Contract No. NAS 8-20015

Man-System Locomotion and Display Criteria for Extra-Terrestrial Vehicles

Progress Report

December 1965

Prepared For

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1. SCOPE

This report covers profiles made in studying man's performance capabilities in vehicle control tasks on a simulated lunar surface. The findings of this research will serve to establish crew station criteria for traversing the lunar surface.

1.1 BACKGROUND

One of the major tasks of the National Aeronautics and Space Administration (NASA) is planning for the manned exploration of space. In support of manned lunar exploration, the Apollo Logistics Support System (ALSS) and the Lunar Exploration System for Apollo (LESA) concepts are being studied. Associated with each of these concepts are manned lunar roving vehicles. The ALSS vehicle has been designated the Lunar Mobile Laboratory (MOLAB) and the vehicle associated with LESA is simply designated the Lunar Roving Vehicle (LRV). Each vehicle supports its respective missions in different ways, but has the common requirement of manned control of vehicle locomotion over the lunar terrain.

At present, both the MOLAB and LRV concepts are being studied as part of ALSS and LESA, and engineering design data is being generated on steering, drive mechanisms, drive-power distribution, drive-power controls, motors, brakes and wheels, from an analysis of vehicle performance, maneuverability, speed and slippage control, power control, braking, suspension requirements, etc. In order to determine the man-system effects due to these requirements, man's capability to perform vehicle locomotion control tasks in the adverse lunar environment must be evaluated. Specifically, from the human factors standpoint, there is a definite need for data on the ability of an operator to perform terrain negotiation and obstacle avoidance while navigating the vehicle over the lunar surface. The task involves the identification of any obstacle or crevice, steering/power/braking decision, and performing the acts associated with the decision as a function of the field of view, cabin interior and display lighting levels, seating and restraint, and inclination of the Sun.

In summary, this investigation is intended to evaluate man's capability to perform lunar vehicle locomotion tasks, with respect to the areas discussed above, from which crew-station design criteria can be evolved.

1.2 OBJECTIVES

The basic objectives of this study are:

- To determine the feasibility of man's operating a maneuverable lunar-roving surface vehicle in forward and reverse mobility situations, and in shirt sleeve or space suit conditions.
- To optimize combinations of steering/drive power/braking hand controls, field of view, lighting intensity and contrast, and crew seating and restraint, relative to human performance.
- To investigate operator performance and workload relative to the locomotion task of obstacle avoidance, terrain negotiation, and navigation between stations.
- To develop drive-power management criteria.

Since mission success is dependent both on the external environment and the vehicle configuration, knowledge of obstacle recognition and vehicle factors affecting the driving task are of paramount importance. For this reason the objectives of this study will be accomplished by two phases of effort. The first is designed to determine the effects of major lunar visual factors (Sun inclination, lunar photometric properties, obstacle size) on man's performance of the driving task. The second phase will examine such vehicle factors as field of view, crew environment, task loading and control mode.

Test schedules for the Mobile Base Simulator and Fixed Base Simulator have been devised to permit comparison of results. This correlation of data will be used to validate and improve the Fixed Base Simulator for more detailed investigations.

1.2.1 Fixed Base Simulator Study Objectives

Fixed Base Simulator study objectives include:

- Investigation of a selected steering control concept.

- Investigation of an integrated (assuming each wheel has a separate drive motor) drive power selector.

- Evaluation of the operator's ability to perform a selected mobility task, utilizing the combination of controls described above, with selected simulated size and shape windows (field of view).

- Designing the mobility task such that the operator will be required to monitor and control several selected displays, in addition to performing the locomotion task.

- Investigation of various contrasting intensity levels and colors of cabin and display lighting during the mobility task evaluation in relation to operator's performance.

1.2.2 Mobile Base Simulator Study Objectives

Mobile Base Simulator study objectives include:

- Evaluation of the locomotion hand control and display concept recommended as a result of the Fixed Base Simulator investigation pertaining to mobile operations over terrain similar to the lunar surface. This concept will include the steering/drive power/braking hand controls, field of view, and lighting.

- Evaluation of crew seating and restraint system requirements with respect to the mobility task.

- Investigation of operator performance relative to workload, when additional mobility and malfunction displays are added to the display panels. These additions increase the complexity of the mobility task to the degree anticipated in a lunar roving vehicle.

1.3 FIXED BASE SIMULATOR - DESCRIPTION

The Fixed Base Simulator consists of a simulated lunar surface, a projected TV display, and a two-man crew station which is servo driven to simulate vehicle movement (Figure 1-1). An analog computer is used to simulate the desired vehicle characteristics. Vehicle velocity is simulated by an endless belt, 5 ft. wide and 22 ft. long, representing a roadbed 125 ft. wide and 500 ft. long. The belt runs over two 9-inch drums driven by a thyratron-controlled servo motor at simulated speeds of 0 to 6 mph. A remote-controlled image orthicon camera, capable of working at a relatively low light level, is used to televise the simulated surface. The camera is pedestal-mounted and rotates on an axis passing through the center of the lens system. A wide angle lens provides a 55 degree field of view. Speed of travel is governed by a sine-cosine potentiometer attached to the yaw servo motor which also controls the speed of the belt.

The lunar surface is simulated by bonding polyurethane to the belt. This material was chosen because the color (dark grey) and the texture of the plastic foam approximates the Moon's albedo and reflection characteristics. The foam is sculptured to depict craters ranging from 2 ft. high to 2 ft. deep, and 5 to 20 ft. in diameter, as well as portions of much larger plateaus and craters. The ratio of the rough areas to the relatively smooth areas approximates those on lunar photographs. Additional obstacles of varying size and geometry may be temporarily attached by using "Velcro" pads.

The Sun's rays on the Moon's surface are simulated by a portable 1,000 watt projection lamp which can be located at any desired incidence angle.

A 525 line Waltham Tele-beam Projector is used to impose a picture of the lunar surface on a rear projection screen.

The two-man crew station is servo driven to provide heave and roll sensations to the driver. Two plastic wheels attached to the TV camera provide input signals to an analog computer. The computer simulates the spring-mass characteristics of a variety of vehicles and transmits the resultant signals to a pair of hydraulic actuators. The actuators heave and roll the simulator cockpit in response to the computer signals.

1.4 MOBILE BASE SIMULATOR - DESCRIPTION

The Mobile Base Simulator has been designed and built as an Earth-based prototype of a lunar roving vehicle which can be transported to the Moon by a LEM descent stage. Its function is to provide experimental verification of predicted vehicle performance on the Moon and the man-machine integration necessary for a successful lunar surface mobile mission.

The Mobile Base Simulator is a two-module, 4-wheeled vehicle with a wheel tread of 140 inches and an overall length of about 31 feet. (Figure 1-2.) The forward module is manned and capable of sustaining a pressure differential with respect to ambient. The aluminum pressure shell consists of a front end elliptical dome, a tapered semi-monocoque transition section and a hemispherical rear dome. Its overall length, width and height are 14-1/2 feet, 9 feet and 7 feet, respectively. The instrument panel, driving controls, and two seats are located in the front end which has standing headroom. The forward dome (in front of the seats) has two windows which can be masked to smaller sizes to ascertain the effects on driving. The left rear side of the transition section has a large outward-opening door which will be part of a two-man airlock in the vehicle. Telemetry equipment has been installed to transmit test data during the vehicle's operation at Grumman's simulated lunar surface test site.

The aft or unmanned module carries the primary power supply. It is configured to accept power supplies under development for LEM. It is a rectangular parallelepiped 13 feet long by 8-1/2 feet wide by 2-3/4 feet high, constructed from aluminum double-face bonded balsa-cored panels bonded to extruded joining members. Currently, the primary power supply consists of a gasoline-engine-driven generator located in the middle of the module. The engine also drives a hydraulic pump for steering and braking the Mobile Base Simulator.

Each module is supported by two Metalastic wheels 5 feet in diameter, each driven by reversible electric motors through a speed reduction unit located at the wheel hubs. Speed is controlled by varying the input voltage to the motors at each wheel.

The Metalastic wheel is a patented Grumman proprietary development in which the metal spokes and rim are allowed to deflect so that the wheel under load has an equivalent diameter, at ground contact, three times larger than the constant diameter of the unloaded wheel. The larger "footprint" distributes the vehicle's weight over a larger area and allows it to traverse soils low in bearing strength.

The manned and unmanned modules are coupled by an articulated joint used for steering the vehicle. This method of steering allows the driver to slew the forward module to the left or right to increase his peripheral field of view without any gross fore or aft motion.

The manned and unmanned modules have identical suspension systems, Metalastic wheels, suspension arm, a variable preload torsion bar spring and a shock absorber. Multi-module vehicle trains can be made up by using articulated steering joints to connect additional powered-wheel modules to the existing modules.

A "Lunar" test site, created for use with the Mobile Base Simulator, consists of about 2 acres contoured to match some of the Ranger photographs and covered with cinders to approximate the Moon's photometric function.

1.5 TASK SCHEDULE

A schedule has been prepared that describes the detail tasks required to accomplish the objectives of the study (Figure 1-3). A short description of the tasks follows:

1.5.1 Task No. 1 - Incorporate Vehicle Dynamics and Simulate Random Motion

Objective: To incorporate vehicle dynamics and simulate random motion which might be encountered by a vehicle traveling over a rough lunar surface. A more detailed description of this task is given in section 3.1.

1.5.2 Task No. 2 - Controller Selection

Objective: To select an integrated controller (drive and steering on same control) and a separated controller. A more detailed description of this task is given in Section 3.1.

1.5.3 Task No. 3 - Obstacle Recognition Study

Objective: To determine man's ability to recognize objects of varying size, geometry, albedo, and backscatter characteristics under varying lighting conditions and vehicle velocities. A more detailed description of this task is given in Section 2.0.

1.5.4 Task No. 4 - Study of Factors Affecting the Driving Task Using the Fixed Base Simulator

Objective: To study the influence of the following factors on the mobility task. This will cover:

- Field of View
- External Light
- Head Light Location
- Vehicle Dynamics

- Control Mode and Type
- Time-Sharing
- Crew Restraint

A more detailed description of this Task is given in Section 3.2.

1.5.5 Task No. 5- Evaluation of NASA- Supplied Net Seat

Objectives: To evaluate the ride qualities of a NASA-supplied net seat, and to design and fabricate support structure for said seat.

1.5.6 Task No. 6 - Study of Factors Affecting the Driving Task Using the Mobile Base Simulator

Objective: To study the influence of the following factors on the mobility task. This will cover:

- Field of View
- Control Mode and Type
- Time Sharing
- Crew Restraint
- Environment

A more detailed description of this Task is given in Section 3.3.

1.5.7 Task No. 7 - Data Correlation

Objective: To correlate data obtained on the Fixed Base Simulator with data obtained on the Mobile Base Simulator. A more detailed description of this task is given in Section 3.4.

1.5.8 Task No. 8 - Report Preparation

Objective: This is the time required to prepare: Task Schedule, Monthly Progress Reports, Presentations, and Final Report.

1.5.9 Task No. 9 - Crew Station Study

Task not defined at this time.

1.6 TASK STATUS

- Task Item (1) - 100% complete
- Task Item (2) - 100% complete
- Task Item (3) - 90% complete
- Task Item (4) - Testing 20% complete
- Task Item (5) - Design and Fabrication 100% complete
- Task Item (6) - Testing 10% complete
- Task Item (7) - Will start when Tasks 4 and 6 are 50% complete
- Task Item (8) - Not applicable
- Task Item (9) - Task not defined

