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A Progress Report for

July 1, 1970 to June 30, 1971

CONTROL ELEMENTS FOR AN UNMANNED
MARTIAN ROVING VEHICLE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MRV71-1

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Submitted by

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Summary

Progress is reported on the development of a Martian Roving Vehicle simulator to act as a test platform in the development of obstacle sensors for an autonomous roving vehicle. Both a short-range tactile sensor and a medium-range laser rangefinder sensor are described. Modifications to the soil sampler-tester are described.

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I. INTRODUCTION

Despite funding limitations it seems probable that a roving vehicle will be sent to Mars. While a stationary probe can report considerable detail for an extended period of time, a considerable number of probes would be necessary to get even a fraction of the information easily obtained by a roving vehicle. The roving vehicle also allows the option of mission alteration if visual or sensor data points out a region of possible interest off the planned course. A more complete study of the advantages and requirements of a Martian Roving Vehicle can be found in the study by a group under J.W. Moore.*

Obstacle sensing is of prime importance to an unmanned roving vehicle if it is to run autonomously, and a Martian Roving Vehicle must run in this manner if it is to rove over any considerable area.* This study has included both a tactile sensor which would be sufficient for vehicle safety but inefficient for travel. When obstacles are sensed the vehicle must stop, reverse, and then go into an obstacle evasion procedure. The laser rangefinder on the other hand will allow evasive techniques before the obstacles are reached thus avoiding the stopping and reversal. The present sensor does not sense negative obstacles - craters and crevasses - which means that another device must be used to cover this function. The present concept calls for the tactile sensor to act as the primary sensor for negative obstacles.

* Moore, J.W., "An Exploratory Investigation of a 1979 Mars Roving Vehicle Mission", Report 760-58, December 1, 1970, Jet Propulsion Laboratory, Pasadena, California.

A roving vehicle which can serve as a test platform has been built and is in operation. Part of the effort during this period has been to improve the operation of the test vehicle so that it can rove in the autonomous state. The objective is to control the test vehicle remotely to simulate, at least partially, the earth-bound control of a Martian Roving Vehicle.

II. SPECIFICATION OF TASKS

A. Obstacle Detectors. Development of both the short-range tactile obstacle sensor and medium-range laser rangefinder will be continued. The short-range sensor will serve as a back-up for positive obstacles and will be the primary detector for negative obstacles.

The laser rangefinder should provide the navigational computer with information regarding the range and direction to all positive obstacles more than 0.77 meters high that are between 1.5 and 9.1 meters away from the vehicle, and lie within a 170^o sector ahead of the vehicle. Laser rangefinder data is required to enable the vehicle to be directed along a path that avoids non-negotiable obstacles.

Development of the short-range obstacle sensor should be in the direction of improving its behavior when the vehicle is turning, and insuring that the sensor itself can negotiate all obstacles that the vehicle can pass over.

The ultimate development of effective and reliable obstacle detectors is essential to the successful completion of the vehicle's mission.

B. Soil Sampler-Tester. A deployment mechanism, suitable for use with a wide variety of different testing heads will be designed and constructed. The soil-sample retrieval scheme will be re-designed and improved. Work on the soil shear-strength and bearing-strength test heads will continue. Suitable transducers for these devices will

C. Navigation and Guidance System. The navigation and guidance system will be further developed in its currently anticipated configuration, with the intent that the sub-systems should become operational as soon as possible. Specifically, computer studies will be made to determine whether approximate heading angles, uncorrected for the effects of pitch and roll, will be good enough to use in the path-finding algorithm. The heading gyro will be operated on its own supply system, and its accuracy checked. It will be interfaced with the communications up-link.

The control computer is designed to allow the vehicle to reach its target if a path is possible when the vehicle is initially located anywhere up to 100 m from the target. The computer continuously up-dates the target location with respect to the vehicle, using a Cartesian coordinate square 200 m by 200 m. The computer receives inputs from the laser sensor of all obstacles sensed in terms of distance and direction from the vehicle heading. A heading input is received from the reference system, and an approximate-distance-travelled input is obtained from a signal that pulses once for each revolution of one of the wheels. From these data, a clear path nearest the direct path to the target is chosen. Distance travelled is broken into components and subtracted from the distance remaining along the appropriate coordinate.

Those sections that have been built in RTL logic are to be maintained in usable condition, and those not yet built will be redesigned using integrated circuits. The intent is that the computer will be completed and completely bench-tested as a check on the validity of the path-finding algorithm, before being completely rebuilt in the best existing family of logic devices.

D. Communication System. The reliability and usefulness of the radio communication system will be improved by efforts to reduce the influence of radio-frequency interference, and by the use of a more advanced coding and decoding scheme, preferably one that is error-correcting, and readily expandable. The probable need for an expandable code, particularly in the down-link, is foreseen as more experimental functions are added.

III. SUMMARY OF RESULTS

A. OBSTACLE DETECTORS

Both a medium range obstacle detector and a short range obstacle detector are described. The medium range detector uses a laser rangefinder principle with mechanical scanning to locate obstacles over 30 inches (762 mm) in height which lie within 30 feet (9.1 m) of the vehicle. The short range detector must contact the obstacle to sense it. The tactile sensor must then be able to negotiate all obstacles which the vehicle can negotiate.

A.1. LASER OBSTACLE DETECTOR*

Since the vehicle is not designed to climb over obstacles that are more than 30 inches (77 cm) high, such obstacles must be detected, preferably in time for the vehicle to avoid them without having to back away. In the system currently being developed, a laser-radar scheme is employed. The laser is fired sequentially 29 times, yielding a series of scans about 6^0 apart, centered dead ahead of the vehicle, and lying in a plane parallel to the plane of the cab on which the scanner is mounted. Whenever an obstacle lies within the sector scanned, and from two to ten meters from the vehicle, laser light is reflected from the obstacle. The distance to the obstacle is proportional to the transit-time; the direction is known from the number of the scan in the sequence. The range and azimuth data is available to the computer which uses it to decide upon, and implement the best evasive action.

Two major problems have appeared and some progress toward their ultimate solution has been realized. The problems are (1) the measurement of the extremely short transit-times with sufficient precision, and

(2) the low intensity of the reflected light. The key to the solution of problem 1, the measurement of the extremely short laser beam transit-times, appears to lie in the reduction of trigger rise-times. The laser-firing trigger problem appears to have been solved through the use of a purchased triggering unit. The delay in triggering upon receipt of the return signal involves a trade-off between fast response, and low background noise. The use of semi-conductor detectors, rather than the photo-multiplier now used, will be studied.

The second problem, the low intensity of the reflected light, has yielded somewhat to an improvement in alignment of the optics, but it may be that a more powerful laser will be needed. See Section A.4, Slope Detection System.

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* "A Laser Rangefinder Obstacle Detector", MRV71-2, Alan Schweitzer, Steven Goodspeed, Ronald Vincent, June 1971.

A.2. LASER RANGEFINDER MECHANICAL SCANNING ASSEMBLY

The mechanical scanning assembly effort was mainly development. The unit is operational and survived field testing of the vehicle while operating in a simulated scanning mode as shown in Figure A.2 . The redesign consisted of developing a lens system to reduce the beam size and to provide for alignment of the laser and mirrors.

The scanning assembly was moved to the center cab, Figure A.1 , to reduce the beam scatter while travelling over rough ground. The effect of this location on obstacle sensing ability has not been tested. One difficulty was experienced in the field tests. The drive unit lost traction allowing the turret to stop. A solution for this problem has been designed.

The laser beam was found to be 21.5 mm. in diameter when adjusted for low beam spread. This size was too large for the mirrors and the exit hole. An additional lens was added to the laser to give a collimated beam 7 mm in diameter. This beam size is easily accomodated by the existing optics. The resulting spot has higher intensity which may be of advantage in reducing background interference.

Optical efficiency was considered. The overall efficiency with the components used is low. The reflectance of the aluminum coated mirrors for 9050 Å light is approximately 0.86. With four of these mirrors in the light path along with two glass lenses, a plastic Fresnel lens, and the bandpass filter, the optical efficiency overall is between 20 and 30 percent. While the bandpass filter limits the efficiency to 68 percent, the optical efficiency can probably be improved to twice the present efficiency. The low efficiency is presently tolerable since high reflectance materials can be used for objects and reduced distances can be used in

