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**Three-Dimensional Graphics Simulator
for Testing Mine Machine Computer-
Controlled Algorithms—Phase 1
Development**

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A ampere

ft foot

cm centimeter

in inch

deg degree

s second

THREE-DIMENSIONAL GRAPHICS SIMULATOR FOR TESTING MINE MACHINE COMPUTER-CONTROLLED ALGORITHMS—PHASE 1 DEVELOPMENT

By Dean H. Ambrose¹

ABSTRACT

Using three-dimensional (3-D) graphics computing to evaluate new technologies for computer-assisted mining systems illustrates how these visual techniques can redefine the way researchers look at raw scientific data. The U.S. Bureau of Mines is using 3-D graphics computing to obtain cheaply, easily, and quickly information about the operation and design of current and proposed mechanical coal and metal-nonmetal mining systems. Bureau engineers developed a graphics simulator for a continuous miner that enables a realistic test for experimental software that controls the functions of a machine. Some of the specific simulated functions of the continuous miner are machine motion, appendage motion, machine position, and machine sensors. The simulator uses data files generated in the laboratory or mine using a computer-assisted mining machine. The data file contains information from a laser-based guidance system and a data acquisition system that records all control commands given to a computer-assisted mining machine. This report documents the first phase in developing the simulator and discusses simulator requirements, features of the initial simulator, and several examples of its application. During this endeavor, Bureau engineers discovered and appreciated the simulator's potential to assist their investigations of machine controls and navigation systems.

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INTRODUCTION

The U.S. Bureau of Mines is keeping its leading edge of innovation by exploring the use of three-dimensional (3-D) graphics computing to evaluate new technologies and designs for computer-assisted mining systems. Three-dimensional graphics computing has been available for some time; however, using it for mining equipment design and evaluation through computer model building and simulation is relatively new. The two most frequently asked questions about the Bureau's 3-D computing activity are, What is 3-D graphics computing? and Why use 3-D graphics computing?

What is 3-D computing? The difference between most static graphics or data printouts and 3-D computing is like the difference between simply reading about how atoms combine into molecules and actually watching it happen. Three-dimensional computing is more than basic animation of an object; it lets the user see and manipulate the visual representation of data while processing occurs.

Three-dimensional computing is an interactive process performed on 3-D data. The process consists of two components: first, computing intensive calculations on the 3-D data, and second, visualizing the results of these calculations using realistic color monitor displays. Three-dimensional computing provides specific functional capabilities for the user (e.g., a 2-D and 3-D graphics processor generating a million pixels for the monitor, multitasking operations, and access to a large base memory), and as a result, requires corresponding specific hardware and software.

A 3-D graphics system must have the power to do calculations on 3-D data. The computer must also have very high speed computing and graphics capabilities to allow smooth motion display. Such features are necessary so that the user can interactively manipulate surfaced and shaded displays of 3-D data. The 3-D graphics computer used by the Bureau is a Silicon Graphics Personal IRIS turbo super graphics workstation.²

Three-dimensional computing requires software capable of creating, displaying, and operating on a data base that fully describes the 3-D geometry of an object. The geometric description produced by 3-D software must include all the geometric features of the object(s). A boundary representation of a surface or solid represents 3-D objects. Internally, the software represents these boundaries or surfaces with collections of planar polygons or facets. For any particular object, stored data include edges shared between facets and points shared between edges. The data also include information allowing a group of facets to represent a single surface such as the facets forming the curved surface of a cylinder. Wireframe objects are

collections of line segments and contain no surface information.

Three-dimensional computing has three application areas: modeling, simulation, and analytical interpretation. Modeling is the process of visualizing, understanding, and interpreting the geometric features of designs. These features include appearance, shape, size, and interference or clearance with other objects. Performing design visualization in a 3-D computer environment often replaces building a physical model.

Simulation involves simulating the functional operation and control of a new design. Simulation often uses analysis tools such as kinematics (all geometrical and time-based properties of motion) and dynamics (all force equations required to cause motion). Applying 3-D computing eliminates the immediate need for building and testing a physical prototype.

Interpreting analytical results involves using 3-D capabilities to display simultaneously the geometry of a part and analytical results, e.g., shades of color that represent real-time temperature changes in a part. The purpose of such a display is to better understand the analytical results and their effect on the object(s) or its parts. Some of the most common types of analyses interpreted this way are from finite element techniques, such as air flow, stress, and thermal.

The Bureau uses CimStation, a computer-aided manufacturing software developed by SILMA. CimStation software is composed of a base system for designing and simulating automated devices. Its functions are easily expanded or customized, because CimStation software is based on an object-oriented, open system architecture. Features include discrete event simulation; task-oriented programming; concurrent programming of devices; device mechanism modeling; computer-aided design, engineering, and manufacturing interfaces; kinematic and dynamic simulation; collision detection and avoidance; and user-friendly interface menus.

Why use 3-D computing? The Bureau is committed to research leading to fundamental technologies that will allow the evolutionary development of computer-assisted mining systems for coal and metal-nonmetal mines. In the near term, the research focuses on developing computer-assisted teleoperation of state-of-the-art mining equipment and methods and developing knowledge-based computer systems to aid in management, maintenance, and safety. In the long term, the creative ingenuity of the mining industry will evolve new mining systems that will take advantage of the specific attributes of the increased technological capabilities. Both the short- and long-term efforts will increase mining efficiency, health and safety, and competitiveness.

²Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

The Bureau's research is divided into three major areas. The first area is an exploratory program of research that explores and develops the fundamental knowledge and hardware. The second is an applied research program that brings the pieces or integrated systems to a field-worthy prototype stage. The third is a customized research program for specific cases that address solutions to mining industry needs.

The research program includes review of robotic machine and autonomous vehicle technologies and current coal and metal-nonmetal mining technology, which provides the basis for developing innovative mining methods; research in navigation and guidance technology, emphasizing control of a continuous mining machine; research on coal-rock-interface-sensing technology for horizon control and rib thickness control in highwall mining; development of computer systems and hierarchical architectures for real-time control; and development of expert systems for machine system fault and predictive maintenance. The status and activities specifically pertaining to each research area are beyond the scope of this paper, but may be found in other references (1-9).³

In one of the projects under this research program, researchers are conducting fundamental studies to assess the use of automation technology to make improvements far beyond the capabilities of current commercial mining systems. These fundamental studies involve two principal efforts: (1) assembly of information on the technologies and capabilities of automation, and (2) examination of the fundamental objectives of mining with the specific aim of designing and testing new mining methods and systems that take advantage of the specific capabilities of available automation technology. Effort 1 is done through hours of reviewing literature and writing topical reports. Effort 2 is done by using 3-D graphics computing.

The Bureau's 3-D graphics computing effort consists of four ongoing tasks: (1) creation of models of various mining equipment, (2) creation of models of mine

environments, (3) use of models to create mining scenarios by programming a sequence of operations, and (4) with computer graphics simulation, study of mining scenarios to examine machine or equipment interactions. Investigators will use these models and scenarios to examine, through graphics simulation, navigation and guidance technology, computer systems and hierarchical architectures for real-time machine control, and robotic technologies adaptable to mining equipment.

The fundamental rationale for using 3-D computing is the desire to obtain cheaply, easily, and quickly knowledge or information about the operation and design of current or proposed mechanical coal and metal-nonmetal mining systems. While the Bureau's work will study new applications of automation by using 3-D computing, the experience and knowledge gained from this study will serve as a basis for examining and disclosing new mining concepts and machine designs. Technology transfer of 3-D computing tasks will allow industry to critique these concepts and designs and to contribute similar creative thinking in search of the best system for the future.

The Bureau successfully developed a graphics simulator for a continuous miner. The continuous miner model also serves as a base from which researchers can generate other coal and metal-nonmetal mining equipment models and simulators with little effort. The simulator provides researchers with a realistic test for experimental software that controls the functions of a continuous mining machine. The simulated functions of the continuous miner are machine motion, appendage motion, machine position, and machine sensors. The simulator uses data generated in the Bureau's Mining Equipment Test Facility (METF) laboratory or in a mine using a data acquisition system on a computer-assisted mining machine. This report documents the first phase in developing the simulator. During this endeavor, Bureau engineers discovered and appreciated the simulator's assistance in their investigations of machine controls and navigation systems.

PREVIOUS MODELING DEVELOPMENTS

Task 1 of the Bureau's 3-D graphics computing effort resulted in a 3-D model (fig. 1) of a computer-assisted Joy 14CM9-10D continuous miner. The model contains six parts: main frame, right and left trams, gathering head, conveyor, shearer (boom with cutter drums), and stabilizer jack (stab-jack). In building the model, researchers used two procedures essential to the success of using 3-D computing: determining parts and subparts of a model and using effective nomenclature when naming the parts.

