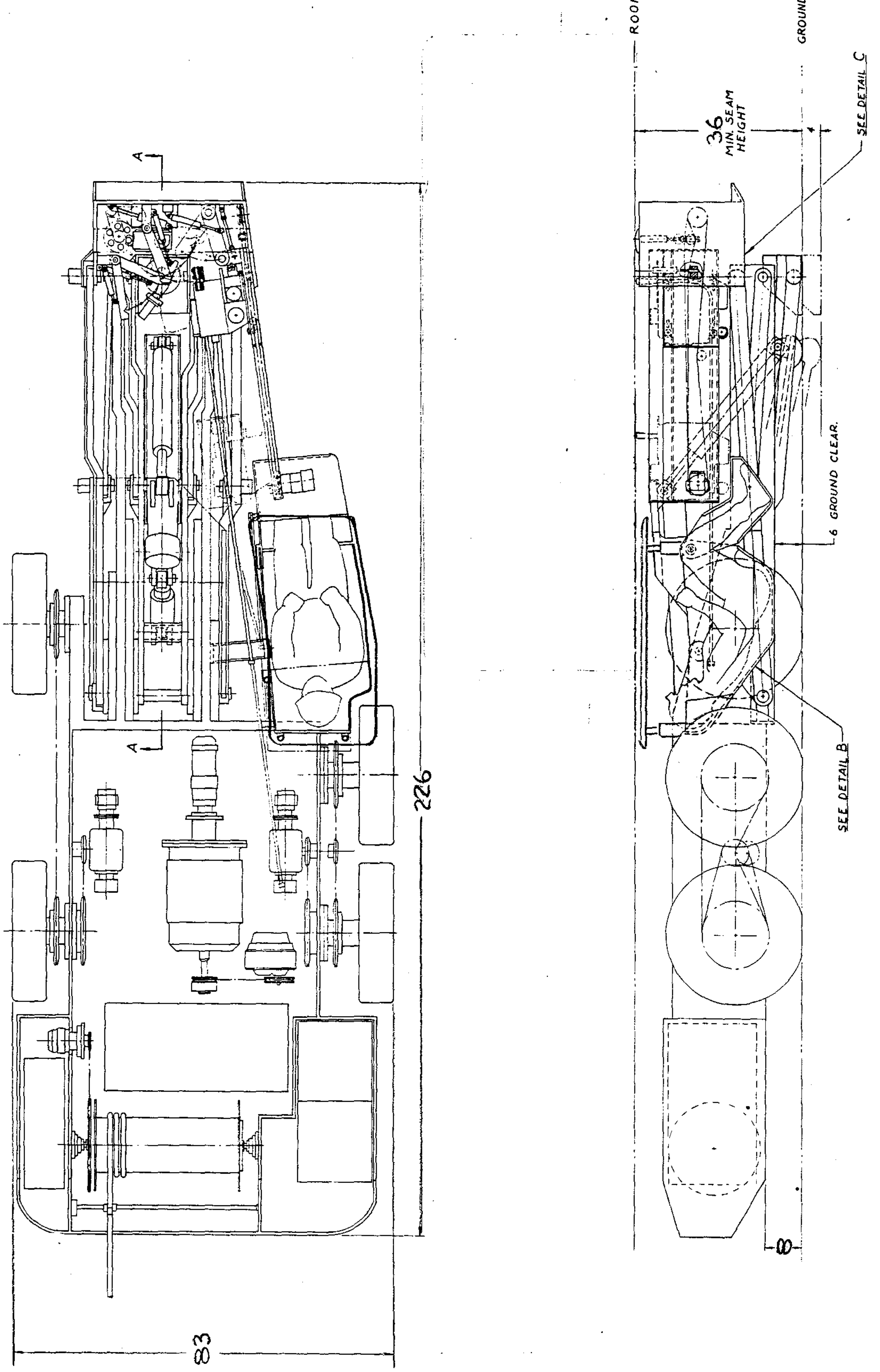


Figure 14: Plan and Elevation Views of the Rod Changer - Bolt Bender Bolter