Scanner Mounted

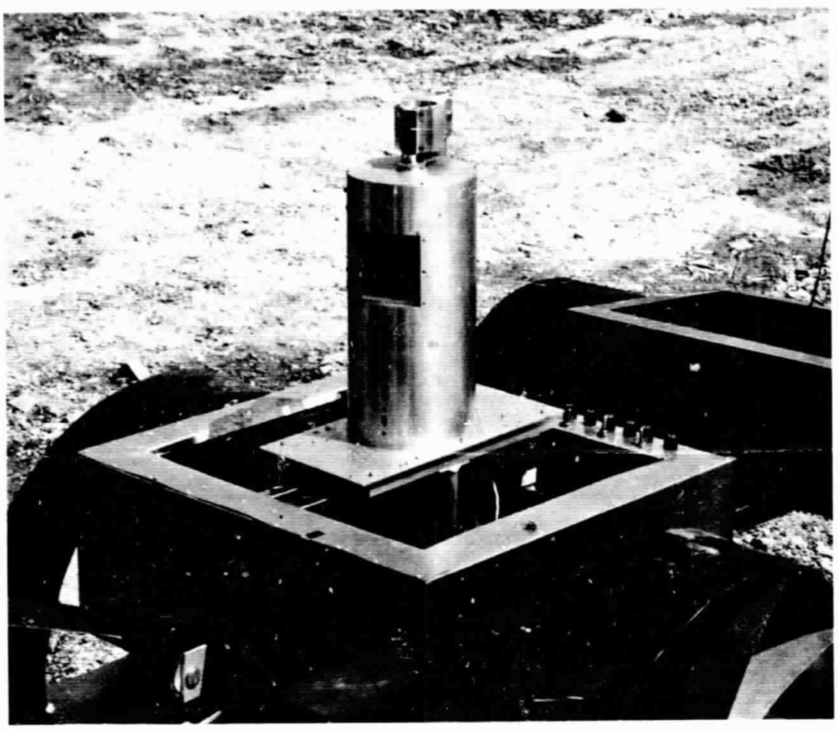


Figure A.1. Scanner Mounted on Center Cab

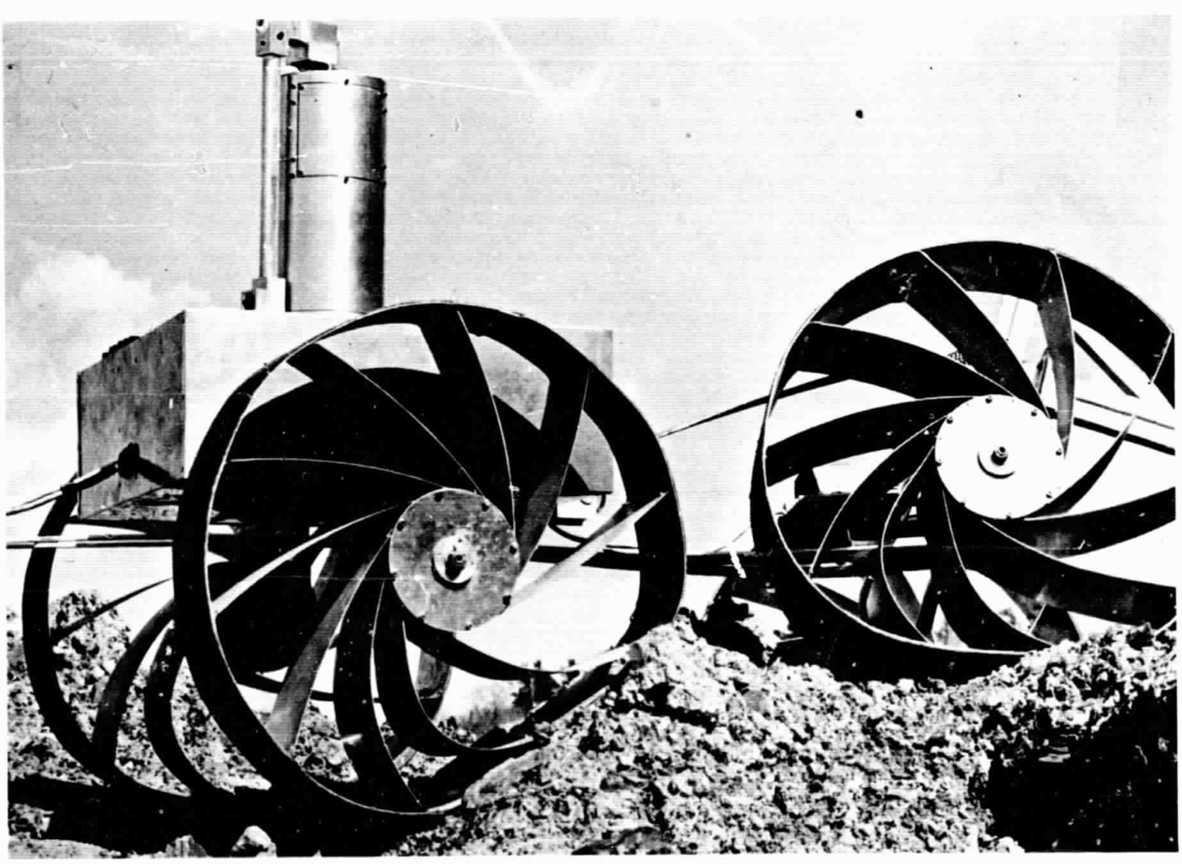


Figure A.2. Field Operation

SCHEMATIC OF SCANNING ASSEMBLY

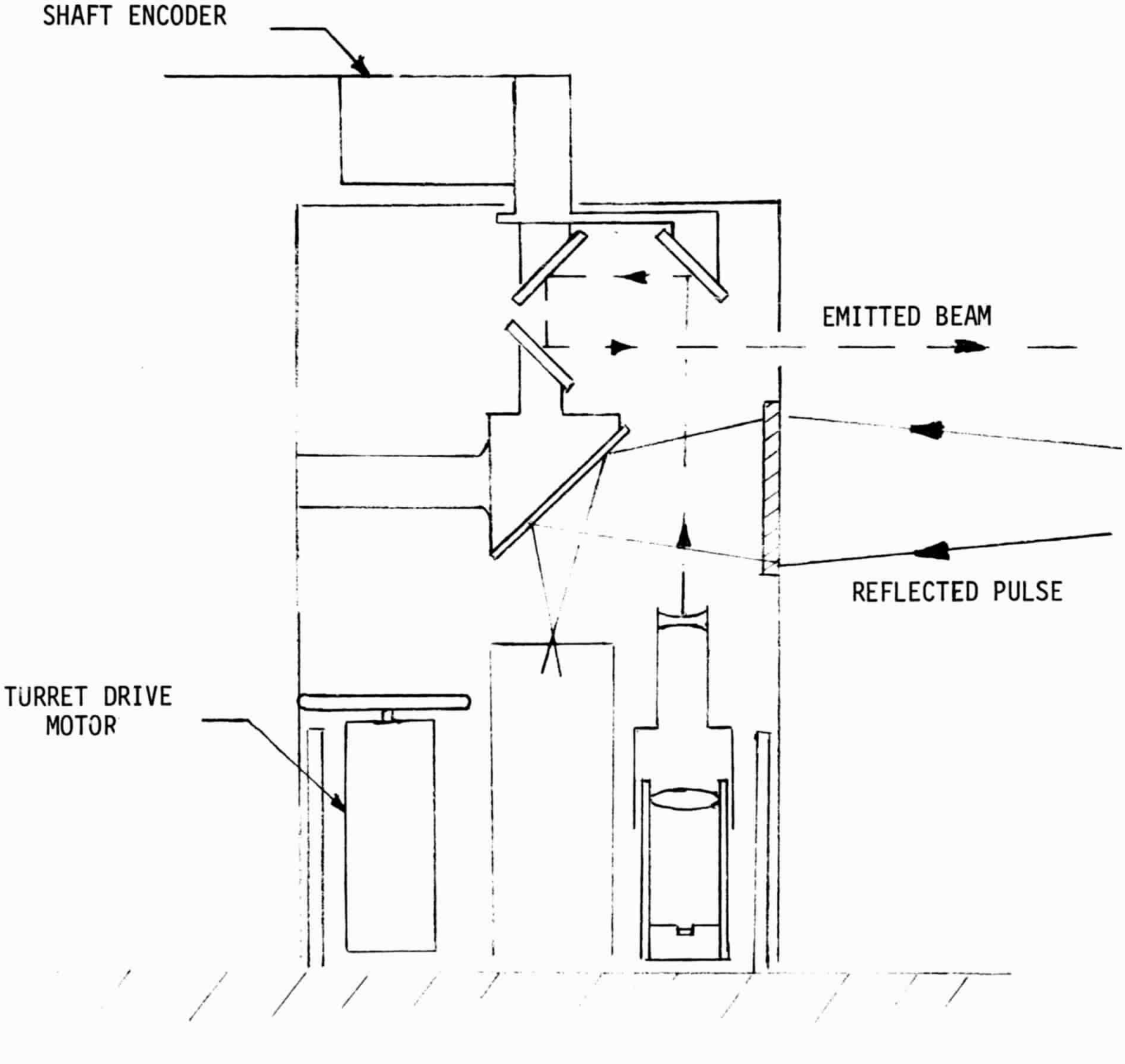
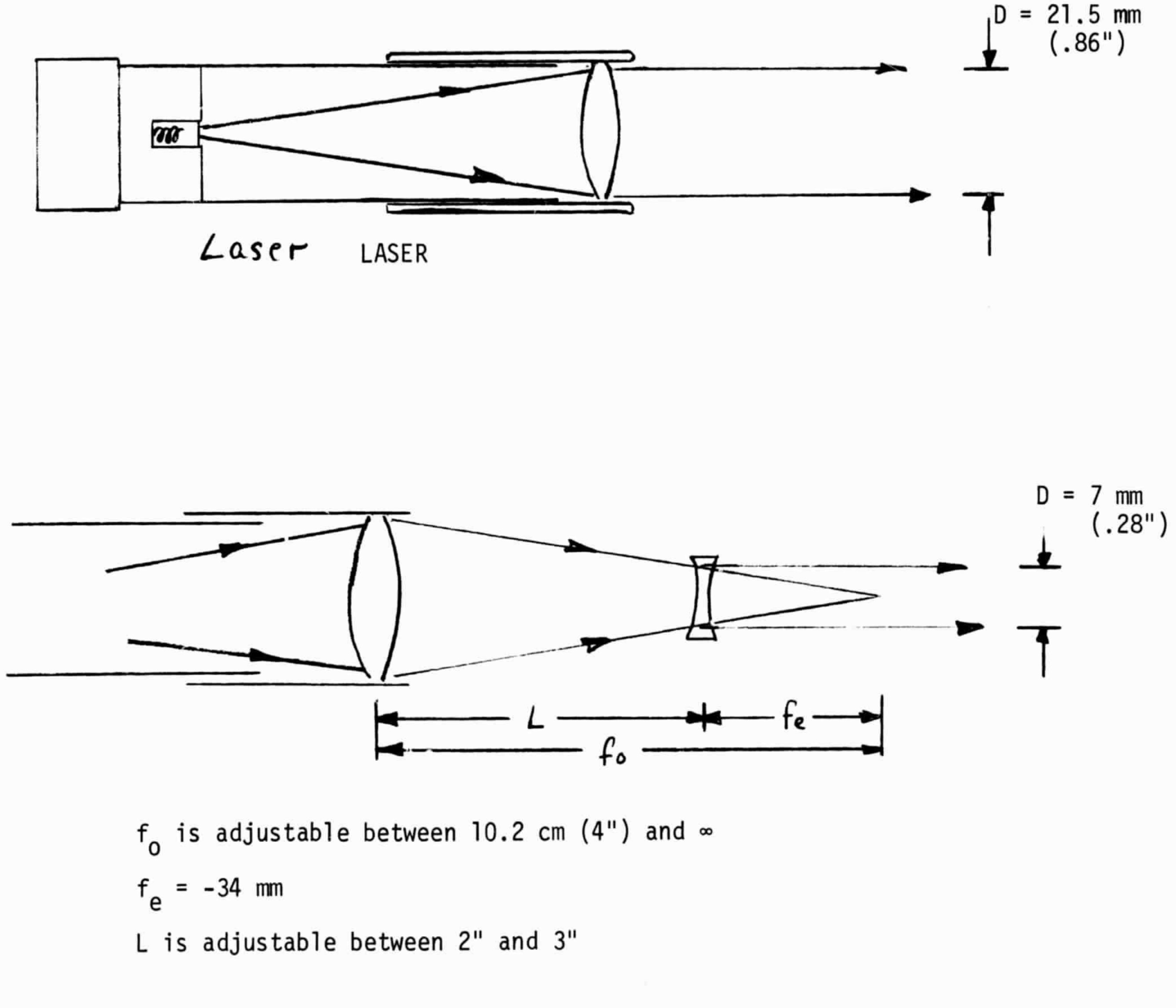


Figure A.3

BEAM REDUCER COLLIMATOR



f_o is adjustable between 10.2 cm (4") and ∞

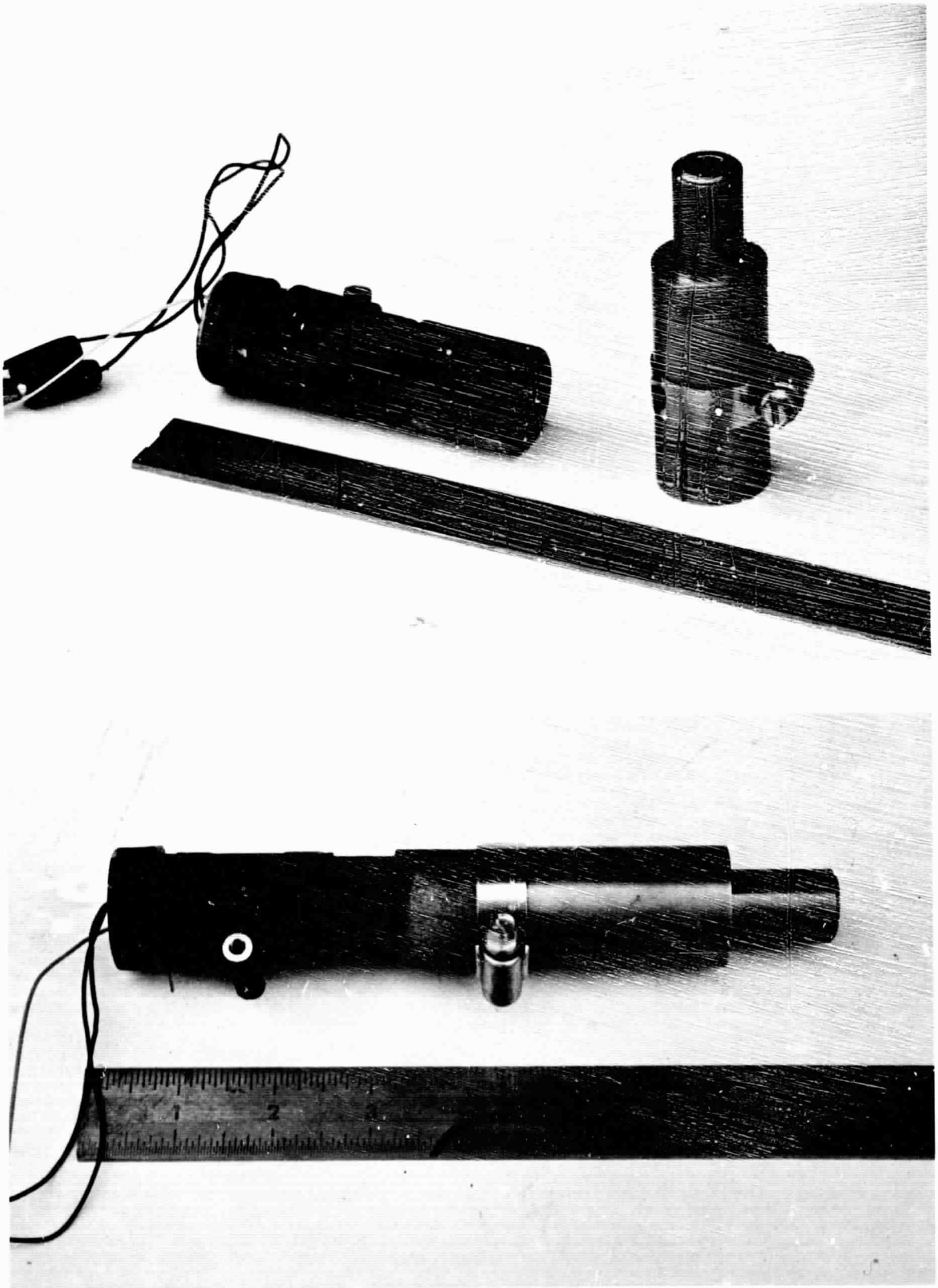
f_e = -34 mm

L is adjustable between 2" and 3"

Figure A.4

Figure A.5.

Laser and Beam Reducer



the initial development stage.

The use of a field aperture plate to limit the extraneous light falling on the photocell is shown in Figure A.6 . The aperture plate is placed at the plane of focus for an object at 4.5 m. The aperture size has not been chosen. One possibility is to select an aperture size to correspond to the image of the beam at 6 m plus an allowance for misalignment. This would reduce the variation in received signal since an increasing portion of the image would be cut off with decreasing distance.

RECEPTION OF REFLECTED SIGNAL

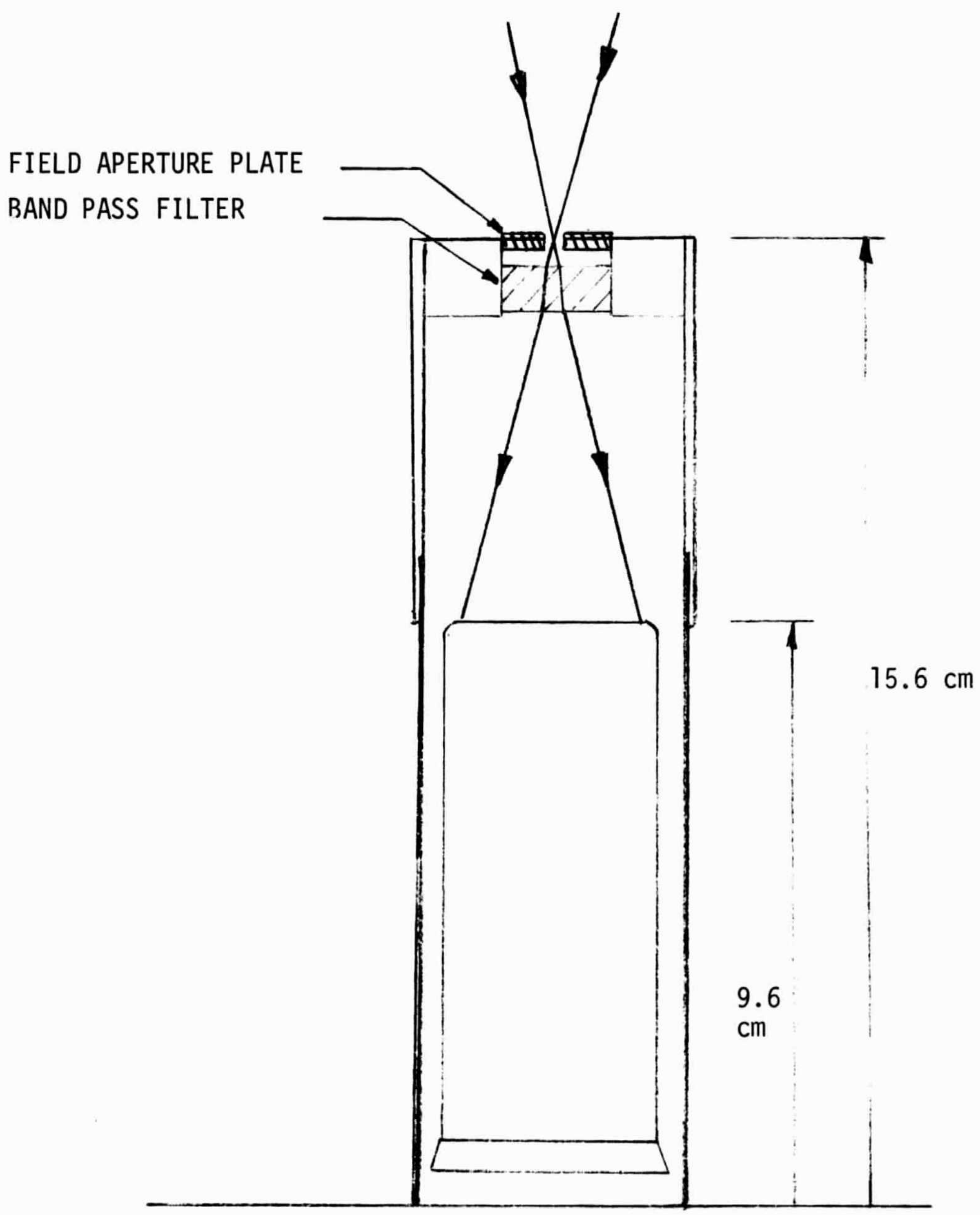


Figure A.6

Figure A.7.