Blueprint drawings provide the best source for selecting parts of the model. Good nomenclature is important to distinguish one part from another while creating and storing parts in a data base for later use, e.g., building models and interchanging parts.

Using mine machine models in simulation requires "tools" that when used together with the model accomplish a number of tasks. A tool is a driven mechanical device (e.g., shearer) attached to the model (e.g., miner) by which objects (e.g., coal) can be acted upon. Most tools contain moving parts; the simulation software, CimStation (10),

³Italic numbers in parentheses refer to items in the list of references at the end of this report.

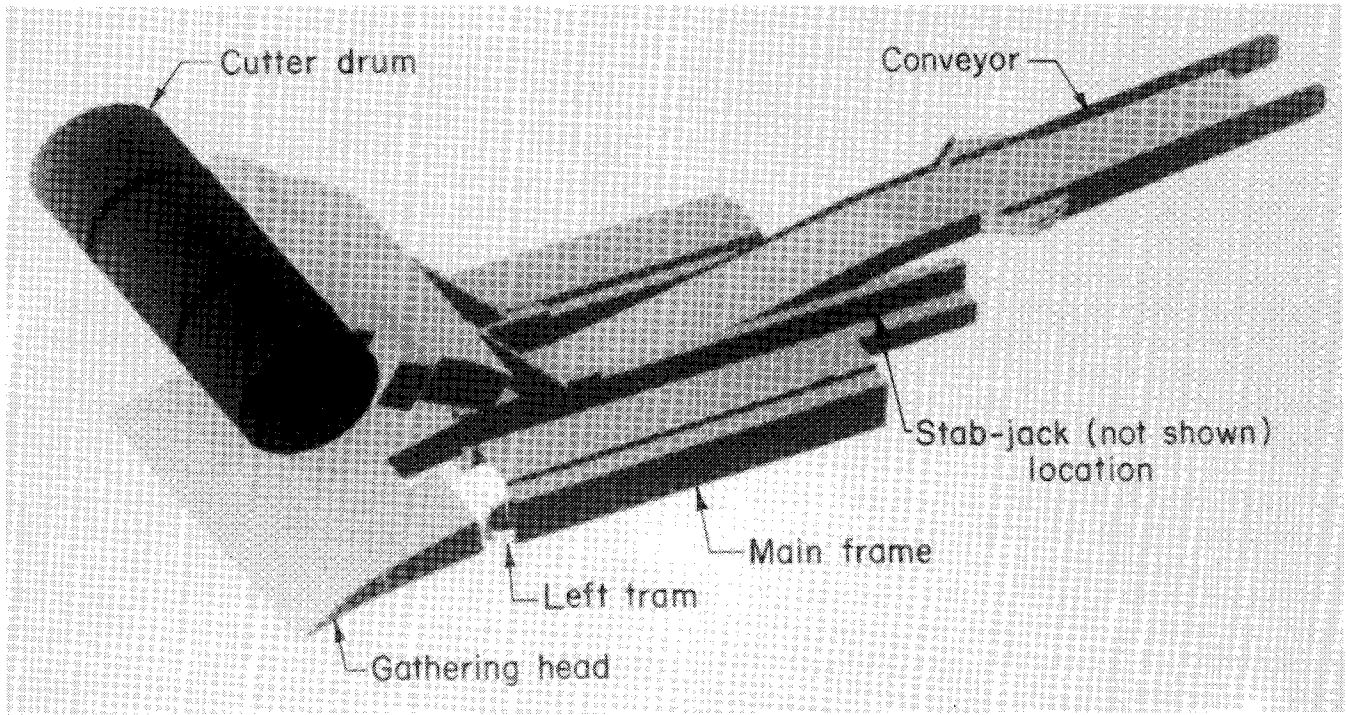


Figure 1.—Three-dimensional model of a continuous miner (photograph taken from 3-D computer graphics monitor).

requires kinematic descriptions (all geometric and time-based properties of motion) of each part. Objects defined as tools are not capable of kinematic motion until the software redefines them to produce kinematic motion. CimStation provides a "create tool" menu allowing the user to set and manipulate the parameters of each part of the tool. The parameters include:

- *open* and *closed* settings to limit the motion of the tool,
- *duration* to set the time (in seconds) for the tool to move from fully closed to fully open,
- *delay* to set the time (in seconds) for the part to begin moving after it is signaled, and
- *servoable* to set the intermediate positions of the part(s), if desired.

Four of the continuous miner model's parts are tools: gathering head, conveyor, shearer, and stab-jack. The gathering head (fig. 2) has one moving part limited to 15.2° between open (15.2°) and closed (0°). Setting the gathering head to 7.2° positions it at the ground level, referencing it to where the tram chain links touch the ground. Zero degrees sets the gathering head 11.18 in

(28.39 cm) below the ground level. The conveyor contains two moving parts: conveyor support and conveyor tail. The conveyor support elevation (fig. 3A) spans 6.5° between open and closed, but it controls the conveyor tail's elevation, which has an 86.63° swing (fig. 3B) between open and closed. At 43.98° , the conveyor tail aligns its midpoint to the conveyor support's midpoint, and is in effect "centered." The shearer (fig. 4) contains one moving part: a boom with cutter drums attached. The shearer spans 44.52° between open and closed, which describes the full motion of the cutter drums. Also, 5° sets the cutter drums at the ground level, referencing the top of the cutter drums to where the tram chain links touch the ground. Setting the shearer to 0° places the cutter drums 9.5 in (24.13 cm) below the ground level. The stab-jack (fig. 5) has one moving part limited to 35.4° between open and closed. Zero degrees sets the stab-jack in the up position. Setting the stab-jack to 35.4° lowers it about 4.46 in (11.328 cm) below the ground level. Table 1 summarizes the various parameter settings for each tool. When operating a tool, the software uses percent as input that relates to the motion between the open and closed settings.

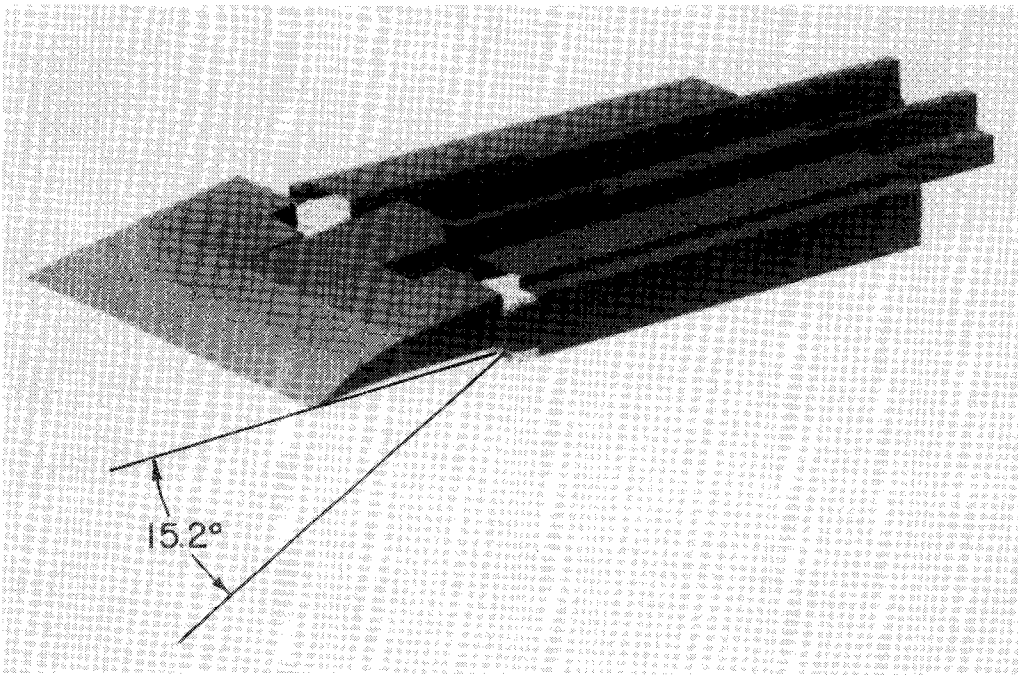


Figure 2.—Gathering head tool (photograph taken from 3-D computer graphics monitor).

Table 1.—Parameter settings for miner model tools

Tool name	Open ¹		Ground level ¹		Midpoint ¹		Closed ¹		Dura- tion, s	Delay, s	Servoable
	deg	%	deg	%	deg	%	deg	%			
Gathering head	15.2	100	7.2	46.05	7.6	50.0	0	0	1	0	Yes
Conveyor support	6.5		NAP	NAP	3.25	50.0					
Conveyor tail	86.63		NAP	NAP	43.98	50.77					
Cutter drum	44.52		5.0	11.23	22.26	50.0					
Stabilizer jack	35.4		22.8	64.4	17.7	50.0					

NAP Not applicable.