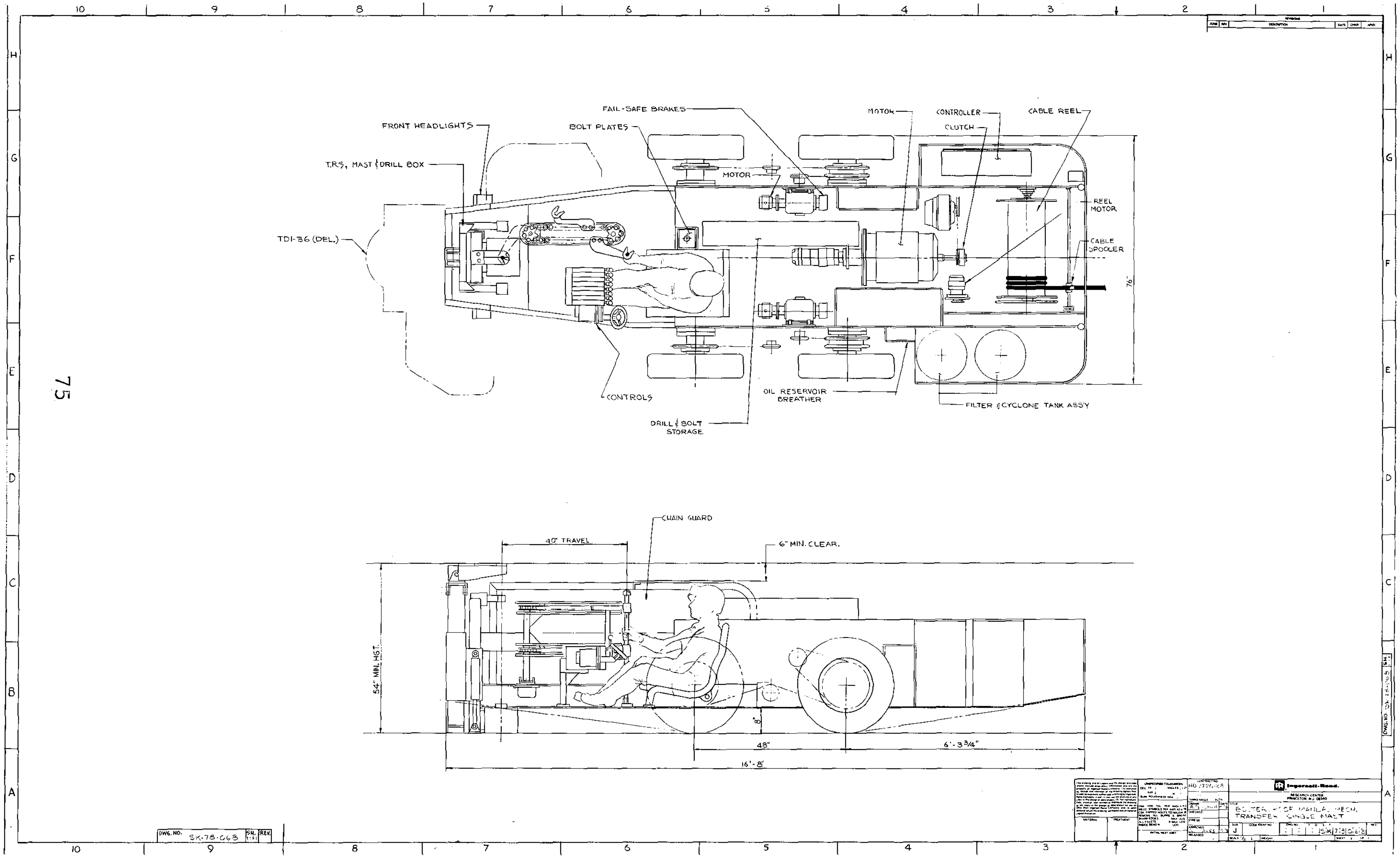


Figure 10: Plan and Elevation Views of the Transfer Bolter - Single Boom (New Chassis)