Interior of Turret

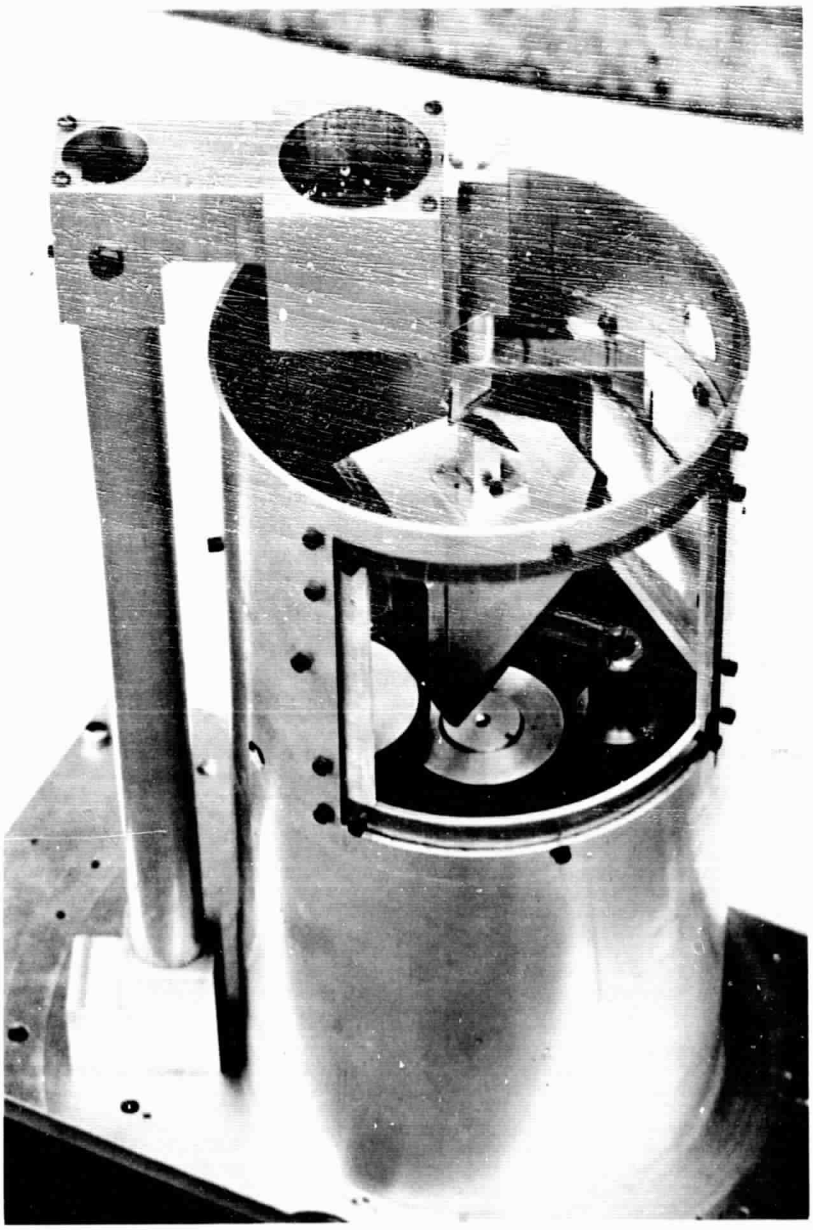
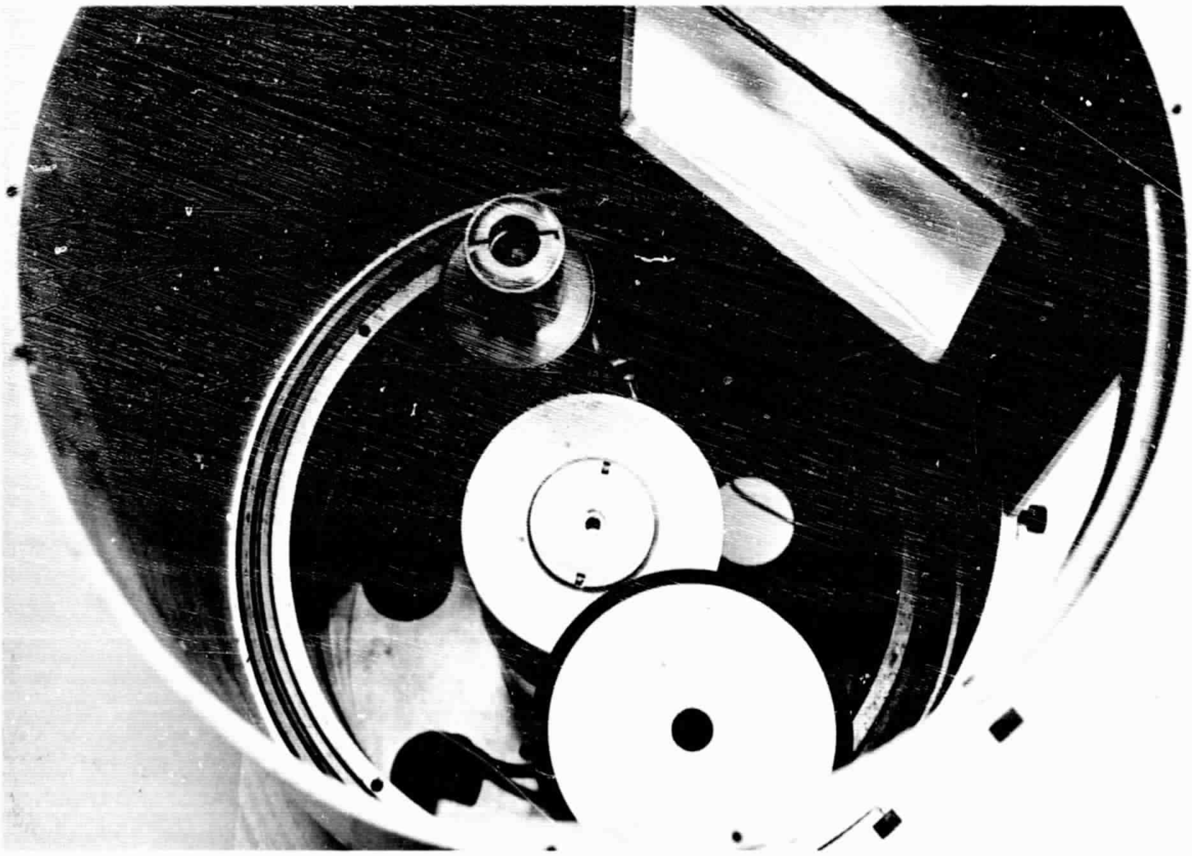


Figure A.8.

Interior of turret



FROM TOP TO BOTTOM:
LASER

PHOTOMULTIPLIER TUBE

DRIVE MOTOR

A.3. TACTILE OBSTACLE DETECTOR *

The tactile obstacle sensor system consists of two unpowered wheels each pushed in front of the rover by a linkage as shown in Figure A.9. Problems with the sensor which have been overcome this year were

1. Failure of the sensor to recover after negotiating small obstacles.

2. Large force necessary to push sensor over obstacles near 0.76 m in height.

3. High ground contact force which results in losses in straight rolling and in large side forces when the vehicle is turning.

Problems one and three were overcome by reduction of the sensor weight and by use of a spring counterbalance as shown in Figure A.10. Field testing showed generally satisfactory performance. Operation clearly indicated that too much counterbalancing would raise the sensor out of operation in some maneuvers. The reaction with rocks in turns was still a problem although no damage occurred during the test.

The force necessary to push the sensor over large obstacles was reduced by introducing guide surfaces to contact the obstacle and produce lifting components. This has worked well in the laboratory. No obstacles this large were encountered during the field test.

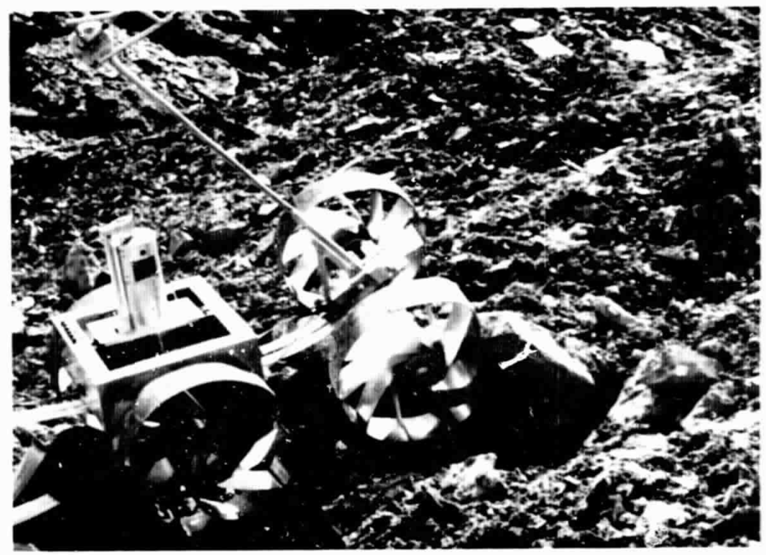
An effort was made to find a damper for the self-centering spring joint. The spring tends to throw the arm and sensor wheel past the neutral point after the sensor negotiates an obstacle. The velocity attained is enough to result in damage if a second obstacle would obstruct the path.

*"Mechanical Obstacle Detection System", MRV71-3, Lawrence Wojcik, and Robert Haluga, June 1971.

a. Vehicle with Tactile Sensor Mounted

b. Vehicle Turning

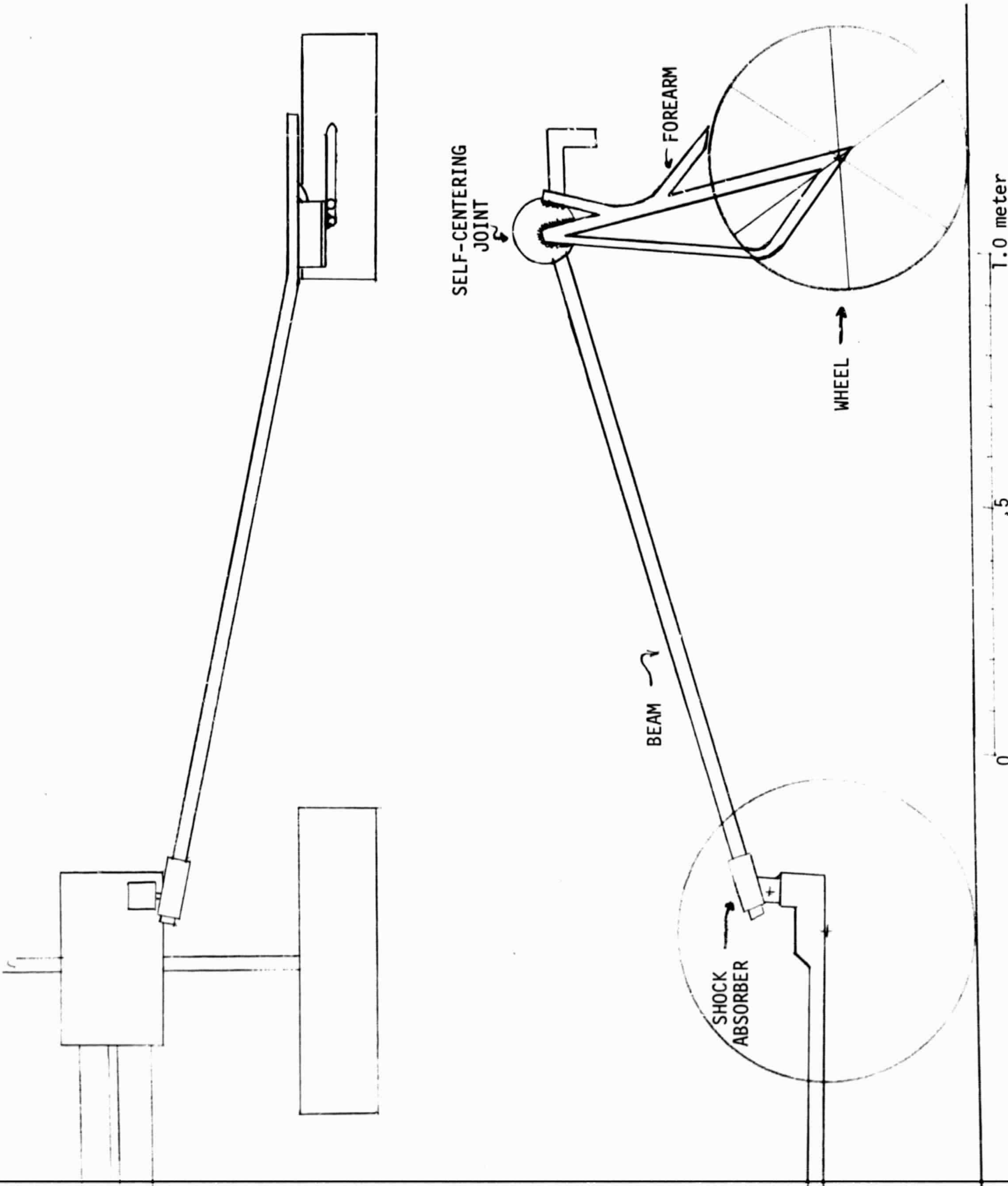
c. Negotiating Rough Terrain



d. Sensor Pulled out of Action by Excessive Counterweight Action

Figure A.9.