¹Degree and percent are input values relating to the motion between the open and closed parameter settings.

Future continuous miner model enhancements will include the gathering arms and conveyor chain. They were not modeled because their details were unnecessary for this phase of continuous miner model development.

Future model enhancements will include simulation code that causes continuous miner models to uniquely mimic circling gathering arms, rotating cutter drums, and a turning conveyor chain.

SIMULATOR

REQUIREMENTS

Researchers formed requirements that define the functional specifications for a simulator that can test the proper functioning and robustness of the control software. These functional specifications were defined according to

the specific operation elements of the actual continuous miner and divided into five categories: general, machine motion, appendage motion, machine position, and machine sensor. The following sections discuss the functions of each operation element planned for the simulator. Essential functions were identified for the initial simulator, and they are designated in *italics*.

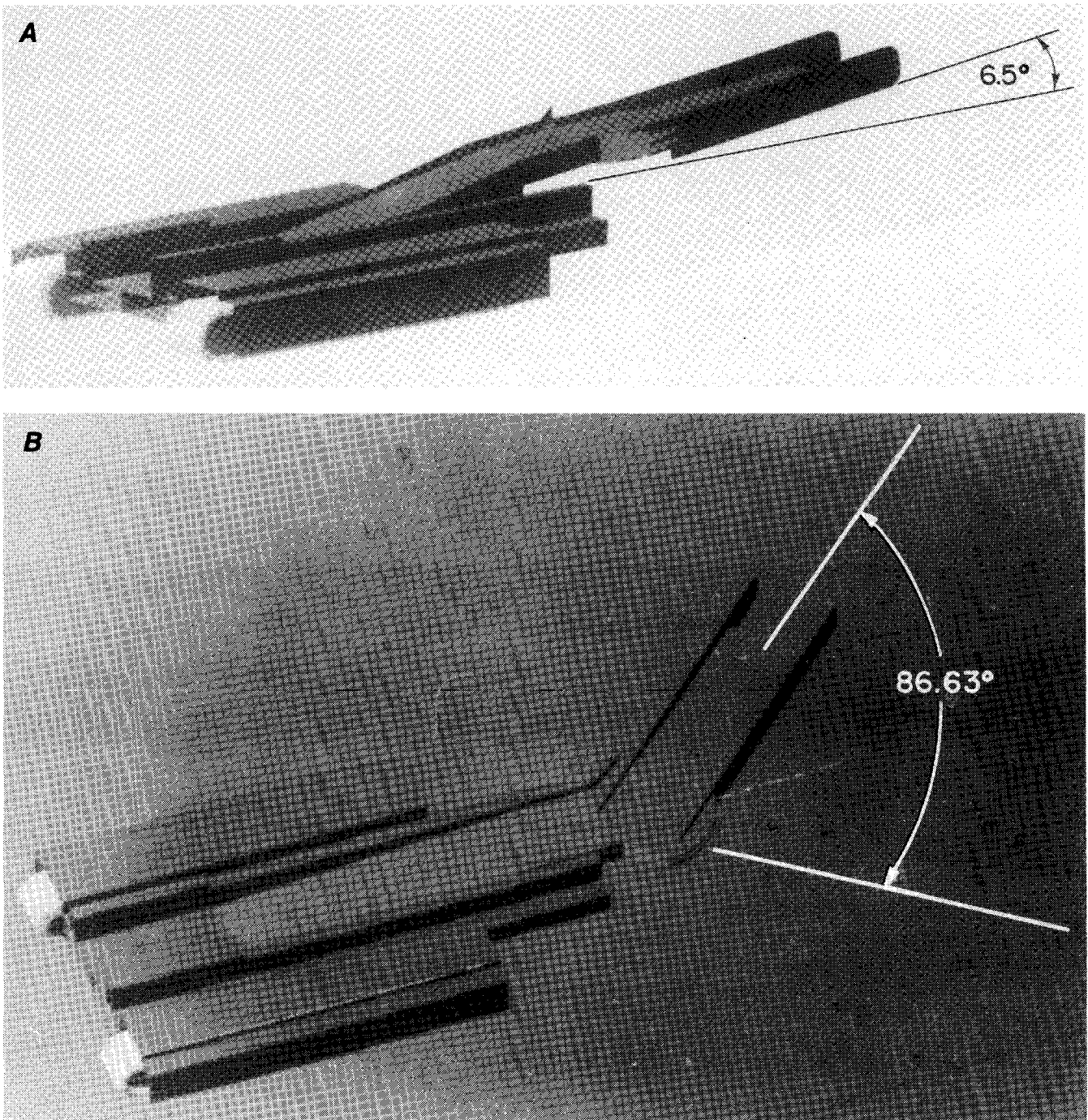


Figure 3.—Conveyor tool. A, Support elevation; B, tail swing (photographs taken from 3-D computer graphics monitor).

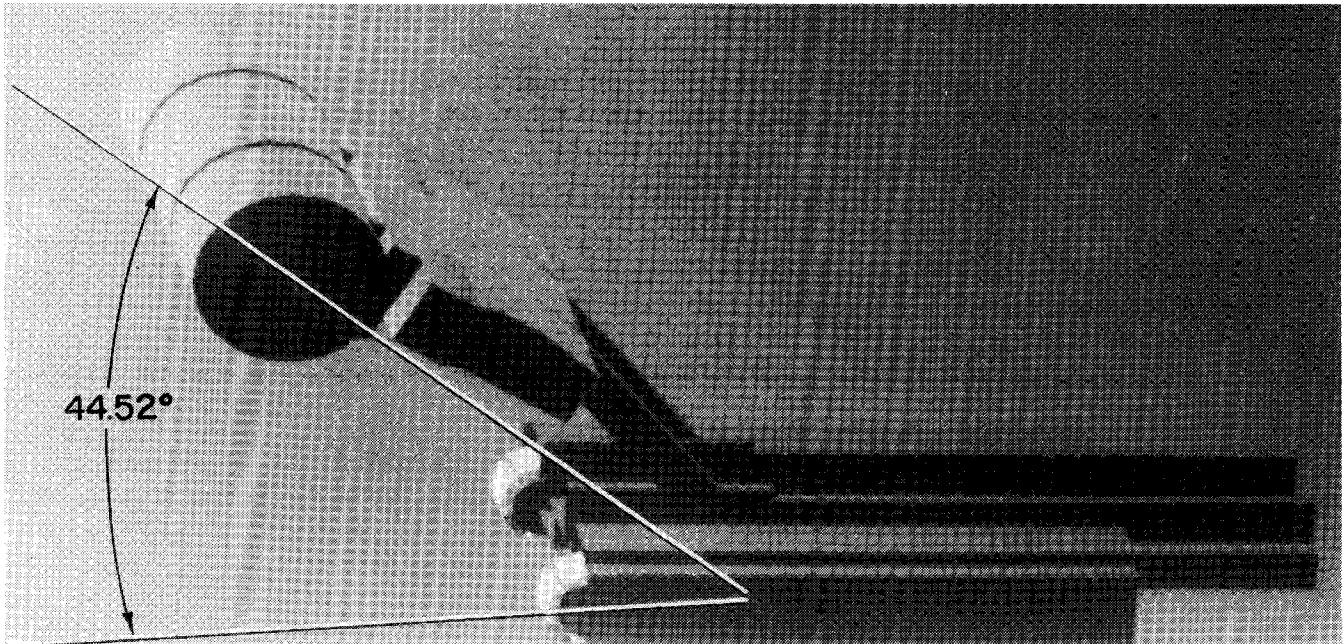


Figure 4.—Shearer tool (boom with cutter drums) (photograph taken from 3-D computer graphics monitor).