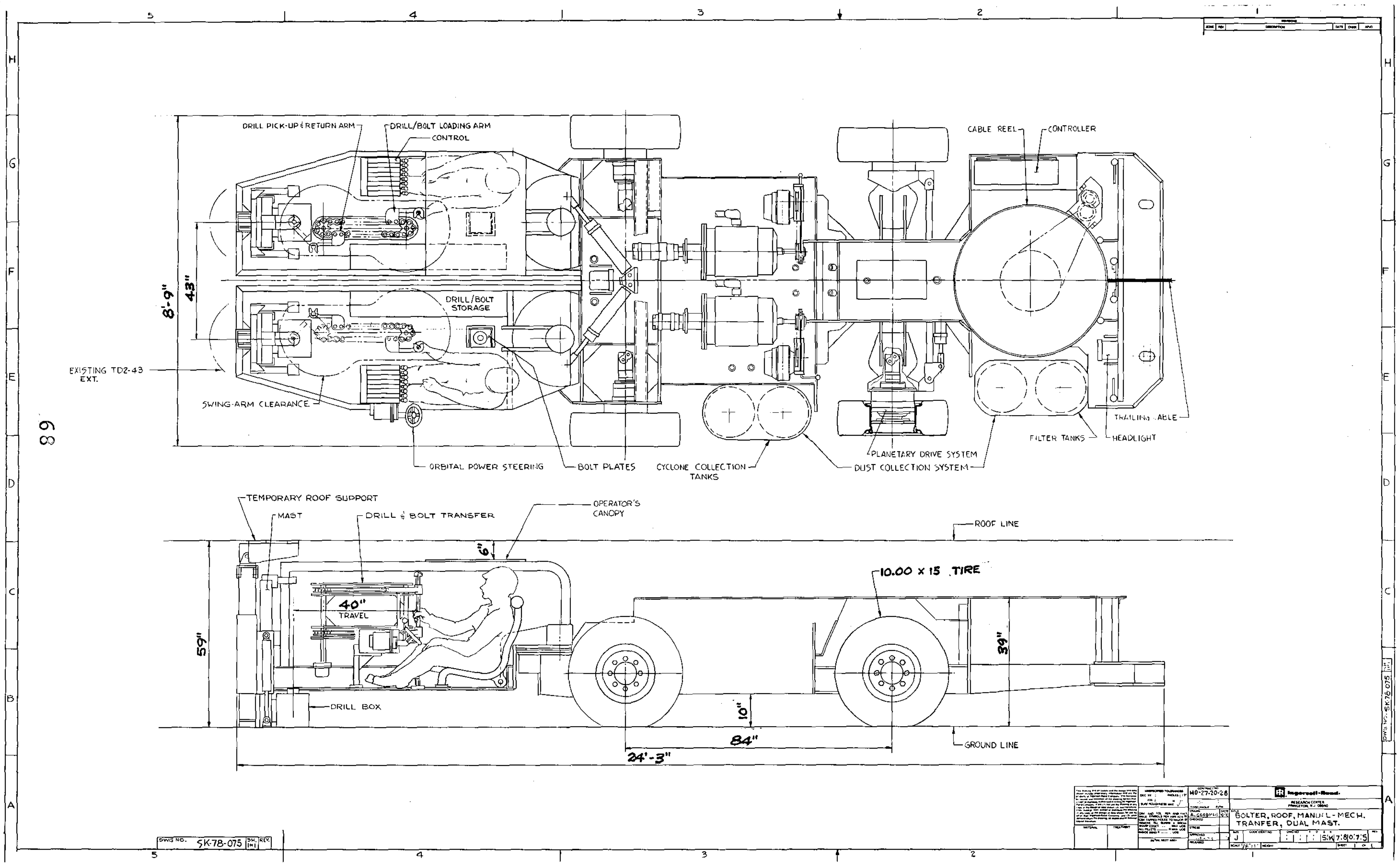


Figure 8: Plan and Elevation Views of the Transfer Bolter - Dual Boom (Standard Chassis)