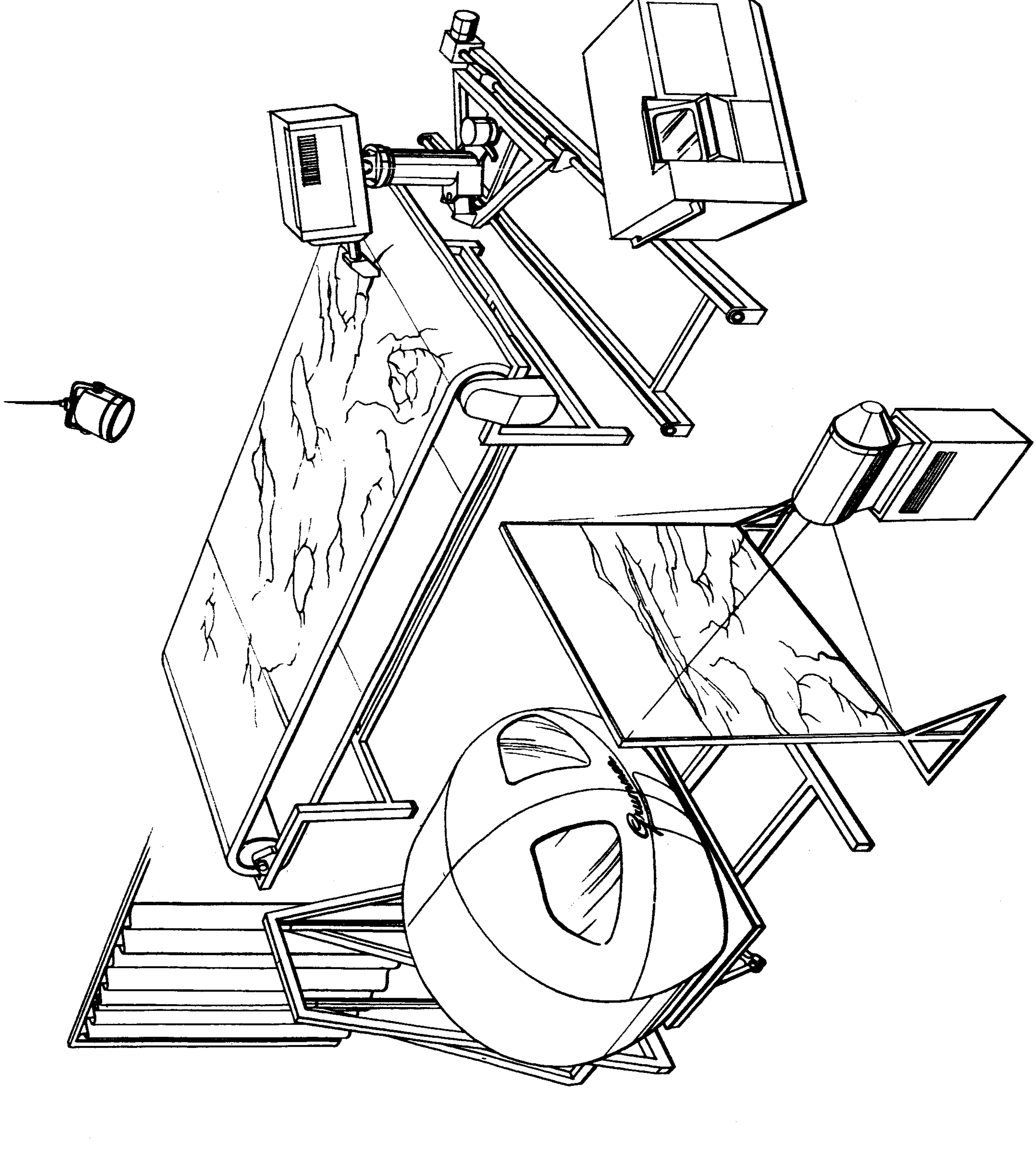


Figure 1-1. Fixed Base Simulator

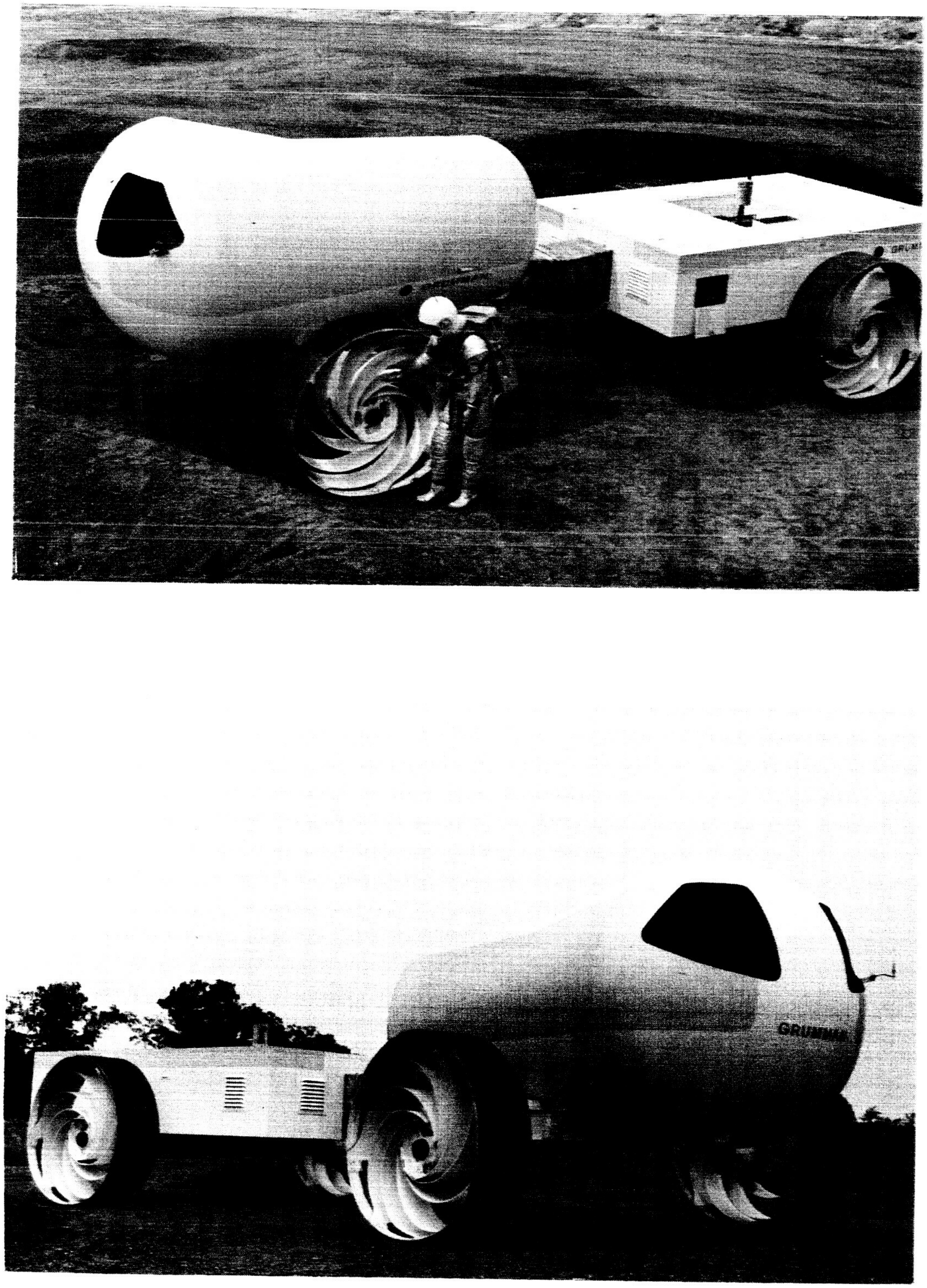


Figure 1-2. Mobile Base Simulator

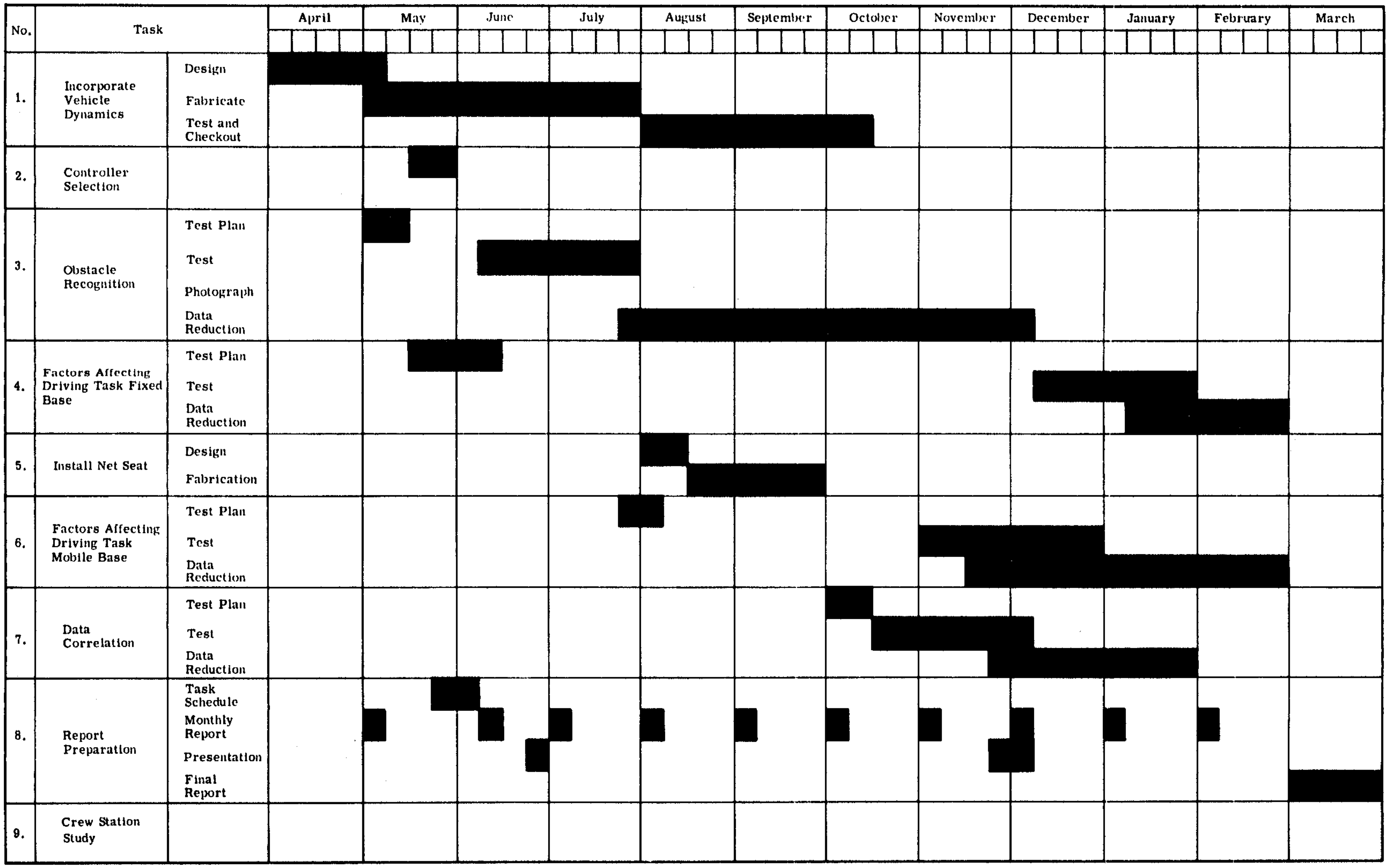


Figure 1-3. Task Schedule

2. OBSTACLE RECOGNITION

2.1 OBJECTIVES

The objectives of the Obstacle Recognition Study were to:

- Determine the salient features of man's visual performance in the environment of the Fixed Base Simulator.
- Determine the effects of major lunar visual factors on man's expected visual performance in the lunar driving task.

The program considered the following factors:

- Obstacle factors - geometry, size, albedo and backscatter characteristics
- Lunar environment factors - lighting angle and intensity, backscatter characteristics of background
- Vehicle factors - vehicle velocity, visual presentation (direct viewing, TV monitor, TV projection)

The subject was required to locate and identify a regular geometric shape placed on a simulated lunar surface. A scorekeeper recorded the distance from the vehicle at which the obstacle was identified and the correctness of the identification.

Motion pictures (16 mm) were taken of one of the test courses. In one instance the camera was set up at the scale height used during the tests and color films were taken while the lighting angle intensity and velocity speed varied. In another instance the same course was repeated and black and white films were taken of the viewing monitor.

2.2 PROCEDURE

The obstacle recognition study was conducted on the Fixed Base Simulator. Eight obstacles were interspersed among the "natural" lunar surface features in four pre-selected configurations. The obstacles were regular geometric shapes consisting of large and small domes and prisms. The large obstacles were sized to be equal in height to the "natural" obstacles; the small obstacles were one-half the size of the "natural" obstacles. (Figure 2-1.) Four of the obstacles were made of foam rubber and coated with Portland cement; two were foam coated with silver chloride; two were made from mat paper. The Portland-cement-coated foam and the silver-chloride-coated foam had back scatter characteristics similar to the "natural" lunar surface, but the Portland cement obstacles' albedo was higher than that of silver chloride. The obstacles were placed on the belt in such a manner as to place them in direct view at all times, and not to obscure them by "natural" obstacles.

The subjects observed the simulated lunar surface directly, via television monitor and a projected television image. The observer's viewing position was 100 in. scale height (4 in. actual) above the surface, with a 54 deg. horizontal field of view, a 5 deg. view angle above the horizon, and 35 deg. down view angle. During direct viewing runs, the subjects viewed the surface through a view port located at the proper height and having the desired field of view. A plan view of a typical course is shown in Figure 2-2. The effects of lighting angle and lighting intensity are shown in Figure 2-3.

The following prepared statement was read to the subject prior to starting the tests:

SUBJECT INSTRUCTIONS FOR OBSTACLE RECOGNITION STUDY

> "As a subject in this obstacle recognition study, you will be viewing a series of eight 'artificial' objects placed on a stretch of simulated 'natural' lunar terrain. The eight objects, which will be pointed out to you in training runs, are eight prisms or domes in two sizes, large and small.
>
> During the actual runs, you will be asked to call out the identification (large or small, prisms or domes) and the position in the field of view (left, center

> or right). You are expected to identify correctly each object as early as possible. Distance at time of correct identification will be recorded. If you incorrectly identify an object and correct your identification later when the object is closer, the distance of correct identification will be scored."

After reading the statement, the subjects were given two practice runs with each of the viewing modes during which the obstacles were pointed out.

Figure 2-4 shows the runs schedule followed during the tests. For each of the viewing modes all factors specified in the objective (obstacle, Lunar environment and vehicle factors) were varied in turn. A scorekeeper recorded the correctness of the identification and the distance from the vehicle at which the obstacles were identified. The motion picture run schedule is shown in Figure 2-5.

2.3 ANALYSIS METHODS

The primary tools for the analysis of the obstacle recognition data are the plots of average recognition distance for each object, non-parametric comparisons of better-worse recognition distances, and error proportions for the conditions of interest.

The data consist of measured recognition distances and error recordings for each subject's response to each of eight objects. The eight objects are presented twice in a row in a fixed "random" setting (course) under fixed environmental conditions (lighting, etc.) and then presented twice again in a second "random" setting under the same conditions. This identical procedure is repeated for each experimental condition. It is clear that settings and conditions can and do change recognition distance distributions and error probabilities in a way not amenable to any of the standard assumptions of analysis variance (normality, longevity of variance, additivity of effects, etc.).

Hence, the necessity for non-parametric analysis supplemented by detailed examination of the data as plotted in Figures 2-6 to 2-9. Subjects are analyzed separately in order not to obscure individual differences.

The Table in Figure 2-10 presents all the comparisons of conditions where the entrance of a test of hypothesis is not obvious. Two types of tests are performed:

- Tests of whether one set of average detection distances is better than another under condition A vs. B (one-sided where prior knowledge gives reason to pick the better condition). A count is made of the number of obstacles detected at longer distances under A than under B. Under the null hypothesis that no difference exists, better detection of a given obstacle is just as likely for A as for B. Consequently, binomial probabilities of unbiased coin-tossing apply. For instance, if A has longer recognition distances than B for 6 out of the 8 objects, the level of significance equals the probability of 6 or more heads out of 8 tosses = .14.

- Tests of whether one error proportion (mistaken identifications + non-detections) is significantly different from another independently determined proportion. The denominator for all proportions is 32, since each subject sees 8 objects 4 times each. The significance level is computed, using the standard comparison of two binomially sampled proportions table in "Non-Parametric and Short-Cut Statistics" by Tate and Clelland.

It is to be noted that in using relatively small-sample sizes and the above non-parametric techniques, the tests of hypothesis involved are not particularly powerful. Consequently, a determination of significance is generally sound, while a conclusion of non-significance may in fact be hiding actual moderate differences between two populations.

2.4 RESULTS AND CONCLUSIONS

- Obstacle differences, Figures 2-6 through 2-9 have obstacles ordered in approximate increasing order of difficulty as determined by over-all average recognition distance under TV conditions.

For TV viewing it is evident from the order that size has a minor influence as compared to photometric properties, since objects group mostly by object coating. Portland cement clearly creates the most difficult condition.

Under direct vision, these conclusions do not hold as one might expect. Here, many more factors than simple photometric differences come into play. These include color, size, geometry, and surface texture - factors which are eliminated or minimized by the black/white, relatively poor resolution nature of the TV display.

- The difference in detection at 2 and 6 mph is clearly significant in both range and errors across subjects, though the actual degradation of detection distance at high speed is not large (less than 25 ft. average). (Figure 2-6.)

- Under TV viewing the TV monitor gives significantly better detection ranges for all but one subject (again, absolute improvement in feet is not large). However, not much improvement in errors is achieved - except for one subject.

- Direct vision under high intensity overhead lighting approximately doubles the detection range and eliminates almost all errors as compared with TV. Under low intensity lighting, recognition distances are comparable to better TV conditions, and error probabilities to worse TV conditions. All differences are significant. (Figure 2-7.)

- Similarly, low intensity overhead lighting for TV projection viewing has a stronger effect on errors than on recognition distance. Error differences are consistently significant; one recognition difference is not significant. (Figure 2-8.)

- For TV viewing, the lighting conditions in increasing order of difficulty are:

1. In front

2. 45° Side

3. Behind

4. Overhead

5. 10° Side

Recognition distance comparisons between above adjacent conditions (1 vs. 2, 2 vs. 3, etc.) are not consistently significantly different on an individual subject basis; the same comparisons considering subjects jointly are at least marginally significant. Error differences among the four are small and non-significant. Conditions non-adjacent in the list and the overhead -10° side lighting recognition distance comparison are significantly different. Furthermore 10° sidelighting induces significantly more errors than overhead lighting.

These results are not as clear-cut as they might be, primarily because there is a strong interaction between object, setting and lighting. That is, individual objects in certain settings may be made clearly visible under what is, in general, a poor lighting condition. The surprisingly poor showing of 10° side-lighting appears to be due to non-photometric considerations: it creates a visual field so full of contrasts and shadows that there is considerable difficulty in picking out the desired objects. (Figure 2-9.)

- For TV viewing there were, in general, considerably more non-detections than misidentifications. Among the misidentifications, size was the dominant error (due to lack of stereo-vision). The large proportion of non-detections is surprising and important, since this is by far the most serious error that can be made in the human driving task.

In general, the study was extremely successful in calibrating and focusing attention on the visual system. It has pointed out that the TV projection system tends to:

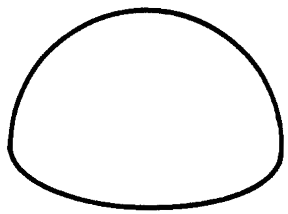
- Emphasize purely photometric factors (as compared with direct vision).

- Decrease detection distances generally

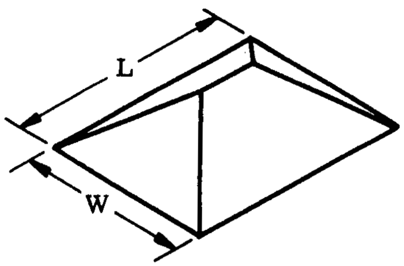
- Trends in TV viewing performance and direct vision performance are similar under decreasing light level

- Increase non-detections - that is, the TV system presents a more difficult visual task as compared to direct vision

Photometric predictions have been verified, at least within ranges where the very important factor of a chaotic visual field does not enter.



	Small Dome	Large Dome
Scale Dia	62.5"	125.0"
Scale Height	12.5"	25.0"
Actual Dia	2.5"	5.0"
Actual Height	0.5"	1.0"

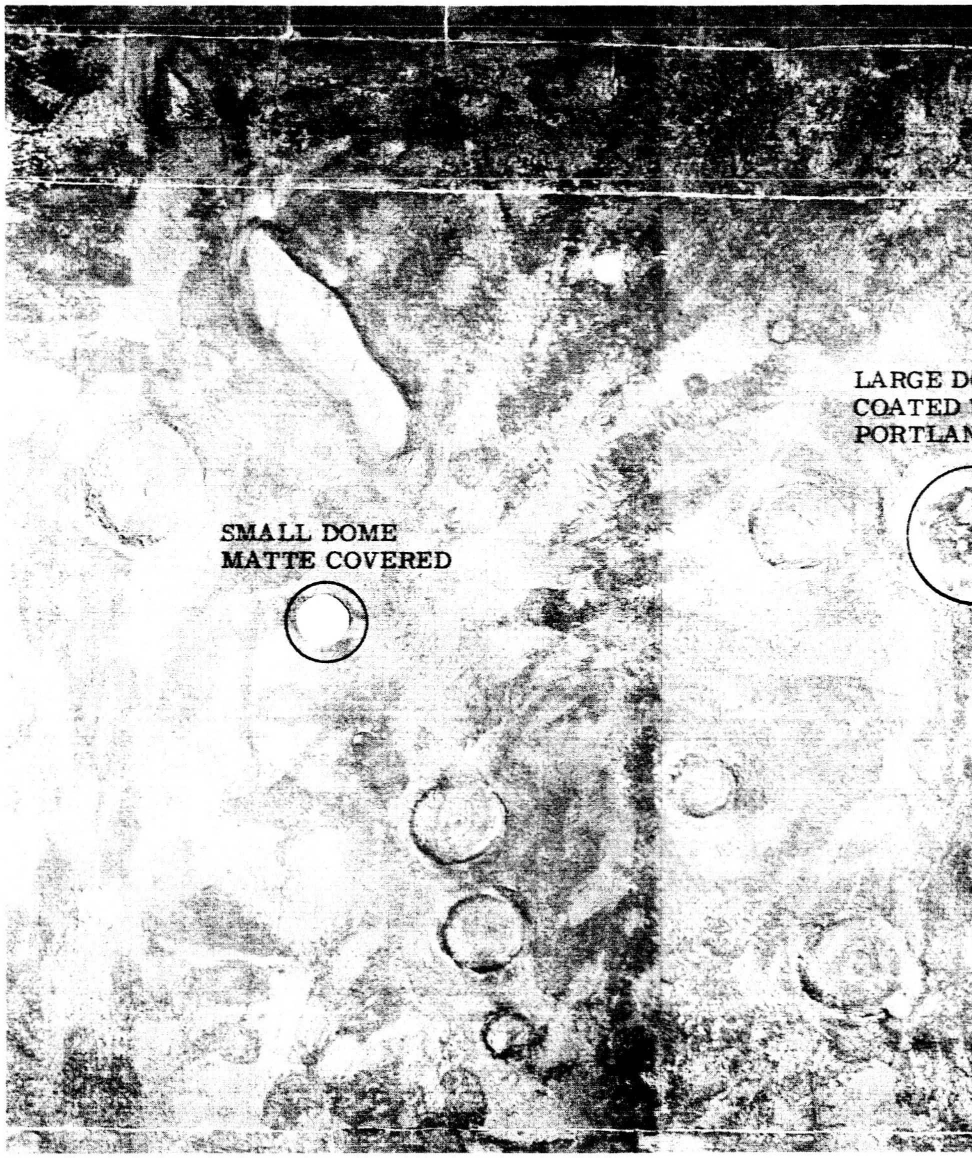


	Small Prism	Large Prism
Scale L	87.5"	175.0"
Scale W	62.5"	125.0"
Scale Height	12.5"	25.0"
Actual L	3.5"	7.0"
Actual W	2.5"	5.0"
Actual Height	0.5"	1.0"

Obstacle	Geometry	Size	Material	Coating
1	Prism	Small	Foam	S
2	Prism	Small	Foam	P
3	Dome	Large	Foam	S
4	Prism	Small	Paper	-
5	Dome	Small	Foam	P
6	Prism	Large	Foam	P
7	Dome	Large	Foam	P
8	Dome	Small	Paper	-