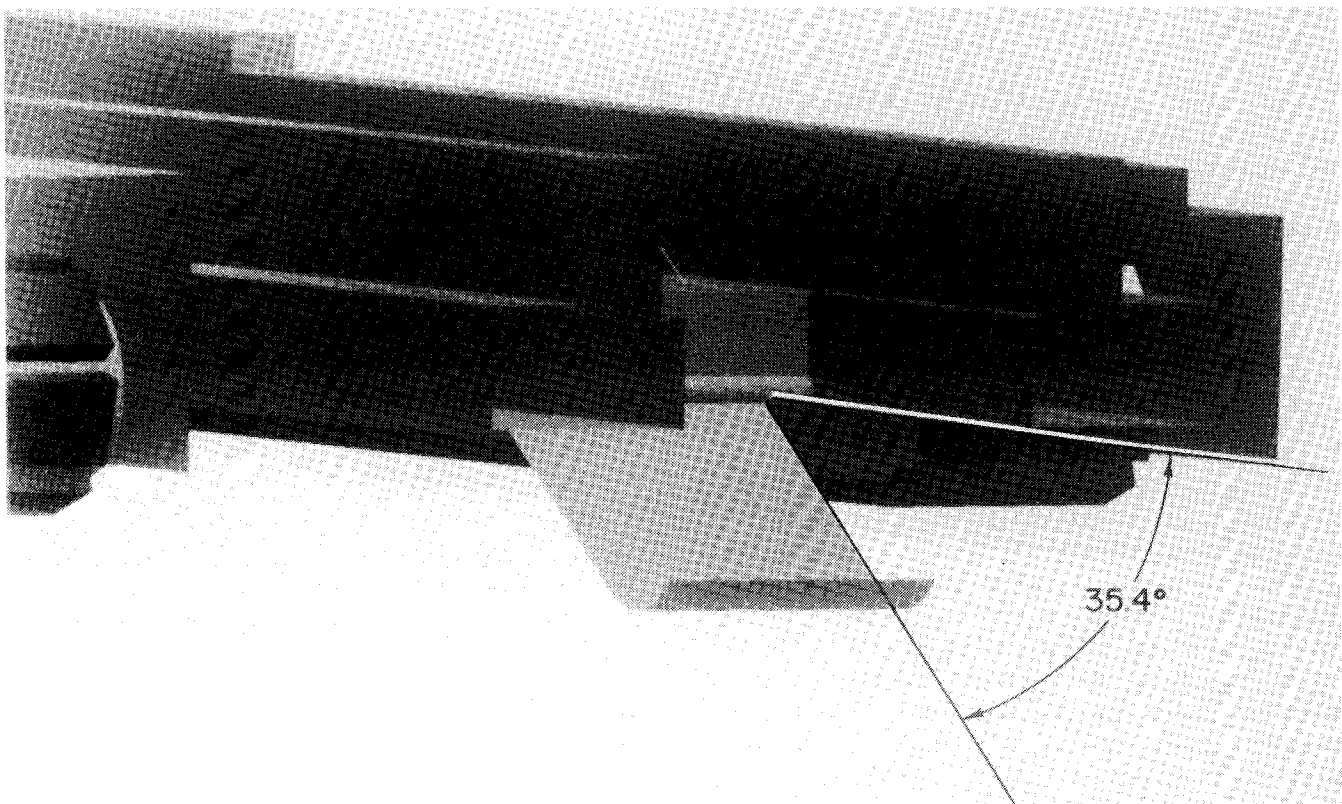


Figure 5.—Stabilizer jack tool (photograph taken from 3-D computer graphics monitor).

General

The simulator will provide a graphical simulation of a continuous mining machine that allows researchers to test control algorithms. The tramming and cutting control software being written by researchers will coordinate the machine movements, shearer and conveyor motor operation, and appendage movements. The simulator must be able to interface smoothly with the tram and shearer control software developed by researchers as if it were a real mining machine. (The control software created for the computer-assisted mining machine is divided into different machine functions that are defined as modes of operation. The computer-assisted machine operator can use these operation modes to program a series of machine movements that execute sequentially on the mining machine; this process is called script programming. For example, a complete mining cycle script is created by using menu selections and then chaining together several machine functions. The operator executes a command script with a single keystroke. Each of the entries in the script will execute sequentially and will continue to the end unless terminated by the machine operator.) Consequently, the scripting software will drive either the simulator or the actual machine. The simulator will provide suitable, user-definable, and quantifiable contingency events to test software behavior in such events. Contingency events are real-life occurrences that a continuous miner actually encounters; examples of these events are discussed under each applicable element below. Also, the simulator will reflect the actions and effects of machine position orientation (x , y , pitch, roll, and yaw) by actuating the tram motors and appendages.

Machine Motion

The simulator's tram motions will include *forward slow*, *forward fast*, *reverse slow*, *pivot turn right*, *pivot turn left*, *forward turn right*, *forward turn left*, *reverse turn right*, and *reverse turn left*. Several parameters were considered for tram simulation: delay time; ramp-up rate of solid-state controls that apply startup power to the motors in a gradual fashion; coast, ramp-down, and overshoot times; crawler rates; and turning rates. The motion of the simulated machine is ideal; however, to create a more realistic testing ground, imperfections in the machine motion are desired. These perturbations will be programmable through a user-selected menu list. Such a list will include unequal but constant left and right crawler speed, sudden transient decrease in one crawler motion, forward and reverse crawler slippage to represent muddy floor conditions, slow drift in the lateral direction to represent side slip on an incline, and machine pushed by a rib to represent bumping a rib.

Appendage Motion

Ongoing research (3) in machine control represents an integration of machine hardware, position sensors, and control computer systems that accurately executes commands that contain targets. For example, in closed-loop control, a function is named and a target value is specified such as destination position, a specific change in position, or a duration for a particular function. The simulator's appendage motion will emulate closed-loop computer position control. Appendages will be controllable by commanding the simulator with an appendage name and a target value in degrees. As soon as the simulator receives the command, it will execute the motion with appropriate delay times, overshoot times, and rates characteristic of the continuous miner in real life. Appendage motions will include

- *shearer elevation*,
- *gathering head elevation* (going up only),
- *gathering head float* (release and it drops to the ground level),
- *conveyor elevation*,
- *conveyor swing*, and
- *stab-jack* (when the stab-jack contacts the floor, the machine tilts forward, pivoting on the front axle of the crawler tracks, and this action contributes to different elevations for the cutter drums and conveyor).

A simulator's interactive menu will allow the user to control the shearer up and down rate. Increasing or decreasing the rate will represent a coal cutting loading effect. The simulator's loading effect relates mainly to the sump distance and will activate when simulated coal contacts the cutter drums. In addition, the cutter drum motors' current will be simulated to rise, causing the rate of tram to diminish by excessive current draw of the cutter drum motors as experienced in real life.

Machine Position

Machine guidance falls naturally into two parts—lateral and vertical (1). The first refers to positioning the machine laterally within the open spaces of an entry. The second refers to keeping the machine within the coal seam relative to the overlying and underlying strata. Ongoing research in laser scanner guidance methods (3-4), mechanical guidance (5), and coal interface detection (CID) techniques (7-8) will provide solutions to machine navigation. The simulator will have the capability to receive or transmit data on *machine guidance coordinates*: x , y , h (h = heading or yaw). These data are accessed by query from the experimental control software. Values for x , y , and h are always referenced to an actual object's coordinate

frame. A simulator's user menu will allow selection of any reference modeled object and its origin and coordinates. In addition, both the target angles for laser-based guidance and the line-pull string lengths for mechanical guidance will be simulated. The user will have the option to place on the machine the laser reflective targets, laser position, and the fastening points of the line-pulls. The investigation of CID is not sufficiently mature to suggest a technique for the simulator, but the simulator will include CID.

Machine Sensors

The machine sensors include *machine gyro emulation* (heading change from last update), machine roll, *machine pitch* (relates to stab-jack and shearer effects), cutter drum motors' current, and appendage angle sensors. The actual ground level, as detected by the gathering head, is important, because the gathering head has a sensor that provides ground level data since the gathering head "floats" on the ground. When the gathering head releases, it drops to rest on the ground. If the stab-jack is not tilting the machine, and there is no rubble under the head, it rests on the ground level. If rubble was placed under the head as

a float parameter to raise the float to aboveground level (fig. 6), it would signal control software that a cleanup action is needed.

DEVELOPMENT

To develop the simulator optimally, the approach must be progressive, i.e., each new accomplishment must enhance the current version of the simulator. Researchers based the simulator's initial functions on both the previously modeled and actual continuous miner. One factor of the Bureau's development was allowing research associates to use the simulator during its development phases. This factor was important because it immediately demonstrated the use of 3-D graphics as an engineering tool to help investigators evaluate developments of the computer-assisted mining machine. It was obvious from the list of simulator requirements that much time was necessary to develop a completely functional simulator using all the specifications. Therefore, simulation researchers divided the requirements into workable subtasks, expecting to enhance the simulator while allowing research associates to use the simulator to assist in their investigations.

