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PHYSICAL SIMULATION TESTING OF ARMAMENT SYSTEMS

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The Kieth L. Ware Simulation Center located at Rock Island Arsenal has facilities and equipment that provide its users unique, valuable, and economical armament system test capability. The center contains large physical simulators mounted in an indoor firing range. This provides facilities to test fire armament systems while they undergo realistic simulation of field conditions. Ware also contains extensive data acquisition and reduction equipment. Where applicable, Ware facilities provide an economical alternative to field testing. Centerpiece of the facility is a six degree of freedom simulator capable of mounting and moving structure weighing up to 18,000 pounds. Test programs have been conducted in which the AH-1 Cobra and AH-64 Apache helicopters have been mounted on the simulator. In both programs, results were obtained which correlated with flight test data. The Ware facilities are available for use by other government or commercial concerns.					
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INTRODUCTION

WSC Mission

One of the missions of the Army Armament Research Development and Engineering Center (ARDEC) is armament system development. Helping support this mission is Close Combat Armament Center's (CCAC) Ware Simulation Center (WSC) located at Rock Island, IL. The general WSC function is to manage, maintain, and operate a physical simulation test facility. Purpose of this facility operation is to obtain data on an armament system while it is subjected to realistic simulation of the environment in which it must operate. This data is needed for the specification, design, development, and modification of weapon systems.

WSC Facilities And Equipment

WSC facilities and equipment are well suited to economically obtain armament system data. The center, located in Building 25 at Rock Island, IL (Figure 1), contains two 1000 inch (25.4m) and two 100 meter indoor ranges along with associated data acquisition and reduction and support rooms (Figure 2). Fired projectiles in each range are caught in a sand pit at its back. Each range and sand pit is designed to allow firing of target practice ammunition up to 30mm and grenades up to 40mm with dummy projectiles.

The 100 meter ranges which have limited data acquisition facilities are used for tests which only require a minimum of data to be taken. As shown in Figure 2, the 1000 inch ranges, on the other hand, have large areas available to set up instrumentation and data acquisition. Consequently, the more elaborately instrumented tests are performed in these ranges.

A large environmental chamber is located in the front end of one 1000 inch range. Temperatures between -70 degrees Fahrenheit and +155 degrees Fahrenheit (-57 degrees Celsius and +68 degrees Celsius) can be produced in this chamber. This allows armament systems to be live fire tested while temperature conditioned and fully instrumented.

Two physical simulators are located at the front of the other 1000 inch range. This range is 25 feet (7.6 meters) wide and 22 feet (6.7 meters) high. The majority of WSC testing is performed in this range using the simulators to provide realistic emulation of the field conditions which the armament systems will encounter.

Advantages of Physical Simulator Laboratory Testing

The ultimate aim of military system testing is to determine if that system can successfully perform in combat. Further, if it is determined that a system will not perform successfully, the test data should indicate what areas need improvement so that the system will be successful in the future.

Due to the high cost of fielding a system and retrofitting fielded equipment, testing is performed throughout development to insure that combat ready equipment is produced. Currently, most development testing of helicopter armament systems consists of costly and time consuming field testing and simple firing tests from hard mounts. The hard mount tests fail to assess the interaction between the weapon, its mount and the vehicle, nor do they provide a realistic environment in which the system must ultimately perform. Consequently, a considerable amount of field testing is required to identify and solve problems which occur because of the interaction between the weapon system and its environment, and thus permit successful combat operation.

Field testing of both airborne and ground vehicle armament systems is expensive and time consuming. In each case test vehicle support represents the majority of the field test cost. This cost includes material needed for vehicle test operation such as fuel, ammunition and spare parts and labor for the flight and ground support crews. In addition to vehicle support, labor costs are incurred by providing the range support personnel who accomplish test administration, safety, range operation and data acquisition and reduction.

Vehicle field testing also requires a substantial amount of time. First, considerable time is needed to properly prepare the vehicle for test flight or ground operation. Second, time will be needed to adequately install the required instrumentation. Finally, time will be lost due to vehicle downtime and weather delays.

Physical simulators can provide a realistic test environment of the weapon-gun-vehicle interaction and some vehicle flight or ground conditions, and, thus, can be used in lieu of some field testing for vehicle armament system development. Where applicable, physical simulation has significant advantages over field testing. These advantages include considerable cost and time savings, test condition control and test repeatability.

Cost savings are realized since material and personnel do not have to be purchased to maintain and operate a vehicle. Also, the number of required range support personnel is much smaller in a simulator range compared to a field test range.

One source of time savings is in equipment downtime. Since physical simulators are considerably less complex than operational vehicles, they have much less equipment downtime. Another time savings is available if the physical simulator and range is contained within a controlled environment as it is at WSC. In this case, no time is lost due to weather delay as it can be in field testing.

When a physical simulator is located in a controlled environment it also provides the advantages of test condition control and repeatability. The test condition includes not only the weather environment but also the system mounting conditions and motion input. In a physical simulator range the weather environment is provided by the indoor range conditions and the mounting and motion inputs are produced by the simulator set up.

When both the range and simulator can be controlled, the test condition can be controlled and repeated as desired. This control provides significant advantages to the tester. Within limits of the equipment, conditions can be set and varied as needed to test the system. Also, the test conditions can be repeated from one test to another. This is a definite advantage when tests must be repeated with competing systems as is often done in development programs.

DESCRIPTION OF WSC EQUIPMENT

WSC contains several individual pieces and systems of equipment that allow the facilities to be used advantageously by obtaining armament system data in a laboratory setting. Physical simulators apply realistic field conditions to the system under test while a modern data acquisition and reduction system gathers and processes the data. State of the art special data acquisition systems allow significant mechanical information about tested hardware to be obtained quickly and accurately.

WSC Physical Simulator Descriptions

Six Degree Of Freedom Simulator

The largest WSC physical simulator is called the six degree of freedom (6-DOF) simulator. This simulator can hold helicopter fuselages or armored personnel carrier turrets and provide simultaneous vertical, pitch and yaw motion. While imparting this motion the simulator can also withstand firing impulses up to 140 lb-sec (620 N-sec) from weapons mounted to it directly or on attached vehicles.

The 6-DOF simulator, shown in Fig. 3, consists of a fork structure attached to a large tower. For stability, sand is placed inside the tower to increase its weight. A gimbal system allowing controlled pitch and yaw motion is mounted between trunnions that are attached to the fork structure. Six actuators are connected in a triangular configuration between the gimbal system and a mounting platform. Vehicles or weapon systems are attached to this platform. A diagram of the simulator components is shown in Figure 4 and its list of characteristics is given in Table 1.

TABLE 1. CHARACTERISTICS OF 6-DOF SIMULATOR

Maximum Suspended Weight	18,000 lbs. (8200 Kg)
Distance From Floor To Mounting Surface	8.1 feet (2.5 m)
Pitch Motion	+45, -10 degrees
Yaw Motion	+75 degrees
Weights	
Tower	
Structure	46,000 lbs. (20,900 Kg)
Sand	108,000 lbs. (49,000 Kg)
Fork Structure	32,000 lbs. (14,500 Kg)
Gimbal	28,000 lbs. (12,700 Kg)

The simulator uses hydraulic power and is electronically controlled. Hydraulic power of 240 gallons per minute (900 liters per minute) at 3,000 psi (20,700 Kpa) is provided by two 250 Hp (186 Kw) pumping motors.

The spring rate and damping ratio of the mounting platform and its attached load's response to firing impulse input is controlled in six degrees of freedom by controlling the trigonal actuator response. These actuator responses are held at the set values by an adaptive electronic control system.

Spring rates can be set between 250 and 250,000 lbs/in. (44 to 44,000 KN/m) and damping ratios can be set between .1 and 1. Some limitations exist on what spring rates can be provided in a given degree of freedom based on what was set in another degree of freedom. The simulator system notifies the operator of these limits during the set-up operation.

Besides providing spring rate and damping response, the six trigonal actuators can be used to impart vertical motion to the attached load. While actuator travel of 3 inches in each direction from the neutral position is possible, the actuators are usually used to impart low magnitude sinusoidal motion to the load. This is used to simulate the vibration present in actual helicopters due to the rotor blade motion. The frequency of this vibration is typically the number of blades times the revolution speed of the rotor. In the Apache the vibration frequency is 19.6 Hertz. The 6-DOF simulator can produce vertical vibration input up to 50 Hertz.

In addition to the spring rate and damping setting and the vertical motion, the 6-DOF simulator can also simultaneously supply pitch and yaw motions to its attached load. The pitch motion is produced by a large hydraulic actuator, while the yaw motion is produced by a hydraulic motor mounted atop the simulator. The yaw and pitch motion limits given in Table 1 are with no load attached. With a long load attached such as a helicopter fuselage tighter motion limits may be imposed by the range walls, floor and ceiling. With the Apache fuselage attached, the pitch limits were +35 and -10 degrees and the yaw limits were +25 degrees.

The velocity and acceleration magnitudes that can be produced by the 6-DOF simulator actuators are dependent on the attached load. Previous testing with a Cobra helicopter fuselage attached to the simulator has shown what the simulator can produce with a vehicle load. In vertical vibrations the triangular actuators could produce double displacement magnitude of 4 inches (10 cm) at 0.2 Hertz and accelerations of 1 g (9.8 m/sec) at 50 Hz. In yaw angular velocities of about 8 degrees/second from 0.3 to 6 Hz are possible while in pitch double amplitude displacement of 18 degrees at 0.3 Hz down to 0.1 degrees at 5 Hz can be achieved.

Due to the complex mathematics involved with the simulator geometry, interface with a minicomputer is required for both simulator initial set up and real time operation. A Data General S/140 Eclipse minicomputer is used for this purpose. A FORTRAN program has been written to make all necessary calculations and is implemented on the computer.

The computer program output provides the data required for the triangular actuator control system to produce the desired performance. Essentially, the control system produces a desired mass-spring-damper system performance from the actuators. In order to operate the control system it needs to know in real time the desired mass, spring rate and damping ratio for each actuator.

Two parameters remain constant during simulator operation. One, the damping ratio, is input by the operator during simulator set up. The specification of the other parameter, the spring rate, is more complex and requires computer assistance. Due to triangular actuator system symmetry only three spring rates can be freely chosen among the six degrees of freedom as once three are chosen the other three are constrained.

During simulator set up the computer program requests the operator to choose the three degrees of freedom in which he wants to specify a spring rate and in which order from the available six: pitch, yaw, roll, x, y and z. The program then handles all necessary calculations and outputs the required spring rates for each of the six actuators to produce the desired performance.

For proper operation, the mass input to the control system for each actuator must be the effective mass felt by the actuator due to the attached load. During simulator set up the computer prompts the operator to input information about the size, weight and center of gravity of the attached load. From this data the computer calculates the effective mass present at each actuator.

Since the effective mass due to the load will change at each actuator as the load is moved in pitch and yaw, the mass calculations must be performed in real time and communicated to the simulator during its operation. The system does this by using analog to digital converters to communicate the simulator pitch and yaw position to the computer, have the computer calculate the effective mass felt at each actuator at this position and communicate these mass values to the simulator control system using digital to analog converters.

The computer is also used to program the simulator actuators to perform desired motions. First, the triangular actuators can be programmed to produce roll motions or put the attached aircraft in realistic flight orientations. Second, the pitch and yaw actuators can be programmed to produce flight motions, such as turns, that are within the actuator velocity and acceleration capabilities.

Multi-Mode Weapon Mount Impedance Simulator

The multi-mode simulator shown in Figure 5 is a tool for measuring weapon characteristics as a function of mounting conditions. This device provides a simulated two mass-spring-damper system response to firing impulse inputs in one degree of freedom. The simulator characteristics are listed in Table 2.

TABLE 2. Multi-Mode Simulator Characteristics

Weapon Weight Range	10 - 100 lbs (4.5 - 450 Kg)
Maximum Projectile Impulse	140 lb-sec (63 Kg-sec)
Maximum Recoil Force	16,000 lbs (7200 Kg)
Spring Rate Range	100 - 100,000 lb/in (18 - 18,000 KN/M)
Damping Ratio Range	0.05 - 1.0

With proper inputs, a two mass-spring-damper system can accurately represent the multi-mode response of a fielded weapon mount. One mass spring and damper simulates the response between the gun and vehicle due to the weapon and gun mount interaction. The other set of parameters represents the response seen between vehicle and ground. Typically the vehicle ground response requires a stiffer spring rate equivalent than the gun-vehicle response. Accurate field gun mounting simulation is achieved when the two mass-spring-dampers are taken in series as the multi-mode simulator does (Figure 6).

Experience has shown that mounting conditions do affect gun performance. The multi-mode simulator can be used to portray existing field mounting conditions or it can be set to several different conditions to discover the best mounting conditions for a given gun. This information can be used to devise an optimal gun mount in a system under development.

Data Acquisition/Reduction System Description

An automated data acquisition and reduction system is available at WSC to gather data from the system under test. A number of sensors are available to measure a variety of parameters. The sensor signals are collected by the acquisition system and stored on analog and digital tape. A digital data reduction system produces data plots in engineering units within minutes of test. This test data can be sent to remote terminals throughout the country for immediate access and evaluation by interested off-site personnel. A block diagram of the

WSC data acquisition/reduction system is shown in Figure 7. Details of the component parts of the system are provided in the following sections.

Data Acquisition System

The data acquisition system includes the transducers which convert system under test phenomena into electrical signals, equipment used to capture and condition these electrical signals and devices used to record these signals. WSC has a wide variety of transducers that are used to measure many different system phenomena. Examples include accelerometers, strain gages, linear variable differential transformers, force washers resolvers and current shunts.