Figure A.10
The Tactile Sensor



CLIMBING SEQUENCE

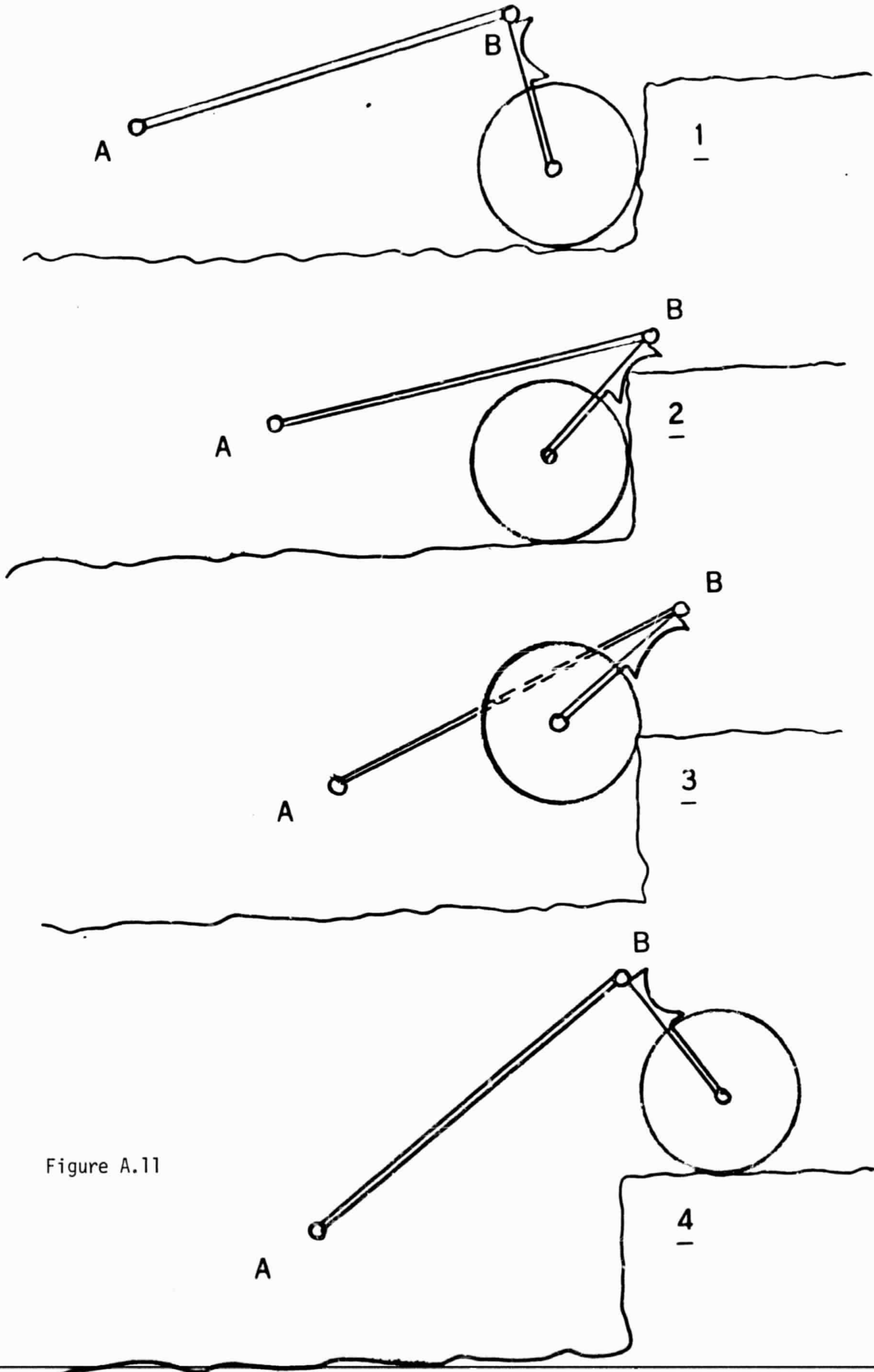


Figure A.11

A.4. SLOPE DETECTION *

The laser rangefinder obstacle-detector that has been under continuing development for some time is not inherently capable of detecting non-negotiable slopes. It might even report negotiable slopes that are long enough to rise 0.77 meters above the plane of the vehicle as non-negotiable vertical steps. Slope detection quite close to the vehicle is possible by using data from the tactile sensor, but at this short range, if evasive action must be taken, it would probably require that the vehicle back away, an entirely possible, but undesirable maneuver.

Several possible schemes for detecting, and measuring slopes were studied. The most promising of these, one that involves the use of an array of semi-conductors to detect laser light reflected from different points on a slope, was carried through the preliminary design phase, in which critical parameters were determined. A search through supplier's literature indicates that the necessary components are currently available. Some components were obtained and appear to be feasible. Some of their characteristics, such as the detector response to extremely low light-levels, are still to be investigated. The mechanical problems appear to be no more severe than those in the original obstacle detector. Since the slope measurement is based on triangulation, the difficult transit time determination is entirely avoided.

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* "Slope Detection System", MRV71-9, Daniel Fellman, June 1971.

B. SOIL SAMPLER-TESTER *

One objective of a Martian Roving Vehicle will be to obtain information relative to the soil at different sites. Devices have been developed to obtain samples of the soil and the soil shear strength. A device has been proposed to determine the shear strength of the soil at variable normal pressures. This will obtain enough information to determine the soil bearing strength as well as the soil type.

The soil sampler head was simplified so that a single rigid part contacts the soil to be sampled. Therefore the difficulties experienced from soil particles interfering with operation are eliminated. The new sampler head has been tested in several soils and has performed well. Difficulty with motor stall was experienced when the sampler blade struck a rock but no damage was done to the sampler head itself. Provision must be made for jamming of the head. This has not yet been corrected.

The device for removing the sample from the sampler head and cleaning the head has been conceptually designed but has not been produced. The principle is to bring a brush into contact with the sampler head and then rotate the head several times in reverse to sweep the head clean. The sample would be caught in a bin below the head.

A new deployment device Figure B.3 has been designed which is more compact and more rigid than the previous device, Figure B.4. The weight saving has not yet been determined. The new design approximately inverts the relationships of the previous device. The support bearings and the ball screw and ball nut are within the reciprocating member which becomes the primary structure component. Further, by use of bellows type dust cover as in Figure B.5 it will be possible to protect the mechanism from the atmosphere.

The soil strength testing philosophy has changed from separate determination of shear strength and bearing strength to a determination of parameters from which these strengths can be found. The test presently recommended is a shear test under several normal loads. This will help identify the soil type as well as provide the values needed for determination of shear and bearing strength. Soils fall generally into the three types of frictional, cohesive, and combined frictional and cohesive as shown in Figure B.6 . A new soil test mechanism, Figure B.7 has been proposed to perform this function. This test head must be placed where it will not tip appreciably. The first attempt will be to locate the test head under the center of gravity of the rear cab.

* "A Soil Sampler-Tester Mechanism for a Mars Roving Vehicle", MRV71-6, Edward M. Cutler, Jr., William W. Blakeslee, and Philip J. Goldman, June 1, 1971.

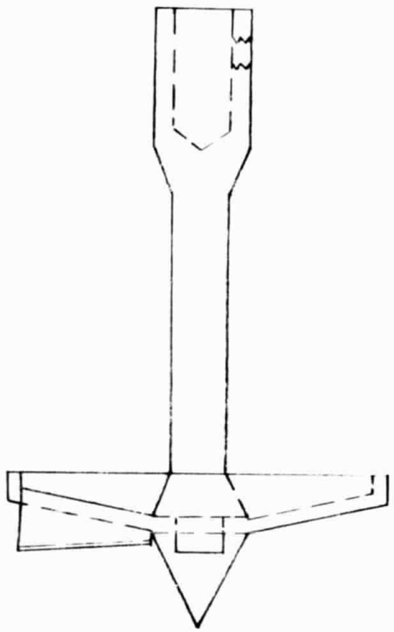


Figure B.1. Sampler Head

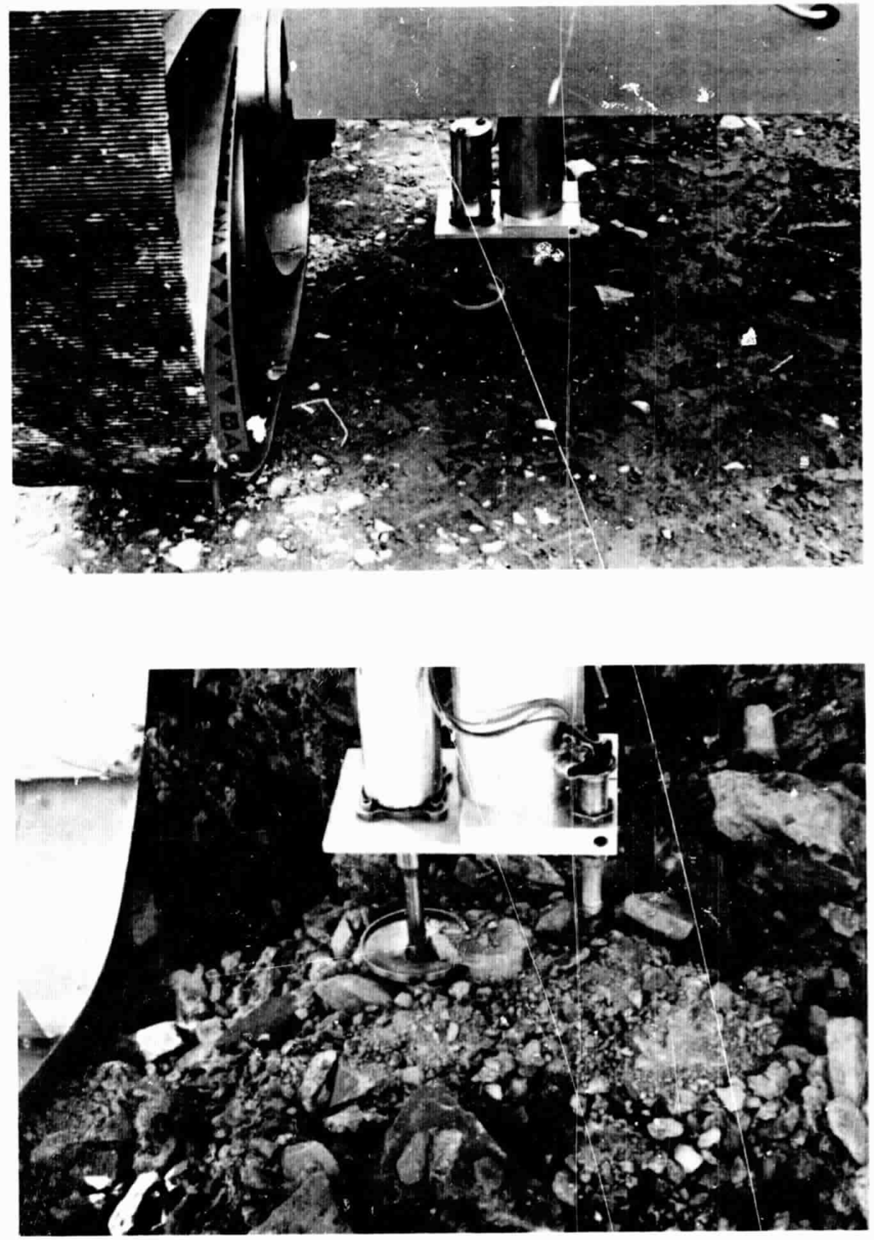


Figure B.2.