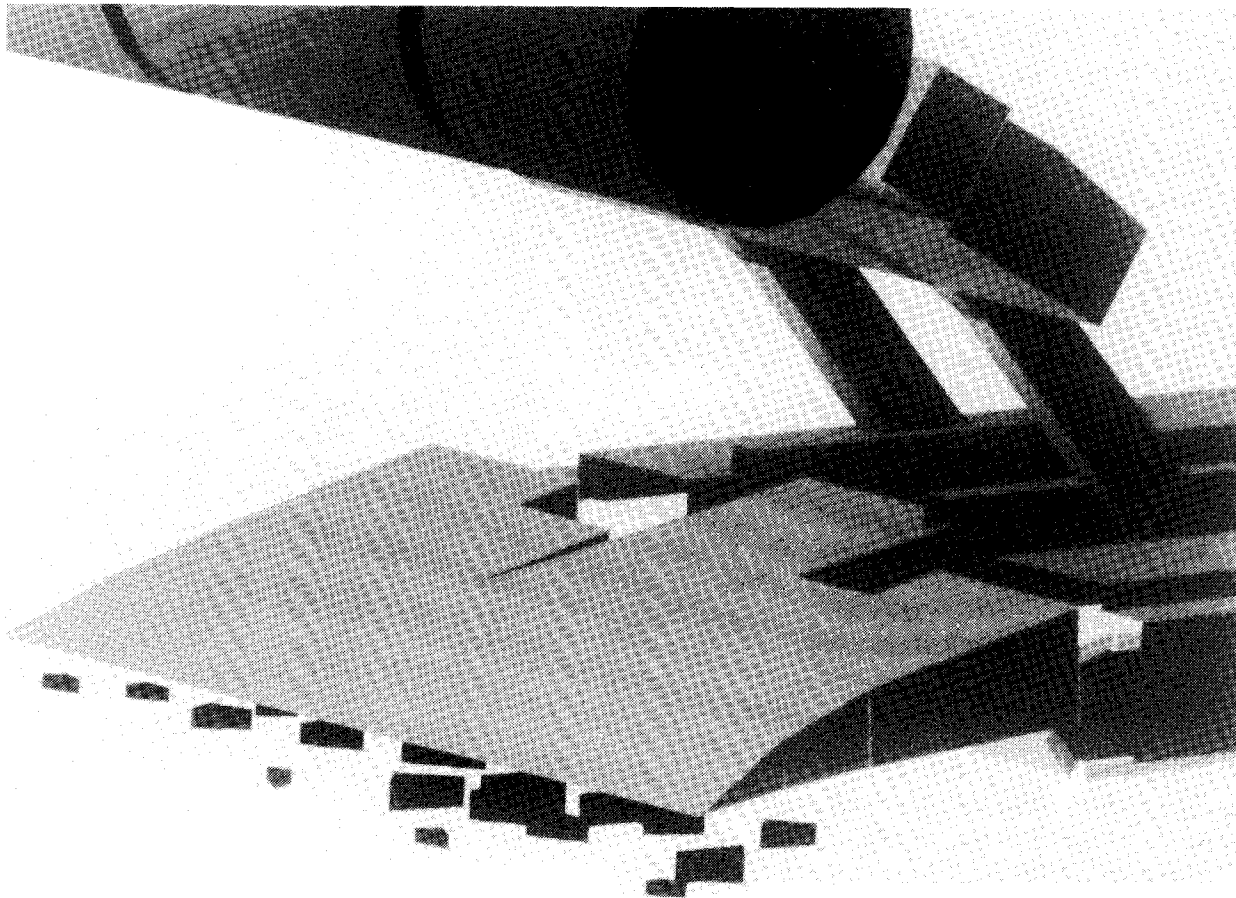


Figure 6.—Rubble raises the gathering head—cleanup action is needed (photograph taken from 3-D computer graphics monitor).

All of the phase 1 development objectives have been completed. The resulting initial simulator reads data files generated in the METF laboratory or in a mine using a data acquisition system on a computer-assisted mining machine. The data files contain information on a continuous mining machine's position and motions of its tram and appendages (shearer, gathering head, conveyor, and stab-jack). Figure 7 shows a data file from actual laser-based navigation system field test data. Also, figure 8 shows a data file from the pendant data and the data acquisition system. ("Pendant" is a term used by miners to describe the machine's remote control box, which is attached to a strap that hangs around the machine operator's neck.) Researchers have developed software that acquires data that reflect all commands sent by the mining machine operator via the pendant (9). Researchers may also manually generate data files in the 3-D graphics laboratory to simulate machine motion, appendage motion, and machine position to imitate live laboratory or field tests.

Active Text

One special feature of the simulator is that it displays active text, text that describes the motion or activity and updates continuously according to what is being simulated at the time. Active-text displays (fig. 9) provide the following information about the simulation and modeled objects involved.

- **Real time text** displays the time marks for each data line in the data file. The laboratory or field test data file shows the actual time of day the data were acquired. The laboratory-generated graphics file shows the time for each line as decided by the researchers; for example, each data line could represent 0.1, 0.5, or 1.0 s. Also displayed with real time is a total elapsed time (in seconds and minutes) showing the duration of the simulation.

- **Tram text** displays the possible tram motions by updating text to "no tram", "tram forward", "tram reverse", "left turn", or "right turn".

- **Cutting text** displays whether the shearer's rotation has been turned on or off by updating the text to "shearer on" or "shearer off".

- **Conveyor text** displays whether the conveyor chain is turning by updating the text to "conveyor on" or "conveyor off".

- **Stab text** displays status of the stab-jack by updating the text to "stab up", "stab going down", "stab down", or "stab going up".

- **Shearer text** displays the status of the cutter drums' elevation by updating the text to "shearer going down", "shearer going up", or "shearer stopped at <degree> and

cutting height <inches>". Note that the cutting height is the height measured between the ground level and top of the cutter drums. For example, if a cutter drum's diameter is 44 in (111.76 cm), cutting height "44 in" would indicate that the bottom of the cutter drum is at ground level.

- **Gathering head text** displays the status of the gathering head elevation by updating the text to "gathering head going down", "gathering head going up", or "gathering head stopped at <degree>".

- **Tail elevator text** displays the status of the conveyor elevation by updating the text to "tail elevator going up", "tail elevator going down", or "tail elevator stopped at <degree>".

- **Tail swing text** displays the status of the conveyor swing by updating the text to "tail swinging left", "tail swinging right", or "tail swing stopped at <degree>".

Other simulator requirements featured in the initial simulator are discussed in the following sections.

TIME OF DAY	X (deg)	Y (deg)	HEADING (deg)
01:53:32:33 PM	9.633	37.221	-1.765
01:53:32:83 PM	9.640	37.228	-1.810
01:53:33:33 PM	9.629	37.236	-1.832
01:53:33:83 PM	9.590	37.236	-1.640
01:53:34:33 PM	9.622	37.242	-1.780
01:53:34:83 PM	9.613	37.229	-1.706
01:53:35:33 PM	9.610	37.230	-1.691
01:53:35:83 PM	9.625	37.226	-1.756
01:53:36:33 PM	9.606	37.226	-1.716
01:53:36:83 PM	9.620	37.234	-1.813
01:53:37:33 PM	9.632	37.245	-1.838
01:53:37:83 PM	9.613	37.235	-1.695
01:53:38:33 PM	9.611	37.226	-1.691
01:53:38:83 PM	9.600	37.212	-1.675
01:53:39:33 PM	9.643	37.224	-1.794
01:53:39:83 PM	9.612	37.228	-1.740
01:53:40:33 PM	9.609	37.221	-1.740
01:53:40:83 PM	9.606	37.240	-1.696
01:53:41:33 PM	9.623	37.221	-1.721
01:53:41:83 PM	9.604	37.218	-1.688
01:53:42:33 PM	9.612	37.235	-1.766
01:53:42:83 PM	9.629	37.235	-1.796
01:53:43:33 PM	9.613	37.239	-1.702
01:53:43:83 PM	9.608	37.224	-1.685
01:53:44:33 PM	9.624	37.225	-1.737
01:53:44:83 PM	9.611	37.216	-1.671
01:53:45:33 PM	9.630	37.223	-1.758
01:53:45:83 PM	9.614	37.234	-1.771
01:53:46:33 PM	9.608	37.235	-1.689
01:53:46:83 PM	9.613	37.229	-1.696

Figure 7.—Laser-based navigation data file.

MAPS Tests M12L1.WK1
 Entry 1, Lift 2, Left Side(box)
 The time is 16:30:22.79.
 The date is 2-27-1991.