Transducer outputs are wired into a panel on the range wall. This panel is connected via underground cabling to signal conditioning equipment in the data acquisition room. Capability exists to replace the transducer outputs at this point with known calibration signals. This allows the calibration signals to be subjected to the same conditioning that the transducer signals are during test. The system thus provides a means for accurate test data calibration. In test data acquisition operation the signal conditioning equipment amplifies and filters the transducer outputs to produce a readable and accurate signal.

Two methods exist to record test data in accordance with test and customer needs. One recording medium is analog tape. Two analog tape recorders and multiplexing equipment are available at WSC with a present total capability of recording 60 data channels. The other recording medium is digital computer disk using analog to digital converters. Currently, up to 16 data channels per test can be processed and saved digitally. The present data channel capability can be increased to 74 analog and 32 digital if necessary.

Besides transducer data, WSC also can gather video data. Closed circuit television pictures are taken of all simulator range firing tests and are viewed from monitors in the data acquisition room. Two cameras are used that can be aimed and focused remotely. Capability exists to record any video camera signal on cassette. Currently, nearly all firing tests are videotaped.

The data acquisition room is shown in Figure 8. Pictured are the control panels for the 6-DOF and multi-mode simulators as well as amplifiers, calibrators and wiring panels used for data acquisition.

Data Reduction System

The WSC data reduction system processes raw test data received through analog to digital converters from the data acquisition system to produce readable output information. This data is produced in graphic and numeric form. Graphic output is produced by a graphics terminal or an X-Y plotter while numeric data is made in tabular form by a line printer.

The data reduction system consists of a digital computer and several peripheral devices. Besides the aforementioned output devices, the peripheral equipment includes control terminals, disks, digital tape unit and a telephone modem. The system digital computer is a Digital Equipment Corporation (DEC) PDP 11/44 minicomputer which is operated through one of several control terminals connected to it at various locations throughout WSC. The bulk of the system is contained in the WSC data reduction system shown in Figure 9.

The computer can process the data and produce plots scaled in engineering units within minutes of test completion. A table of output variable values also in engineering units can be printed at the same time. Typical graphical and tabular data are shown in Figures 10 and 11.

The computer is also programmed to further process the output data by performing the useful analysis functions of addition, subtraction, multiplication and division by a constant or between channels and integration of a given data channel. All of the application software was written in FORTRAN at WSC specifically for the system.

Data can be downloaded from disk to 9 track 1600 bits per inch digital tape after test completion. Tapes are made both for WSC storage and off-site shipment in DEC machine compatible format. Tape data content is made to customer specification concerning test numbers and amount of processing.

Capability exists to transfer data available on the WSC data reduction system directly to off site personnel throughout the country. One method is to send data files built according to the customers specifications to their site via the Defense Department Network. Another method is to use available telephone modems and software that allow off-site personnel with Tektronix compatible terminals access to the WSC data reduction system.

Using either of these methods data specifically formatted to meet a customer's needs can be sent to a remote location. This permits closed loop testing wherein a customer can stay at his office, analyze the data, direct new testing and quickly converge on design solutions.

Special Data Acquisition Equipment

In addition to transducers that measure specific test variables, WSC has two larger state of the art instrumentation systems which quantify general mechanical properties of test items. One system measures dynamic motion and the other modal response.

Dynamic Motion Analyzer

Beside normal speed video capacity, WSC also has state of the art high speed videotaping capability with its Kodak Dynamic Motion Analysis System. This system can tape up to 6000 pictures per second and replay them at normal video playback of 30 frames per second or in a frame by frame mode. Two solid state video imagers equipped with remote control focus and zoom lens are available to connect to the system. The two imager outputs can be simultaneously recorded by the system.

The Dynamic Motion Analyzer equipment allows detailed slowed down views of high speed phenomena such as during gun fire. The two imagers make it possible to view two separate areas during a high speed event. One application would be to look at the helicopter fuselage and gun turret motion simultaneously during gun firing.

Dynamic motion during quick events can be quantified using the analyzer system. Using the frame by frame jog mode, motion of the item of interest such as a turret arm can be quantified by comparing its motion with the size of a known part in the same picture. A reticle can be placed on the screen to aid this process. Using two imagers and a split screen allows relative motion of two separate parts to be quantified. All quantification is automated using application software, communications hardware and a PC. The Dynamic Motion Analyzer is shown in Figure 12.

Modal Analysis System

With their Modal Analysis System, WSC personnel can find a structure's modal response using structure acceleration response to impulse input measurements. The system is comprised of a modern spectrum analyzer, microcomputer, impulse hammer and application software.

A structural analysis is begun by inputting test structure geometry to the analyzer. Impulse input is then introduced at various points on the test structure using an impulse hammer. In each case, the magnitude of the impulse input is measured by the hammer and sent to the analyzer. Acceleration response to each impulse is measured and also sent to the analyzer. When testing is complete the analysis system computer uses the input and output data to calculate the structure's transfer function or modal frequency response.

Once this frequency response is found the analysis system can calculate the test structure response to a given input. In fact the analysis system can display an animated pictorial display of what this response looks like. This provides test personnel an excellent tool to predict test structure response before an actual physical test such as a gun firing test is conducted. This allows personnel to change mounting hardware and instrumentation as needed. The modal information is also useful after a test is completed to aid the data analysis.

The modal analysis system also allows a user to input proposed structural changes to a test structure to the analyzer model. The system then predicts the modal response of this theoretically altered structure. This is a valuable capability which allows mechanical designers and analysts to develop optimal structures for mounting weapons or other hardware subject to dynamic motions.

The analysis system can also be adapted using other application software to perform control system analysis. Here the input signal and control system response are directed to the analyzer. The analyzer then calculates the control system transfer function. This capability allows personnel to analyze present control system performance and design and predict the behavior of new control systems.

PREVIOUS WSC TEST PROGRAMS

Many test programs have been conducted previously in which various WSC facilities have been used to obtain valuable data economically.

Testing From 6-DOF Simulators

A majority of test programs at WSC have used the 6-DOF simulator. Various hardware has been attached to the simulator for these programs including helicopter fuselages, turret fixtures and gun systems. In each case the simulator was used to impart realistic field conditions to the tested system as descriptive data was gathered.

Testing Using Cobra Fuselage

Several test programs were conducted using a Cobra fuselage suspended from the 6-DOF simulator as shown in Figure 13. Purpose of one program was to obtain data to evaluate and develop more precise helicopter armament systems which have smaller firing dispersions than fielded systems.

This program consisted of a series of tests. All tests were conducted with a Cobra fuselage suspended from the simulator with the Universal Turret System (UTS) in turn attached to the Cobra as in fielded aircraft. The simulator triangular actuator spring rates and damping ratios were set to obtain helicopter motion in response to gun firing emulating that seen in the field. First tests provided information on UTS hardware with which new more accurate controllers could be designed and on UTS performance with which new controllers performance could be compared.

In the second test series the new controllers were implemented on the UTS and tested. Sufficient tests were run with each controller to determine with good statistical confidence if the new controller did produce smaller firing dispersions than the fielded UTS controller. Results showed that most of the new controllers did produce smaller dispersions.

Testing with the Cobra fuselage and UTS continued when digital controllers for the UTS were developed and tested. Again, data was taken with which to compare the new controller performance with that of the fielded controller.

Another test program conducted using the Cobra and 6-DOF simulator was an effort to develop a soft recoil system for a helicopter mounted gun. This hardware, called Medium Impulse Recoil System, used hydraulic power to produce forward gun velocity at firing time. This forward momentum absorbs some of the gun recoil impulse and thus reduces the disturbance felt in the turret and vehicle. During testing, considerable recoil and gun velocity data was taken that aided in the development effort.

A third test program using the Cobra was the Precision Mount Test Fixture (PMTF) effort. In this program an entirely new turret was developed, mounted in the Cobra on the 6-DOF simulator and tested. Precision aiming techniques previously used in sights were applied to gun turrets with the PMTF. These techniques include using a coarse-fine gimbal scheme, gun fire energy absorbing coils and frictionless electromagnetic actuators. Test data taken for this program included various internal turret electronic signals that aided hardware development and firing burst dispersions that allowed PMTF performance comparison with fielded turrets.

Testing Using Apache Fuselage

A crash damaged Apache helicopter under the control of the U.S. Army Armament, Munitions and Chemical Command (AMCCOM) Maintenance Directorate was used at WSC for testing in support of a helicopter armament research and development program. A picture of the Apache mounted on the 6-DOF simulator is shown in Figure 14.

Purpose of the supported program, called the Integrated Air-to-Air Weapon (INTAAW) program, is to develop a more accurate helicopter weapon aiming and delivery system that will give Army helicopters successful air-to-air combat capability. Testing was conducted using the Apache helicopter on the 6-DOF simulator to obtain existing weapon system performance data. This data will assist new system developers and will be used to compare new system to existing system performance.

Firing and non-firing tests were conducted. The non-firing tests yielded data demonstrating turret performance undergoing step and tracking movements. Firing tests were performed with the helicopter pointed straight ahead and 20 degrees to the left, both with and without vertical vibration input simulating the effect of the rotor blade movement. Firing test data include firing dispersion, helicopter and turret motion and various turret control system signals.

Much useful information was obtained from the testing. Firing dispersion data showed that while rotor blade vibration did not significantly affect dispersion, the helicopter position during firing did. Also, analysis of the turret during gun firing using the dynamic motion analyzer indicated considerable system bending.

Testing Using Apache Area Weapon System Mount

Unfortunately, the crashed Apache helicopter is currently not available for testing new technology turret systems since it was reclaimed by AMCCOM for their maintenance training mission. Also, attempts to get another Apache fuselage for research and development turret testing have proved unsuccessful. Thus, in place of a vehicle a test fixture which holds the Apache ammunition handling system and turret was developed. This fixture is also made to attach to the 6-DOF simulator and locates the ammunition system and turret in the same position relative to the simulator center of rotation that they are in the vehicle. Fig. 15 shows the fixture mounted on the simulator.

The dynamic motion analyzer can be used to determine fixture motion during gun fire. Then, the simulator spring rate and damping can be adjusted to obtain fixture motion as close as possible to vehicle motion.

M242 Gun Vibration Test

Testing has been performed in which the 6-DOF simulator was used to apply motion to loads smaller than vehicle sections. An example is the M242 Gun Vibration Test where a M242 25mm gun was mounted into a fixture which was attached directly on the simulator. The gun and fixture mounted on the simulator are shown in Figure 16.

Purpose of the test was to determine if the M242 feed chute release buttons would move sufficiently to disengage during field operations in the Bradley Fighting Vehicle. Such disengagement would not allow ammunition to be fed to the gun which would result in a failure to fire.

The test purpose was accomplished by collecting data on weapon movement during M242 burst firing as the 6-DOF simulator applied vertical vibrations. Swept sinusoidal frequency input signals were used to drive the simulator triangular actuators to produce vertical vibrations that emulated the Bradley vehicle environment.

Firing tests were performed and the data recorded with firing bursts executed using several different amounts of ammunition chute loading. The differing chute loads simulated different amounts of ammunition in the box. Test data analysis indicated that the disengagement problem could occur with release buttons dimensioned near tolerance limits and with large ammunition chute loading.

Testing From Multi-Mode Simulator

Weapons have been mounted on and tested from the Multi-Mode simulator using its variable spring mount capability. Data gathered has included recoil force, blast pressure, rate of fire and target dispersion.

MK19 Grenade Launcher Test

A test involving the MK19 40mm Grenade Launcher was conducted using the multi-mode simulator. A picture of the MK19 mounted on the simulator for testing is shown in Figure 17. The test was conducted to determine the MK19 recoil forces transmitted to the mount trunnions and to find the effect of mount spring rate on the MK19 rate of fire.

Firing tests were conducted using several multi-mode simulator spring rate settings and data was taken. This data was to be used by mount designers for application of the MK19 on the Hummer vehicle. Results indicated that the MK19 firing rate did decrease as the mount spring rate was softened.

30mm Automatic Self-Powered Gun Test

Another test in which the multi-mode simulator was used was a test involving two 30mm automatic self-powered weapons. A picture of one of the guns mounted on the simulator is shown in Figure 18. In this testing, performance data was gathered on 30mm self-powered guns from two manufacturers. Data taken included blast pressure, rate of fire and target dispersion.

DATA CORRELATION

Data from WSC tests involving vehicles mounted on the 6-DOF simulator has been compared with operational vehicle test data to determine the correlation between simulator and vehicle test data. Such Cobra data comparisons have shown that the simulator motion of the Cobra fuselage during firing tests closely matches vehicle motion seen during hover firing. These comparisons were made at several firing rates and different helicopter attitude angles with respect to the gun.

Firing dispersions measured from Cobra simulator tests compare closely with firing dispersions measured from an operational Cobra flying in a hover. Data from Development Test IIB flight tests of the Enhanced Cobra Armament Systems showed an average burst dispersion of 3.07 milliradians using the standard UTS and M197 cannon. Firings with the Cobra mounted on the 6-DOF simulator also using the UTS and M197 with the simulator set to imitate a hover condition produced an average dispersion of 3.27 milliradians. Thus, these data comparisons have shown that firings from the Cobra fuselage on the 6-DOF simulator are sufficiently realistic to accurately assess gun and turret performance.