S = Silver Chloride
P = Portland Cement

Figure 2-1. Obstacle Geometry and Coating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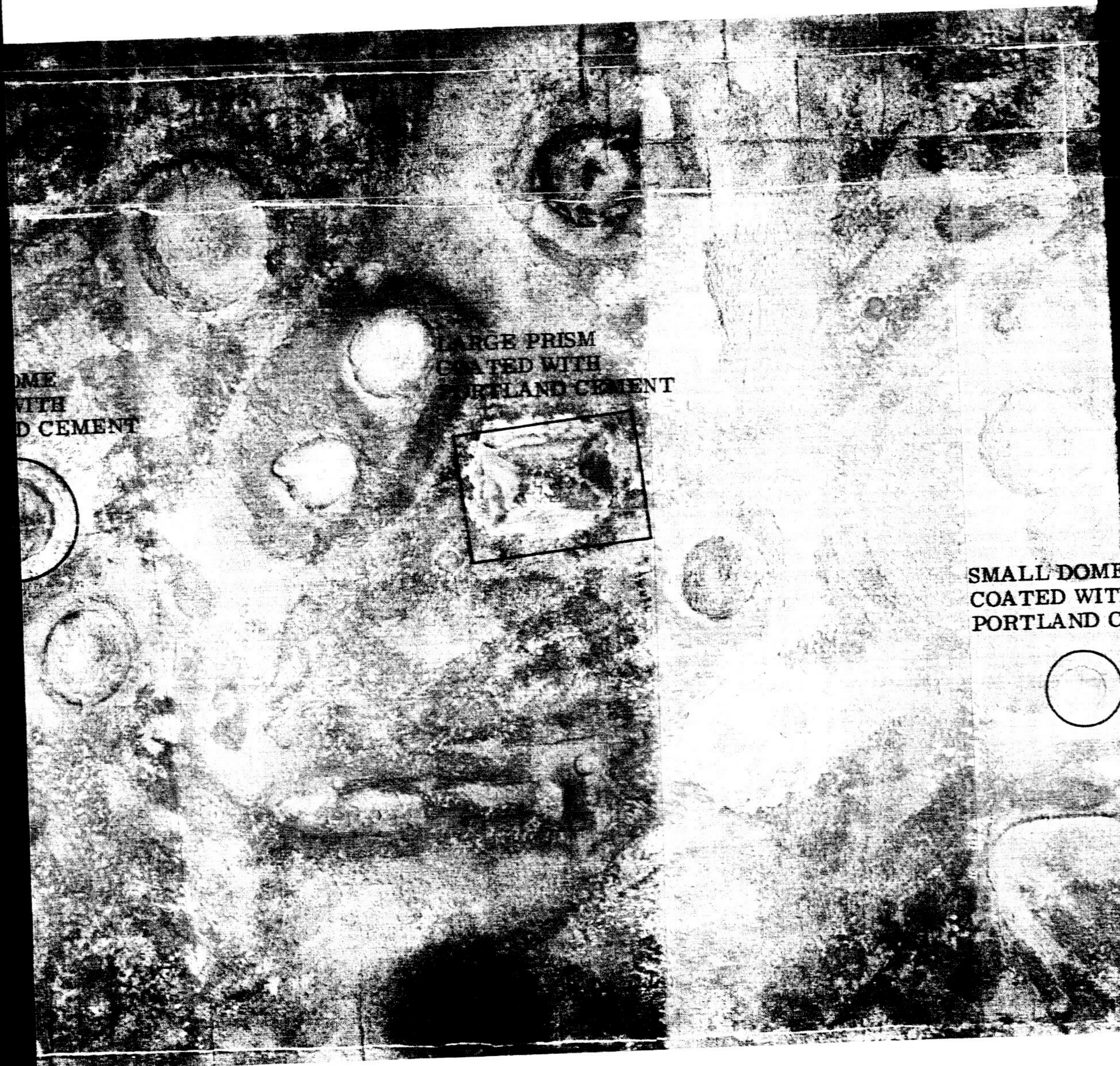

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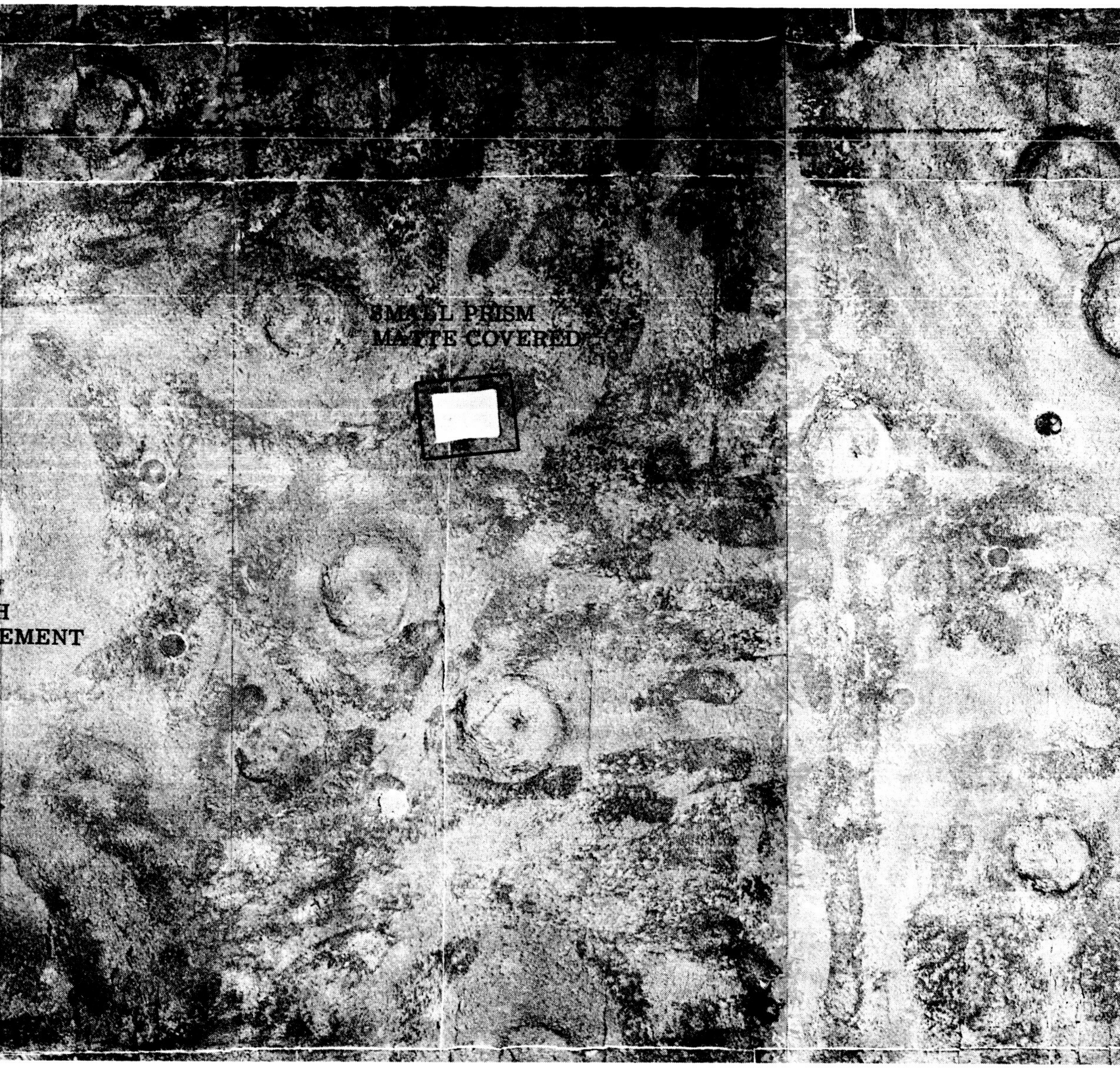
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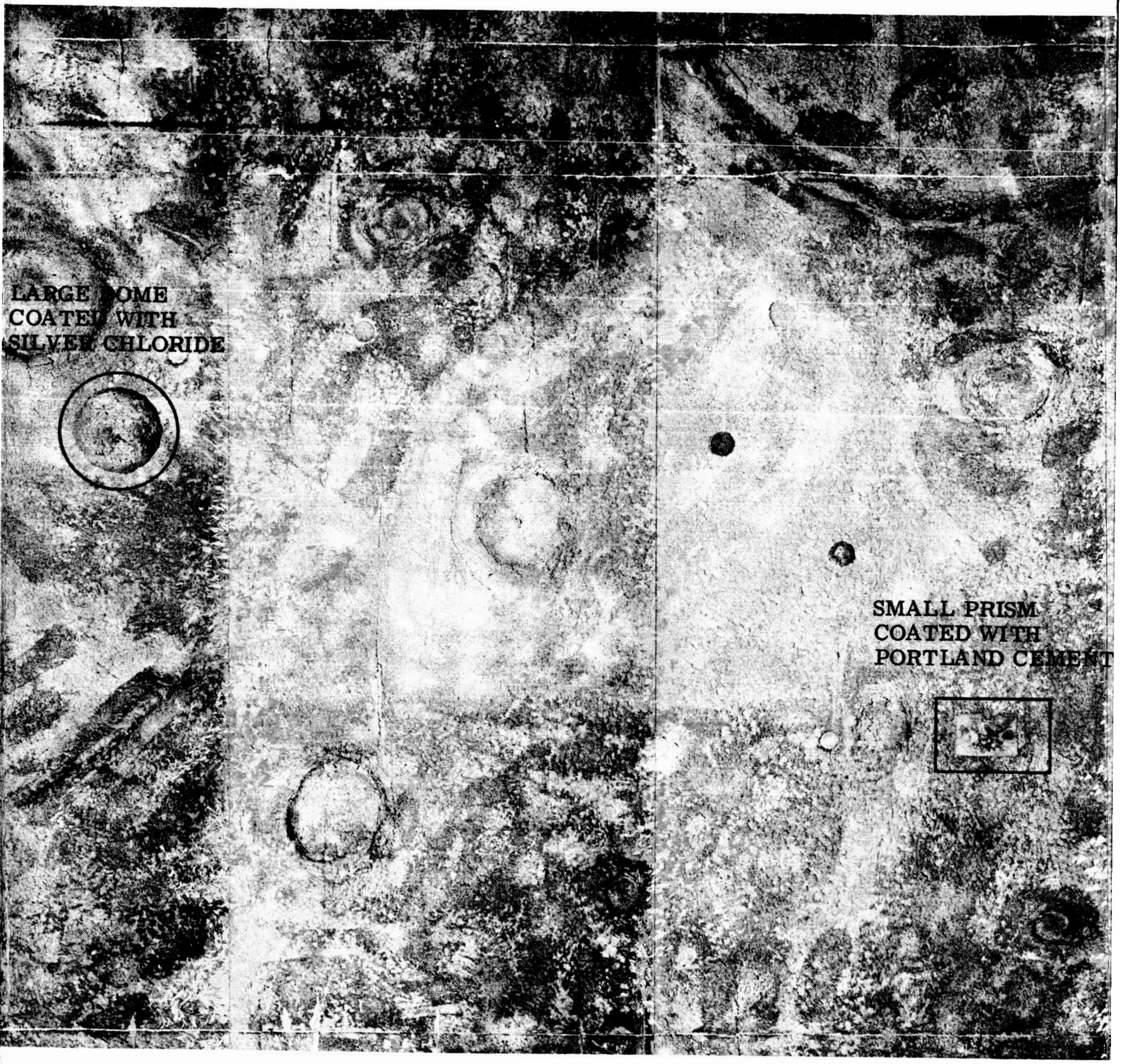


One of four obstacle arr
Illumination directly ove

rangements
erhead

Figure 2-2. Plan View of Typical Obstacle Recognition Course

5

SUNLIGHT IN BACK OF OBSERVER

SUNLIGHT OVERHEAD

SUNLIGHT IN FRONT OF OBSERVER

45° SIDE LIGHT

10° SIDE LIGHT

EARTHSHINE

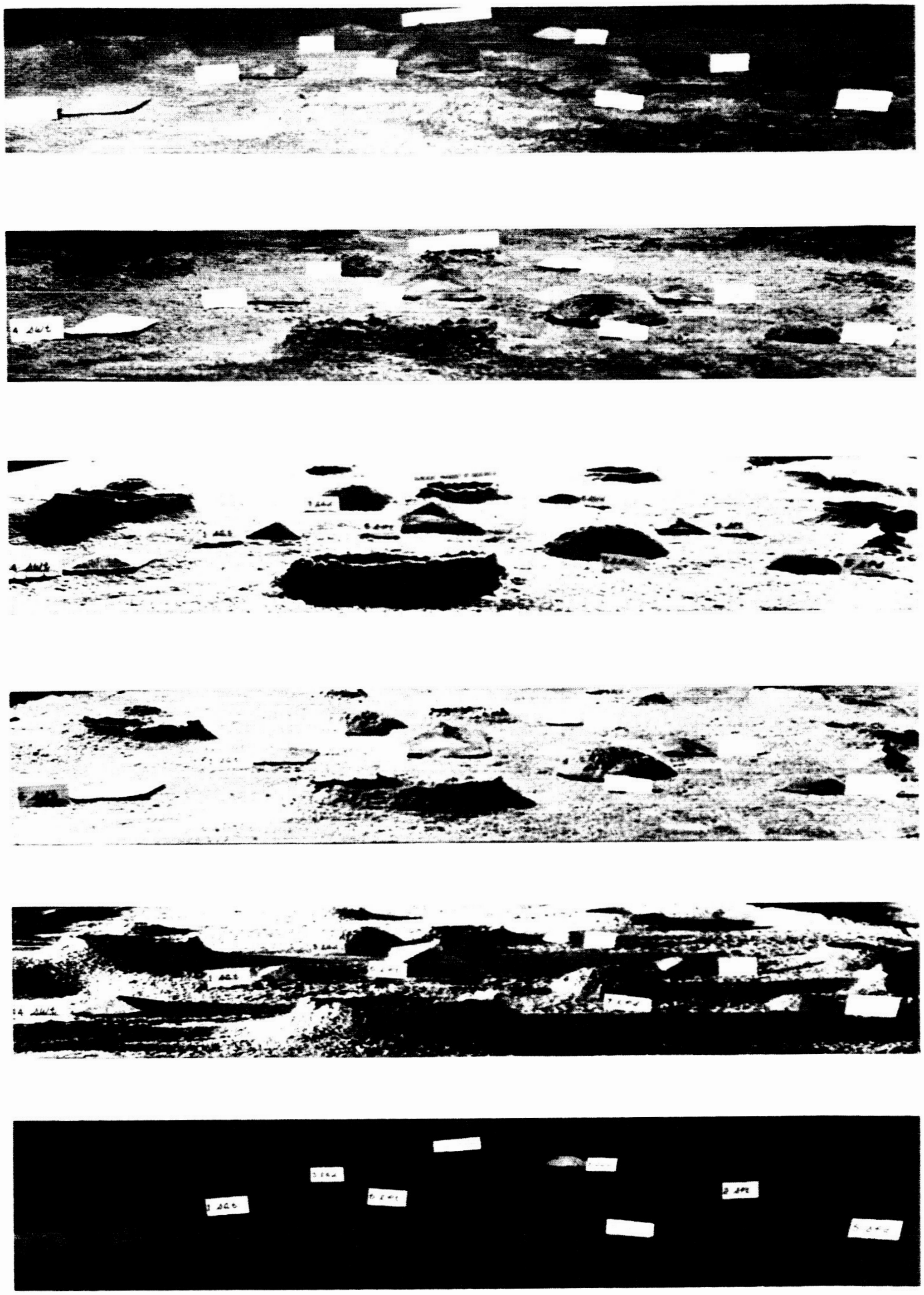


Figure 2-3. Effect of Lighting Angle and Lighting Intensity

Item	Symbol	Variable	1	2	3	4a	4b	4c	4d	4e	5	6
			Test Runs									
Obstacles			■	■	■	■	■	■	■	■	■	■
Viewing Mode	E	Direct Eye		■								
	M	T. V. Monitor			■							■
	P	Projected View	■			■	■	■	■	■	■	
Road Speed	S	Slow - 2 MPH	■	■	■		■	■	■	■	■	■
	F	Fast - 6 MPH				■						
Lighting Intensity	H	Sunlight	■	■	■	■	■	■	■	■		
	L	Earthshine									■	■
Lighting Position	B	Behind Observ.					■					
	O	Overhead	■	■	■	■					■	■
	I	In Front						■				
	T	⊥ - 10° Incident							■			
	F	⊥ - 45° Incident								■		

Figure 2-4. Obstacle Recognition Test Run Schedule

Item	Symbol	Variable	Run 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Viewing Fidelity		Objects	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	C	Camera Direct	■	■	■	■	■	■	■	■	■	■	■	■												
	M	T. V. Monitor													■	■	■	■	■	■	■	■	■	■	■	■
Road Speed	S	Slow - 2 MPH	■	■	■	■	■	■							■	■	■	■	■	■						
	F	Fast - 6 MPH							■	■	■	■	■	■							■	■	■	■	■	■
Lighting Intensity	H	Sunlight	■	■	■	■	■		■	■	■	■	■		■	■	■	■	■		■	■	■	■	■	
	L	Earthshine						■						■						■						■
Lighting Position	B	Behind Observ.	■						■						■						■					
	O	Overhead		■				■		■				■		■				■		■				■
	I	In Front			■						■						■						■			
	T	⊥- 10° Incident				■						■						■						■		
	F	⊥-45° Incident					■						■						■						■	