02-27-1991
 16:31:31.01

TIME OF DAY	SHEARER (deg)	PITCH (deg)	ROLL (deg)	CUTTER (A)	LEFT TRAM (A)	RIGHT TRAM (A)	TIME (s)	SHEARER UP	SHEARER DOWN	LEFT FORWARD TRAM	RIGHT FORWARD TRAM	LEFT REVERSE TRAM	RIGHT REVERSE TRAM	CONVEYOR ON
16 31 30.918	17.45	-16.23	-85.91	0.07	0	0.02	0.0	0	0	0	0	0	0	0
16 31 31.418	17.47	-16.27	-86.00	0.04	0	0.01	0.5	0	0	0	0	0	0	0
16 31 31.918	17.47	-16.43	-85.88	0.08	0	0.02	1.0	0	0	0	0	0	0	0
16 31 32.418	17.48	-16.36	-86.04	0.04	0	0.05	1.5	0	0	0	0	0	0	0
16 31 32.918	17.48	-16.45	-86.04	0.06	0	0.02	2.0	0	0	0	0	0	0	1
16 31 33.418	17.47	-16.33	-86.01	0.06	0	0.03	2.5	0	0	0	0	0	0	1
16 31 33.918	17.46	-16.31	-85.99	0.04	0	0.02	3.0	0	0	0	0	0	0	1
16 31 34.418	17.49	-16.37	-85.90	0.04	0	0.02	3.5	0	0	0	0	0	0	1
16 31 34.918	17.50	-16.29	-85.87	0.05	0	0.06	4.0	0	0	0	0	0	0	1
16 31 35.418	17.46	-16.35	-85.99	0.03	0	0.04	4.5	0	0	0	0	0	0	0
16 31 35.918	17.45	-16.44	-85.98	0.02	0	0.01	5.0	0	0	0	0	0	0	0
16 31 36.418	17.49	-16.41	-85.90	0.11	0	0.04	5.5	0	0	0	0	0	0	0
16 31 36.918	17.50	-16.28	-86.06	0.03	0	0.05	6.0	0	0	0	0	0	0	0
16 31 37.418	17.48	-16.31	-85.95	0.01	0	0.02	6.5	0	0	0	0	0	0	0
16 31 37.918	17.46	-16.36	-85.81	0.05	0	0.01	7.0	0	0	0	0	0	0	0
16 31 38.418	17.48	-16.26	-85.96	0.03	0	0.05	7.5	0	0	0	0	0	0	0
16 31 38.918	17.49	-16.28	-86.05	0.07	0	0.03	8.0	0	0	0	0	0	0	0
16 31 39.418	17.48	-16.43	-85.96	0.04	0	0.02	8.5	0	0	0	0	0	0	0
16 31 39.918	17.46	-16.35	-85.92	0.08	0	0.02	9.0	0	0	0	0	0	0	0
16 31 40.418	17.47	-16.23	-86.01	0.04	0	0.04	9.5	0	0	0	0	0	0	0
16 31 40.918	17.49	-16.29	-85.95	0.02	0	0.03	10.0	0	0	0	0	0	0	1
16 31 41.418	17.48	-16.43	-86.00	0.05	0	0.06	10.5	0	0	0	0	0	0	1
16 31 41.918	17.47	-16.44	-85.96	0.05	0	0.04	11.0	0	0	0	0	0	0	1
16 31 42.418	17.46	-16.25	-85.90	0.02	0	0.06	11.5	0	0	0	0	0	0	1
16 31 42.918	17.49	-16.36	-85.93	0.05	0	0.01	12.0	0	0	0	0	0	0	1
16 31 43.418	17.50	-16.37	-85.93	0.07	0	0.02	12.5	0	0	0	0	0	0	0
16 31 43.918	17.47	-16.31	-85.88	0.07	0	0.01	13.0	0	0	0	0	0	0	0
16 31 44.418	17.45	-16.32	-85.95	0.03	0	0.01	13.5	0	0	0	0	0	0	0
16 31 44.918	17.49	-16.25	-85.90	0.06	0	0.03	14.0	0	0	0	0	0	0	0

¹ 1 equals on and 0 equals off

Figure 8.—Pendant data file.

Machine Motion

The simulator can exhibit all tram motions. Any turns other than pivot turns, which have left and right crawlers moving in opposite directions, are considered unavailable for closed-loop control; therefore, machine motion work focuses on pivot turns only. Bureau investigators state that to effectively turn the machine both crawlers must move. The other turns have only one crawler in motion; on mud floors, a stationary crawler is an effective lock against machine turning, so the moving crawler ends up digging a trench. The parameters for crawler and turning rates currently incorporated in the simulator are "fast" and "slow". At times the tram motion is difficult to see on the

graphics monitor because rate of change during simulation is so small. To assist the researcher, the simulator displays two symbols to show tram motion of the mining machine: an arrow (fig. 10A) depicting forward or reverse motion and a diamond (fig. 10B) indicating no tram motion.

Appendage Motion

All simulated appendages emulate closed-loop computer position control. The parameters currently incorporated into the simulator are the rates and delay times for each appendage.

The stab-jack requires additional simulation code to mimic the action generated by its motion. Under real-life

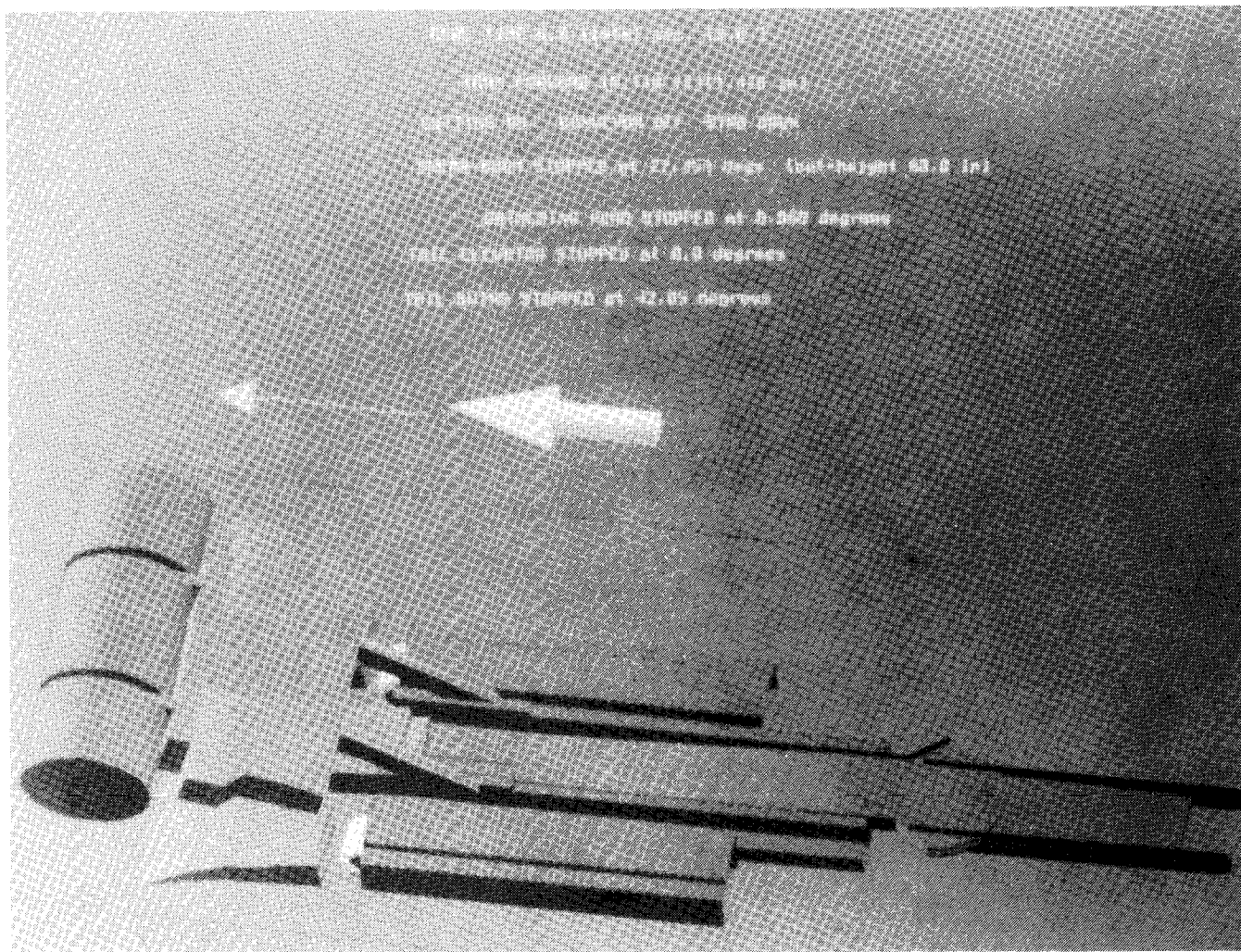


Figure 9.—Active text (photograph taken from 3-D computer graphics monitor).

operation the stab-jack lifts the rear of the machine. This action begins when the stab-jack lowers, and after 22.8° of rotation it makes contact with level ground. A simulated tool operation of this appendage will show this rotation, but the simulator needs additional programming to generate the motion that mimics the machine lifting.

As mentioned in the "Previous Modeling Developments" section of this report, the continuous miner did not include the motion of rotating cutter drums or conveyor chain. However, to help mimic their rotation, the simulator is programmed to change the colors of these tools when they have been activated to rotate.

Machine Position

The simulator reads data files containing machine coordinates or pendant data. The machine coordinates x , y , and h are obtained from a laser-based guidance system. The pendant data are obtained from a data acquisition

system used to record all control commands performed by the mining machine operator, such as left and right tram controls. Machine simulator coordinates are also created by laboratory-generated data files. The simulator allows the user to choose the reference point of the machine. The reference point can be any other modeled object, such as the mobile control structure (MCS) or a miner's surveyor mark. Bureau researchers investigated the use of an actual mobile roof support structure (renamed MCS) as a reference for guidance in the face area and for additional functions such as supporting the roof, supporting ventilation tubing, and making environmental measurements (4).