Some preliminary data correlation study has been performed regarding Apache testing. Data from the Gun Accuracy Improvement flight test showed peak Apache helicopter pitch of 8 milliradians during hover gun firing. Data from the simulator testing indicated a peak fuselage pitch of 4.5 milliradians during gun firing. While this

easily shows order of magnitude agreement, closer agreement can be reached in the future by adjusting the triangular actuator settings. This will be done in the upcoming Apache AWS mount testing. Further Apache correlation work will be accomplished when more field test data is received.

POTENTIAL FUTURE TEST ACTIVITIES

The unique combination of large physical simulators, indoor firing ranges and modern data acquisition and reduction equipment provide opportunity for many test activities. The 6-DOF simulator can mount and provide realistic physical simulation for many military helicopters including the APACHE and proposed LHX. In addition, a turret adapter is available that can mount armored vehicle turrets with diameters up to 56 inches on the 6-DOF simulator and provide vertical motion up to 200 Hertz. This adapter, shown in Figure 19, can provide physical simulation of a ground vehicle environment. Finally, the multi-mode simulator can produce a realistic emulation of a gun system mounting in the field.

The 6-DOF simulator with or without the turret adapter and the multi-mode simulator can be used for many programs involving armament systems testing. The tests can be performed in a laboratory setting with the test item undergoing realistic simulation of some field conditions.

WSC instrumentation systems such as the dynamic and modal analysis equipment can be used in a wide variety of applications both in conjunction with the simulators and by themselves. Possible uses include vehicle, turret and weapon motion during firing, weapon mount and other structural analysis, feed system movement during operation, autoloader function and control system analysis.

ADMINISTRATIVE INFORMATION

Facility Usage Inquiries

Ware Simulation Center is an element of U. S. Army Armament Munitions and Chemical Command's Armament Research Development and Engineering Center. The WSC facilities and personnel are available for use by government and commercial organizations. Details about using the facilities can be obtained by interested organizations by telephoning Commercial (309) 782-6868 or 782-4544 or Autovon 793-6868 or 793-4544, or by writing to:

Commander
Rock Island Arsenal
Ware Simulation Center, Building 25
ATTN: SMCAR-CCI-EW
Rock Island, IL 61299-7300

Support Costs

Charges for using WSC are based on personnel time consumed in support of the test using the hourly labor rate currently in effect. Additional charge is applied if a special test fixture or materiel must be manufactured or procured for the test. There is no separate charge for use of facilities or equipment on hand.

A typical WSC test program requires 4 or 5 support personnel. In fiscal year 89 using the labor rate of about \$50/hour this would result in a test program cost to the customer of \$10,000/week. A cost estimate can be provided to a potential customer when a scope-of-work is provided.

Location

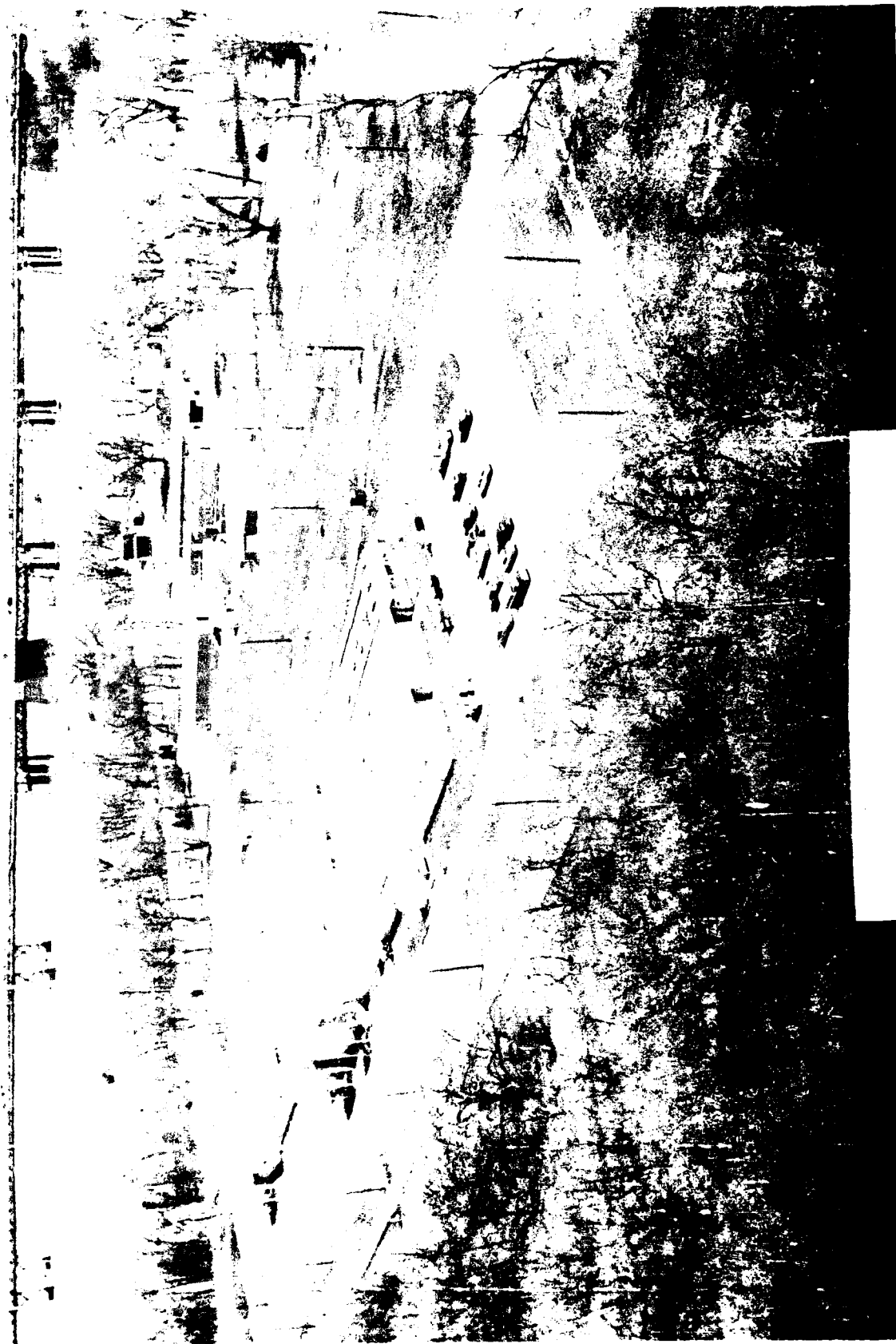
Ware Simulation Center is located at the eastern end of Rock Island Arsenal in Building 25. Rock Island Arsenal is situated on a 946 acre island in the Mississippi River on the Illinois-Iowa border. The arsenal is surrounded by a metropolitan area called the "Quad Cities" including Rock Island and Moline in Illinois and Davenport and Bettendorf in Iowa. Quad City Airport in Moline, IL which is served by several airlines provides air transportation to the area.

Overnight Accomodations

Rock Island Arsenal does not have government quarters available and hence government personnel traveling on orders need not obtain a statement of quarters nonavailability in order to be paid commercial lodging costs. Since there are many motels in the Quad City area representing most major chains, lodging should not be a problem.

Security

WSC is located within a restricted area of Rock Island Arsenal and can handle both classified and unclassified projects. WSC visitors working on unclassified projects need not send a security clearance. However, all visitors upon first entering Rock Island Arsenal should report to the visitor center to register and receive clearance to the Building 25 area for the duration of their visit.



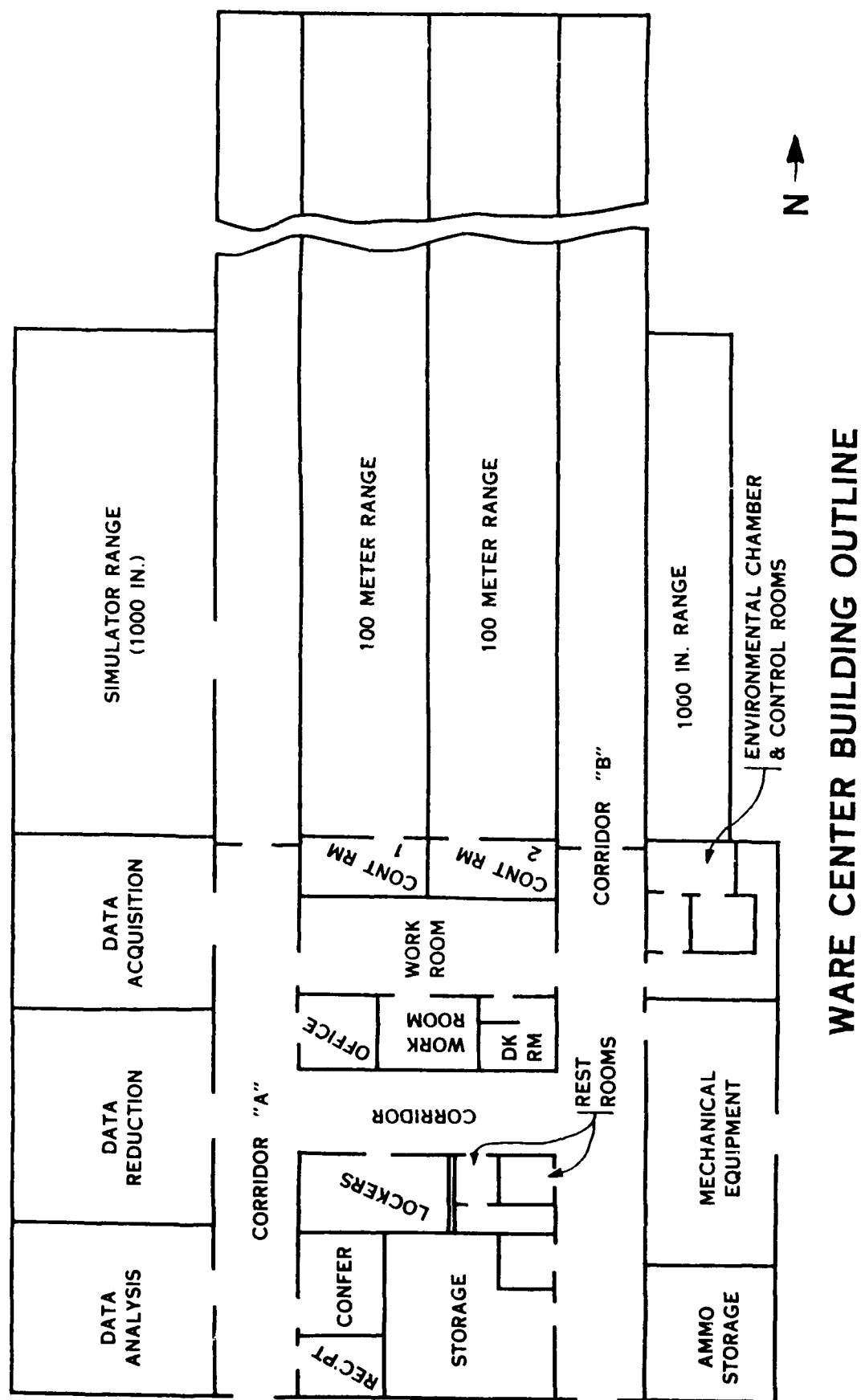
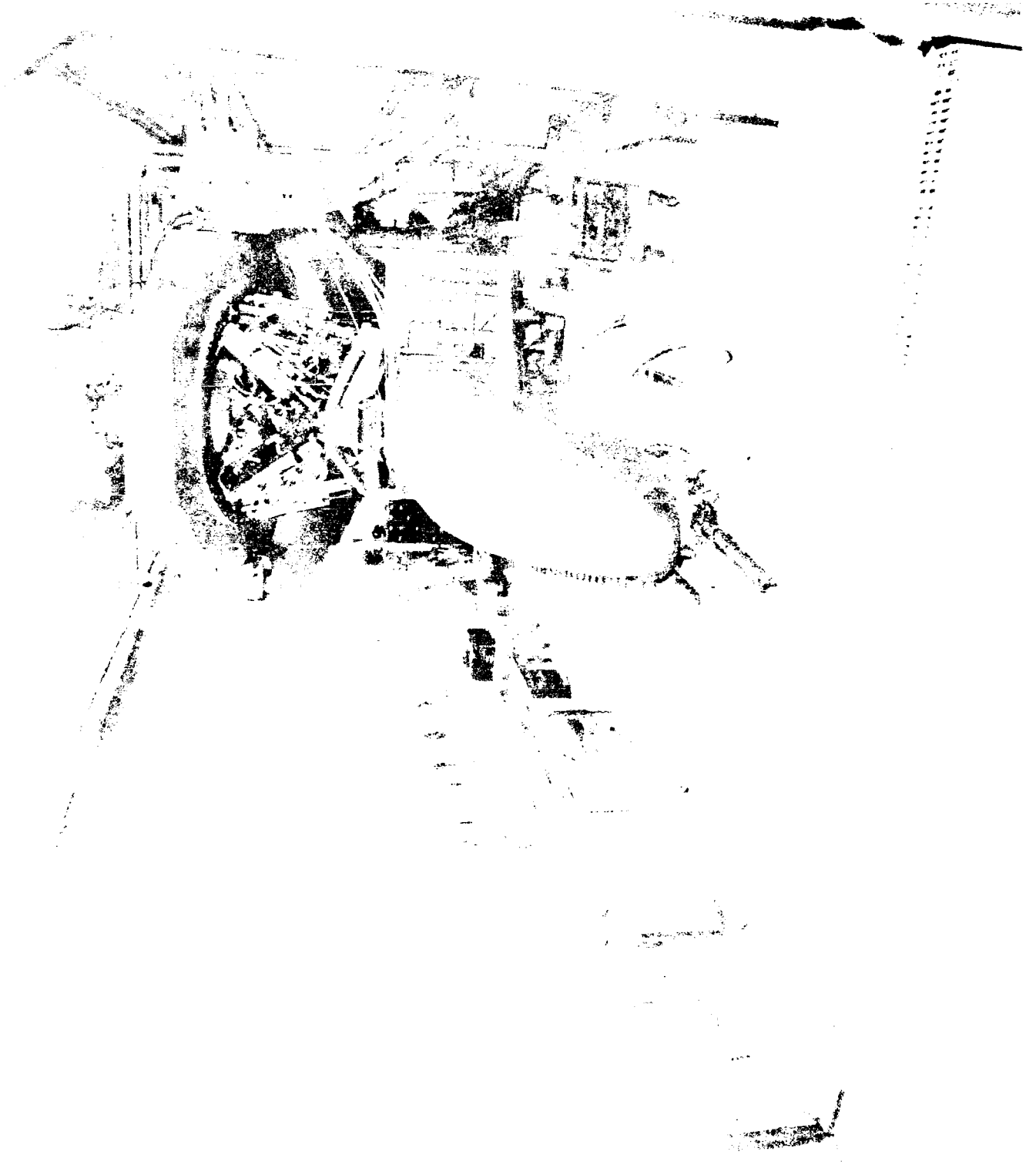