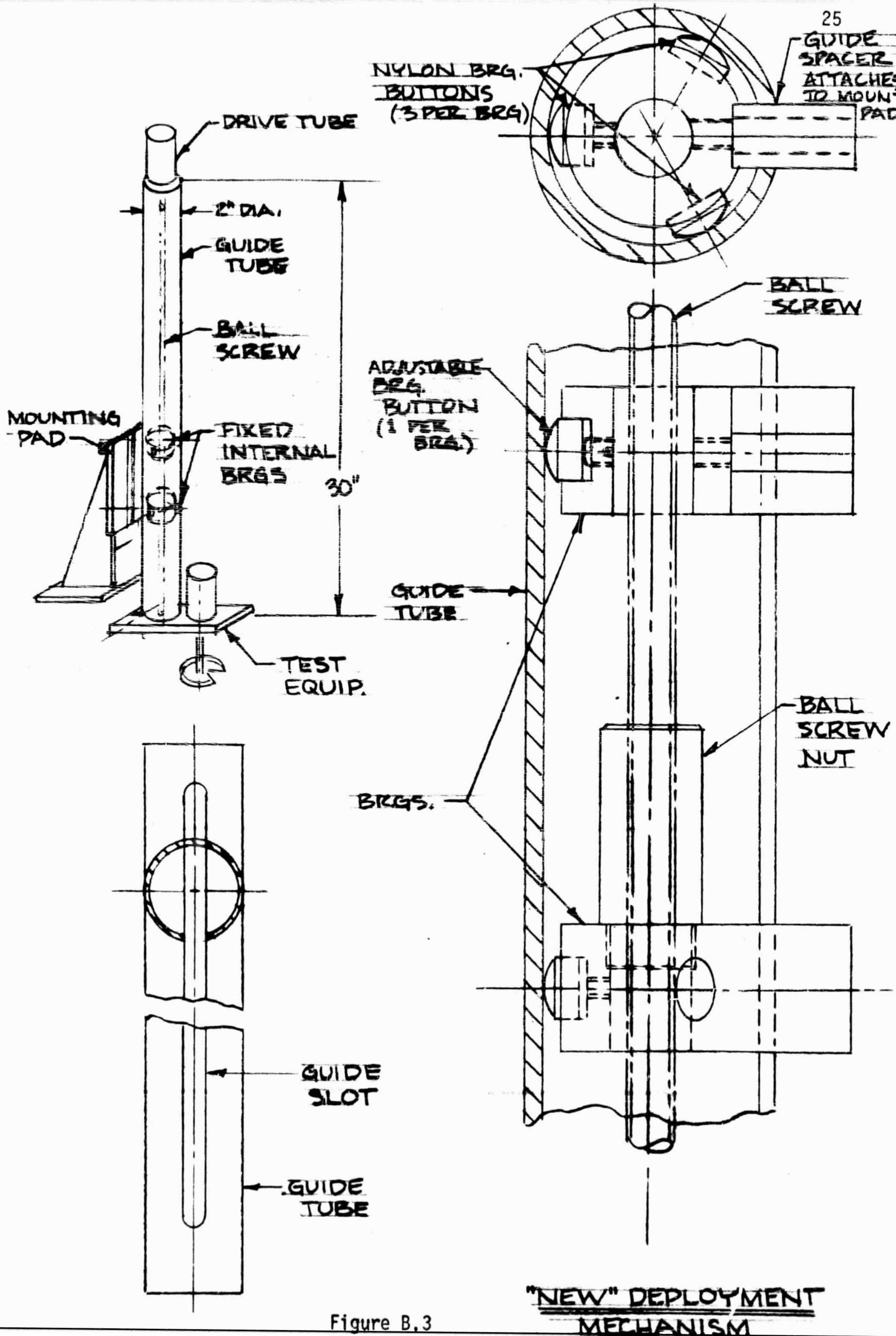

NYLON BRG. BUTTONS (3 PER BRG)
GUIDE SPACER ATTACHES TO MOUNT PAD
DRIVE TUBE
2" DIA.
GUIDE TUBE
BALL SCREW
MOUNTING PAD
FIXED INTERNAL BRGS
30"
TEST EQUIP.
BALL SCREW
ADJUSTABLE BRG. BUTTON (1 PER BRG.)
GUIDE TUBE
BALL SCREW NUT
BRGS.
GUIDE SLOT
GUIDE TUBE
"NEW" DEPLOYMENT MECHANISM

Figure B.3

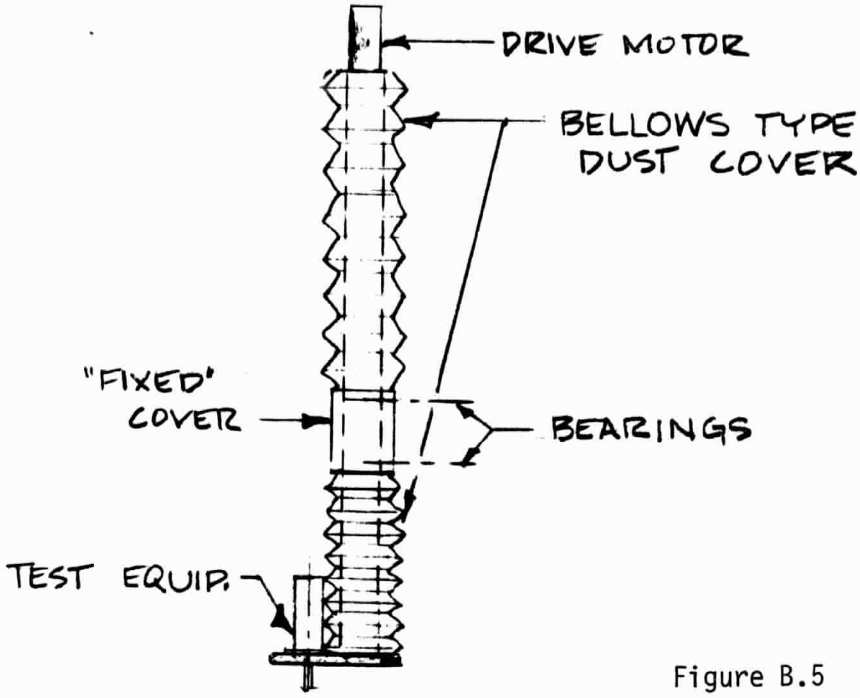


Figure B.5

Figure B.6

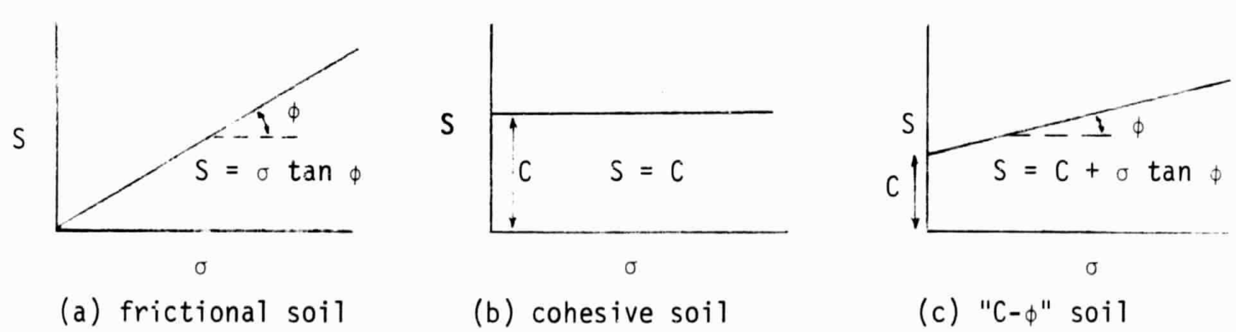
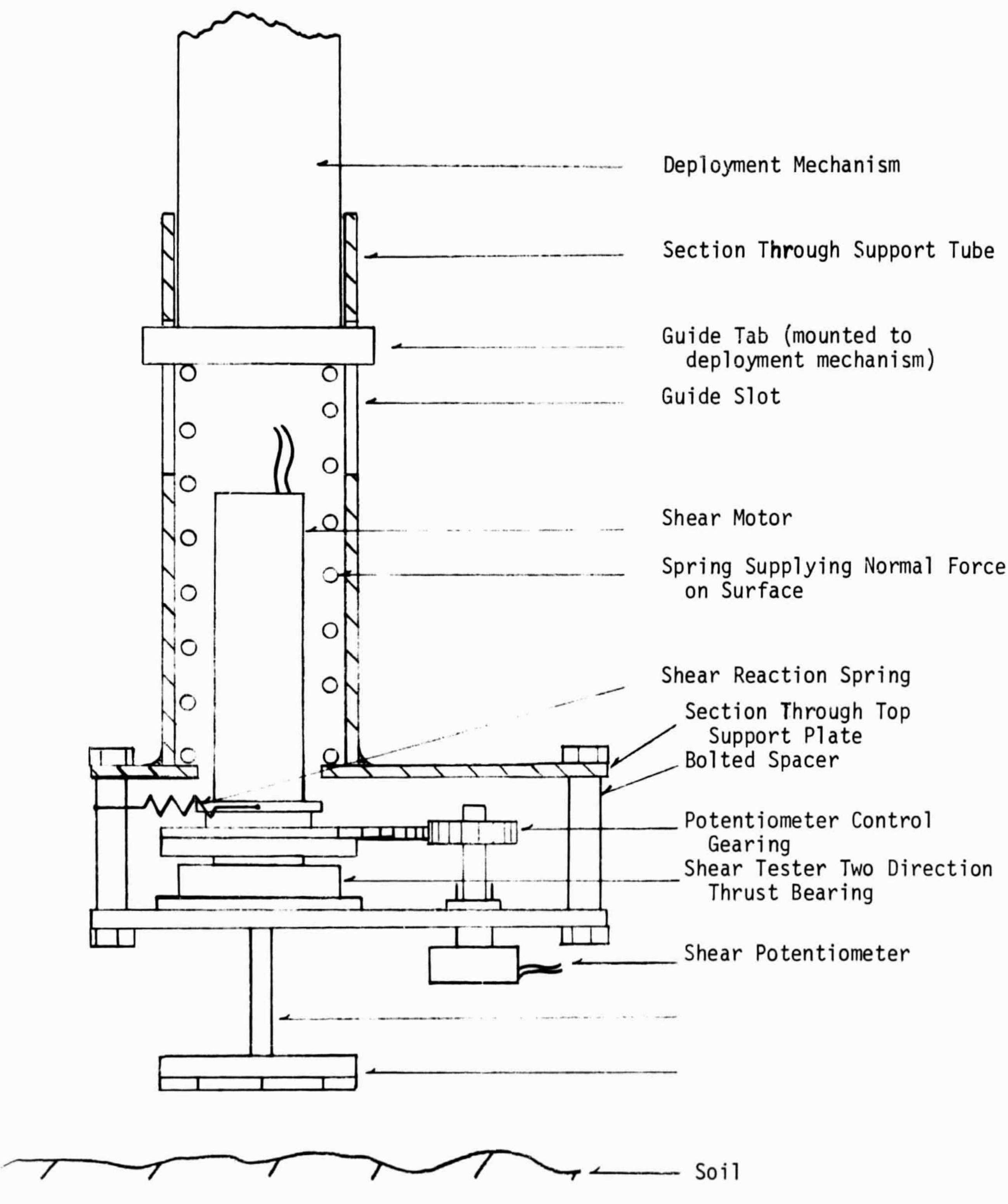


FIGURE B.7

THE SOIL TEST MECHANISM



C.1. NAVIGATION COMPUTER

Since construction of the navigational computer was started some three years ago, several generations of logic, each better than its predecessors have appeared. The parts that were built using the original logic, RTL, were re-checked, and necessary repairs made so that those parts now operate as originally intended. Newer logic was used, in part, for advancing the work that was done during this past year. The intent was to get the computer into operation, with a minimum number of changes, in order to prove the algorithm. Once this was done, the computer then could be re-built with the most modern logic family then available. By the end of the term, the computer was nearly complete and all parts that had been completed were operating properly. We expect that the computer will be completed and tested during the 1971 summer recess. One of the students who will be supported by the project during the 1971-72 academic year has been assigned to this task.

This computer has a single function, navigation. While this is an extremely complicated task, the computer cannot be used for any other purpose. Since other computer facilities will undoubtedly be needed, alternatives to the on-board navigation computer have been studied. (See Section C.2, Alternatives to the Navigational Computer).

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* "Navigation Computer for the Unmanned Mars Roving Vehicle", MRV71-5, Fred Boericke, William Lee, and Walter Dowell, June 1971.

BLOCK DIAGRAM OF NAVIGATION COMPUTER

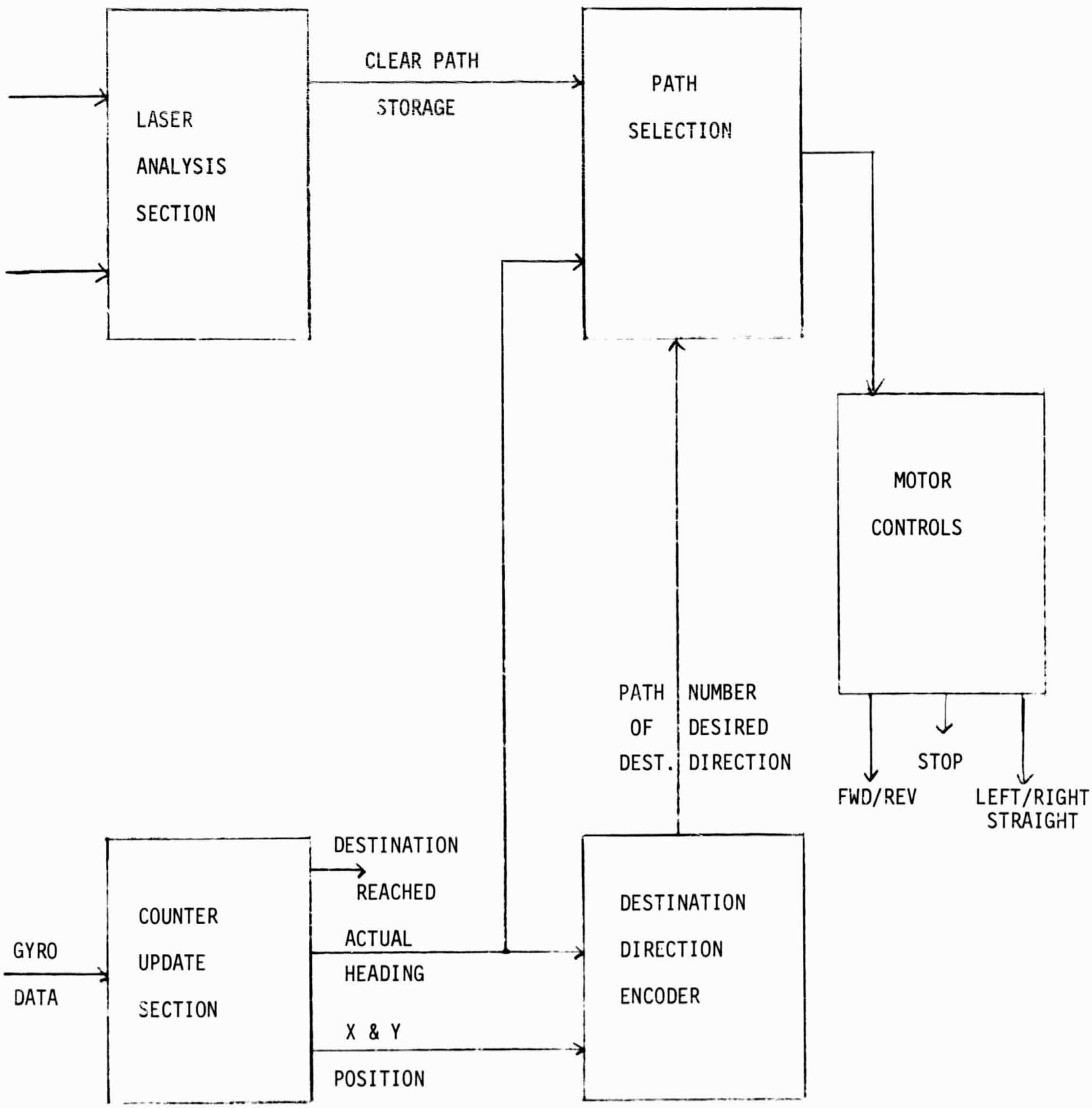

Figure C.1

C.2. ALTERNATIVES TO THE NAVIGATION COMPUTER *

The Mars Rover must ultimately be capable of much more than mere safe and accurate navigation. Its primary function is to perform and report the results of numerous scientific experiments. Commands must be sent from the base to the computer, and a great deal of data must be sent from the computer to the base. Decisions are to be made, scientific data processed, television records stored and transmitted, engineering data re the vehicle operating conditions reported, etc.