Machine Sensors

The simulator can simulate the yaw, pitch, and roll of the machine from a reference point anywhere on the machine or another modeled object. Machine pitch specifically relates to the stab-jack effects, its reference point

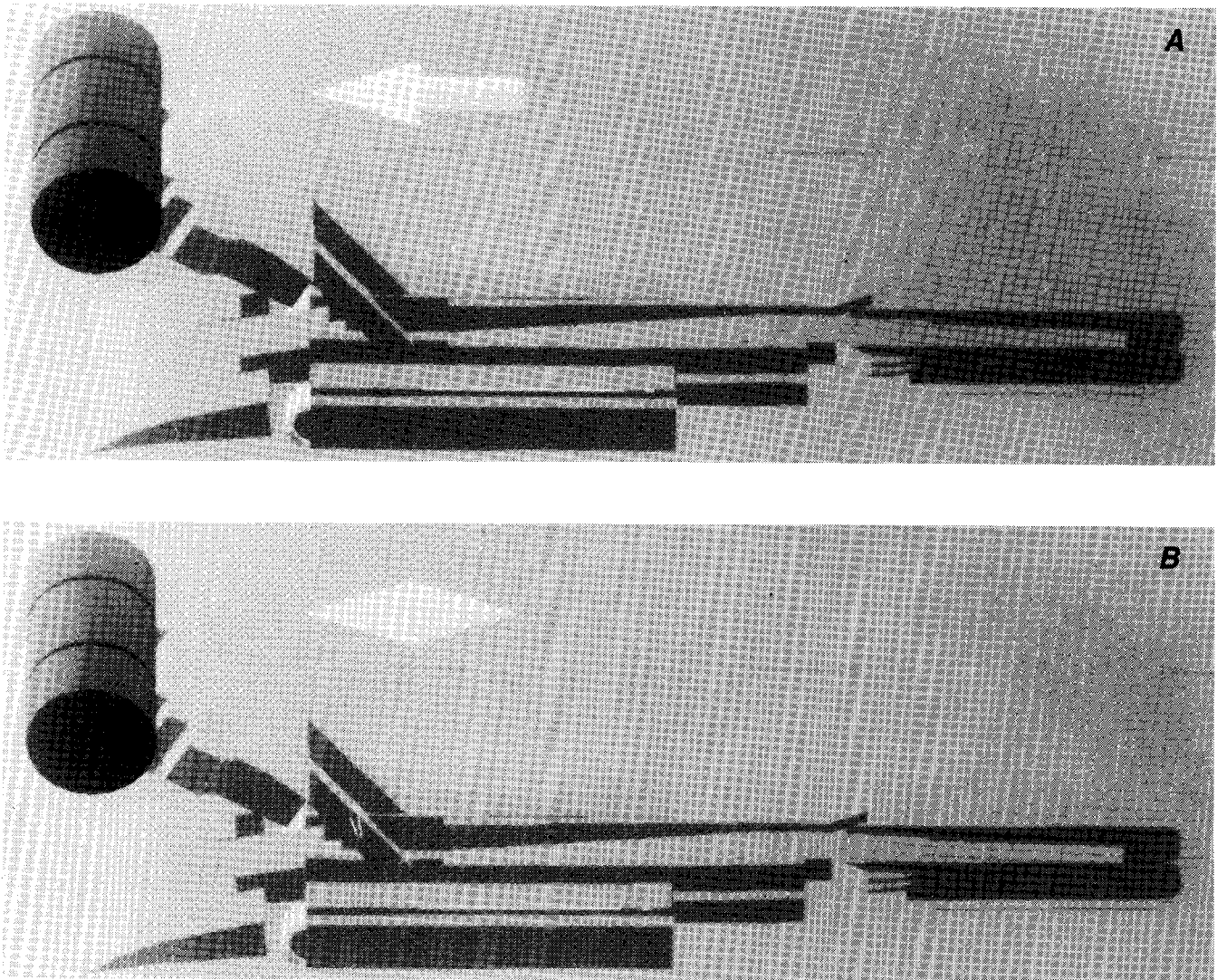


Figure 10.—Tram motion. A, Arrow depicting forward tram motion; B, diamond depicting no tram motion (photographs taken from 3-D computer graphics monitor).

being the front axle of the crawler tracks. The simulator's emulation of the machine gyro only shows the resulting output of the sensor—the heading change from the last update, not a simulated model of the gyro system. The

simulator uses three symbols to show changes in the heading or direction of the mining machine: straight arrow, right-curved arrow, or left-curved arrow (fig. 11).

APPLICATION EXAMPLES

Using 3-D graphics computing as an engineering tool to help evaluate new technologies for computer-assisted mining systems is now a fact. Applications will increase while development continues to expand the simulator's

capabilities as an engineering tool. The following are examples of how 3-D graphics visual techniques redefine the way researchers look at raw scientific data.

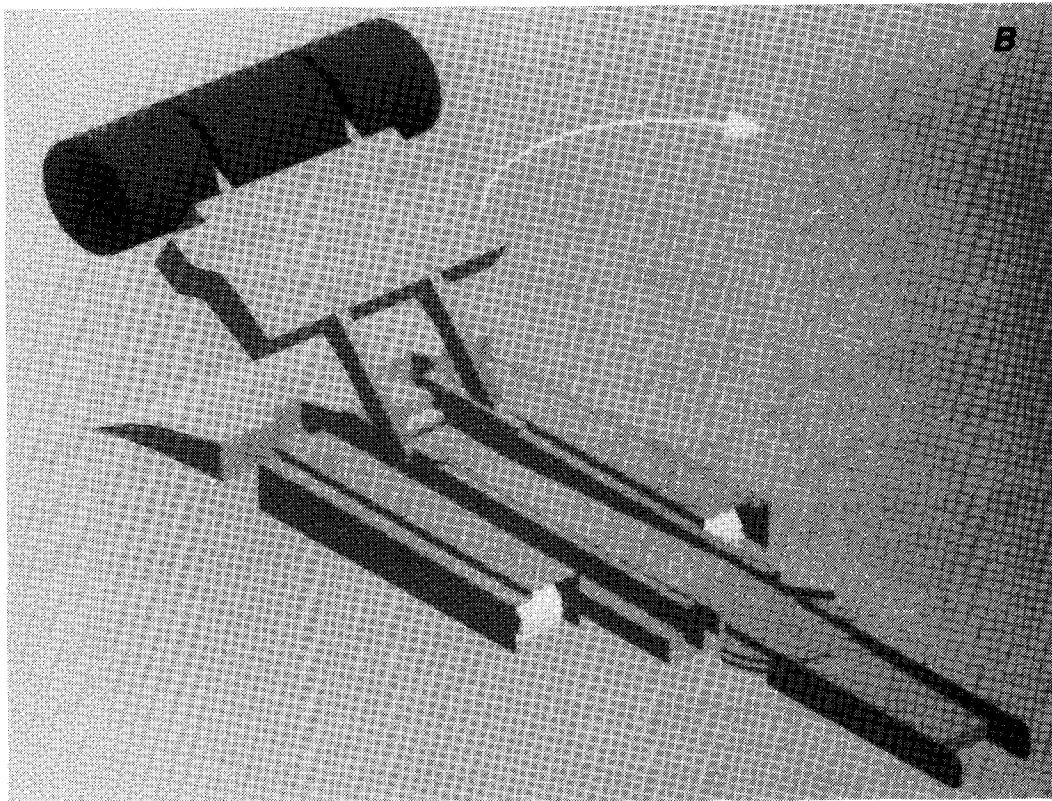
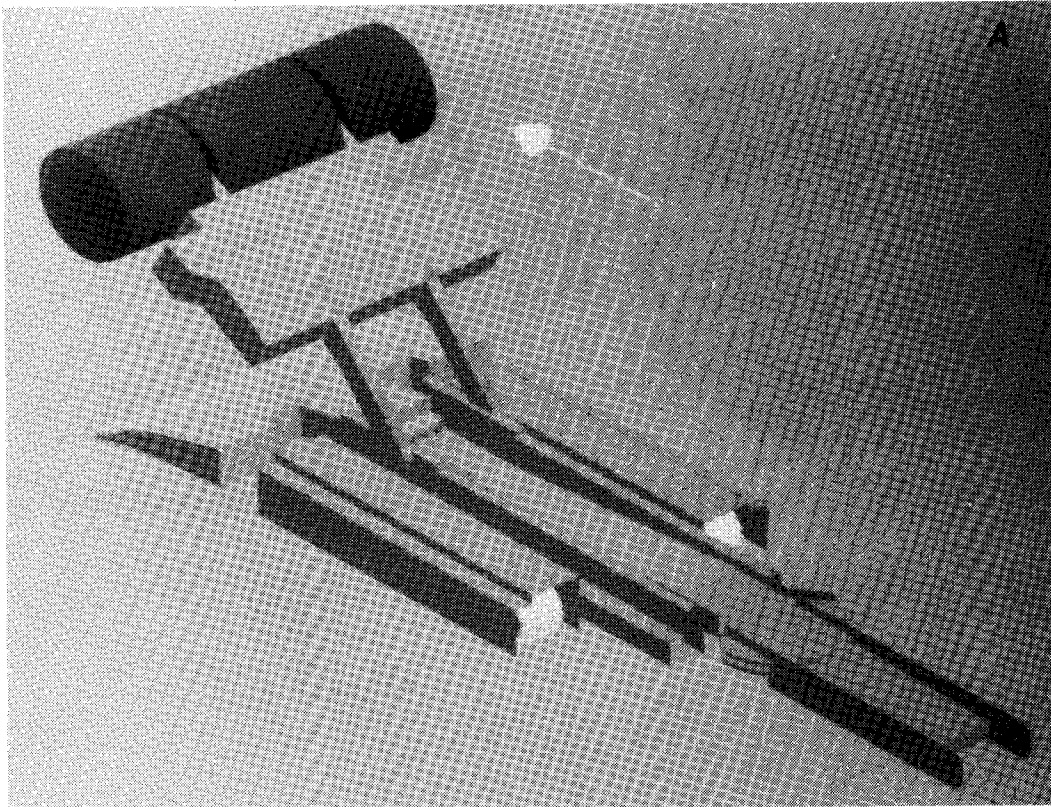