FIGURE 2: Floor Plan of Ware Simulation Center



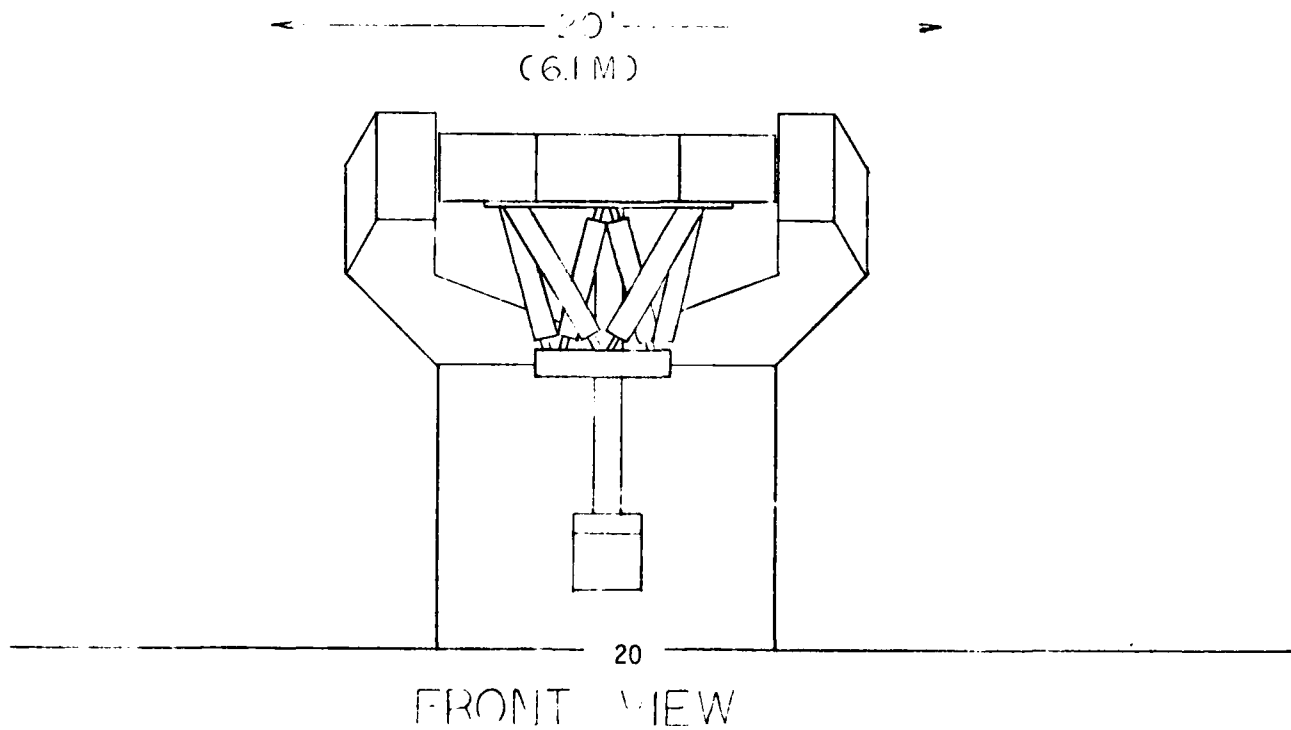
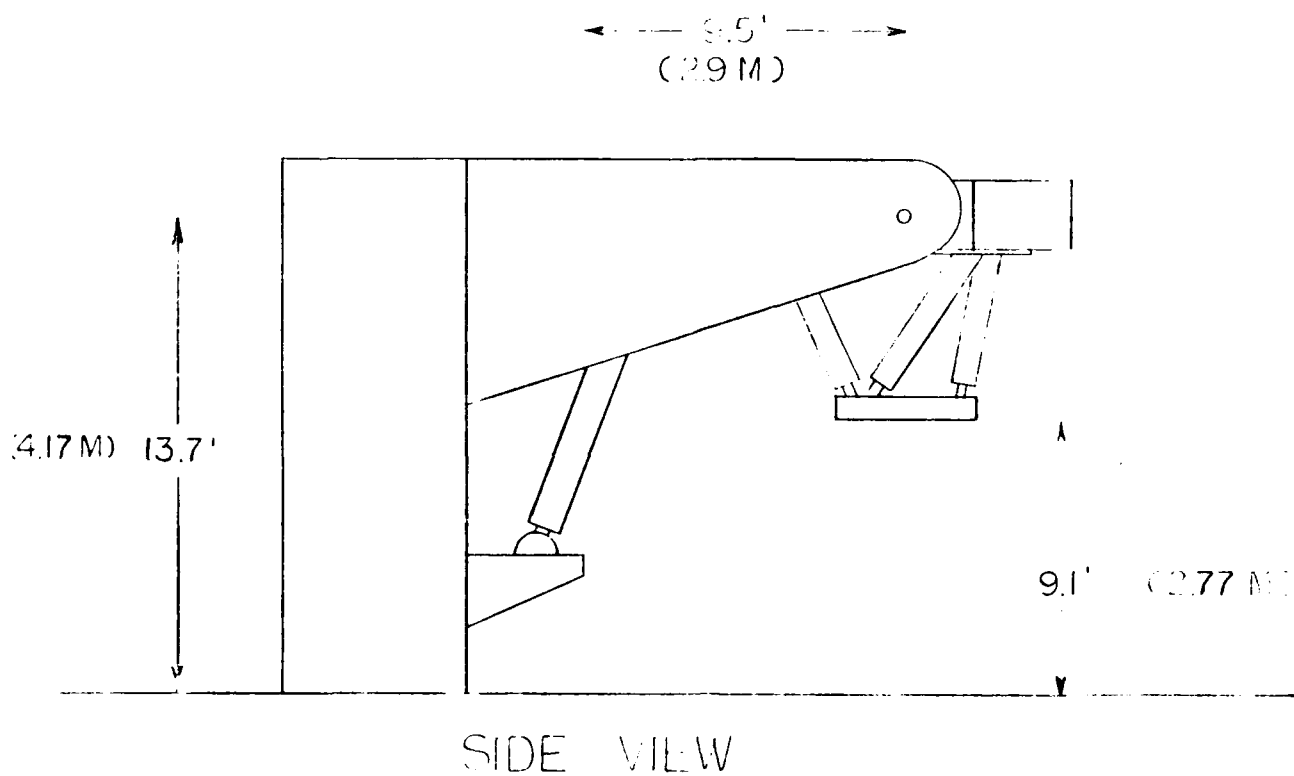
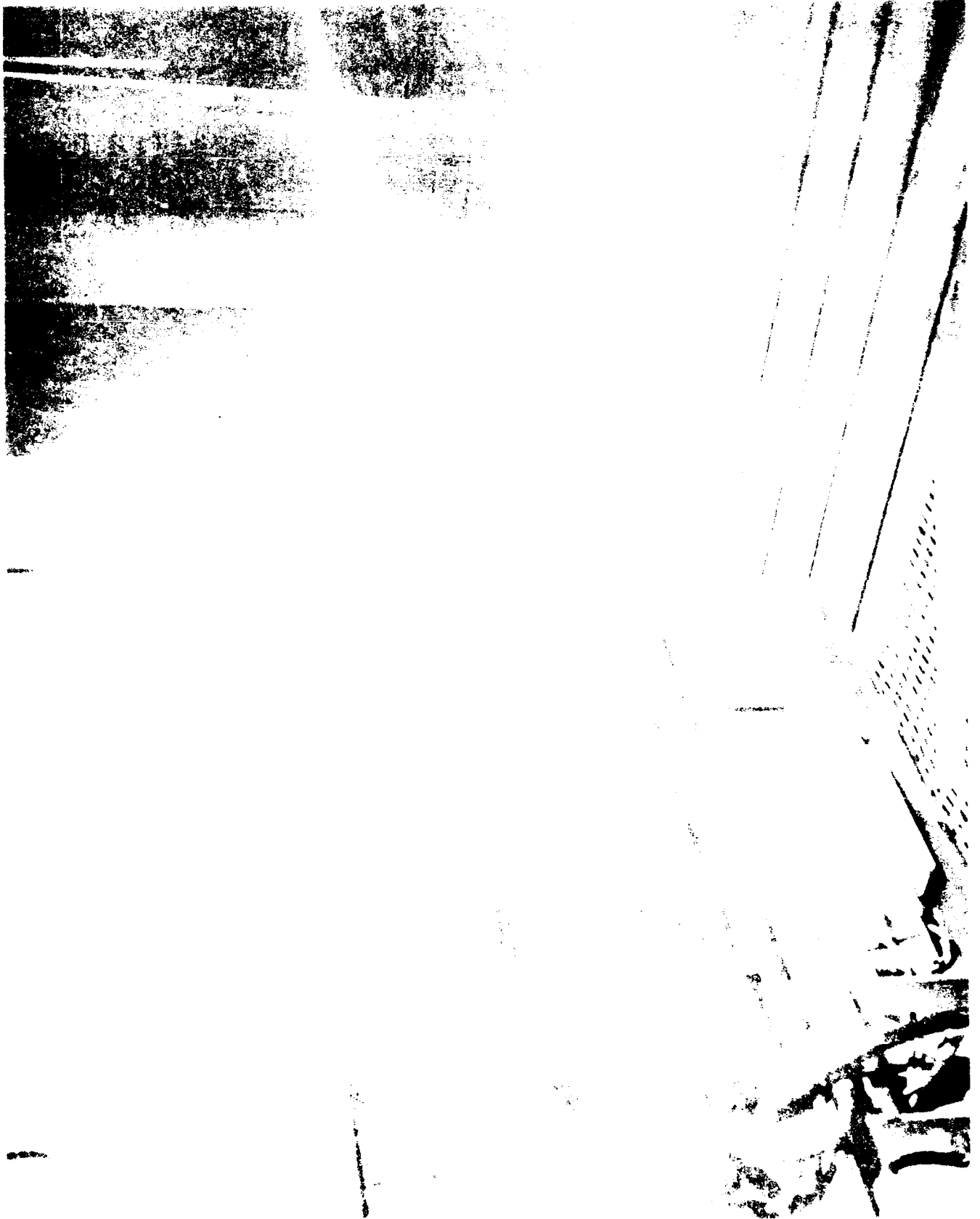
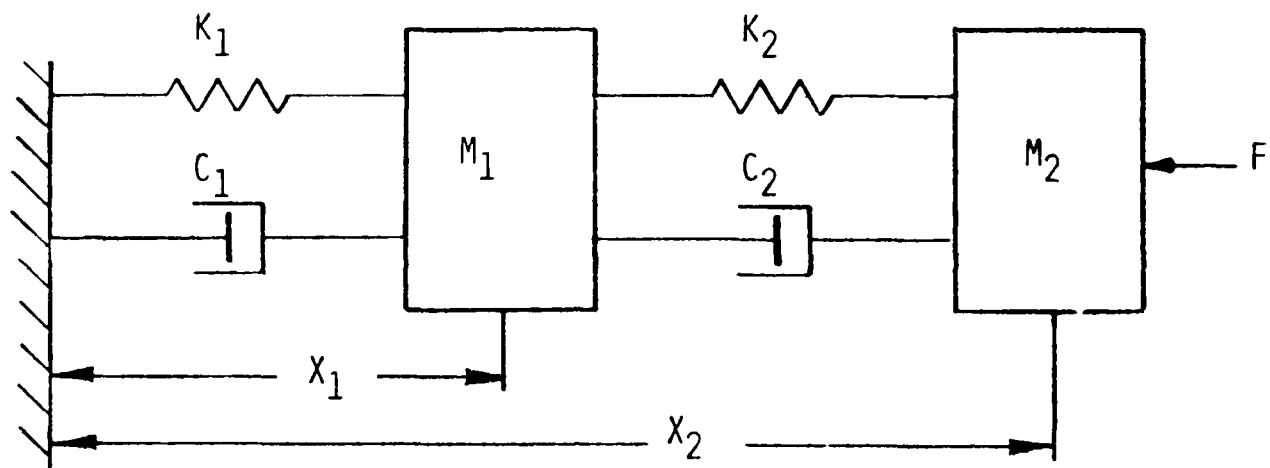