With the recent advent and continuing rapid development of small-sized, low-weight, reasonably-priced, general-purpose computers (mini-computers), the original concept, which was to use several single-purpose computers may no longer be valid.

Hardware and wiring changes are involved in modifying special-purpose computers; only soft-ware changes are needed for general-purpose computers. The required soft-ware can be developed on any of several computers currently available on campus, and with moderate changes, adapted to the mini-computer.

A fairly exhaustive survey of currently manufactured mini-computers, and recent trends in their development suggests a probability that mini-computers, suitable for use on board the rover will be available during the spring of 1972. Consequently, concentration of computer effort on interfacing the Rover subsystems with the mini-computer to be purchased ultimately is recommended.

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* " Alternatives to the Navigational Computer", MRV71-10, Alan Huang, June 1971.

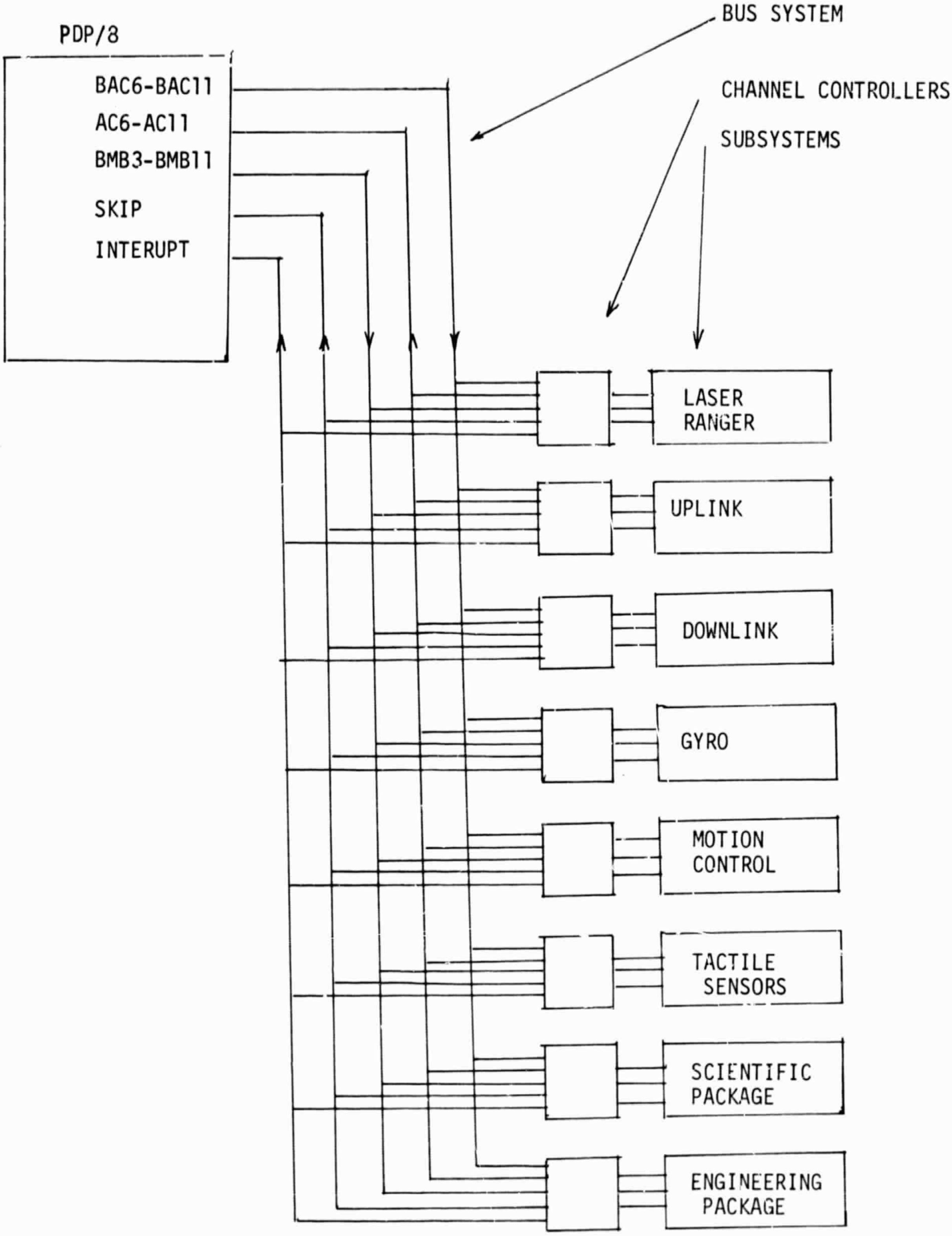
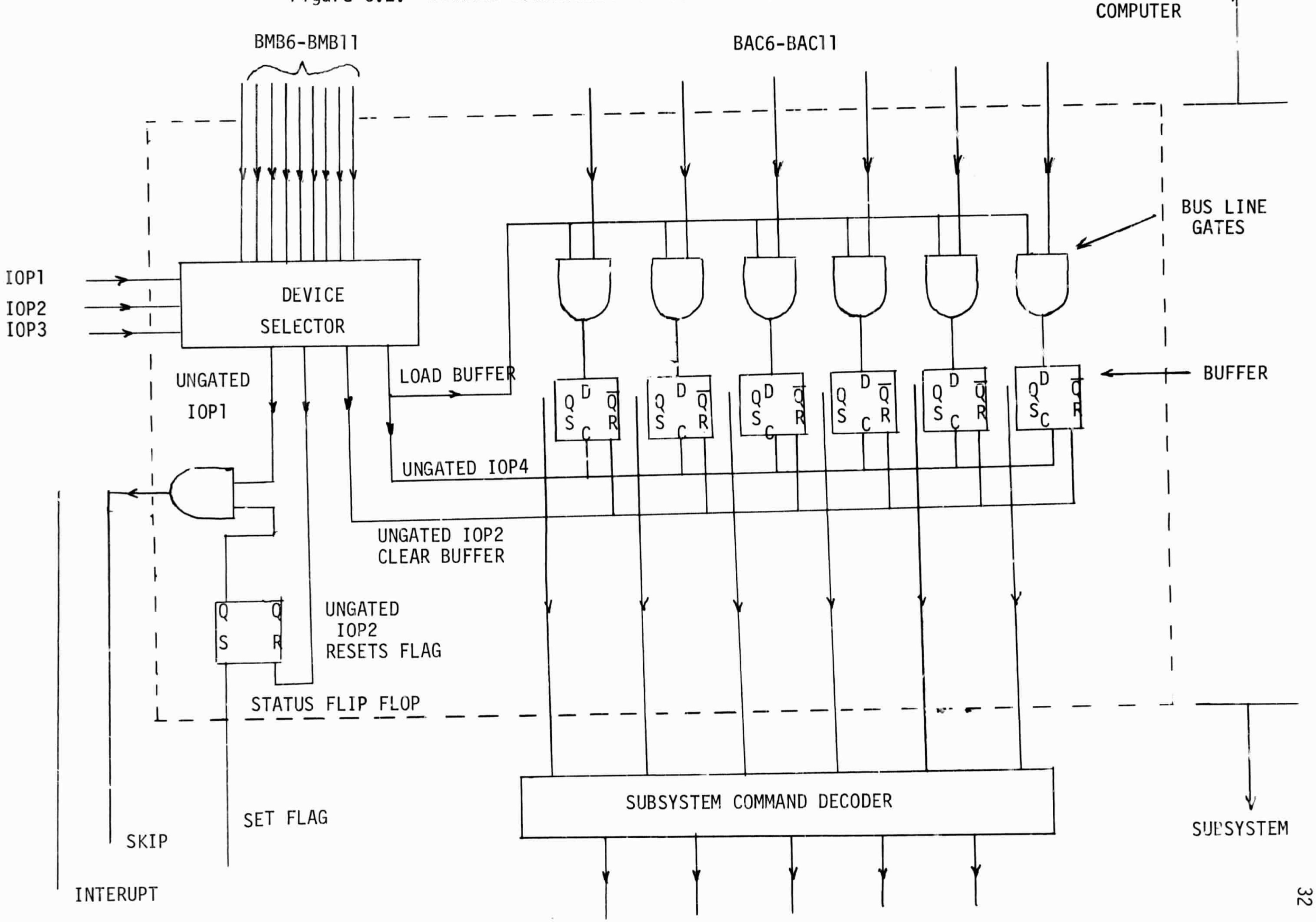


Figure C.2. PROPOSED COMPUTATIONAL CONFIGURATION

Figure C.2. CHANNEL CONTROLLER FOR COMPUTER OUTPUT SUBSYSTEM



C.3. HEADING AND NAVIGATION *

The heading detection system provides information concerning the direction in which the vehicle is progressing. Specifically, the sine and the cosine of the horizontal angle between the current vehicle heading and the original heading, are determined, and made available to the on-board navigation computer.

The sine and cosine of the heading angle are the outputs of a gyroscope whose characteristics have been the subject of fairly extensive study. A three-phase, 400-cycle inverter for driving the spin-motor has been built and tested. An experimental determination of errors in the gyro system was made. Corrections for pitch and roll appear to be unnecessary. In addition to testing the gyro directly, several computer analysis of the effect of ignoring gimbal errors were performed.

The experimental work on the gyro system was impeded seriously by two gyro failures, each of which put the gyro out of service for several weeks during which repairs were being made. The most probable cause of the gyro failures (an unsuspected limitation on operating conditions) has been determined, and will be avoided in the future.

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* "Heading and Navigation for an Unmanned Mars Roving Vehicle", MRV71-4, Thomas Armour and Clifford Cole, June 1971.

D. COMMUNICATION SYSTEMS*

Two communication systems are needed; one, the up-link for sending commands to the vehicle, the other, the down-link for sending information from the vehicle back to the base station. The two systems can be identical, except that the down-link will need to handle a much larger quantity of data than will the up-link. Also, the equipment at the base station is not subject to the same weight, volume, and energy restrictions that are imposed upon the on-board equipment.

At the start of the period covered by this report, an operational up-link system, and the coding and decoding sections for a down-link were in existence. The radio-frequency (RF) sections were modified citizen's band (CB) walkie-talkies using amplitude modulation (AM). To send a logic "1", the carrier was modulated by an audio frequency (AF) tone; a logic "0" was indicated by the absence of modulation. Alert codes were used, signals sampled twice, and errors were indicated, but not corrected. While these systems worked, they were thought not to be sufficiently dependable. The AM sections are extremely susceptable to noise, both from the vehicle itself, from the high concentration of CB activity in Ithaca, and from other experimenters carrying on research here at Cornell.

This year, the noise-problem was solved by using a frequency-modulation (FM) system. The possibility of interpreting a logic "1" sent, but not received, as a logic "0" was avoided by modulating with one AF signal for a "1", and by another AF signal for a "0". A cyclic, self-correcting, and easily expandable code was used. One such system, used as the up-link, was built and tested extensively. So far it has not experienced any failures. It has been used to start, cage, uncage, and stop the gyro, and should be able to operate other subsystems whenever they are ready.

The down-link will be designed to be similar to the up-link, but with a larger bit-capacity.

The communication system, in its present form, is modular, on removable drawers, and should be rather easy to repair, if need for repair should arise. In this,the first model, the dimensions are fairly generous, intentionally so, to make its fabrication simpler. Operationally, it is good enough; the only modification contemplated is a reduction in over-all linear dimensions, which will be undertaken only if on-board space becomes a critical problem.

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* "Communication Systems", MRV71-7, Deane C. Osborne, Paul J, Kampas, Jean M. Canaguier and Jeffrey A. Haber.