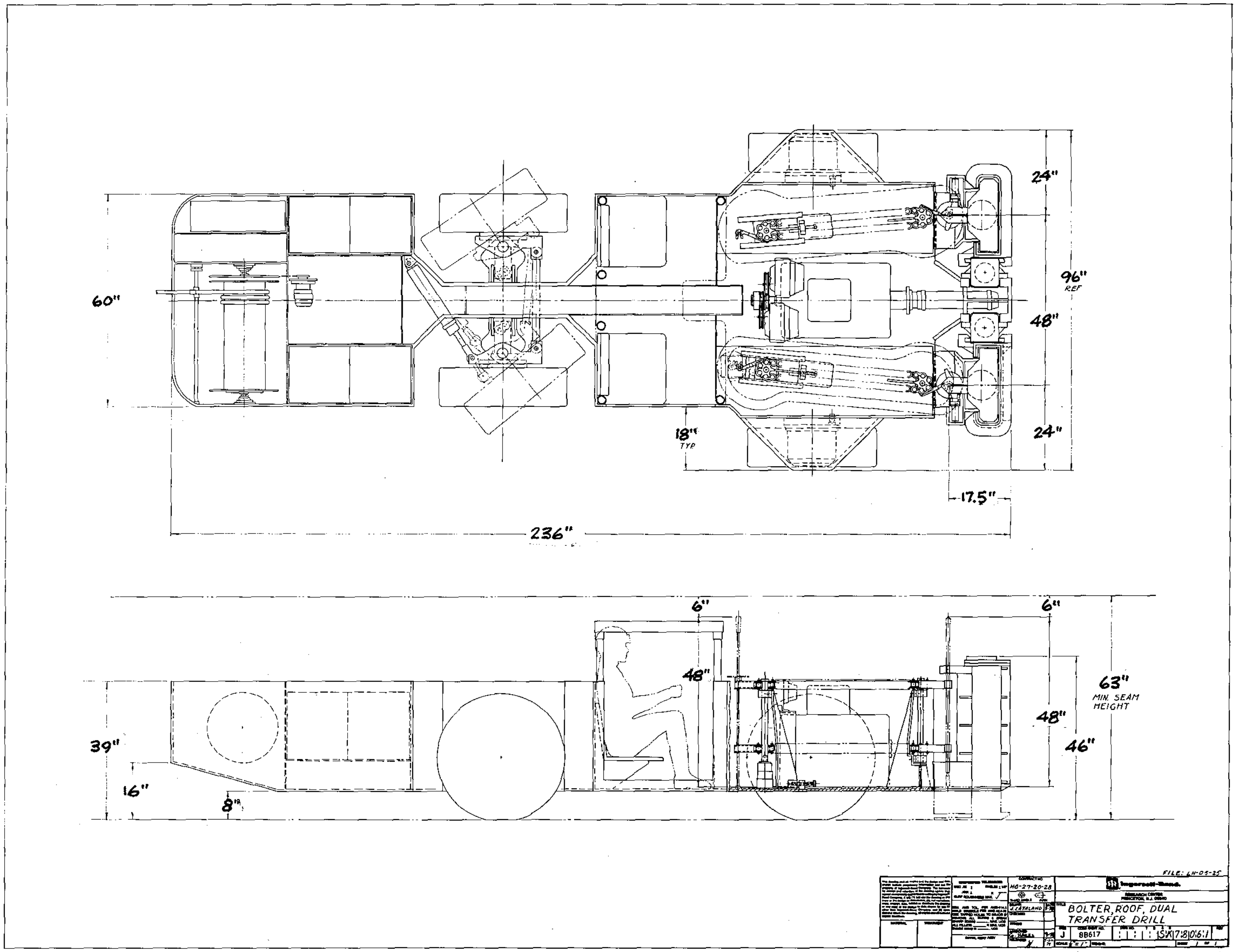


Figure 3: Plan and Elevation Views of the Transfer Bolter - Dual Boom (New Chassis)