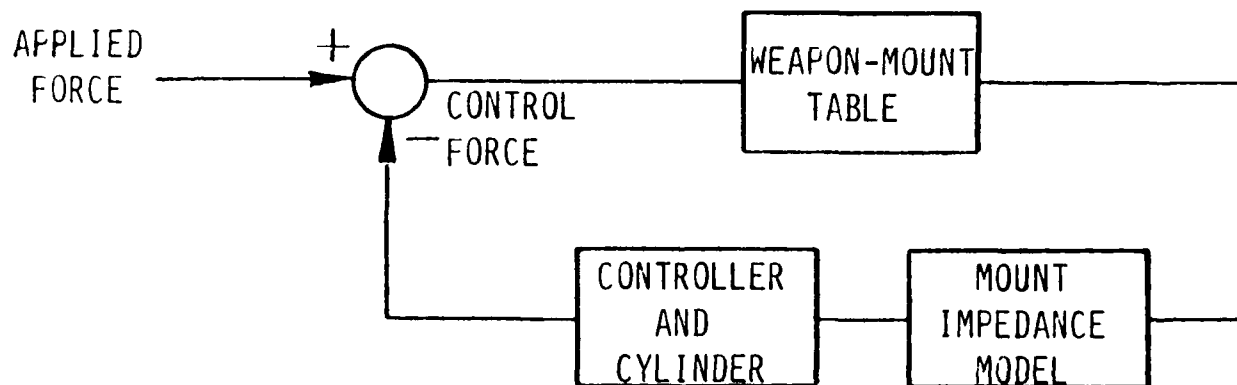
FIGURE 4: Six Degree of Freedom Simulator Diagram





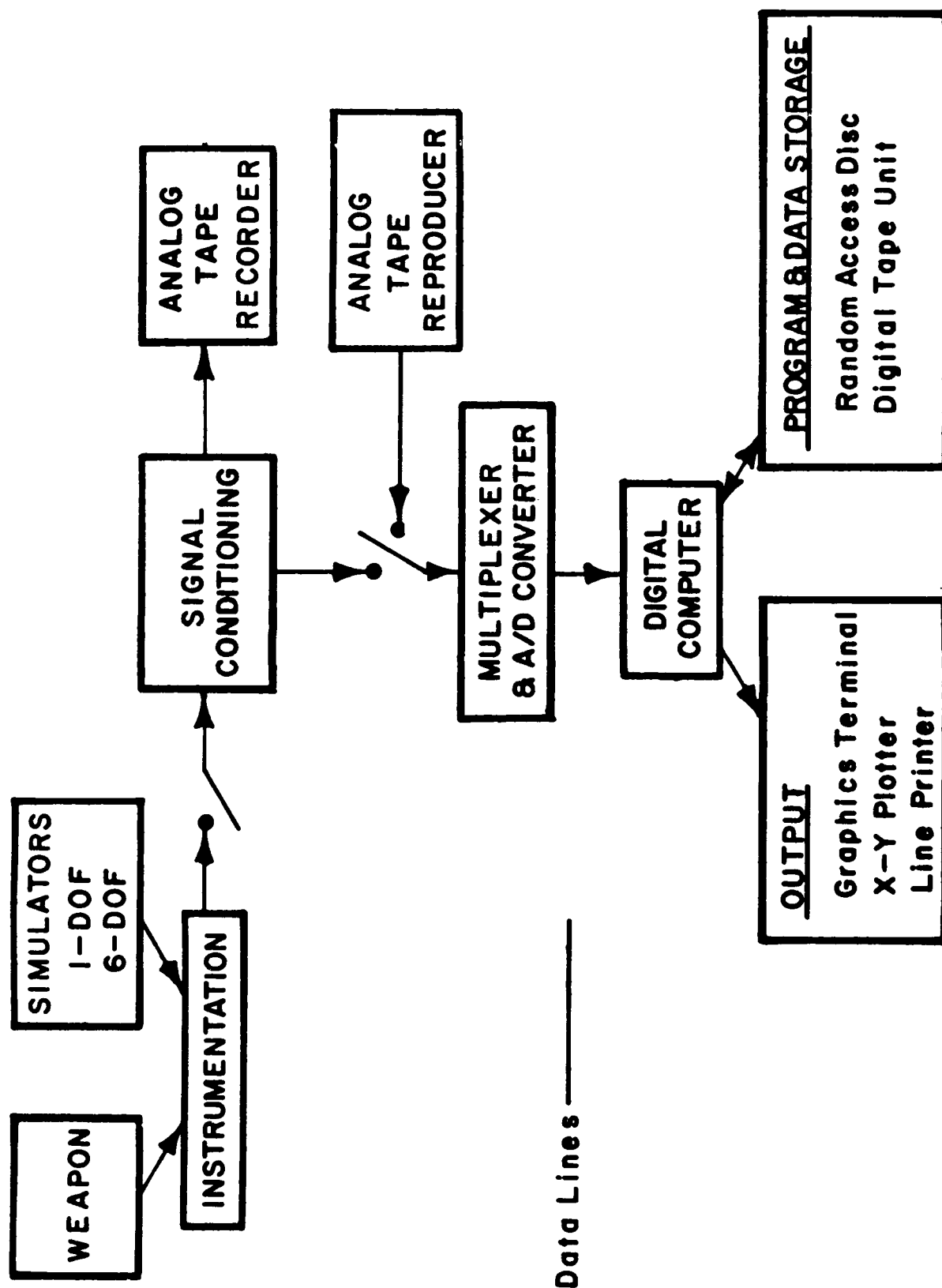
$$M_2 \ddot{x}_2 = F - K_2(x_2 - x_1) - C_2(\dot{x}_2 - \dot{x}_1)$$

$$M_1 \ddot{x}_1 = K_2(x_2 - x_1) + C_2(\dot{x}_2 - \dot{x}_1) - K_1 x_1 - C_1 \dot{x}_1$$