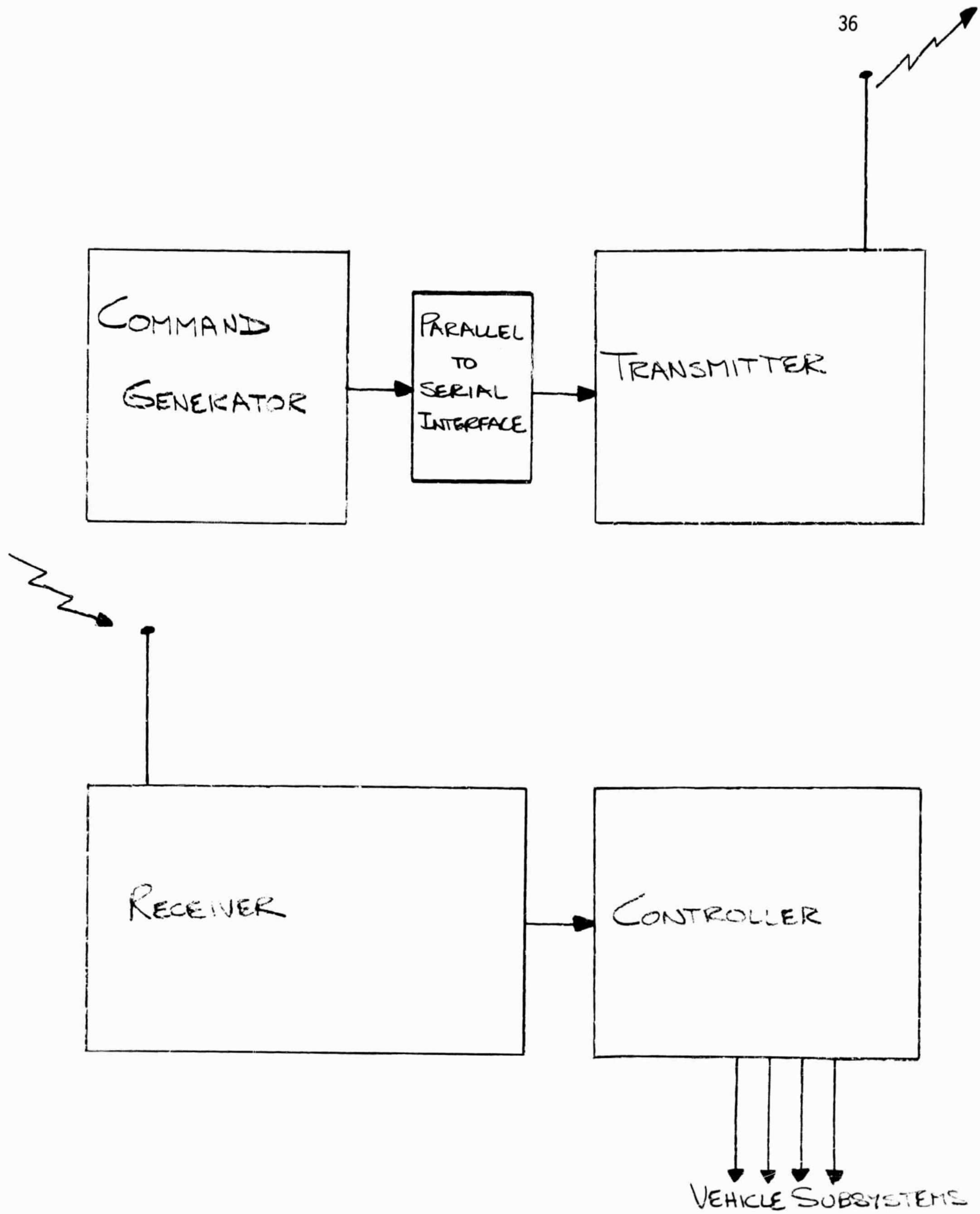
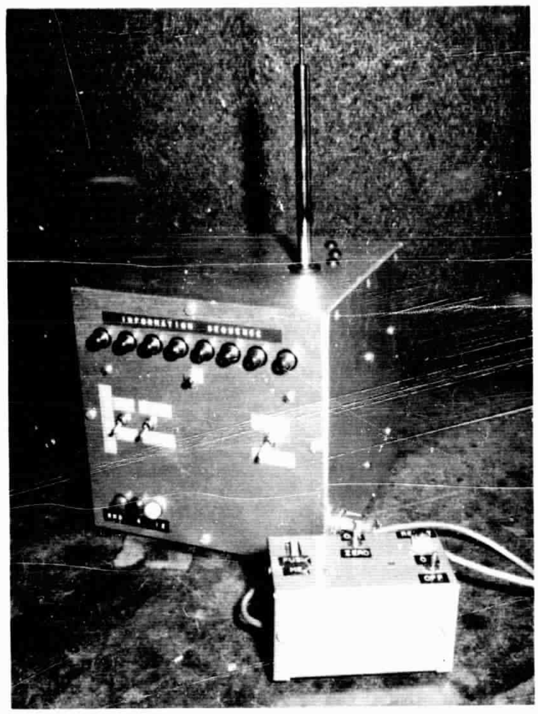