Figure 2-5. Motion Picture Run Schedule

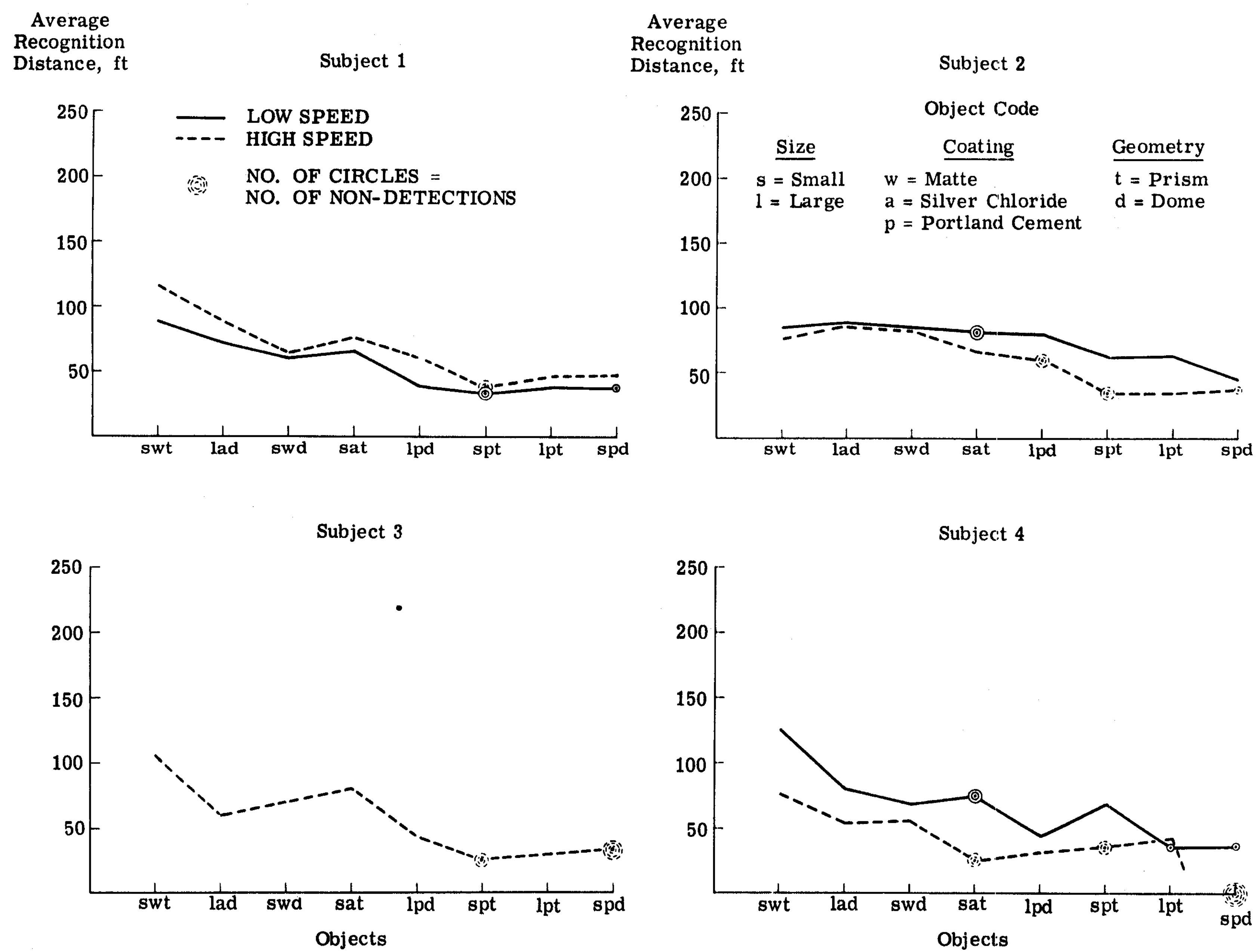


Figure 2-6. Effect of Vehicle Speed on Recognition Distance

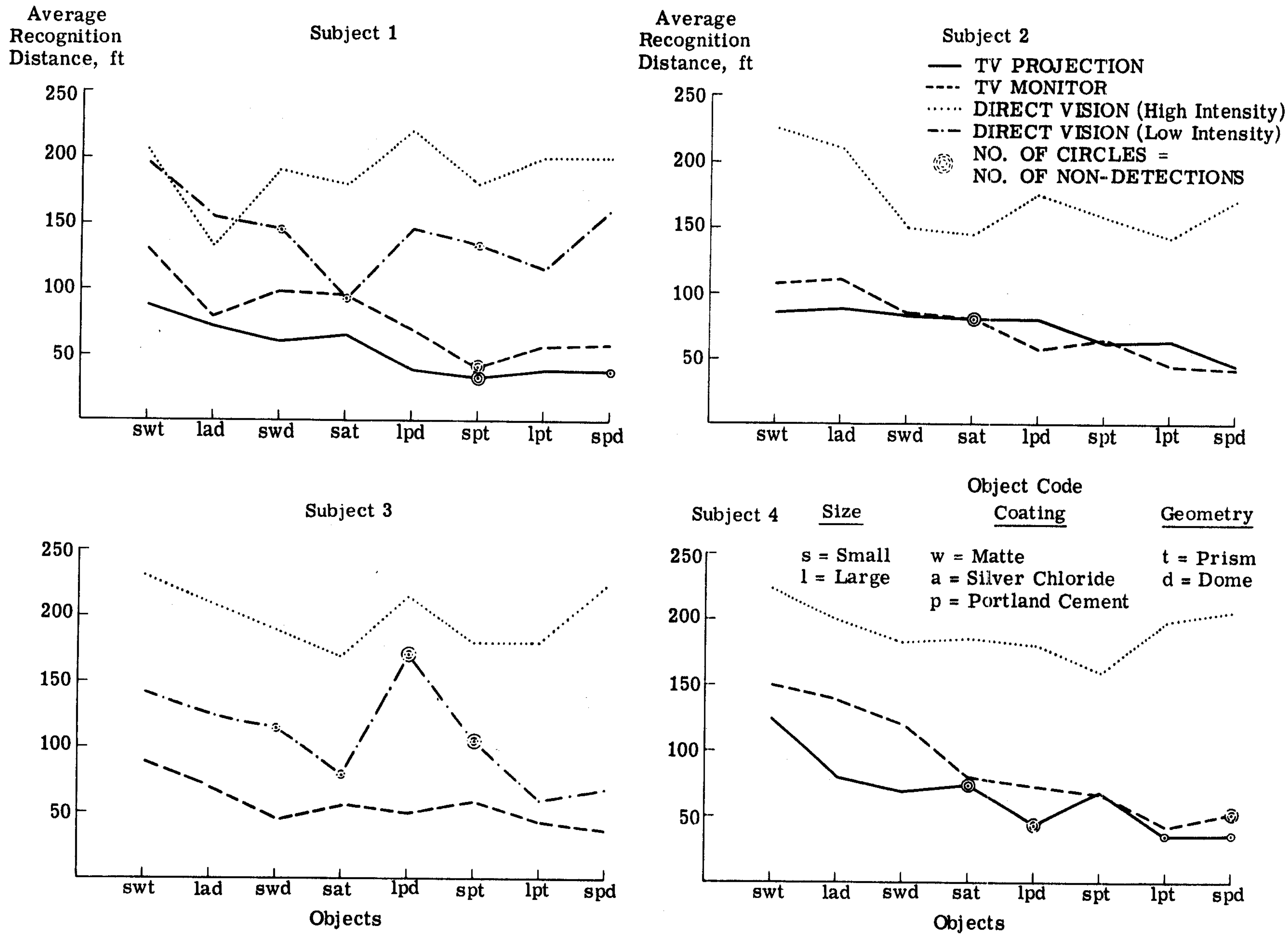


Figure 2-7. Comparison of Recognition Distances for TV Monitor, TV Projection, and Direct Viewing

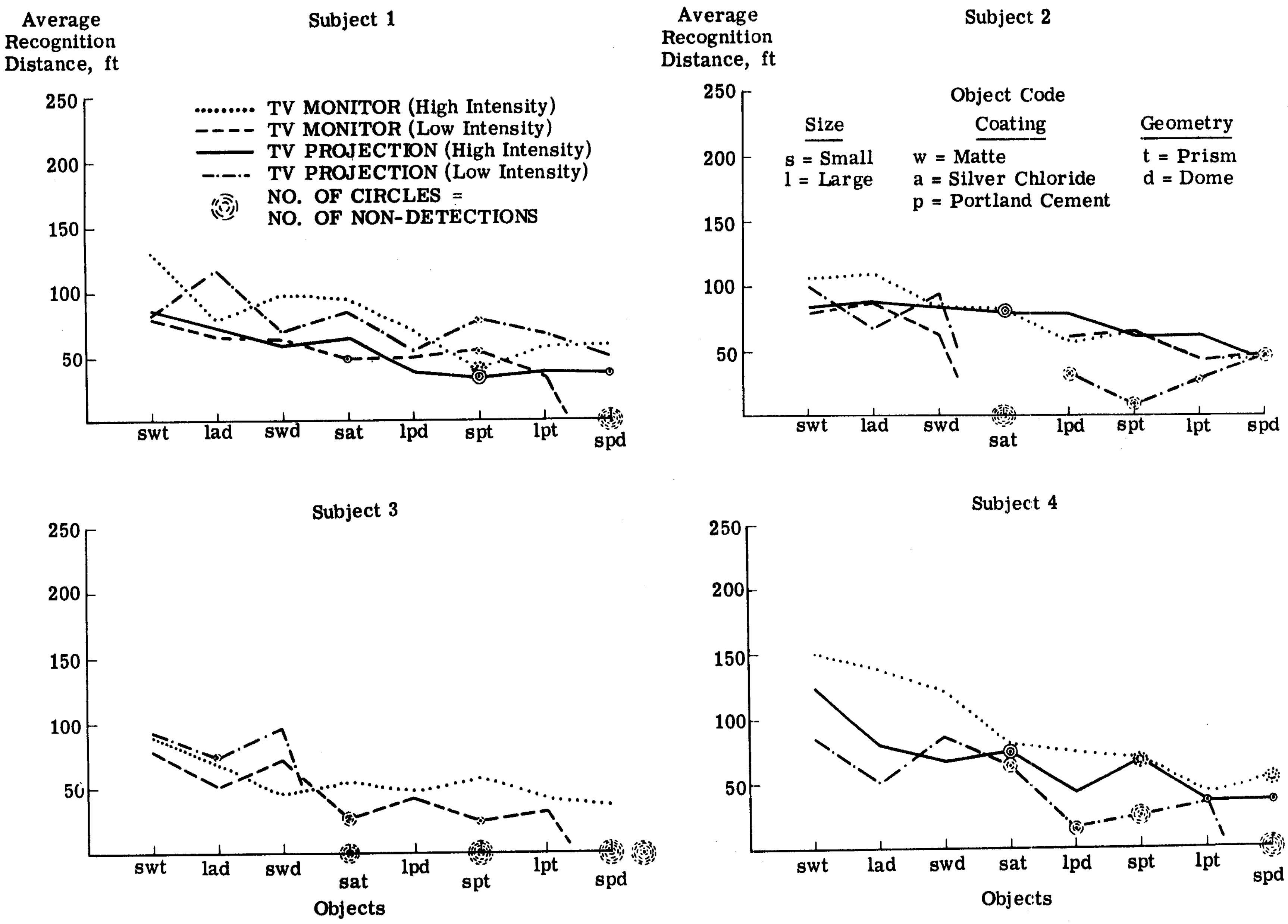


Figure 2-8. Comparison of Recognition Distances for High and Low Intensity Lighting

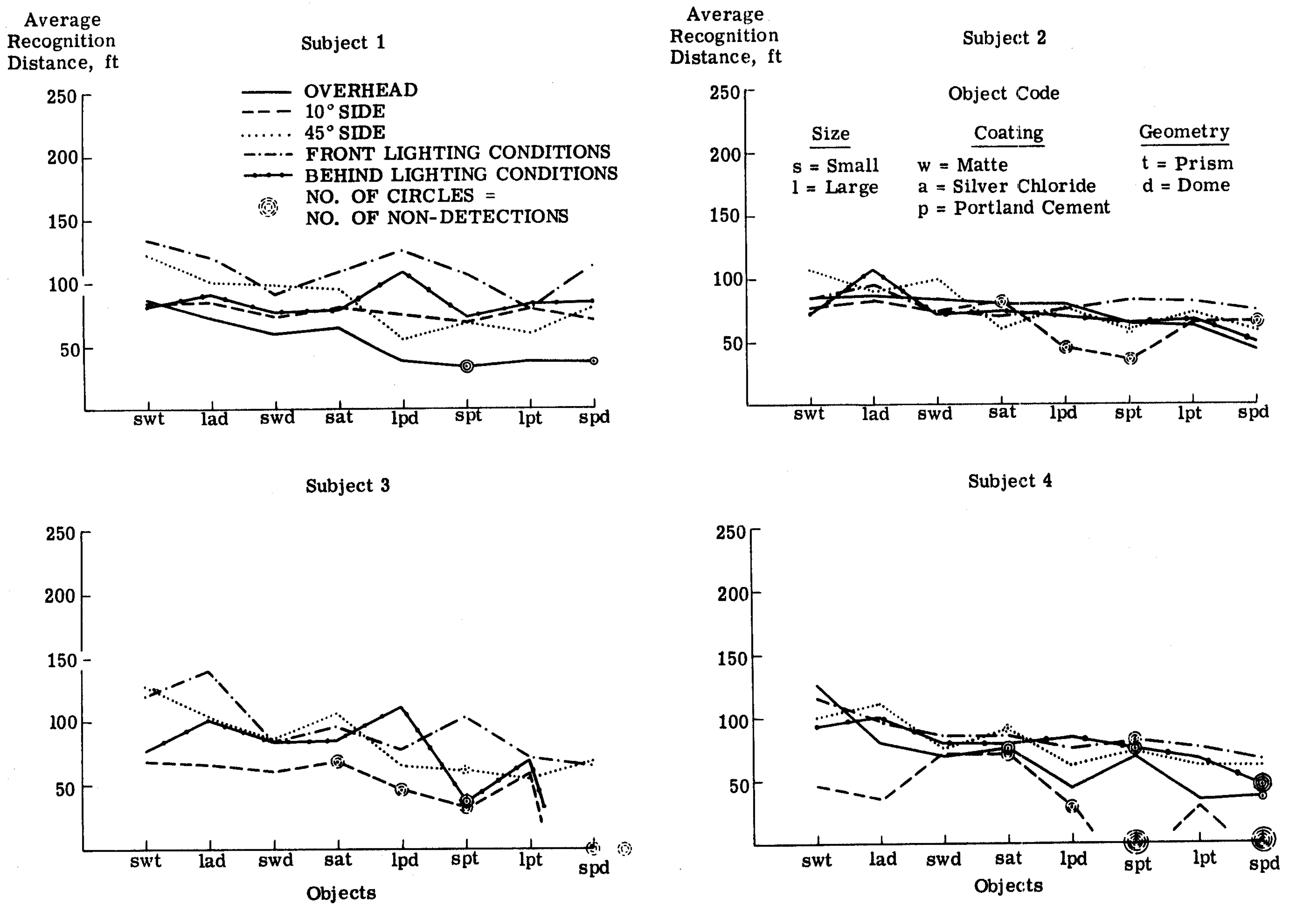


Figure 2-9. Effect of Lighting Position on Recognition Distance

COMPARISON A vs B		SUBJECT 2		SUBJECT 3		SUBJECT 4	
Condition A	Condition B	DETECTION DISTANCE ADVANTAGE A OVER B	DETECTION ERRORS	DETECTION DISTANCE ADVANTAGE A OVER B	DETECTION ERRORS	DETECTION DISTANCE ADVANTAGE A OVER B	DETECTION ERRORS
Overhead Lighting	10° Side Lighting	6 vs 2 S - 14%	2/32 vs 8/32 S - 10%			7 vs 1 S - 4%	2/32 vs 12/32 S - 1%
45° Side Lighting	Overhead Lighting	5 vs 3 N.S.	1/32 vs 2/32 N.S.			7 vs 1 S - 4%	3/32 vs 3/32 N.S.
Front Lighting	45° Side Lighting	5 vs 3 N.S.	0/32 vs 1/32 N.S.	5 vs 3 N.S.	0/32 vs 1/32 N.S.	6 vs 2 S - 14%	2/32 vs 3/32 N.S.
Behind Observer Lighting	Overhead Lighting	4 vs 4 N.S.	0/32 vs 2/32 N.S.			7 vs 1 S - 4%	5/32 vs 3/32 N.S.
45° Side Lighting	Behind Observer Lighting	5 vs 3 N.S.	1/32 vs 0/32 N.S.	6 vs 2	1/32 vs 6/32 S - 10%	4 vs 4 N.S.	5/32 vs 3/32 N.S.
TV Monitor Viewing	TV Projection Viewing	4 vs 4 N.S.	0/32 vs 2/32 N.S.	7 vs 1	1/32 vs 6/32 S - 10%	7 vs 1 S - 4%	4/32 vs 3/32 N.S.
Low Speed	High Speed	8 vs 0 S - 1%	2/32 vs 5/32 N.S.			7 vs 1 S - 4%	3/32 vs 8/32 S - 10%
DIRECT VISION High Intensity Lighting	Low Intensity Lighting			8 vs 0	2/32 vs 7/32 S - 10%		
TV PROJECTION Low Intensity Lighting	High Intensity Lighting	5 vs 3 N.S.	2/32 vs 11/32 S - 5%			7 vs 1 S - 4%	3/32 vs 11/32 S - 5%

S - 14%: Marginally Significant at 14% Level
N.S: Not Significant
n/32: Number of Errors/32 Presentations

Figure 2-10. Comparison of Average Detection Distances

3. STUDY OF FACTORS AFFECTING THE MOBILITY TASK

3.1 OBJECTIVES AND GENERAL APPROACH

This study is intended to supply information for design compromises and to indicate directions conducive to optimization of a lunar roving vehicle. This does not imply research-type investigation of all factors and all interactions. Only those of direct design interest will be investigated.

The program has been planned to be as sequential and flexible as possible; later tests and investigations will be based as much as possible on experience and results of earlier tests. This implies a need for a series of small experimental designs and prompt data reduction and analysis (at least on a preliminary basis). Such a procedure allows much more investigation in the direction of optimization than a single large fixed design.

Since man is such a vital element in the total system, considerable effort must be expended to control the well-known variability of human subjects. Advantage will be taken of the fact that performance of a given human in complex tasks is considerably less variable in comparison within subjects than across subjects.

This performance will be measured on the basis of time-to-complete-task, number of mistakes, and control inputs.

Tasks designed to evaluate differences in configurations must not only be realistic, but must also be designed to the proper subject stress level. Results from other simulations show that stress levels too high or too low tend to obscure differences. Furthermore, the ever-present confounding factor of learning must be controlled by allowing adequate training on each configuration and the use of replications well-spaced in time to check for learning and repeatability. This will be done, if necessary, at the expense of a number of subjects.

This study program has been divided into two phases. One phase will be conducted on the Fixed Base Simulator, the remaining phase on the Mobile Base Simulator. A number of the experiments have been made common to both Simulators in order to correlate data.

3.1.1 Controller Selection

One of the tasks of this study is to compare the performance of integrated and separated controllers. An integrated controller serves as a single control for steering, drive power, and braking, whereas in the separated controllers, steering is accomplished by one controller and the drive power and braking are governed by another controller.

An early model of a LEM attitude controller was selected as the integrated controller. The original controller had a T-bar handle and three-axis control (pitch, roll, yaw). Yaw mode was locked out and pitch mode is used for drive and braking; the roll mode is used for steering. Initially, the T-bar handle was replaced by a late version of the LEM attitude control grip (Figure 3-1A). This proved to be unsatisfactory because the mass of the grip, located on a long pivot arm, produced unwanted control inputs. Relocation of the pivot axis would have solved the problem, but this would have required considerable rework to the controller. Instead, the T-bar was reinstated, and a horseshoe collar was added to prevent the fingers from slipping off (Figure 3-1B). This grip is presently being evaluated. The integrated controller is spring-loaded to return to neutral steering position and zero drive position (Figure 3-2A).

The separated controllers are composed of the aforementioned integrated controller on the driver's right-hand side, and a modified LEM translation controller on the left-hand side (No. 2 in Figure 3-1A). Fore and aft motion is locked out on the integrated controller and the drive power/brake function is accomplished with the modified LEM translation controller.

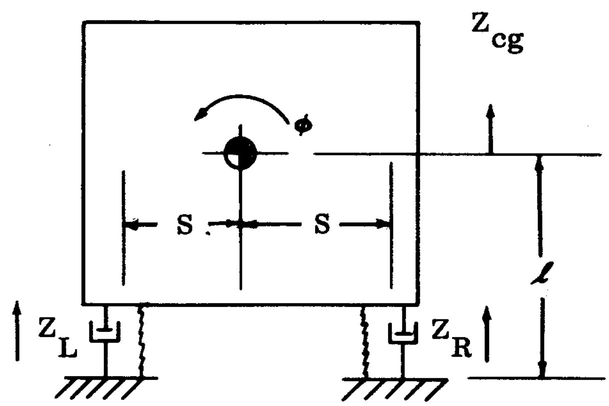
In this mode of operation the drive power controller is held in place by friction. The brake control is spring-loaded to "off" position (see Figure 3-2B).