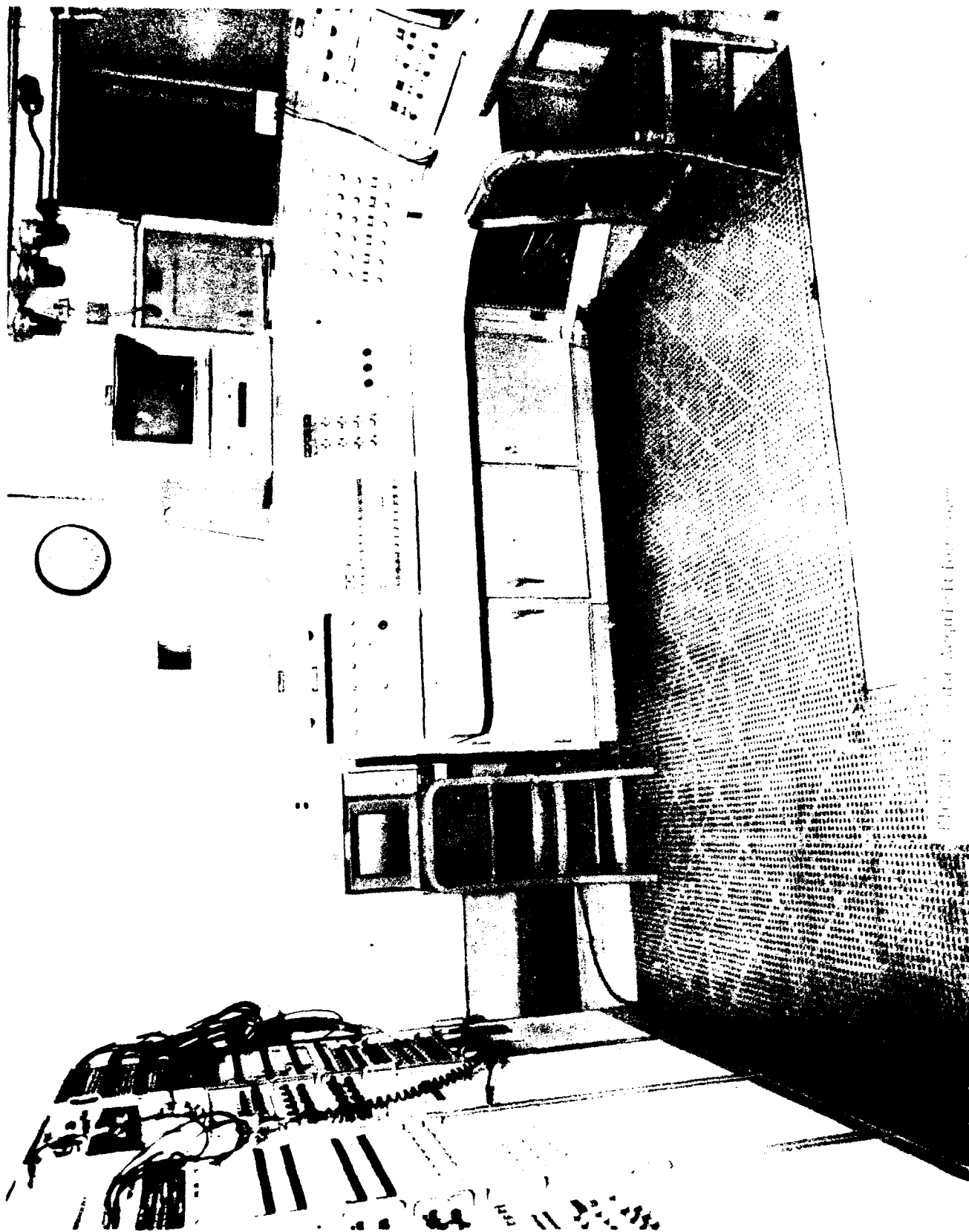
SCHEMATIC OF PROGRAMMABLE WEAPON-MOUNT IMPEDANCE CONTROL SYSTEM

FIGURE 6: Mathematical Representation of Multi-Mode Simulator



Data Lines —

FIGURE 7: Data Acquisition/Reduction System Diagram



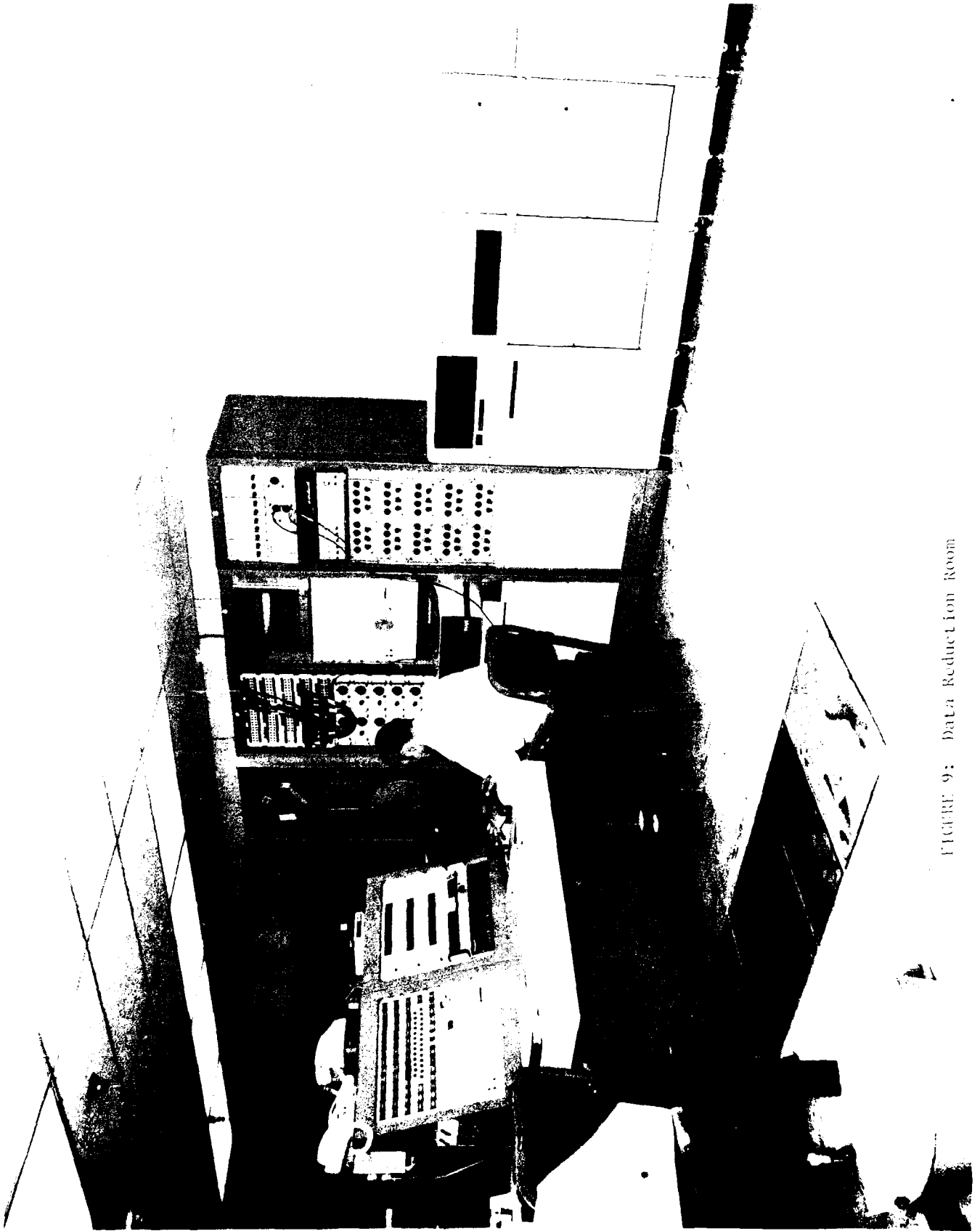


FIGURE 9: Data Reduction Room

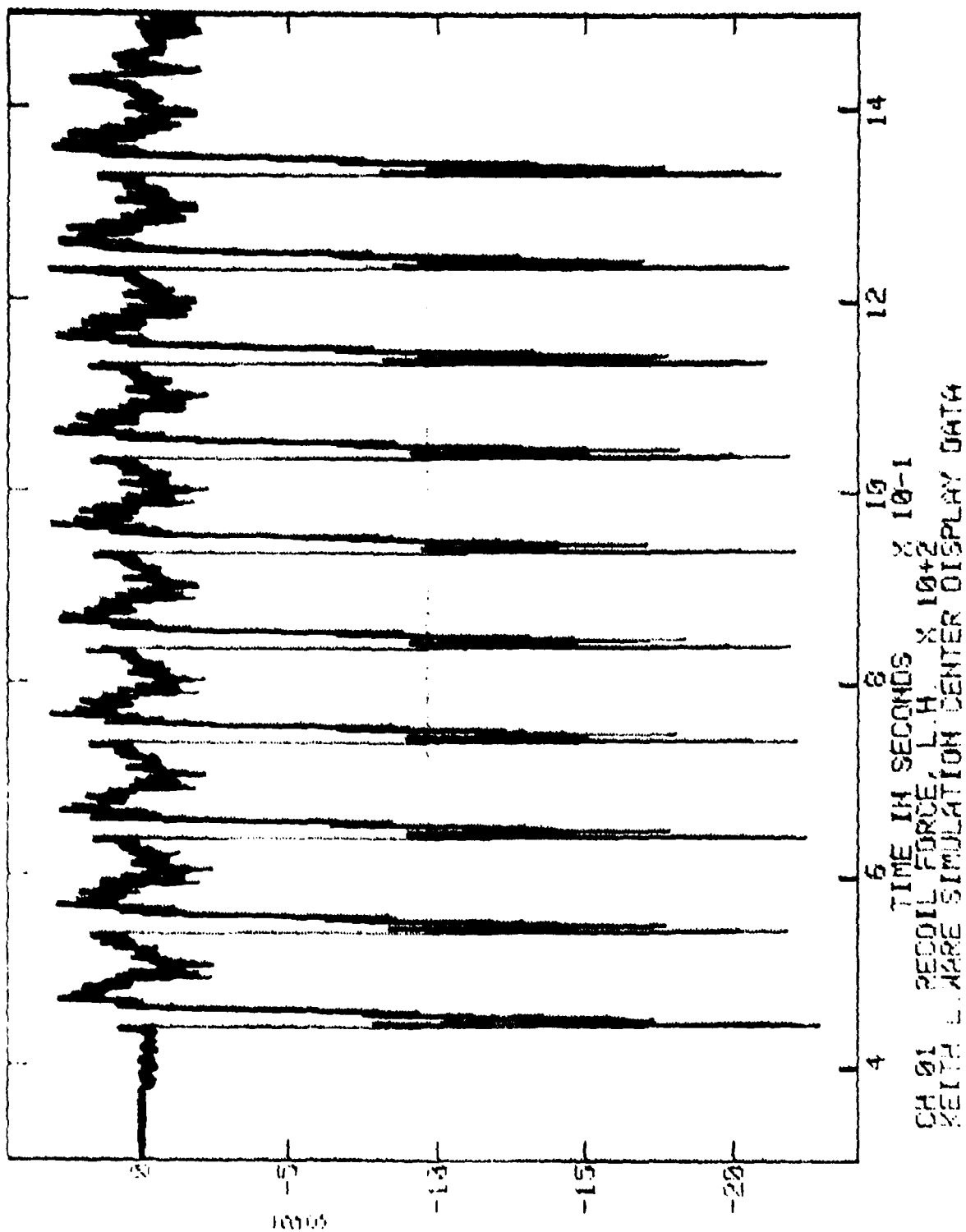


FIGURE 10a: Typical WSC Graphical Output Data

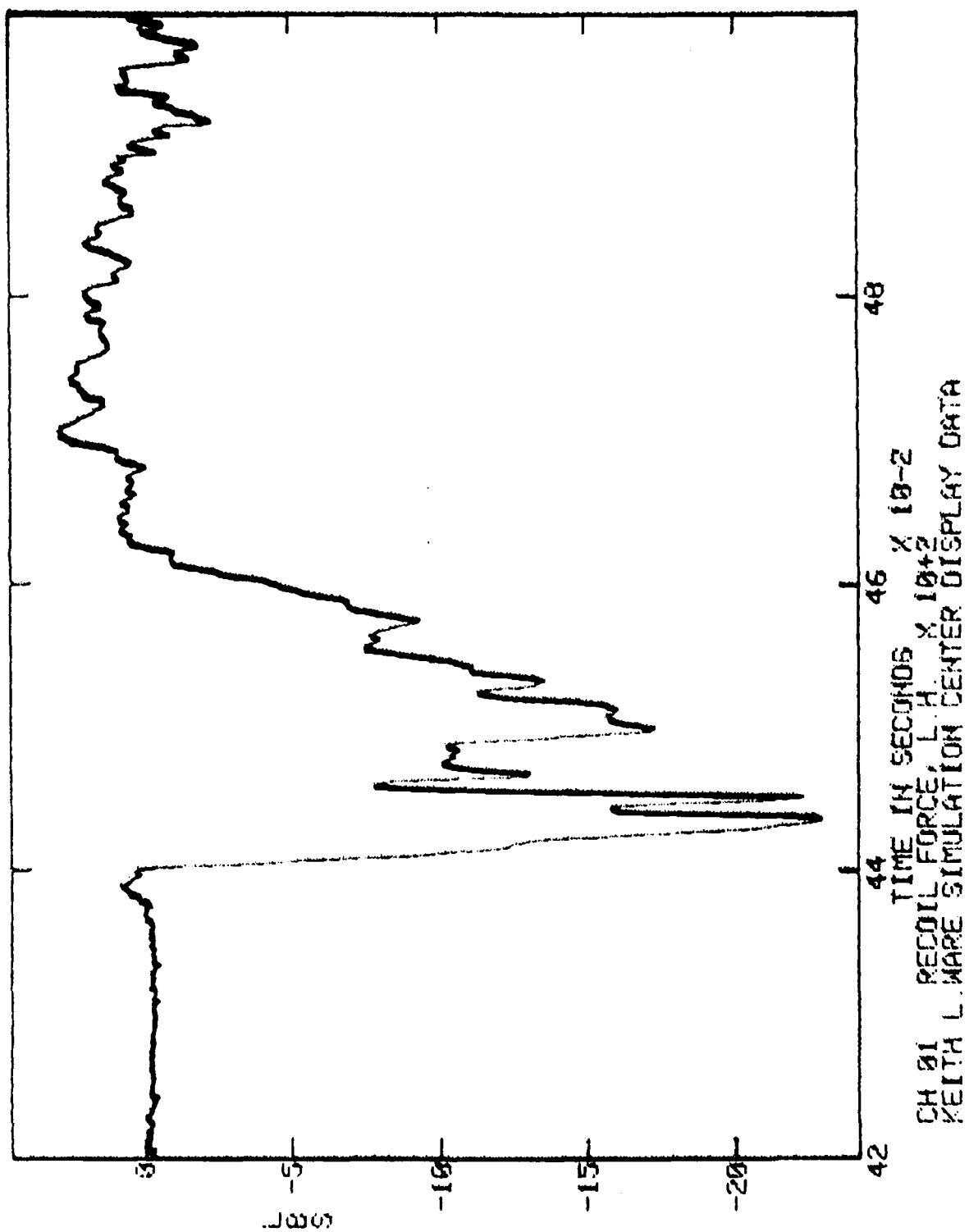


FIGURE 10b: Typical WSC Graphical Output Data

CH 01 RECOIL FORCE, L.H.
KEITH L.WARE SIMULATION CENTER DISPLAY DATA
REALTIME DATA

MAX TMAX MIN TMIN TOT PNTS PNTS/SEC
330.429 1.232 -2274.532 0.444 13000. 10000.

CAL INFO STEP VOLTAGE UNIT
1 0.0000 0.0000
2 5.0000 2995.0000

TIME = 0.4352

	0.000000	0.000100	0.000200	0.000300	0.000400	0.000500
0.435200	-26.191	-23.263	-23.263	-14.499	23.268	-17.422
0.435800	-20.345	-26.191	-17.422	-26.191	-26.191	-20.345
0.436400	-20.345	-11.576	-11.576	-5.729	0.117	-2.806
0.437000	0.117	0.117	-2.806	-2.806	-5.729	-2.806
0.437600	-14.499	-5.729	-5.729	3.040	20.579	20.579
0.438200	23.502	32.271	43.964	55.656	61.502	61.502
0.438800	70.272	73.195	81.964	70.272	55.656	52.733
0.439400	46.887	41.041	23.502	17.656	26.425	39.348
0.440000	26.425	0.117	-32.037	-99.269	-207.425	-318.503
0.440600	-432.505	-523.122	-607.892	-718.971	-827.126	-908.973
0.441200	-955.743	-1022.975	-1107.745	-1154.516	-1192.516	-1227.594
0.441800	-1236.363	-1253.901	-1286.056	-1297.748	-1335.749	-1426.366
0.442400	-1534.521	-1630.215	-1777.140	-1853.141	-1952.527	-2043.144
0.443000	-2089.914	-2145.453	-2206.839	-2238.993	-2268.224	-2291.609
0.443600	-2294.532	-2282.840	-2250.686	-2171.761	-2025.605	-1841.449
0.444200	-1692.370	-1604.676	-1581.291	-1598.830	-1671.908	-1788.833
0.444800	-1946.681	-2089.914	-2190.531	-2230.224	-2195.146	-2092.837
0.445400	-1923.296	-1686.523	-1432.212	-1192.516	-993.744	-844.665
0.446000	-780.356	-789.125	-838.818	-929.435	-1043.437	-1145.746
0.446600	-1242.207	-1297.748	-1303.395	-1298.979	-1242.209	-1166.200
0.447200	-1110.669	-1055.129	-1031.744	-1008.359	-1014.206	-1031.744
0.447800	-1022.975	-1052.206				