Figure 11.—Change in heading or direction. A, Straight arrow means no change; B, right-curved arrow shows change (photographs taken from 3-D computer graphics monitor).

PRE-MINE-TEST EXPERIMENTS

Experiment One

A computer-controlled field test experiment was graphically simulated before researchers performed it in the mine. The simulation allowed researchers to examine the motion and actions of the machine before actual in-mine tests. A command script written for the experiment was transformed into an applicable input data file for the simulator. A study of the graphics simulation showed that each machine-driven device finished its movement before another device started; this raised a question as to the sequencing of machine commands. Why not command machine devices powered electrically and hydraulically to operate simultaneously? Changes were made to the command script so that electrically powered functions (tramming) occurred while hydraulically powered functions (shearer or conveyor positioning) were being done. Using simulation saved researchers test time by making changes before actual mine tests; engineers also gained confidence in test result expectations.

Experiment Two

A mining machine's cutting cycle was graphically simulated for a distance of 20 ft (6.096 m), which was defined as the "perfect cut." The results of this simulation will be compared with results of an actual 20-ft (6.096-m) cut performed in a mine. Researchers want to study how machine actions during the simulated perfect cut differ from those during actual cuts. Another simulation was accomplished by using the perfect cut, which included a wireframe model of an entry generated from actual cross-sectional measurements of an entry at a mine. This simulation illustrates that the simulator can simultaneously mimic the machine's cutting actions and display the machine within the resulting entry. Studying such simulations will yield information to assist researchers in developing effective command scripts to efficiently control the machine.

POST-MINE-TEST EXPERIMENTS

Experiment One

Researchers simulated actual field test data representing a pendant data file to observe the various control commands provided by machine operators. The simulator, through 3-D graphics representation of data, answered questions about the data that could not be answered when studied by using only X-Y plots. Studies of X-Y plots

suggested several possible scenarios as to how the machine was trammed into position, but the 3-D graphics simulation left no question as to how the machine got to the position. Each machine operator varies in style and technique when operating a machine during mining cycles. For example, some operators use the shearer as leverage to adjust machine position without the use of tramming. Simulation compares machine tramming and appendage control among several machine operators, but comparing the operator style and technique is impractical using X-Y plots. These observations helped researchers understand the control operations of machine operators and to develop the command scripts to control the computer-assisted machine.

Experiment Two

Researchers simulated laser-based navigation field test data. The machine tram locations were acquired by the laser-based navigation system rather than by pendant data. Researchers observed the x, y, and h of the machine through the simulator, which assisted in understanding the tram control operations during a command-script test session of the machine. The shearer and gathering head control actions were also observed. Basically, this experiment illustrated the versatility of the simulator by showing its ability to accept input data from a laser-based navigation system.

OTHER EXPERIMENTS

Experiment One

There has been a question as to the significance of the stab-jack action on the other machine appendage positions. Investigators could not perform accurate measurements on the computer-assisted mining machine to answer this question because the machine was in a mine for field tests. However, by using the simulator, investigators examined the shearer cutting motion when the stab-jack is in the full down position. The preliminary results show that the stab-jack causes the rear of the mining machine to lift approximately 4.93 in (12.522 cm). This in turn lowers the cutter drums by 2.65 in (6.731 cm). Subsequently, the drum maximum height is reduced from 125.9 in (319.786 cm) to 123.25 in (313.055 cm). There are no sensors on the computer-assisted mining machine to detect this offset. The offset effect on the gathering head pan is not significant because the pan is usually in the float control mode. However, the conveyor tail distance from the ground is increased approximately 8.93 in (22.682 cm) when the conveyor tail is centered.

Experiment Two

During a simulation of a perfect cut, researchers were able to observe the action of the cutter drums through a line-tracing feature. This feature, offered by the Cim-Station utility, showed single line traces of the cutter drums' motions. These traces, when observed from side and top views, illustrate a cross-sectional view of the entry being formed by the cutting process. Researchers found this a useful graphical image to help study the up, down, and lateral movements of the cutter drums from machine operator's or command script's control. In addition, Bureau engineers are examining the use of this line-tracing feature to determine, through simulation, how much coal is extracted. Simulated productivity (coal extracted) can be a parameter by which researchers measure the efficiency of command scripts used to control a computer-assisted machine.

TECHNOLOGY TRANSFER

Technology transfer (TT) is a significant step in the research and technologic investigations conducted by Bureau personnel. It allows engineers to disseminate the results of their research to industry for critique, and contributes to the search for the best mining system for the future. Researchers plan to prepare video tapes that depict the current accomplishments of the 3-D computer graphics modeling and simulation efforts for subsequent TT distribution. The tapes will show the modeled continuous mining machine and the simulated operation of the stab-jack, shearer, gathering head, conveyor, and crawlers. Also included on the tapes will be applications illustrating several uses of 3-D graphics simulation to assist in research investigations of machine guidance, navigation, and control of computer-assisted mining machines.

SUMMARY

The Bureau has a graphics simulator for a continuous miner that allows researchers to test experimental software for controlling the functions of a continuous mining machine. Researchers based the simulator's initial requirements on the functions of a computer-assisted Joy 14CM9-10D continuous miner. Simulated functions of the continuous miner include machine motion, appendage motion, machine position, and machine sensors. The simulator reads data files generated in the laboratory or in a mine using an autonomous mining machine. The data files contain information on continuous mining machine position and motions of tram and appendages (shearer, gathering head, conveyor, and stab-jack). Features of this initial simulator are as follows:

- It displays active text, text that updates continuously according to the motion or activity being simulated at the time.
- It can exhibit all tram motion fundamentals (forward, reverse, and turns).
- All appendages emulate closed-loop computer position control.
- To indicate the motion of rotating cutter drums or conveyor chain, the simulator is programmed to change their colors when they have been activated to rotate.
- It reads data files containing machine coordinates that are obtained from a laser-based guidance system or pendant information obtained from a data acquisition system used to record all control commands performed on the mining machine.

- It simulates the yaw, pitch, and roll of the machine from any reference point. This reference point can be anywhere on the machine model or another modeled object.

Examples of using 3-D graphics computing as an engineering tool to help evaluate new technologies for computer-assisted mining systems illustrate how 3-D graphics visual techniques redefine the way researchers examine data. These techniques are significant because:

- The simulator allows researchers to examine the motion and actions of the machine before or after actual in-mine tests. These observations helped researchers understand the control operations of machine operators and develop command scripts to control the computer-assisted machine.
- The simulator, through 3-D graphics representation of data, answers questions about the data that cannot be answered using only X-Y plots. For example, studies of X-Y plots suggested several possible scenarios of how the machine was trammed into position, whereas graphics simulation identified which scenario was correct.
- The simulator allowed investigators to perform accurate measurements on the computer-assisted mining machine to answer questions about effects of the stab-jack action on other machine appendage positions. If researchers had to conduct similar measurements in the mine, one can speculate that it might have been hazardous for personnel, caused interruptions to scheduled in-mine testing, and resulted in inaccurate measurements.

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