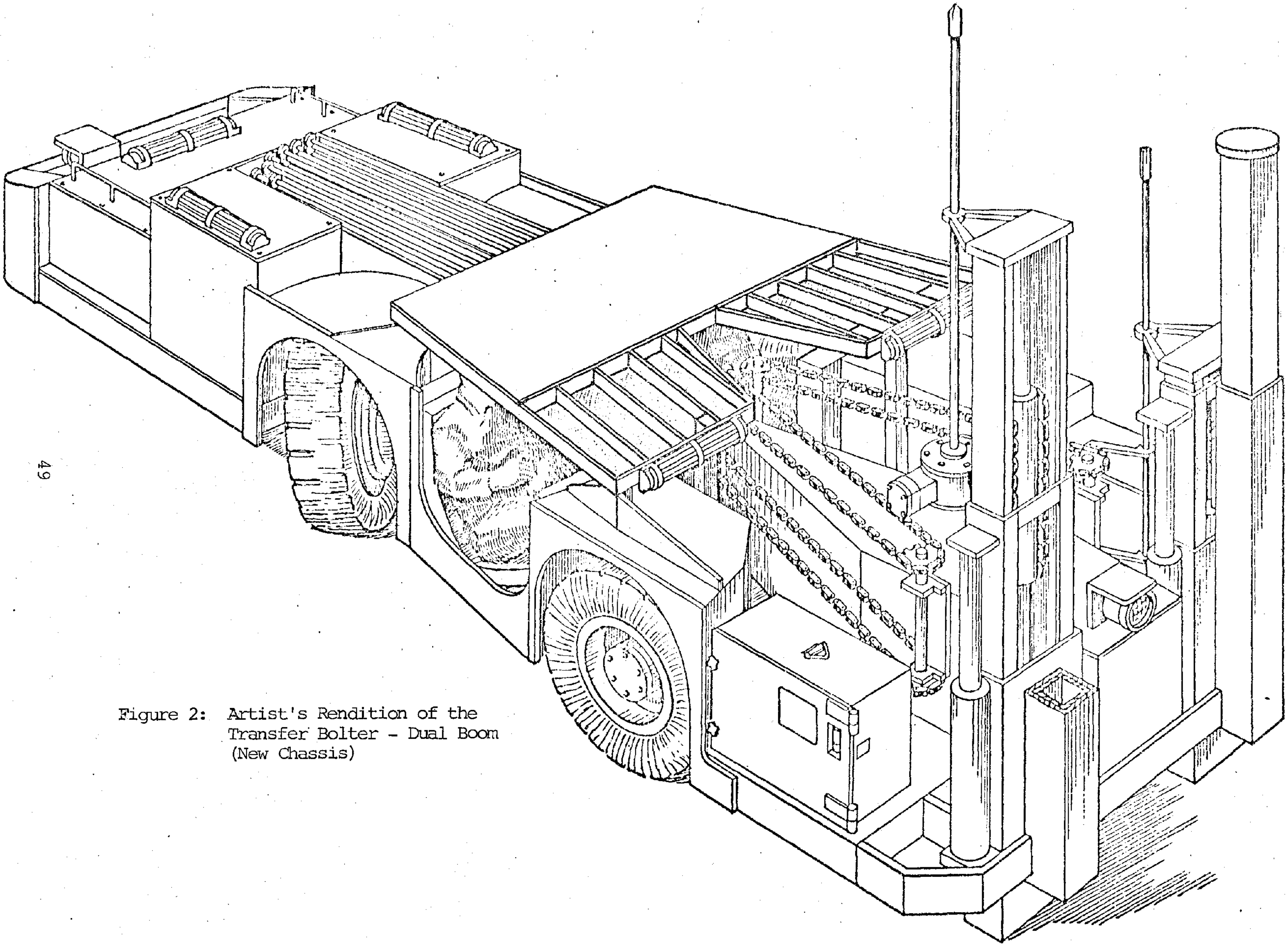


Figure 2: Artist's Rendition of the Transfer Bolter - Dual Boom (New Chassis)