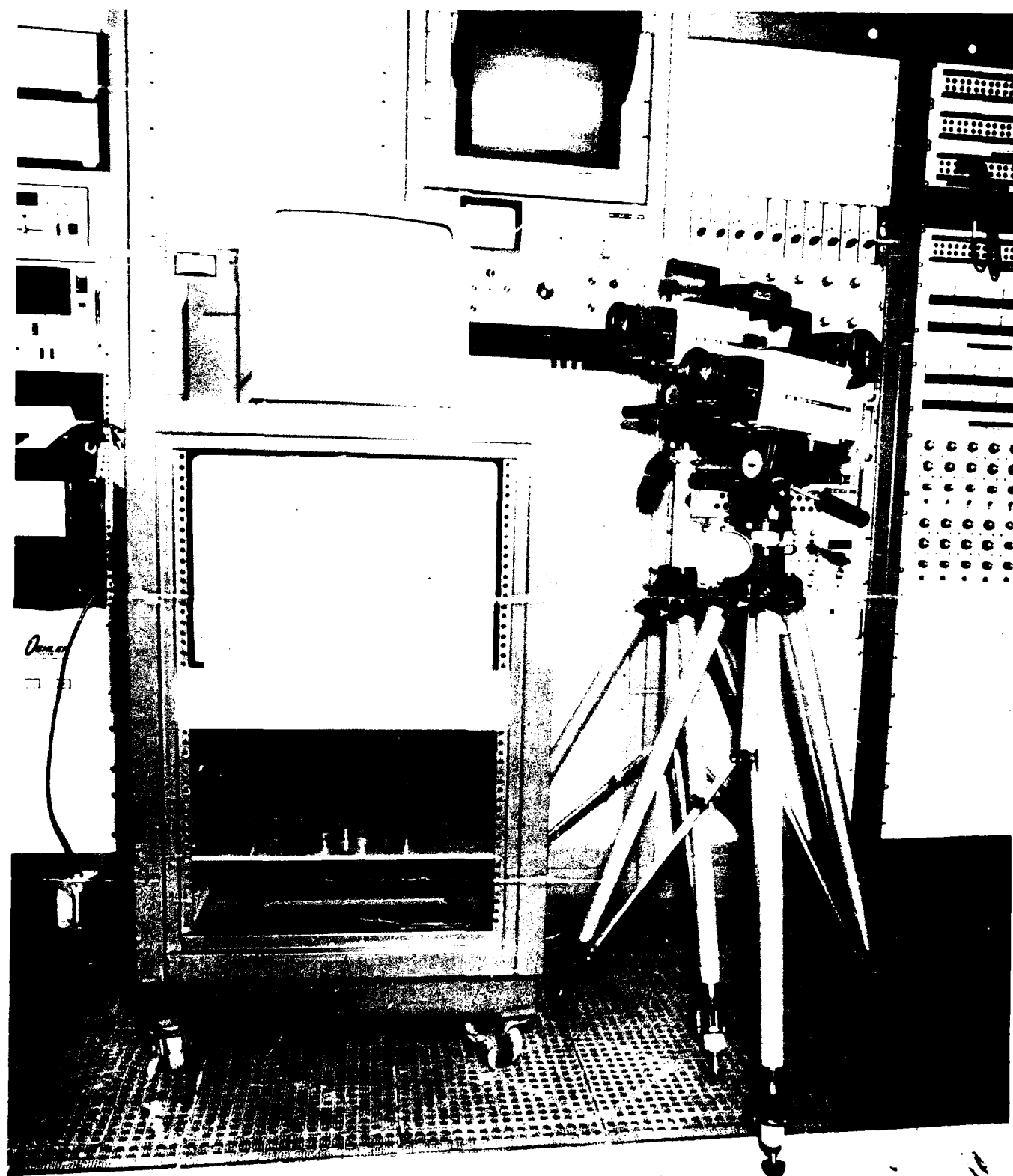
TIME = 0.4480

	0.000000	0.000100	0.000200	0.000300	0.000400	0.000500
0.448000	-1046.360	-1034.667	-1046.360	-1066.822	-1060.976	-1052.206
0.448600	-1049.283	-1025.898	-1022.975	-1063.899	-1116.515	-1198.362
0.449200	-1297.748	-1397.134	-1499.444	-1575.445	-1645.600	-1689.446
0.449800	-1718.678	-1727.447	-1724.521	-1689.446	-1674.831	-1654.369
0.450400	-1616.369	-1584.214	-1575.445	-1572.521	-1575.445	-1569.599
0.451000	-1590.060	-1595.906	-1601.753	-1592.984	-1584.214	-1566.675
0.451600	-1566.675	-1546.214	-1493.597	-1467.289	-1414.673	-1356.211
0.452200	-1283.133	-1215.901	-1160.362	-1131.130	-1128.207	-1160.362
0.452800	-1207.132	-1274.363	-1321.133	-1332.826	-1332.826	-1353.288
0.453400	-1338.672	-1329.903	-1312.364	-1271.440	-1236.363	-1177.900
0.454000	-1142.823	-1104.822	-1104.822	-1110.669	-1096.053	-1072.669
0.454600	-1063.899	-1049.283	-1031.744	-990.821	-964.513	-929.435
0.455200	-900.204	-859.280	-812.510	-774.510	-745.279	-748.202
0.455800	-748.202	-765.741	-786.202	-794.972	-794.972	-789.125
0.456400	-774.510	-771.587	-777.433	-786.202	-797.895	-824.203
0.457000	-832.972	-838.818	-862.203	-900.204	-920.666	-926.512
0.457600	-932.358	-917.743	-891.435	-850.511	-821.280	-789.125
0.458200	-774.510	-748.202	-710.201	-678.509	-689.739	-689.739
0.458800	-695.586	-680.970	-683.893	-663.431	-637.123	-604.969
0.459400	-578.661	-559.199	-537.737	-511.429	-493.890	-470.505
0.460000	-455.890	-450.044	-438.351	-420.812	-400.350	-371.119
0.460600	-336.042	-303.388				

TIME = 0.4608

	0.000000	0.000100	0.000200	0.000300	0.000400	0.000500
0.460800	-274.656	-254.195	-239.579	-216.194	-186.963	-160.655
0.461400	-134.347	-102.192	-96.346	-96.346	-93.423	-93.423
0.462000	-93.423	-99.269	-99.269	-87.577	-75.884	-66.653
0.462600	-14.499	0.117	26.425	46.887	52.733	58.579
0.463200	58.579	46.887	46.887	64.426	64.426	79.041
0.463800	84.887	81.964	76.118	61.502	61.502	67.349
0.464400	76.118	87.811	87.811	90.734	81.964	79.041
0.465000	61.502	58.579	58.579	61.502	58.579	55.656
0.465600	70.272	81.964	76.118	61.502	46.887	43.964
0.466200	32.271	35.194	43.964	55.656	64.426	58.579
0.466800	49.810	46.887	41.041	41.041	46.887	49.810
0.467400	55.656	61.502	49.810	41.041	26.425	8.886
0.468000	3.040	3.040	0.117	20.579	32.271	52.733
0.468600	67.349	81.964	84.887	99.503	93.657	93.657
0.469200	96.580	96.580	102.426	122.888	140.427	169.658
0.469800	198.889	222.274	239.813	260.275	274.990	283.660
0.470400	289.506	292.429	289.506	289.506	286.583	289.506