3.1.2 Vehicle Dynamics on Fixed Base Simulator

The operation of the Fixed Base Simulator was described in Section 1.3. It was stated there that two plastic wheels rolling over the simulated lunar surface generated electrical voltages proportional to the vertical displacement of the wheels. These analog voltages are sent to a Reeves Reac #100 Computer programmed to solve the following equations:

$$\ddot{Z}_{cg} = -\frac{1}{M}\left[2C\dot{Z}_{cg} + 2K_v Z_{cg} - C(\dot{Z}_L + \dot{Z}_R) - K_v(Z_L + Z_R) + M_g\right] \quad (1)$$

$$\ddot{\phi} = -\frac{1}{I}\left[2S^2C\dot{\phi} + 2S^2K_v\phi \;\; SC(Z_L - Z_R) + SK_v(\dot{Z}_L - \dot{Z}_R) + \frac{MV^2}{R}\ell\right] \quad (2)$$



where the variables are:

Z_L and Z_R	=	Left and Right wheel vertical displacements
$\dot{Z}_L$ and $\dot{Z}_R$	=	Left and Right wheel vertical velocities
Z_{cg}	=	Vertical Displacement of cg
$\dot{Z}_{cg}$	=	Vertical Velocity of cg
$\ddot{Z}_{cg}$	=	Vertical Acceleration of cg
ϕ	=	Roll Angle
$\dot{\phi}$	=	Roll Velocity
$\ddot{\phi}$	=	Roll Acceleration

V = Vehicle Forward Velocity

R = Turn Radius

and the constants are:

Mass	$50 \leq M \leq 300$ slugs
Damping	$0 \leq C \leq M$ lbs/rad/sec
Wheel Spring Rate	$0 \leq K_v \leq 1{,}000$ lbs/ft
Gravity	$g_m = 5.35$ ft/sec^2 (Moon)
	$g = 32.2$ ft/sec^2 (Earth)
Roll Inertia	$800 \leq I \leq 3{,}000$ slug ft^2
Lateral Wheel to cg dist.	$4 \leq S \leq 8$ ft
Vertical cg Height	$0 \leq \ell \leq 20$ ft

A voltage proportional to the solution of the two simultaneous equations is sent to one of two electro-hydraulic actuators. Equal and simultaneous displacement of the actuators in the same direction produces a heave motion, and differential actuator displacement produces a roll motion of the crew station.

The computer is programmed with the following constants for the study of factors affecting the mobility task (Section 3.2).

MBS (Light Damp)

Mass	162 Slugs
Damping	35 lb/sec/ft

Wheel Spring rate	2670 lbs/ft
Gravity	32.2 ft/sec^2
Roll Inertia	2060 slug ft^2
Lateral Wheel to cg test	5.8 ft
Vertical cg height	4.0 ft

MBS (Well Damp)

Same as above, except:

Damping	350 lb/sec ft

3.1.3 Headlight Location

One of the areas of concern relative to lunar night driving is the location of vehicle headlights. Will the reflective nature of the lunar surface seriously affect the location of vehicle headlights? How will the driver's performance be affected by headlight location? A part of the study of factors affecting the mobility task will consist of night driving of a simulated lunar vehicle.

In order to get some indication of the magnitude of the problem, a simple experiment was conducted at Grumman's lunar site at Peconic. An auto was driven to the site and a camera was located mid-way between and approximately 76 inches above the headlights (Figure 3-3). A time exposure was taken of the "moon" craters (Figure 3-3A). Next, a flash bulb was placed at the center of each headlight and a flash picture of the surface was taken (Figure 3-3B). The final picture was taken with the flashbulbs moved up to the level of the camera (Figure 3-3C).

The above cited figures show that a high headlight location presented an ostensibly safe surface that actually was quite treacherous; the low headlight location creates shadows that aid in distinguishing the obstacles.

3.1.4 Seat Installation

Task No. 5 requires that a NASA-supplied net seat be evaluated in the Mobile Base Simulator. Before the seat could be installed in the Mobile Base Simulator, a supporting structure had to be designed. This is shown in Figure 3-4. The structure has been designed so that the seat can be adjusted 5 inches in a vertical plane, and 2 inches in a fore-and-aft plane.

3.2 STUDY OF FACTORS AFFECTING THE MOBILITY TASK USING THE FIXED BASE SIMULATOR

3.2.1 Task Objective

To assess the importance of the following factors in the manned lunar driving task, with emphasis on factors affecting vehicle design:

- Field of View
- Time Sharing
- Crew Restraint
- Control Mode and Type
- External Lighting
- Headlight Location
- Vehicle Dynamics

3.2.2 Procedure

A series of separate experiments have been designed to investigate the effect of changes of one variable at a time, in terms of differences in a basic configuration (Configuration of Run 1 in run schedule). This basic configuration is used for training and control re-run, to check for designing effects. Four subjects will be used throughout the test program.

The subjects are given a series of training runs over the courses, and with the basic configuration, until their performance reaches a plateau. Formal testing commences when this plateau is achieved.

A run consists of three replications of three different courses of approximately 5 minutes duration per replication (approximately 45 minutes total per run).

The courses are designed to simulate two different driving conditions. One course simulates the problem of driving while navigating by means of a star sighting. Two other courses simulate the problem of following beacon markers. Star sighting is simulated by placing a white marker on a black background. Beacons are simulated by translucent flags located along the course (Figures 3-7 and 3-8).

The subjects are required to maintain the highest velocity compatible with safety. Before starting a run they must read the following prepared statements:

General

"You are on the Moon and you are trying to RETURN SAFELY to your home base in the SHORTEST TIME. If you stall or incapacitate your vehicle you will increase your time and jeopardize your safety."

Additional Instructions for Course Four

"The dot on the horizon represents a star that you are using to guide your way home. Remember you are trying to get home safely in the shortest possible time without incapacitating the vehicle."

Additional Instructions for Courses Five and Six

"The white markers represent beacons that you are following to your base. Drive over the markers. If you miss a marker continue on to the next one."

3.2.3 Variables

The following variables are being tested (see Figure 3-7):

- Field of View: With the cockpit window masked, three vertical and three horizontal settings will be employed.

- Time Sharing: A "bit box" which consists of an amber light operated by a push button, a green light operated by a toggle switch, and a variable frequency flasher, is used to impose a secondary task on the driver. Two frequency levels representing moderate stress and high stress will be used.

- Crew Restraint: Seated and standing restrained modes will be investigated.

- Control Mode: A proportional control (steering angle proportional to stick deflection) and an open loop (stick activation produces fixed steering angle rate) will be investigated.

- Control Type: A representative integrated controller (both steering and power/brake in one 2-degree of freedom control) and a representative separated controller (one controller for steering, one for power/brake) will be evaluated.

- External Lighting: Four positions of sun location will be investigated: Overhead, 10 degree side, 45 degree side, back.

- Headlight Location: Two headlight positions shall be investigated: headlights below driver's eye level, headlights at driver's eye level.

- Vehicle Dynamics: Two conditions of vehicle dynamics will be evaluated: the Mobile Base Simulator dynamics (natural frequency, damping), and a highly damped vehicle with the same natural frequency.

3.2.4 Recorded Data

The following is a list of the basic recorded data and the derived statistics to be analyzed:

Recorded	Statistical Measure
Time	Time
Total distance covered	Distance traveled/course length
Power/Brake input	RMS Average Absolute Derivative (AAD)
Steering input	Mean Absolute Deviation (MAD) Average Absolute Derivative (AAD) Number of times control limit reached Number of times vehicle limit reached
Seat normal acceleration	Mean Absolute Deviation Number of threshold crossings

Standard debriefing forms are accomplished by all subjects at the end of each experiment to record subjective evaluations for collation with quantitative results.

3.2.5 Analysis Methods

3.2.5.1 Preliminary Analysis

Plots of each performance variable vs. conditions (using each replication as point - see Figure 3-8A) for individual subjects will be constructed to help decide which performance measures give the best resolution. The average performance measure for each subject will then be superimposed on one plot for each performance measure of interest (Figure 3-8B).

3.2.5.2 Formal Analysis

Where warranted by distribution and homogeneity of scatter, an analysis of variance will be used to test F-ratios corresponding to hypotheses of interest. Multiple comparison and combination of significance tests (where indicated by hypotheses) will be used. Otherwise, non-parametric procedures (e. g. , rank tests) on comparisons of interest will be used.

Results will be pooled across subjects and/or conditions, only where results show sufficient homogeneity to make pooling meaningful.

Estimate of scatter of results using mean absolute deviation or percentile range will be made as warranted.

3.3 STUDY OF FACTORS AFFECTING THE MOBILITY TASK USING THE MOBILE BASE SIMULATOR

3.3.1 Task Objective

The task objective is to study the influence of the following factors on the mobility task:

- Field of View
- Control Mode and Type
- Time Sharing
- Crew Restraint
- Environment

3.3.2 Procedure

The lunar test site at Grumman's Peconic facility does not duplicate the surface used in the Fixed Base Simulator; a different set of courses had to be established. Three different courses of varying difficulty have been designed. Each course is planned for approximately 5 minutes driving time (Figures 3-9 through 3-11).

As in the Fixed Base Simulator tests, a run consists of three replications of three courses for each change of variable.

The experimental design consists of a series of separate experiments to investigate the effect of changes of one variable at a time in terms of differences from a basic configuration (Configuration of Run 1 in Run Schedule) (Figure 3-12). This basic configuration is used for training and control re-run, to check for designing effects.

The subjects are given a series of training runs over the courses with the basic configuration until their performance reaches a plateau, after which time formal testing commences. As in the Fixed Base Simulator tests, the subjects are required to maintain the highest velocity compatible with safety. Before starting a run, the subjects are required to read the following prepared statement:

> "You are on the Moon and you are trying to RETURN SAFELY to your home base in the SHORTEST TIME. If you stall or incapacitate your vehicle you will increase your time and jeopardize your safety.
>
> You may back up if you feel that this maneuver will help you get home safely."

3.3.3 Variables

The variables that are being tested are:

- Field of View - Three vertical and three horizontal settings will be employed using masks over the cockpit windows.

- Control Mode - A proportional control (steering angle proportional to stick deflection) and an open loop control (stick activation produces fixed steering angle rate) will be investigated.

- Control Type - A representative integrated controller (both steering and power/brake in one 2-degree of freedom control) and a representative separated controller (one control for steering, one for power/brake) will be evaluated.

- Crew Position - Seated and restraining standing modes will be investigated.

- Environment - Shirtsleeve and pressure suit environments will be explored.

- Time-Sharing - As in the Fixed Base Simulator, time sharing will be investigated using a "bit box."

3.3.4 Recorded Data

The following is a list of basic recorded data and derived statistics to be analyzed:

Recorded	Statistical Measure
Time (per course)	Time
Speed	Mean Mean Absolute Deviation (MAD)
Total Distance Covered	Distance Traveled/Course Length
Steering Input	MAD Average Absolute Derivative (AAD) Number of Times Limit is Reached
Acceleration/Deceleration Input	Mean Absolute Deviation AAD
Vehicle Accelerations of Seat (heave and roll)	Mean Absolute Deviation Number of Threshold Crossings

Standard debriefing is completed by all subjects at the end of each experiment, to record subjective evaluations for collation with quantitative results.

3.3.5 Analysis Methods

The same preliminary analysis and formal analysis techniques will be used for the Mobile Base and Fixed Base Simulators (see Fixed Base Simulator - Analysis Methods).

3.4 DATA CORRELATION

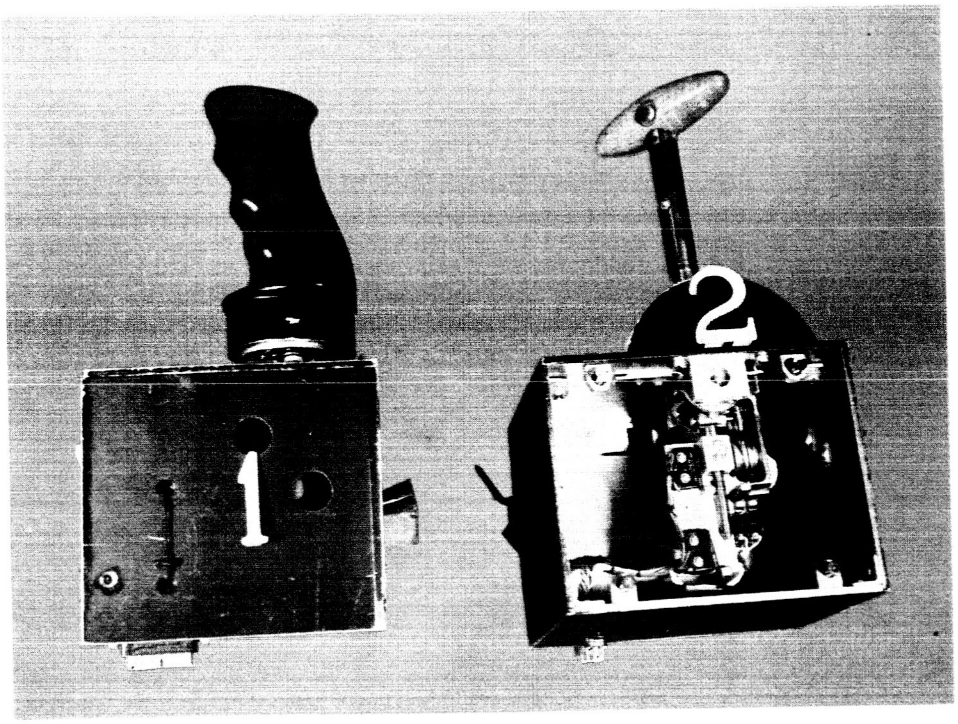
3.4.1 Task Objectives

To correlate the performance results obtained on the Mobile Base Simulator with those results obtained on the Fixed Base Simulator; to validate and improve the Fixed Base Simulator for further, more detailed, investigations; to obtain confidence in Fixed Base Simulator results.

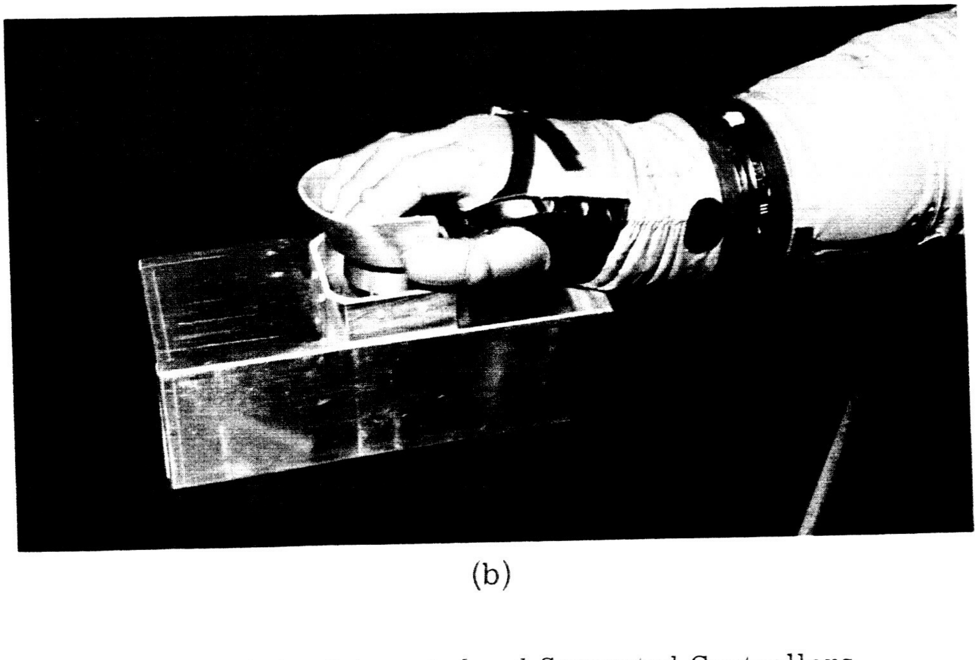
3.4.2 Approach

It is anticipated that the Mobile Base runs will give detailed results on the area of validity of the Fixed Base Simulator (i.e., determining where fixed base comparisons give the same trends as Mobile Base comparisons); this will permit empirically justified judgments on which further detailed investigations may be implemented on the Fixed Base, and those which must be done on the more expensive and time-consuming Mobile Base Simulator.

To accomplish the data correlation task, the Runs 1 through 11 on both simulators have been made identical.