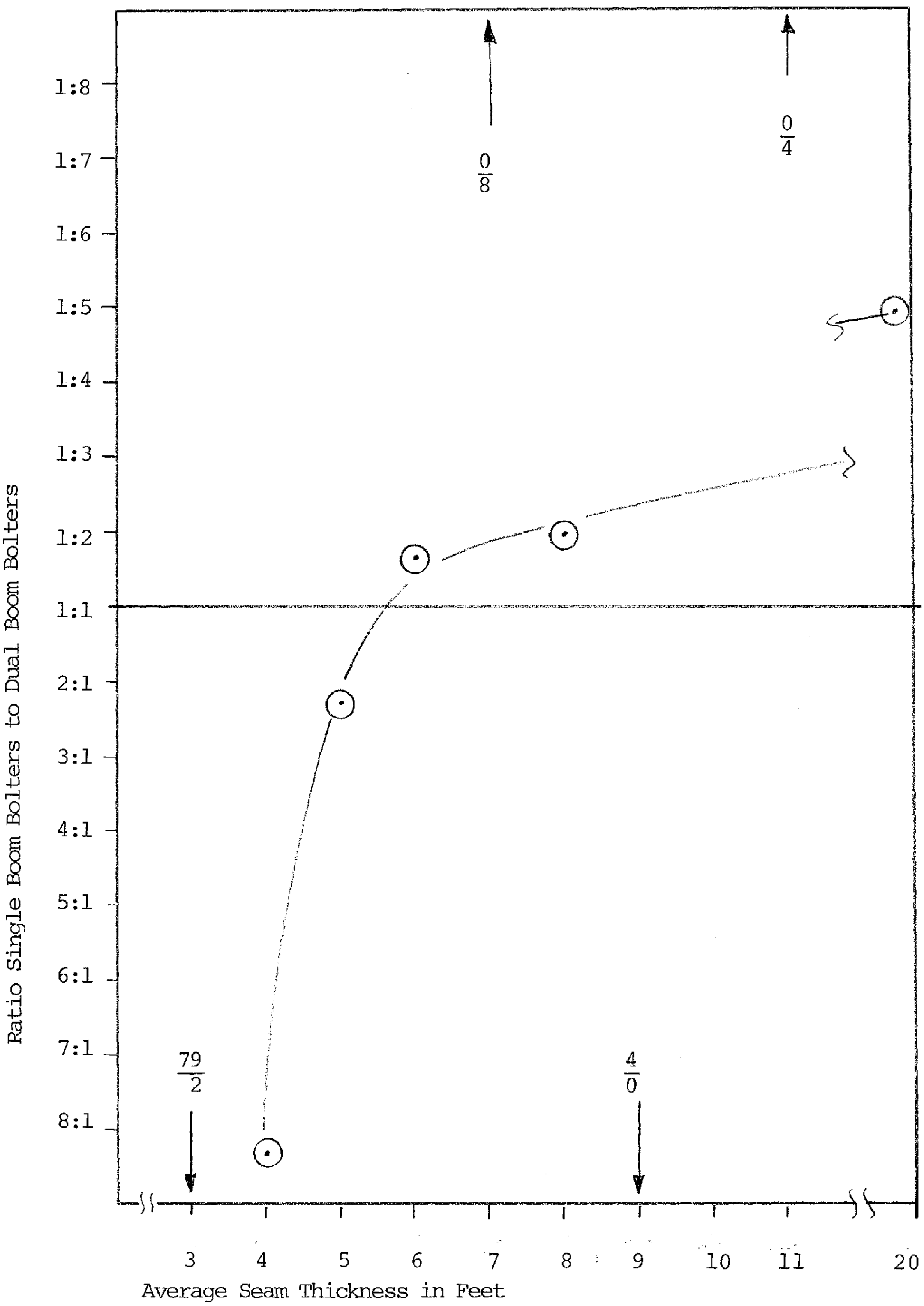


Figure 1: Seam Thickness vs. Single/Dual Boom Bolter Ratio

TABLE 1

MINE GROUP DATA BANK [2]