FIGURE 11: Typical WSC Tabular Output
Data



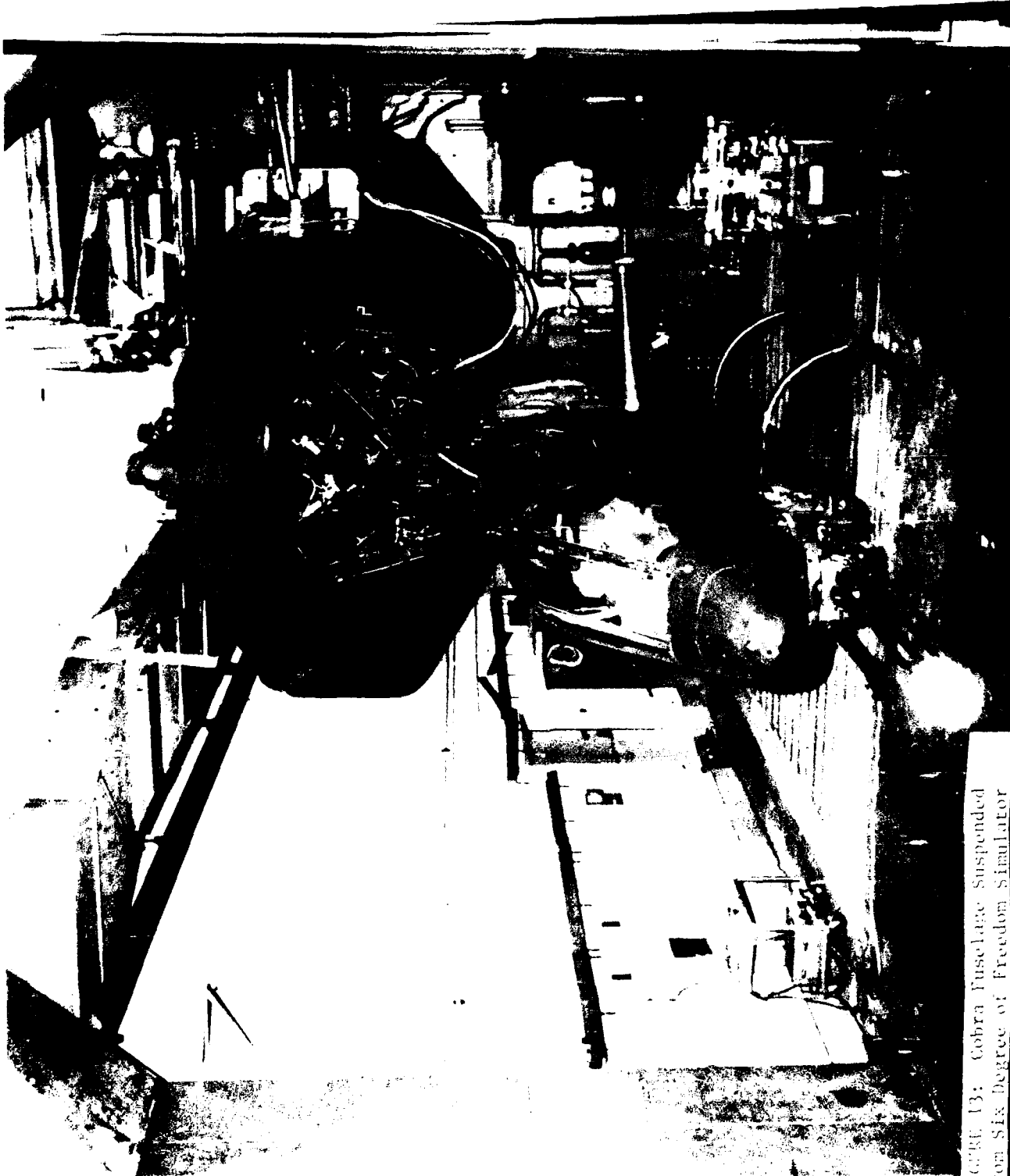


FIGURE 13: Cobra Fuselage Suspended from Six Degree of Freedom Simulator

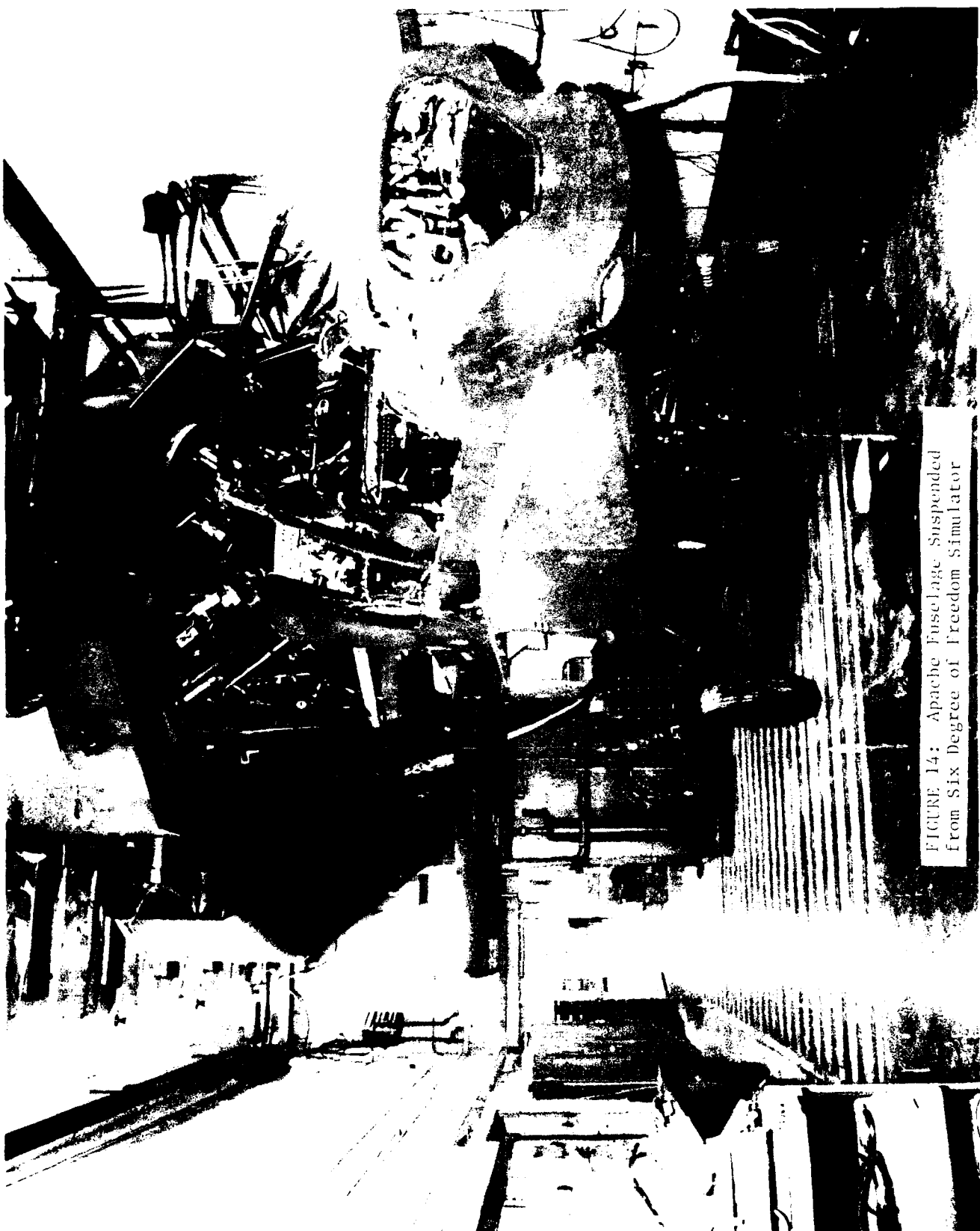


FIGURE 14: Apache Fuselage Suspended
from Six Degree of Freedom Simulator

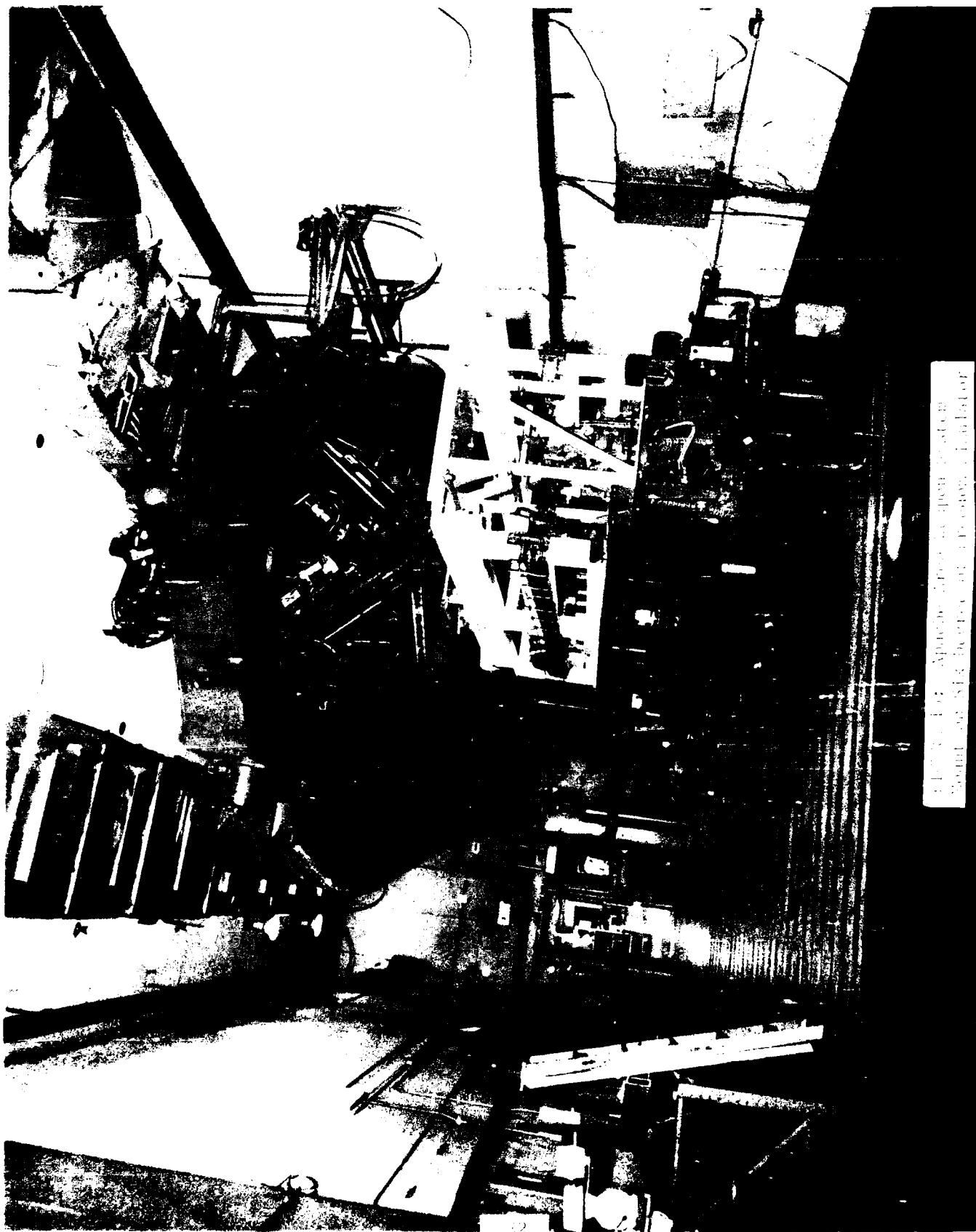
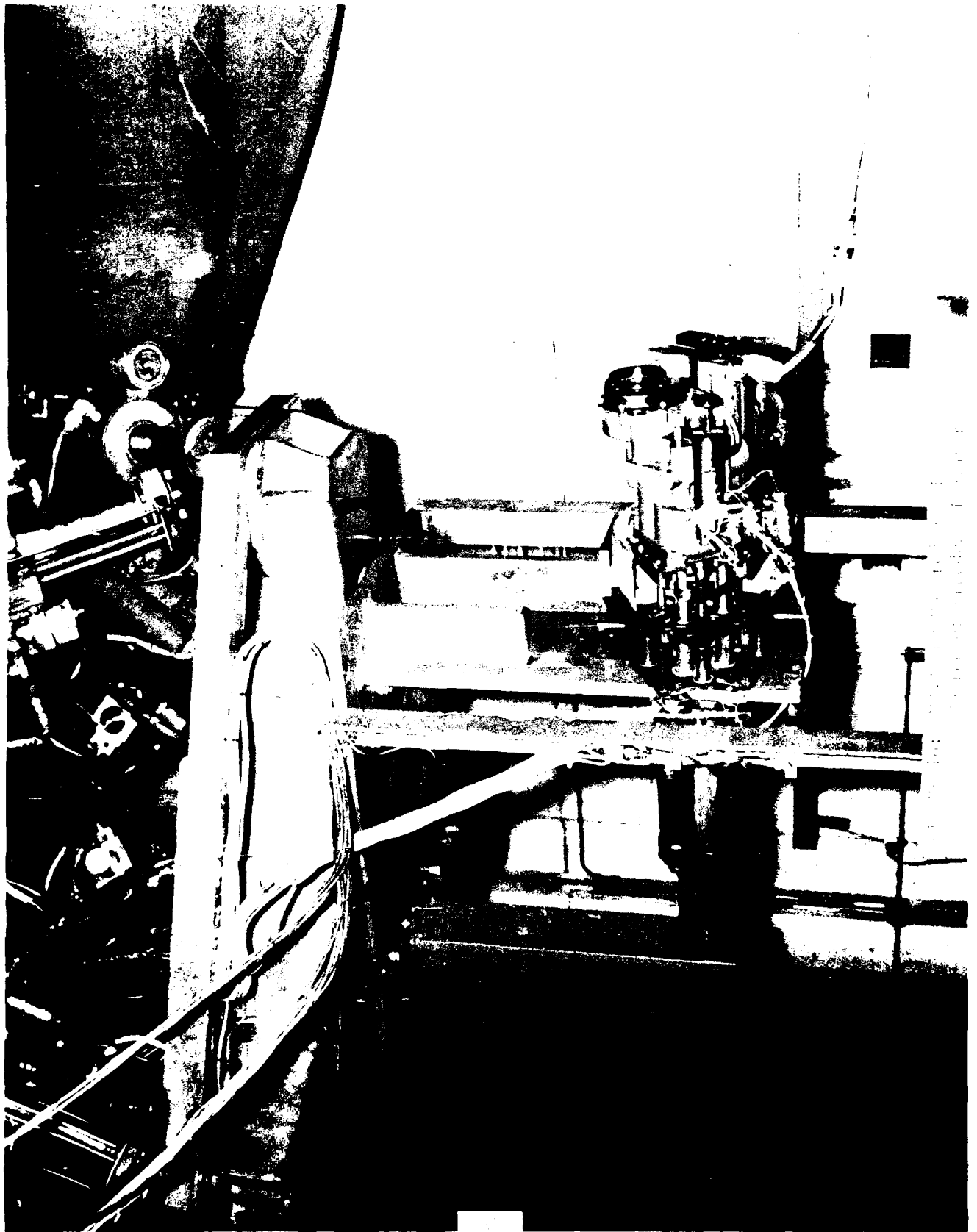
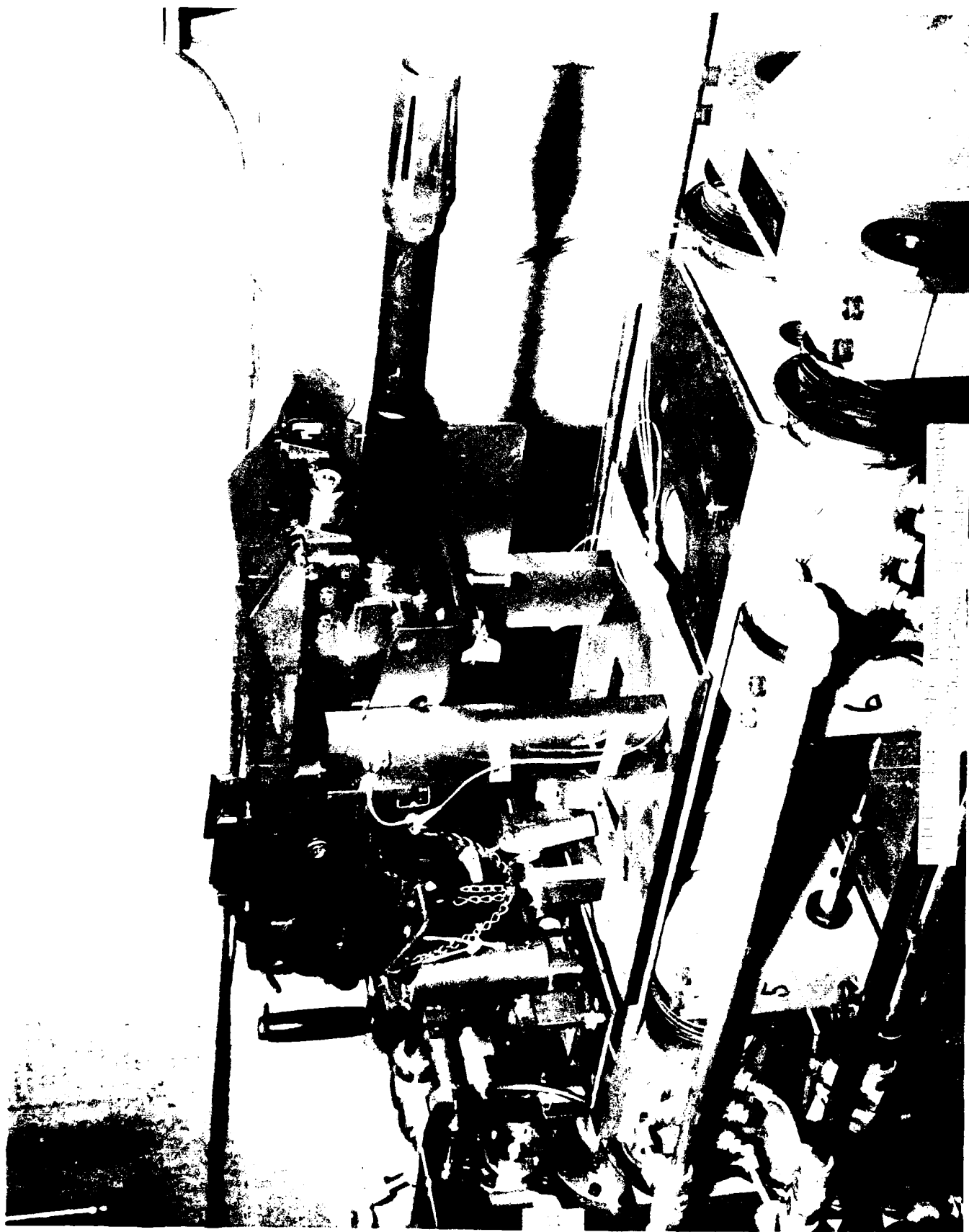


Fig. 1. Schematic diagram of the detector system.
1 - detector; 2 - amplifier; 3 - recorder; 4 - generator.





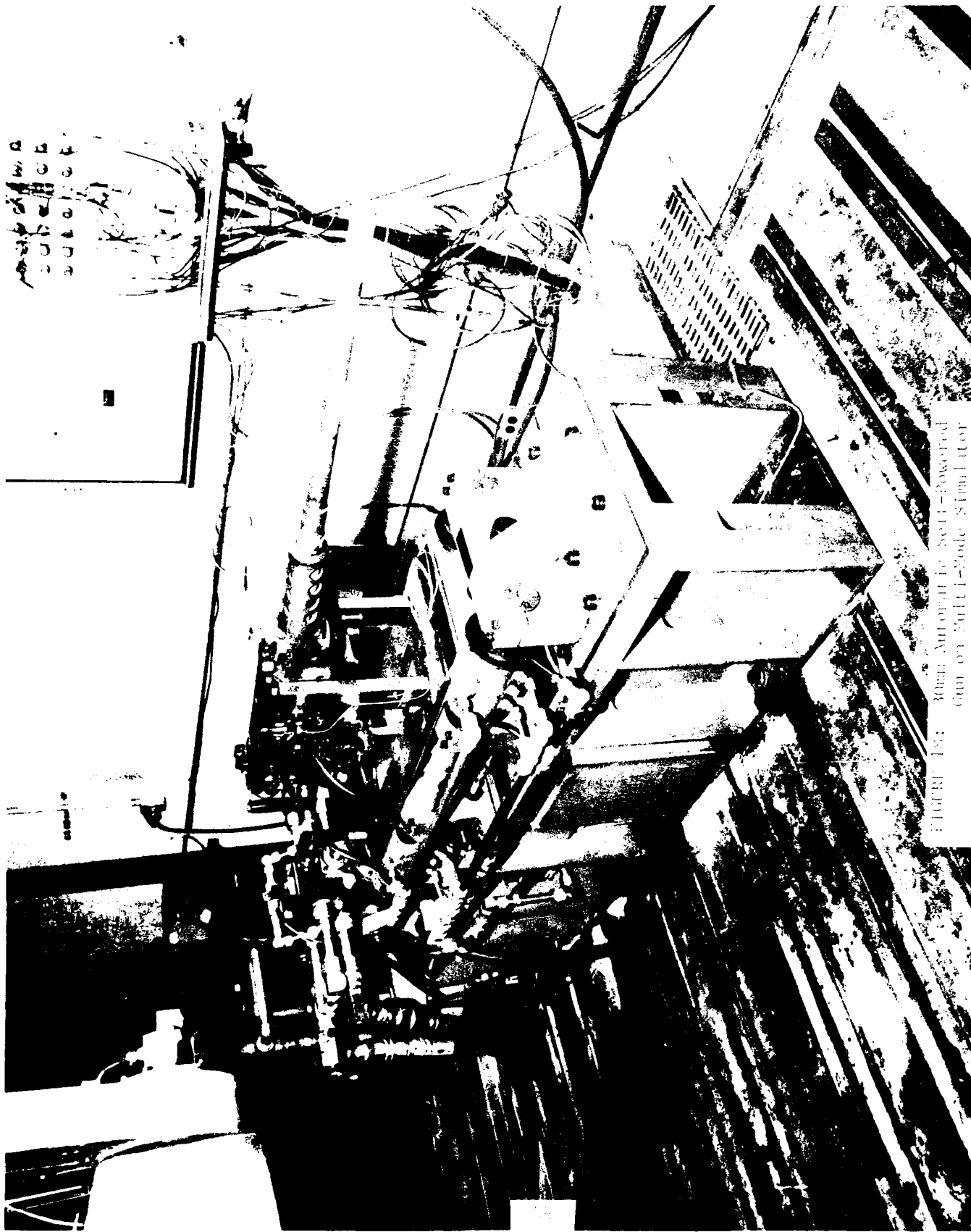


FIGURE 104 30mm Anti-aircraft Gun on Multi-Code Simulator



FIGURE 19: Turret Adapter for Six
Degree of Freedom Simulator

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