(a)



(b)

Figure 3-1. Integrated and Separated Controllers

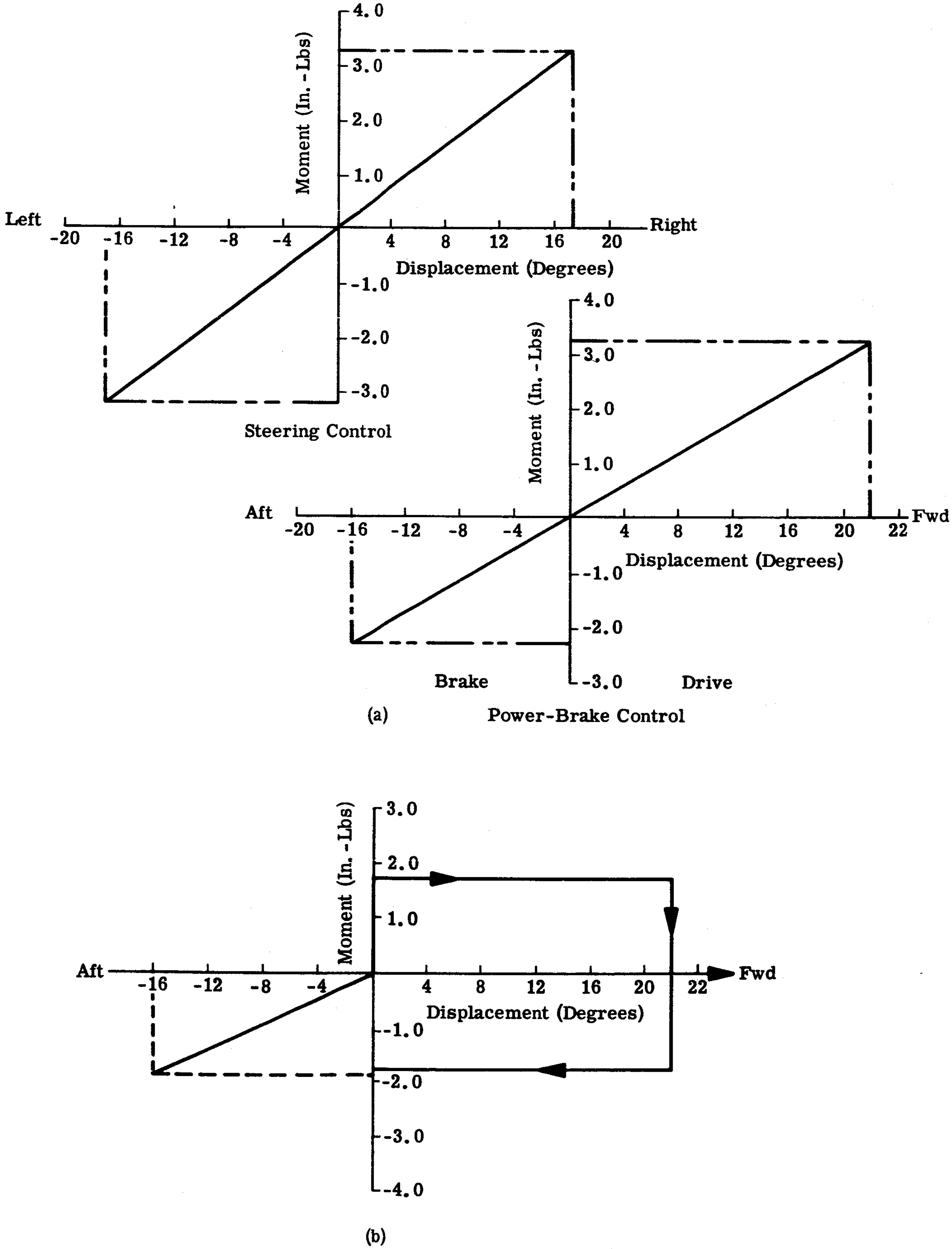
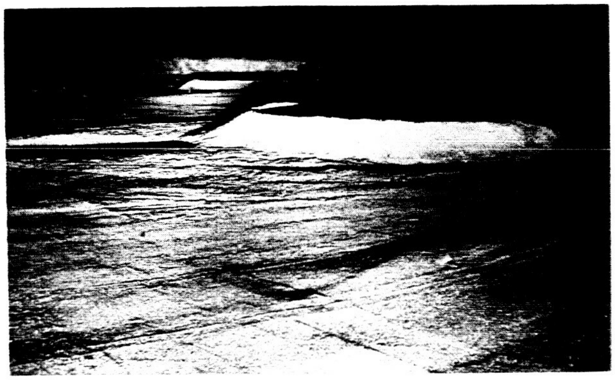
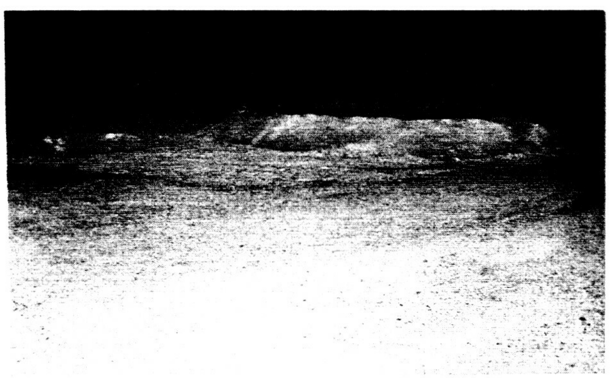


Figure 3-2. Moment-Displacement Characteristics of Controllers

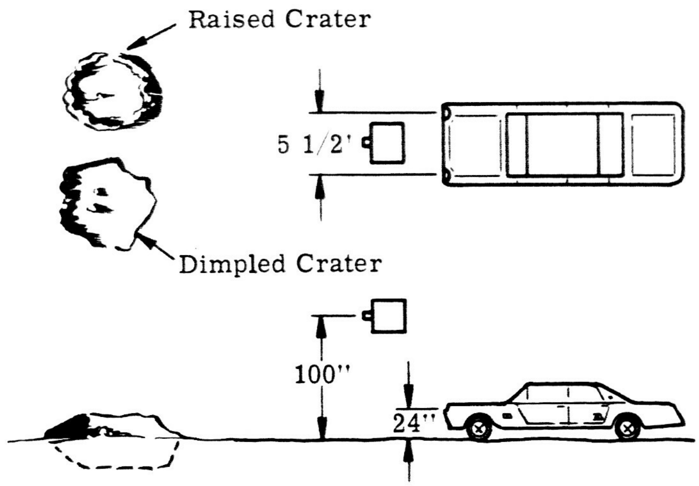


(a)
Two Auto Headlights Below Camera Level

(b)
Two Flash Bulbs Below Camera Level



(c)
Two Flashbulbs At Camera Level



(d)

Figure 3-3. Effect of Headlight Location

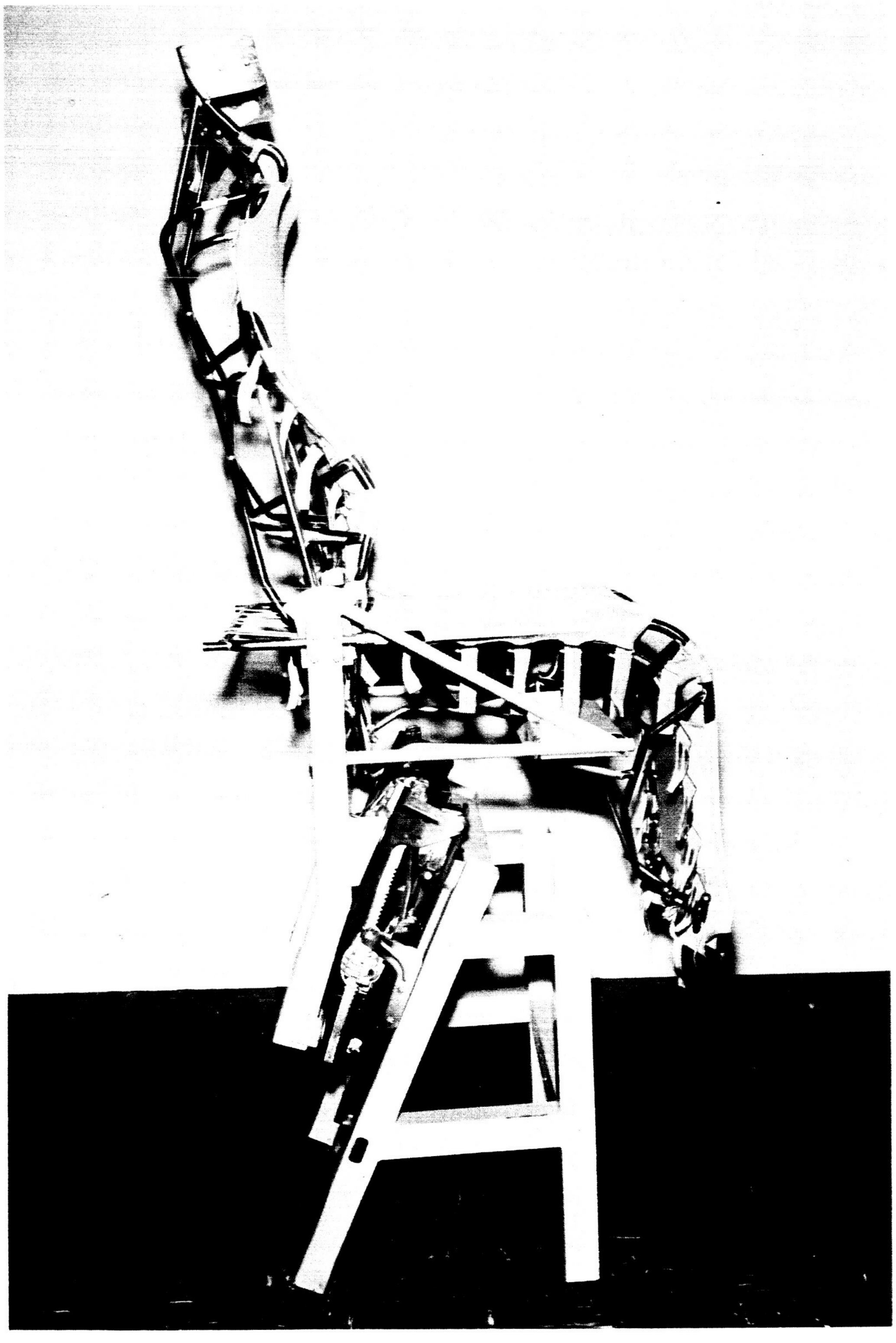
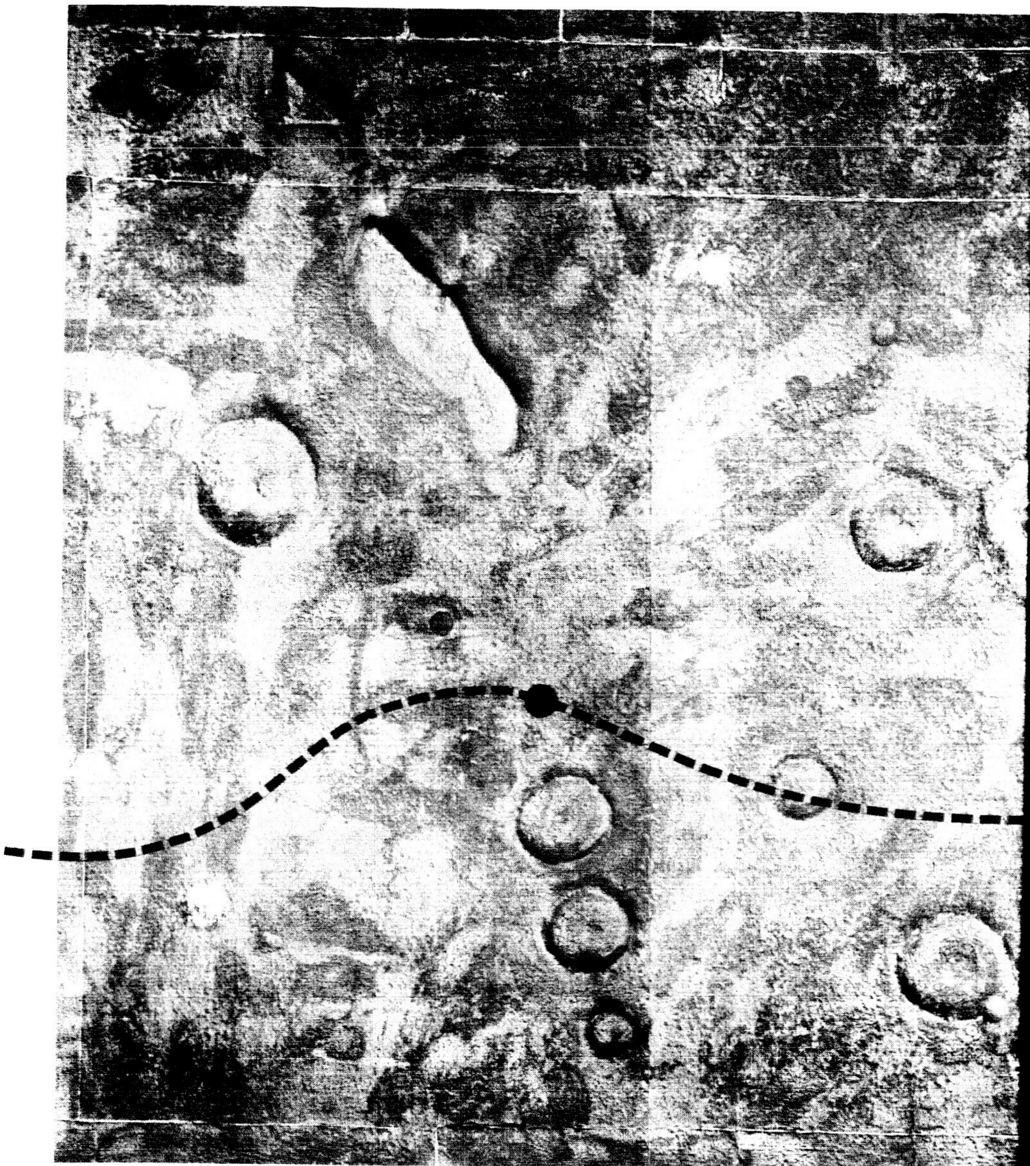
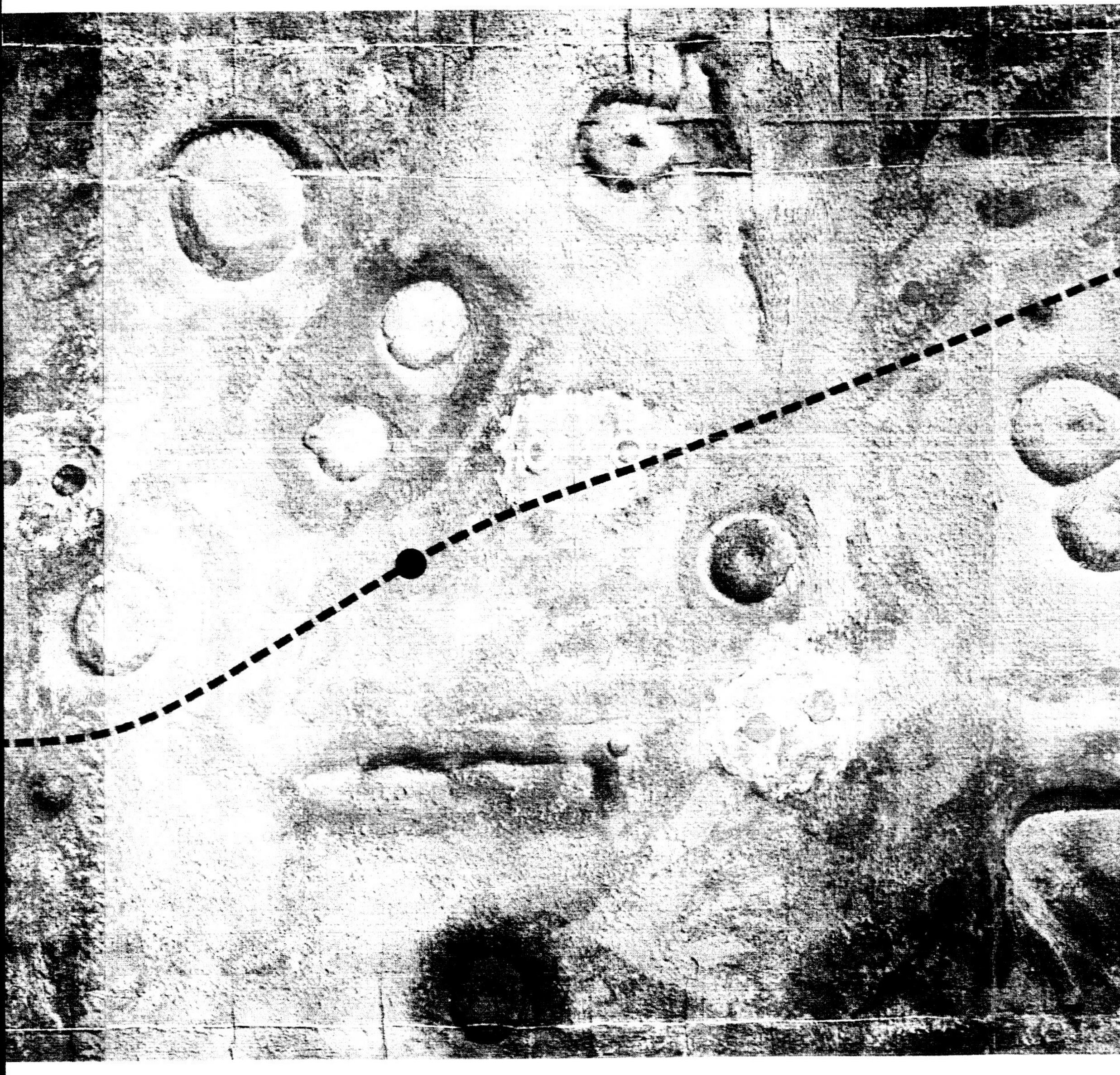
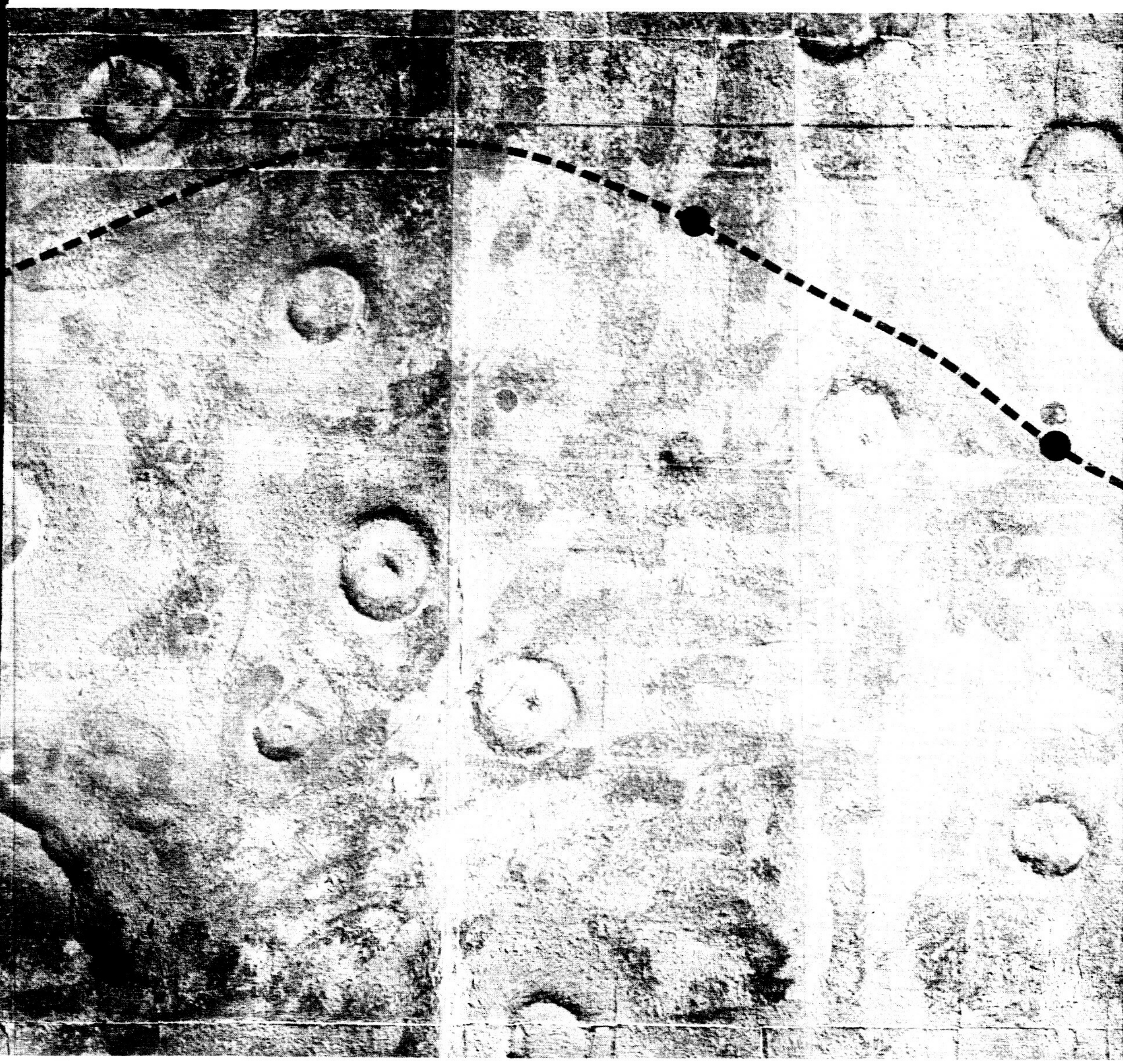