	LOCATION	NO. MINES	NUMBER WORKING SECTIONS	MINING PLAN(S) R & P CM	CONV.	LONG WALL	SEAM THK. RANGE	SEAM THK. AVERAGE	TYPICAL DRIVEN ENTRY WIDTH	PILLAR ℄ DISTANCE	ROOF STABILITY 1-5 SCALE	BOLT LENGTH & TYPE MECH.	RESIN	SEAM PITCH AVE.	MAX.	TRAM DIFFICULTY	WATER PRESENT	BOLTER POPULATION [1] (NUMBER OF BOOMS) FMC/GA… 1	FMC/GA… 2	LEE-NORSE 1	LEE-NORSE 2	FLETCHER 1	FLETCHER 2	ACME 1	ACME 2	OTHER 1	OTHER 2	MINE-BOLTER CAPABILITIES
1	CENTRAL PENNSYLVANIA	4	12	9*		3	3½'-5'	4'	18'	100'	1	6'	6'-7'	2%	8%	1	✓	7				2		3				1
2	CENTRAL PENNSYLVANIA	3	7	4		3	3½'-4½'	4'	16'	100'	1	TRACE	4'		10%	1	✓	10				2	1	5				1
3	CENTRAL PENNSYLVANIA	1	8	7		1	4'-7½'	6'	18'-20'	100'	2	4'-8'	5'	2%	6%	0	✓	2		6	3			1 (STOPER)		1 (LONG AIRDOX)		—
4	NORTHERN WEST VIRGINIA	1	8	7		1	5'-7½'	6'	15½' FULL CUT. WIDTH		4	6'		FLAT		0				8 (MINER BOLTER)								L
5	NORTHERN WEST VIRGINIA	1	6	6			5'-6'	5½'	16'		2	7'-10'	5'	FLAT		2	✓			4	4	5						R, L
6	NORTHERN WEST VIRGINIA	1	8	7		1	7'-8'	7½'	20'	80'	3	6'-8'		3%	10%	1	✓							(STOPER) 8				—
7	NORTHERN WEST VIRGINIA	2	6	6			3½'-6'	5'			3	2½'-6'	5'	FLAT		2	✓											—
8	CENTRAL WEST VIRGINIA	5	30	30			3'-9'	15 × 3', 15 × 6'	20'	75'	3	4'-10'	3'-8'	1%		0	✓	21			11							—
9	WESTERN VIRGINIA	2	19	19			3'-8'	4½'	18'	80'	3*	3'-6'	4'	7%	14%	2,1	✓	35	8									—
10	CENTRAL WEST VIRGINIA	9	19	18*		1D	3½'-13'	5'			3	6'	4'	FLAT		0	✓		19 ✓									1
11	WESTERN VIRGINIA	1	4	4			3'-4'	3½'	20'	60'	3 × 5, 1 × 1	2½'	5'	FLAT		2	✓						1	4		3 (WILCOX)		L
12	WESTERN VIRGINIA	1	1	1			4'-7'	5'			5	2½'		FLAT		0										2 (PAUL'S PINNER)		1
13	WESTERN VIRGINIA	1	8	7		1,1D	4'-6½'	5'	18'		3		4'	FLAT		0			8									—
14	WESTERN VIRGINIA	8	30	15	10	4	2½'-8'	3½'			3	3'-6'	4'-5'	3%	6%	3		55	1			1						S (FL. SINGLE)
15	WESTERN VIRGINIA	17	40	40			4'-6'	5'			3	3'-4'	TRACE			2					6	20		24				—
16	EASTERN KENTUCKY	5	14	14			3½'-6'	4½'	20'	60'	4	3'-4'		ROLLS		0	✓	13	3			1	1	1				—
17	NORTHERN ALABAMA	1	3			3D	5'-9'	9'	20'		5*	4'		1%	2%	0				✓						✓ (JOY)		1
18	NORTHERN ALABAMA	8	30	30*			2½'-10'	4'		80'	4	3'	TRACE		5%	0		15 ✓		10 ✓				5 ✓				1
19	WESTERN KENTUCKY	1	2 (7 PLANNED)	2			5'	5'	20'-22'		5	2'		FLAT		2				27 (CAMP DIV.)								1
20	WESTERN KENTUCKY	1	5		5		5'	5'			2		4'	0%	5%	0		8	1		1							—
21	WESTERN KENTUCKY	1	3	1	2		3½'	3½'			2		3½'-6'	3%	5%	0		3										1
22	SOUTHERN ILLINOIS	1	10	10*			6½'-10'	8'	16'-18'		3*	6'			12%	0				7	3		1					R, L
23	SOUTHERN ILLINOIS	1	16	16*			8'	8'	14'		3	8'		0%	4%	0					16 (MANSON)							—
24	SOUTHERN ILLINOIS	1	9	9°			6'-7'	6½'			3	4'-6'		FLAT		0					6			4				—
25	SOUTHERN COLORADO	1	11	9*		2	6'	6'	16'		2		4'	4%	25%	1,2												L
26	NORTHERN NEW MEXICO	1	8	6*		2	6'-10'	8'			2	5'-6'	4'-8'	FLAT		1,2	✓		9			1	1					R, L, S
27	CENTRAL UTAH	1	4	4*			10'-12'	11'	22'		3*	4'-5'	4'-5'	9%	10%	1	✓				2		2					R, L, S
28	CENTRAL UTAH	1	5	5			18'-24'	20'	18'-22'		4 × 4 *, 1 × 2		✓	10%	15%	0	✓						3		2	1 (JOY)		R, L, S
29	CENTRAL UTAH	1	6	6			4'-10'	8'	20'		1*	3'-4'	5'-6'	7½%	18%	1				7								1
30	CENTRAL UTAH	1	6	6			5'-11'	9'	20'		3*	3'-5'	4'-6'		12%	3				3								1

1. Reference to specific brands, equipment or trademarks in this report is made to facilitate understanding and does not imply endorsement by the U.S. Bureau of Mines.
2. See next page for key to symbols.