Figure 3-4. Net Seat Assembly

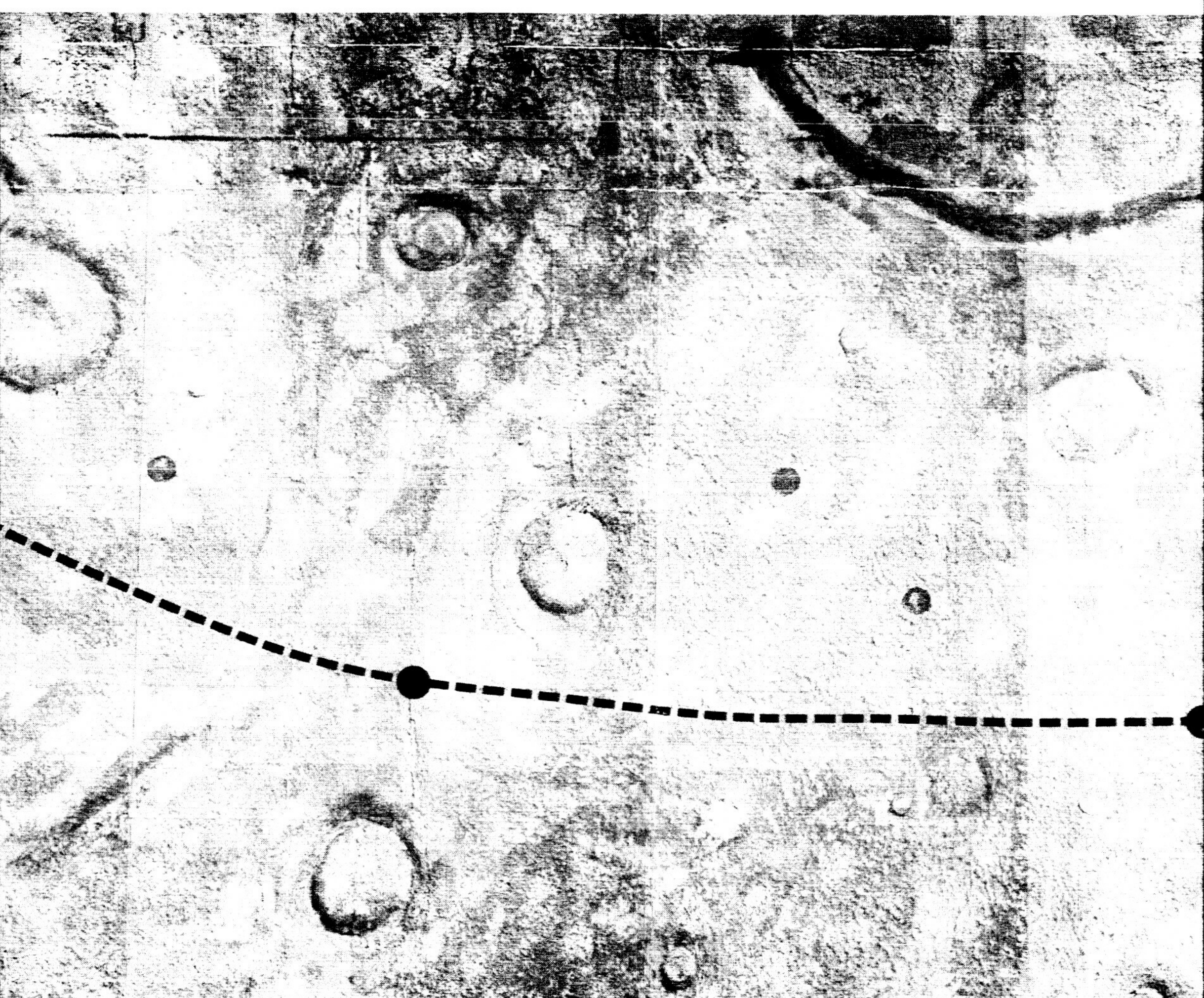


1



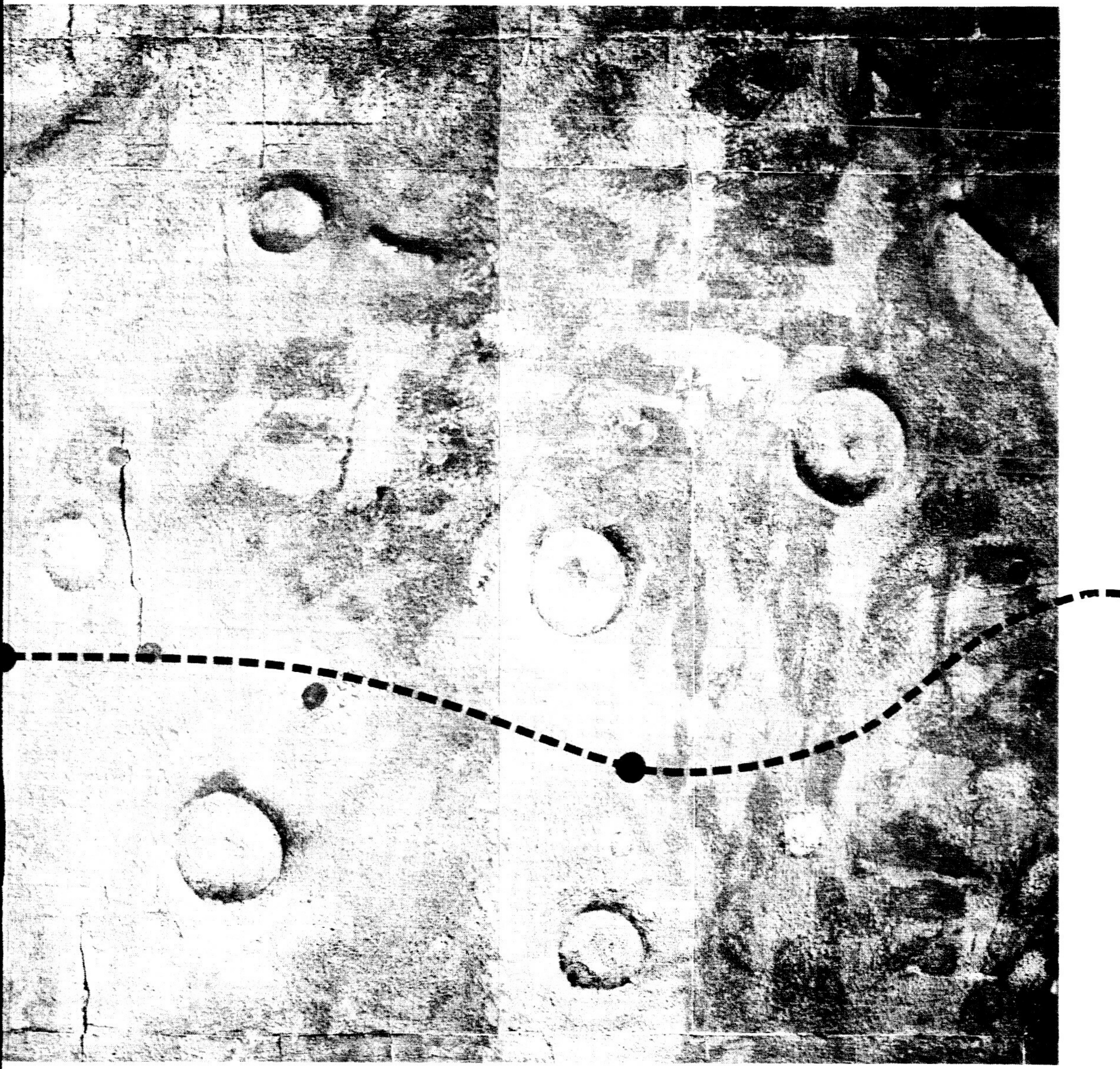


3



Dots show marker

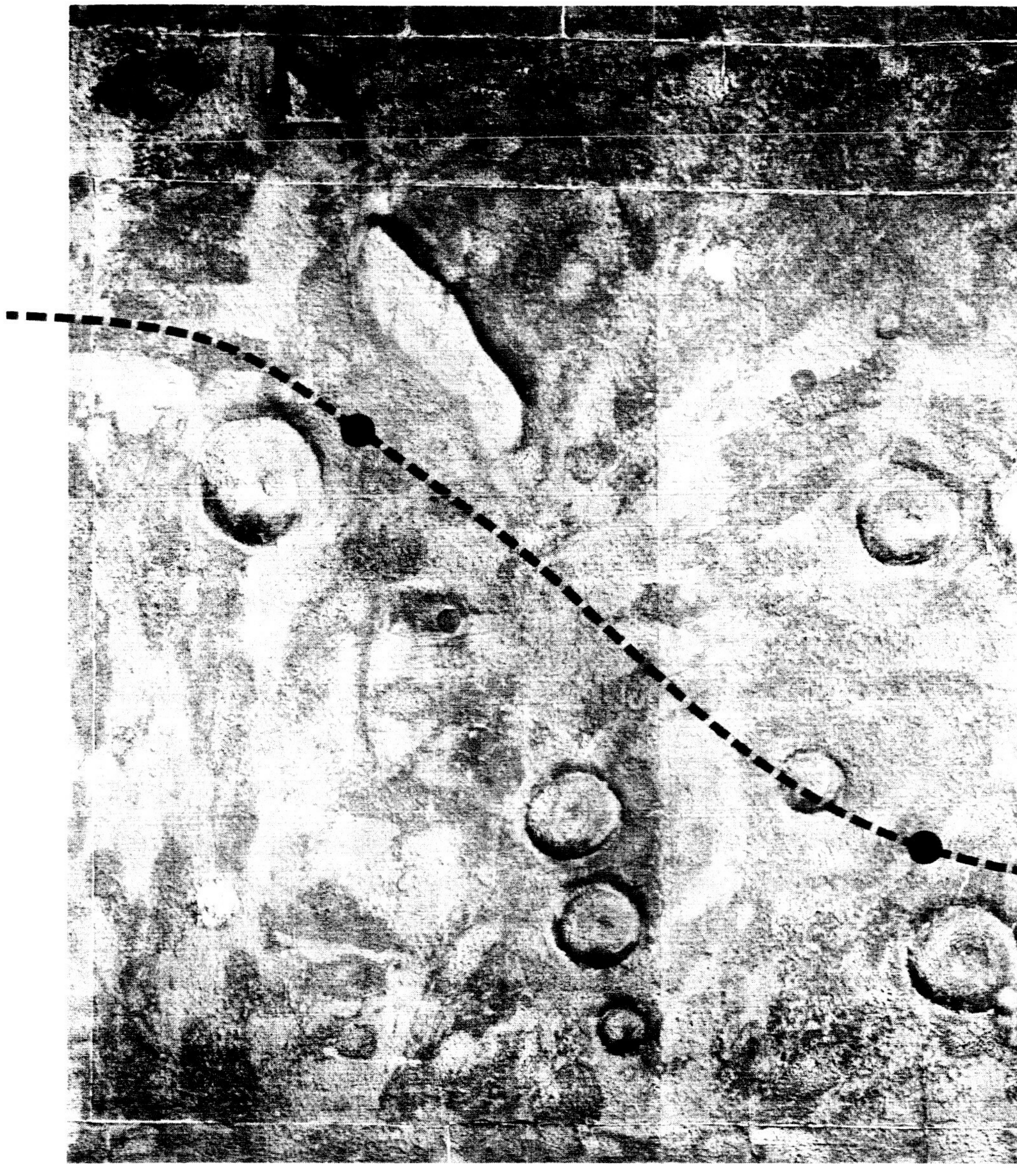
4

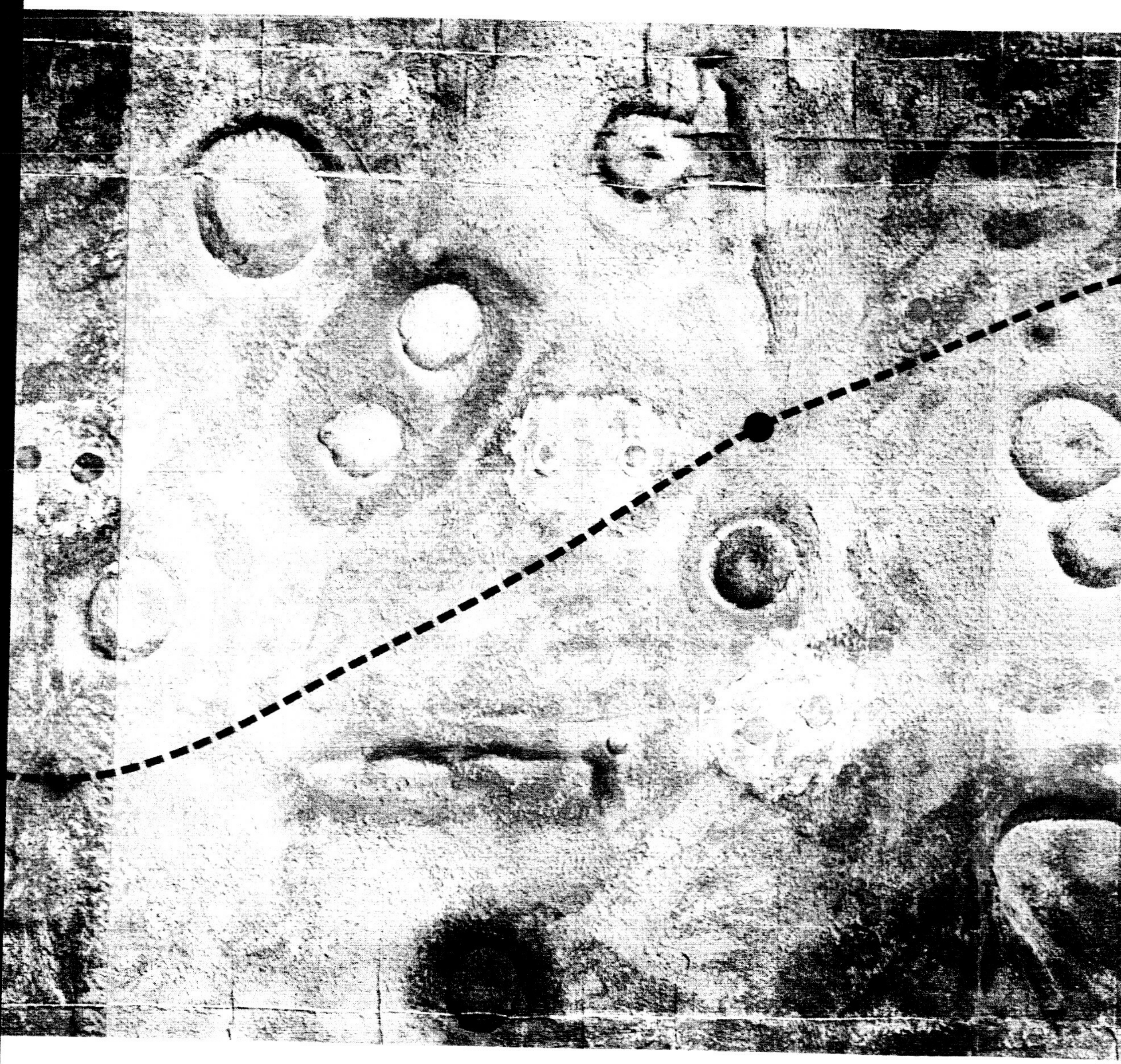


locations

Figure 3-5. Plan View of Course No. 5

5





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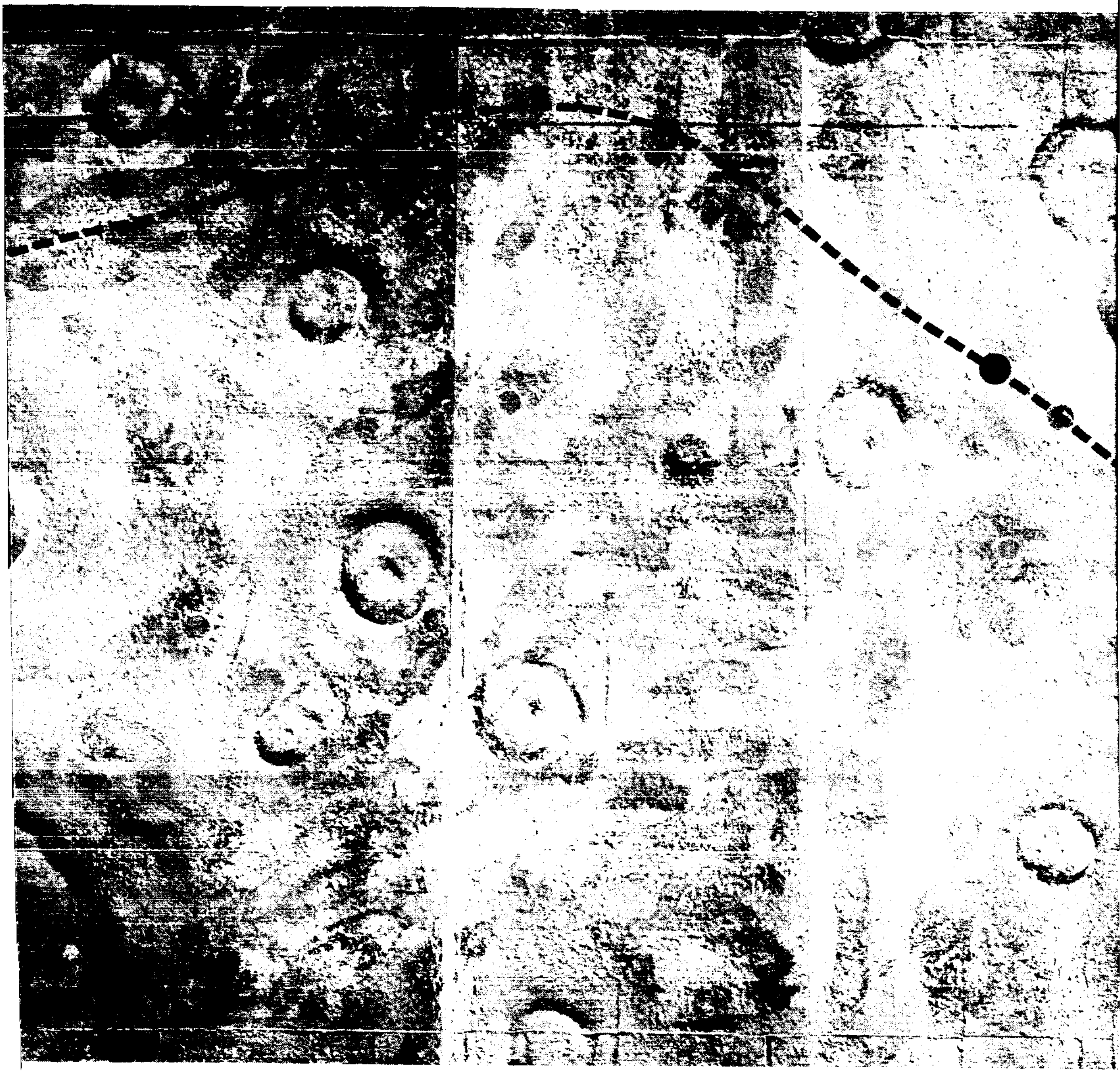
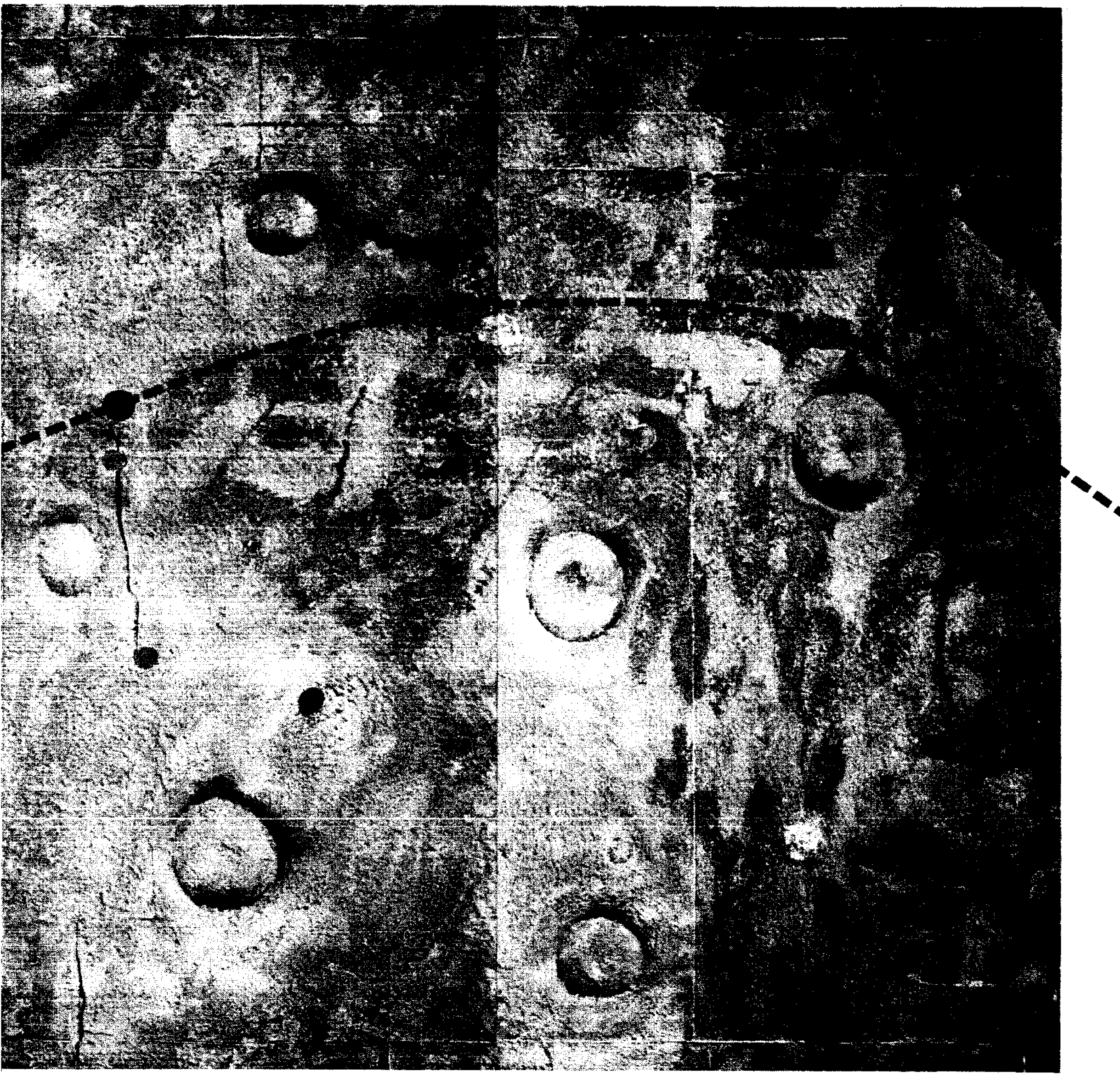


3

Dots show marker locati

4

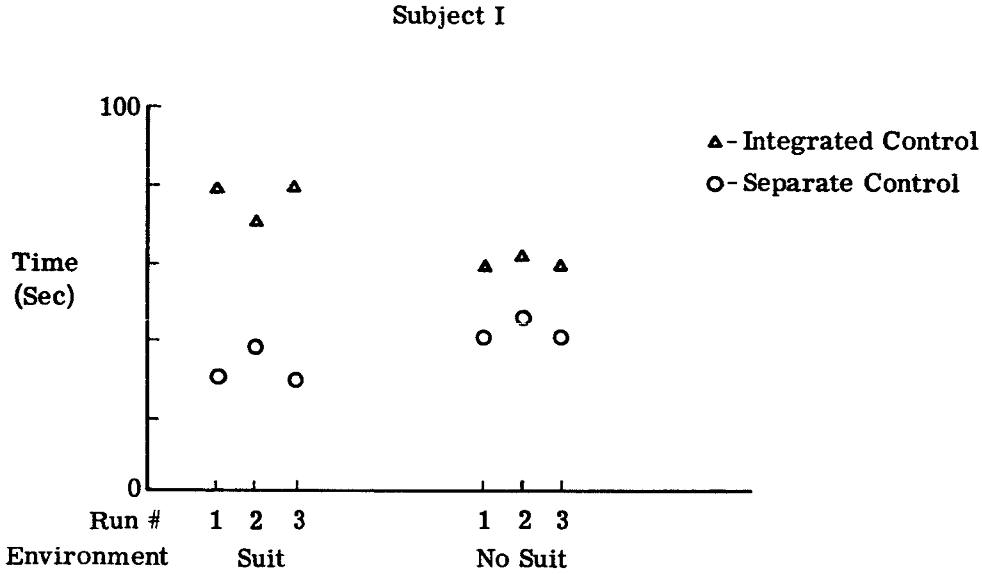


ons

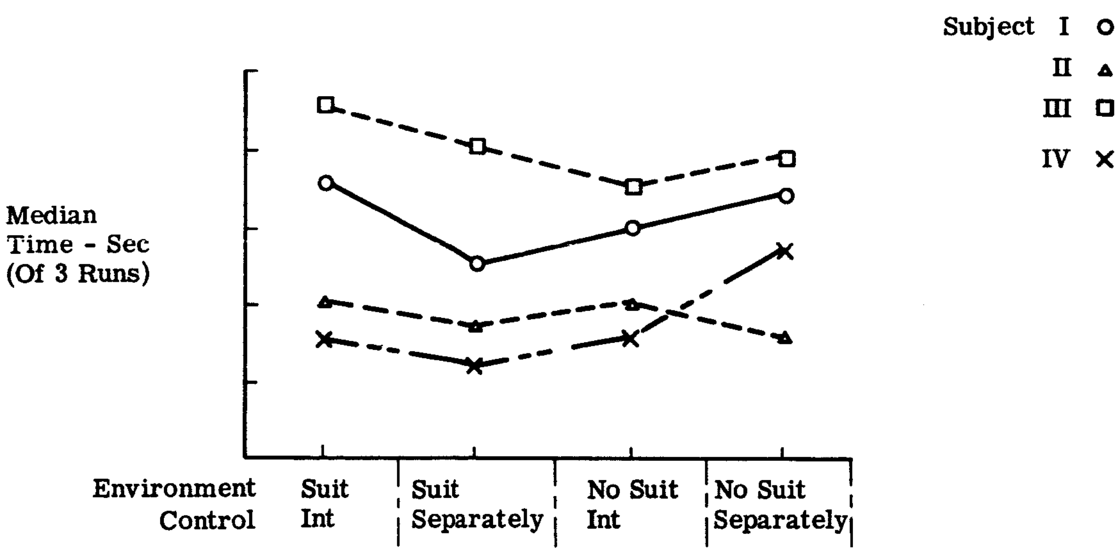
Figure 3-6. Plan View of Course No. 6

	Experiment	Configuration \ Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Field Of View	Side - Max (53°)	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■
		- Median (20)		■															
		- Min (13)			■														
		Down - Max (35°)	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■
		- Median (20)				■													
		- Min (10°)					■												
2	Time Sharing	- None	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■
		- Moderate						■											
		- High							■										
3	Crew Position	- Seated	■	■	■	■	■	■	■			■	■	■	■	■	■	■	■
		Standing								■	■								
	Environment	Shirtsleeve	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4	Control Mode and Type	Intg. Prop. Steer	■	■	■	■	■	■	■	■				■	■	■	■	■	■
		Intg - Rate Steer											■						
		Sep - Prop. Steer									■	■							
5	External Lighting	- Overhead												■					
		- 10° Side													■				
		- 45° Side	■	■	■	■	■	■	■	■	■	■	■						■
		- Back														■			
		Night															■	■	
6	Vehicle Headlights	High															■		
		Low																■	
7	Vehicle Dynamics	M. B. S. (Light Damp)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
		M. B. S. (Well Damp)																	■

Figure 3-7. Fixed Base Simulator Test Run Schedule



(a)



(b)

Figure 3-8. Sample Preliminary Plot

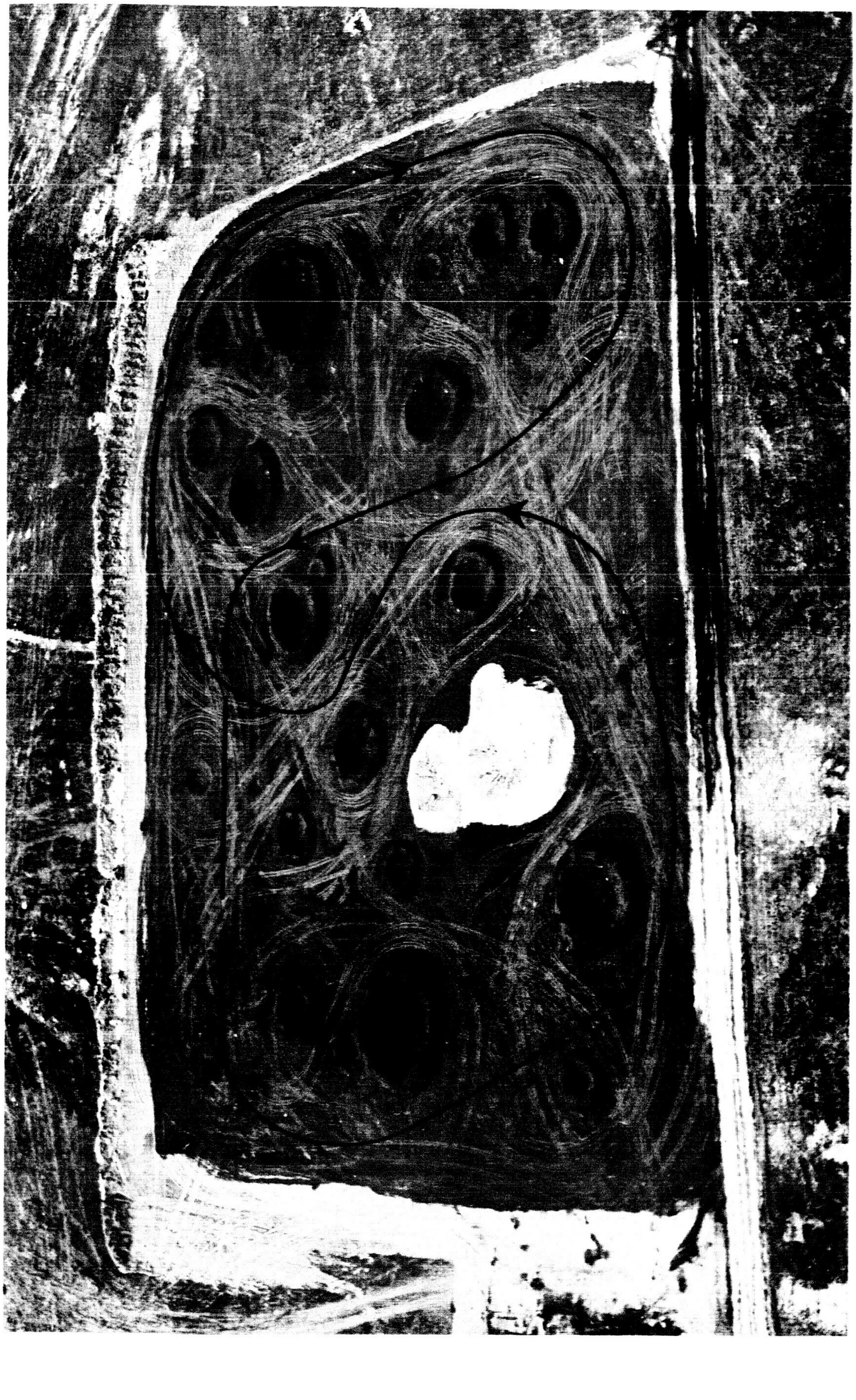


Figure 3-9. Plan View of Course No. 1

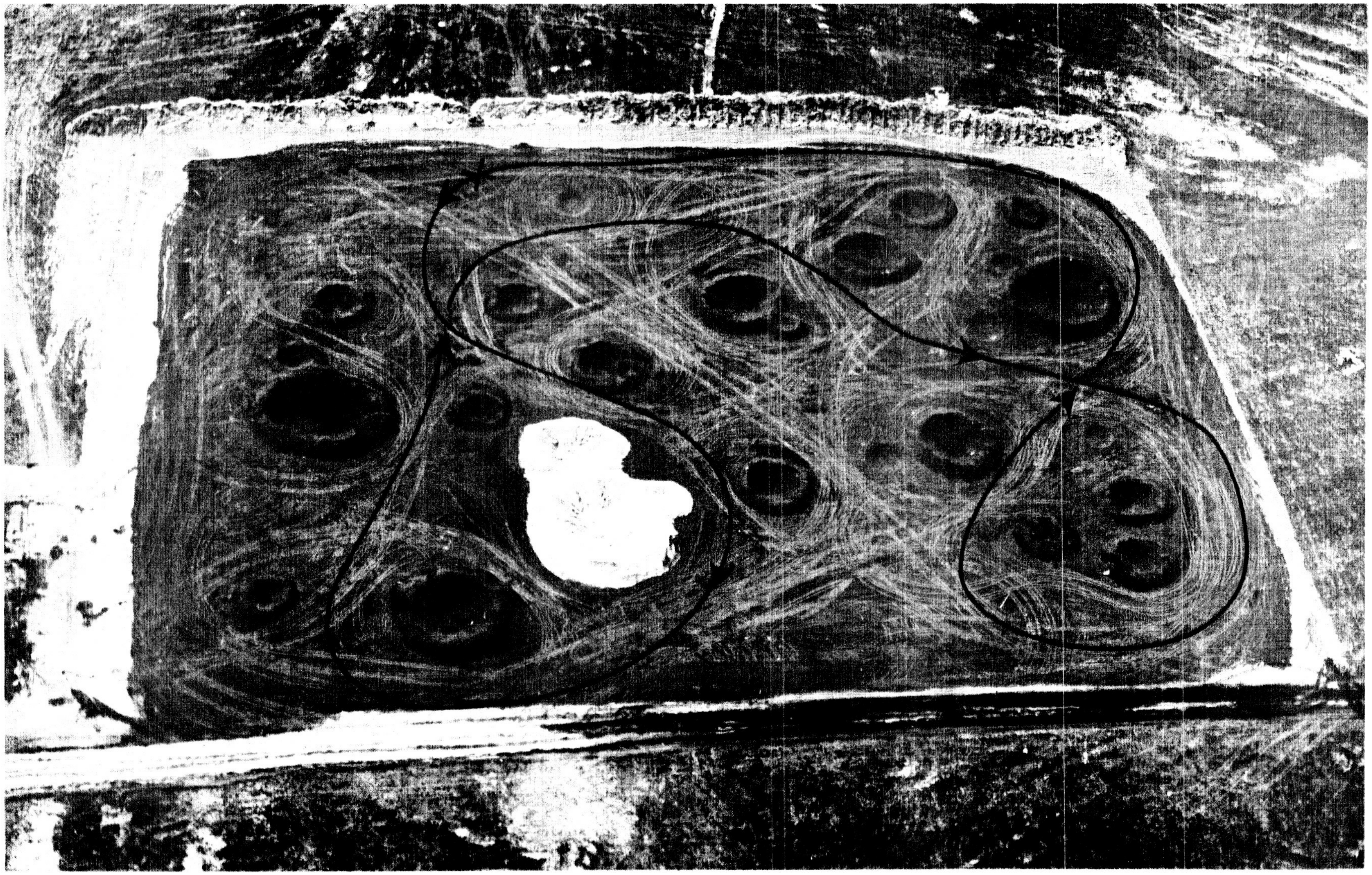


Figure 3-10. Plan View of Course No. 2

Figure 3-11. Plan View of Course No. 3

Experiment	Configuration \ Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Field of View	Side - Max (*)	■			■	■	■	■	■	■	■	■	■	■	■	■	■		■
	- Median (±20)		■															■	
	- Min (±13)			■															
	Down - Max (35°)	■	■	■			■	■	■	■	■	■	■	■	■	■	■		■
	- Median (20)				■													■	
	- Min (10°)					■													
2 Time Sharing	- None	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■	■
	- Moderate						■												
	High							■											
3 Crew Position	Seated	■	■	■	■	■	■	■			■	■	■	■	■			■	■
	Standing								■	■						■	■		
Environment	Pressurized													■	■	■	■		
	Shirtsleeve	■	■	■	■	■	■	■	■	■	■	■	■					■	■
4 Control Mode and Type	Intg. Prop. Steer	■	■	■	■	■	■	■	■					■			■	■	■
	Intg. Rate Steer											■							
	Sep. Prop. Steer									■	■				■	■			
	Sep. Rate Steer												■						
5 NASA Field of View**																			
																		**	
6 NASA Crew Seat																			
																			■

* Maximum side view is obtained using both windows with a field of view of 12° Right - 48° Left out of drivers window and an additional 62° out of observers window.

** NASA Field of View = ±20° Side, 5° Up, 20° Down

Figure 3-12. Mobile Base Simulator Run Schedule