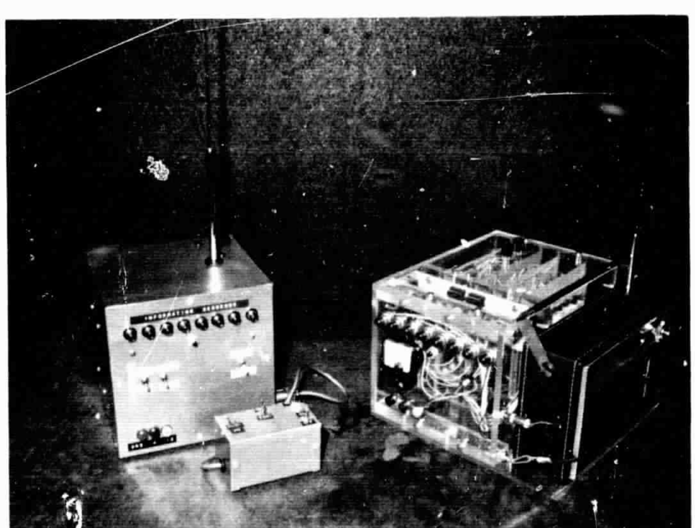
FIGURE D.1

BASE TO VEHICLE SYSTEM



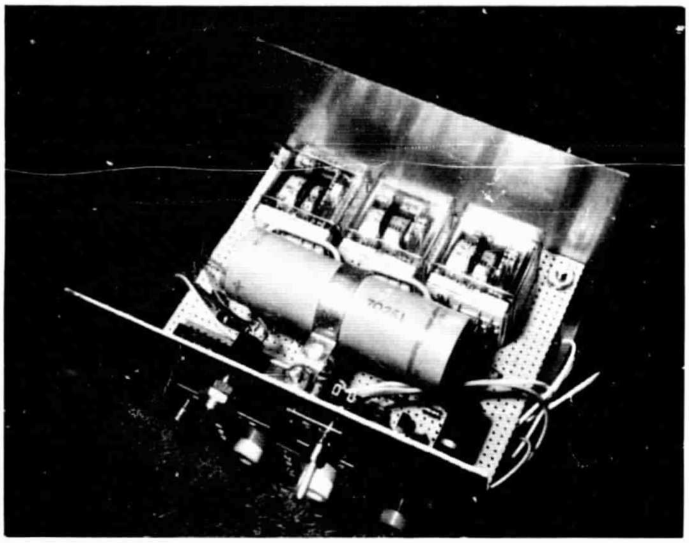
TRANSMITTER

Figure D.2



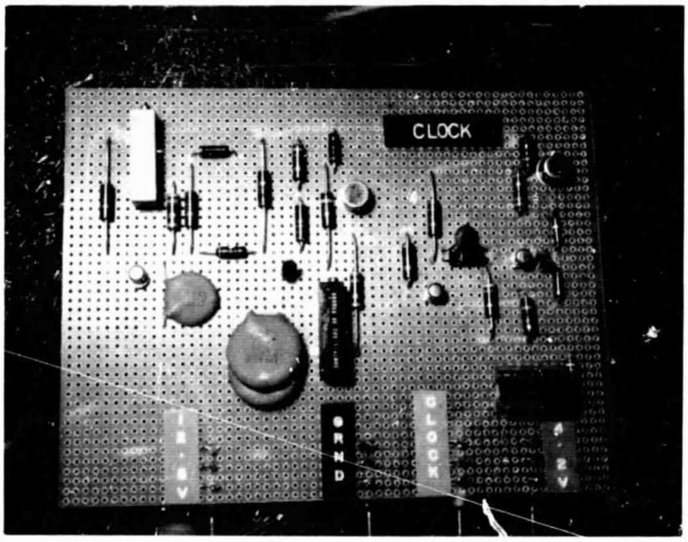
TRANSMITTER WITH RECEIVER

Figure D.3



A SOIL SAMPLER INTERFACE

Figure D.4



A CIRCUIT CARD TYPICAL OF THE MODULAR CONSTRUCTION
OF ALL THE COMMUNICATIONS EQUIPMENT

Figure D.5

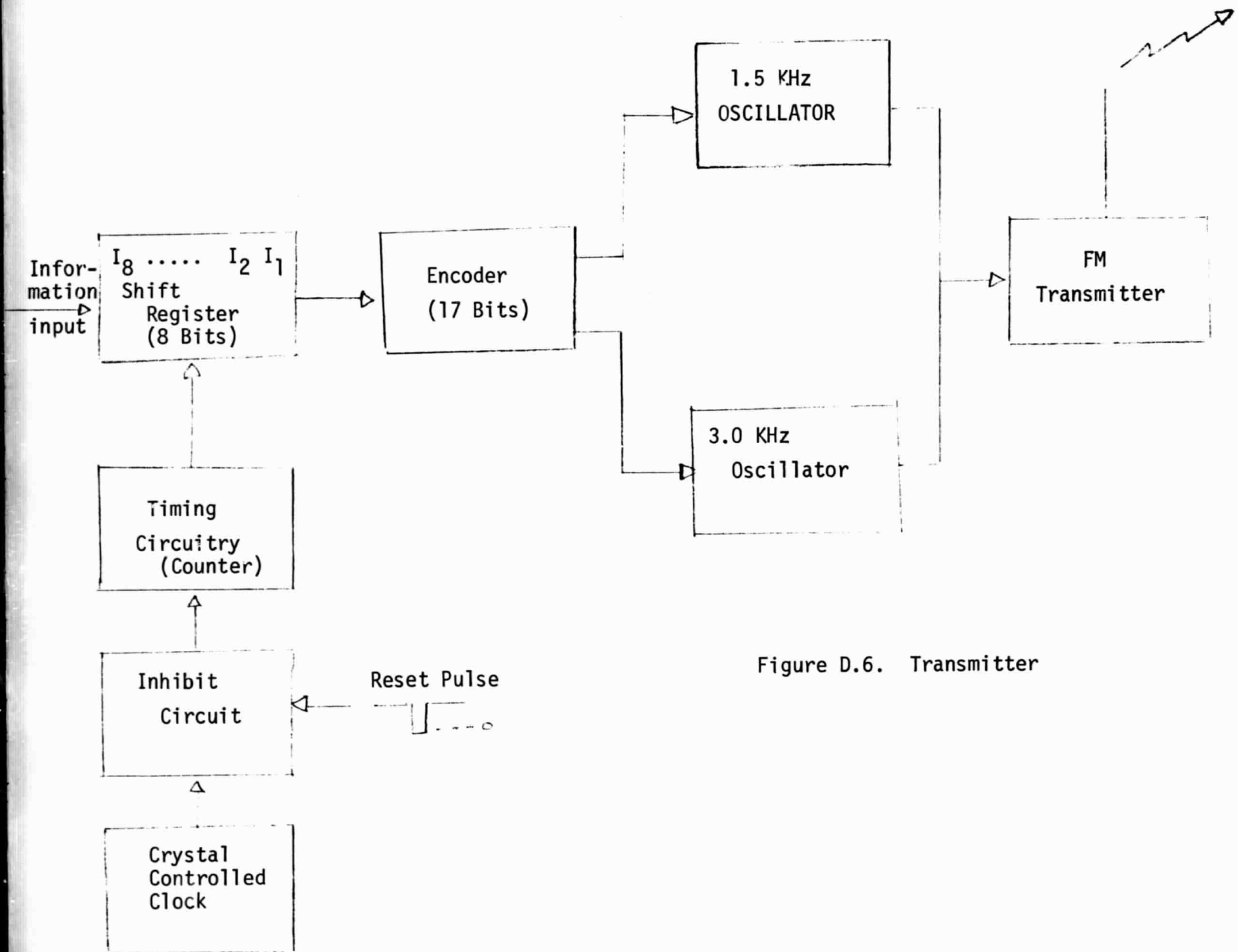


Figure D.6. Transmitter

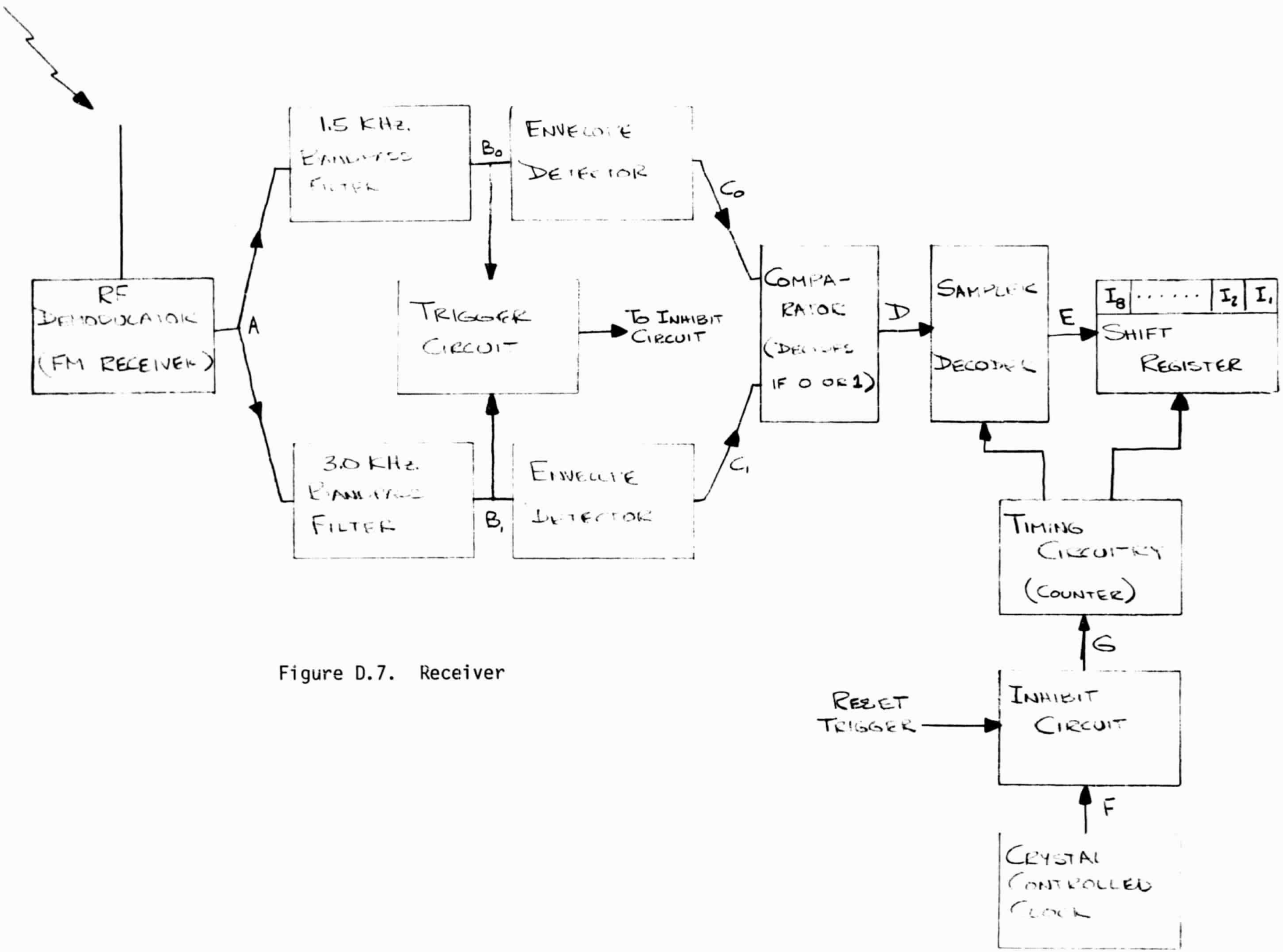


Figure D.7. Receiver

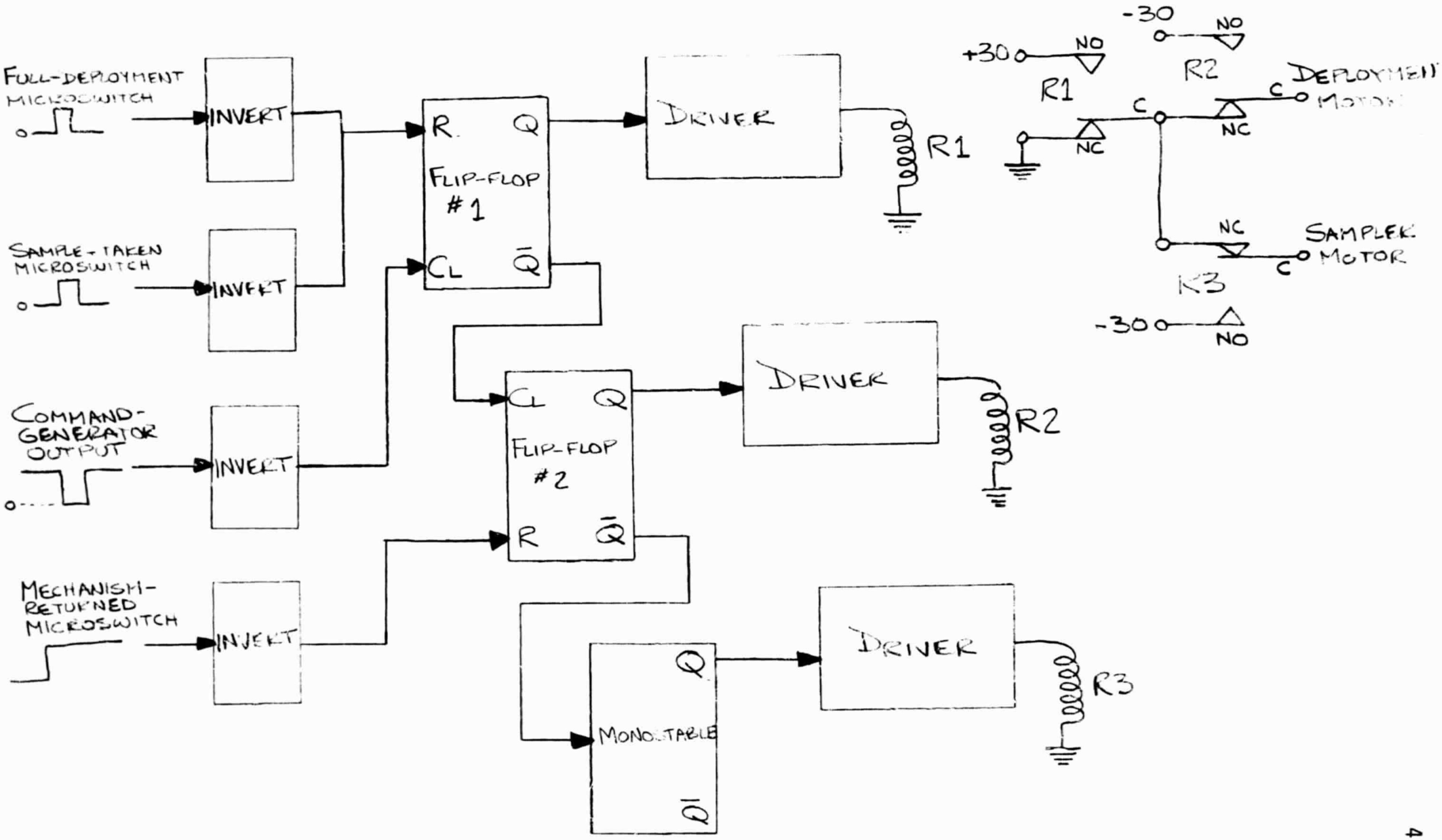


Figure D.8. Soil Sampler Interface

E.1. VEHICLE MECHANICS*

The roving vehicle shown in Figure A.9 was designed as a test platform for the devices being developed to operate on a Martian rover. The design is an adaptation of the rover built for the Jet Propulsion Laboratory by the General Motors Defense Research Laboratory. The elastic wheels are a variation of the Grumman metelastic wheels.

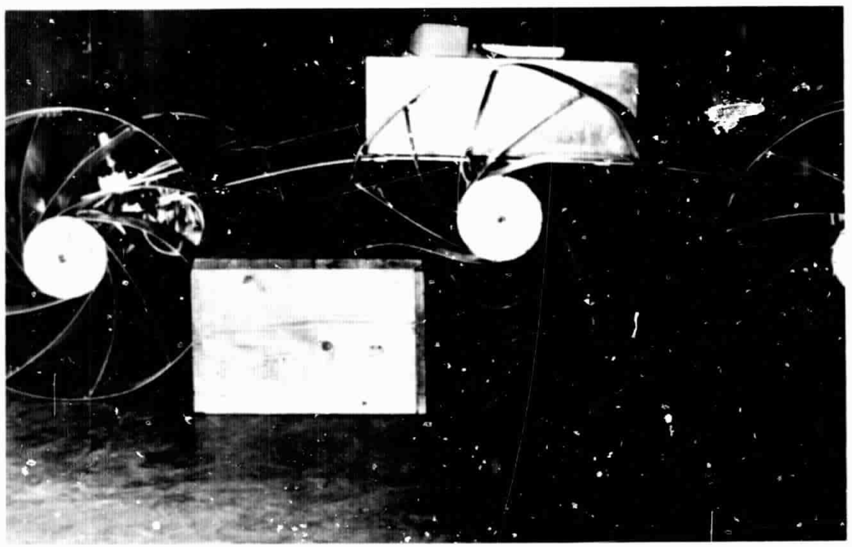
The following areas were covered in this year's work:

1. Vehicle Testing
2. Wheel Improvement
3. Motion Study
4. Structure Improvement
5. Steering System Development
6. Brake System Study

The major effort was to have a fully operating vehicle available for field tests of components. The vehicle was put in the field twice. The second test was made with the tactile sensor, the laser rangefinder housing, and the soil sampler mounted on the vehicle. A 16 mm motion picture was made of the second test. Two copies are being made of the film. These will be sent to Mr. Paul Tarver and Mr. Jesse Moore.

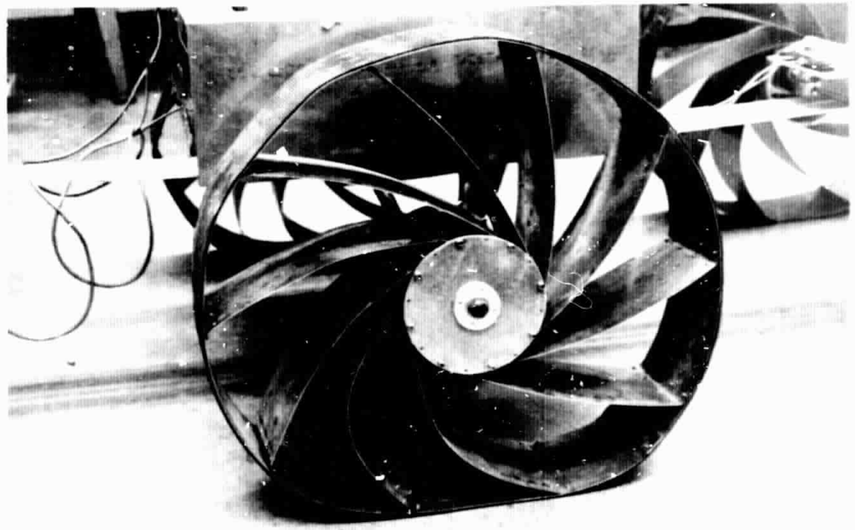
When operating the vehicle in the laboratory, under one condition the entire vehicle weight was taken on the center cab wheels as they were on the edge of an obstacle as shown in Figure E.1 . This caused the wheel rim to bend leaving the wheel as shown in Figure E.2. This failure brught attention to the wheels and several candidate wheels were examined. While some interesting prospects were developed, the wheels on the vehicle continued to function in a reasonably satisfactory manner and have not been replaced.

a. Severe Wheel Loading (Stationary)

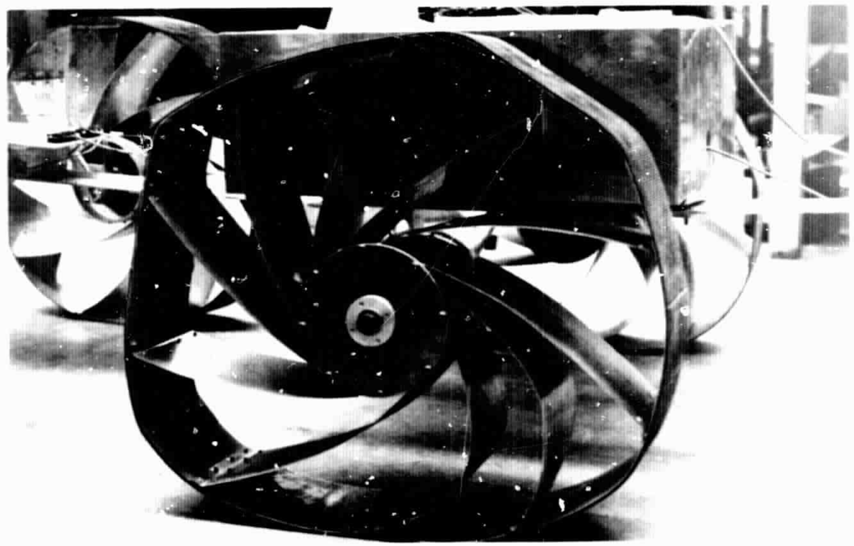


b. Severe Wheel Loading (Moving)

Figure E.1.



a. Undeformed Wheel



b. Wheel Bent Due to Loading

Figure E.2.

Angular oscillation of the cabs during operation will cause the laser beam to be pointed above or below the desired scanning point. This will result in erroneous signals both indicating impassible objects where none exist and failing to indicate obstacles which do exist. While this problem might be solved in a number of ways, one straightforward approach is to reduce the magnitude of the cab oscillation. The study made so far found an optimum spring rate for the wheels which was too low to work well in other respects. This study will be continued.

Modifications made to the existing vehicle frames had weakened them to the point where new frames were required. New frames have been made which are lighter in weight and approximately four times as rigid as the existing frames. A problem not yet solved is the inelastic yielding of the elastic member joining the cabs. This occurs in obstacle negotiation when the rear cab torque is high. Solutions have been suggested but none has yet been examined critically.

The steering system presently is a simple microswitch and cam arrangement which allows full right or full left turn or straight ahead. In the straight ahead mode a considerable deadband exists to take care of overtravel of the carriage after the motor is shut off. A study has been made which indicates that a proportional steering would improve steering accuracy at the expense of greater power consumption and more complexity in the system. This study will continue to explore the alternatives to find a satisfactory system.

Control of the vehicle on both upgrades and downgrades requires the addition of braking capability. An initial study of the amount of braking torque required has been made. A number of candidate systems have been examined in some detail, but no system has been selected.

* "Vehicle Mechanics", MRV71-8, Christopher J. Campbell, Lawrence Hellings, Thomas F. Nix. and Daniel Livingston, June 1971.

E.2. MOTION CONTROL SYSTEM

Throughout the entire year the vehicle was capable of moving under its own power, controlled by an operator using a control box attached to the vehicle by a long, flexible cable. The vehicle was kept in a ready-to-run condition so that whenever any sub-system group might wish to test under mobile conditions, the vehicle would be ready. The forward-stop-reverse control used a relay-contactor arrangement protected by fuses and interlocks. All six wheel-driving motors were line-started through a single set of contactors. A similar scheme was used to operate the two steering motors, so that the vehicle could turn right, turn left, or proceed along a straight line.

While keeping the vehicle ready to use, the control systems were gradually improved so that at term's end, the drive-motor armature current was limited by an easily adjustable semi-conductor circuit. With limited armature current, the starting torque is reduced to an acceptable value, and the probability of armature burn-out under long-time overload is reduced also. Dynamic braking was provided. Each of the motors on any one axle has a torque equal to that of the other.

Limit switches were added to the steering-motor circuit, providing a deadband for straight-ahead motion, and preventing excessive turning angle.

F. SYSTEMS CO-ORDINATION AND CONTROL*

With several of the subsystems approaching a time when they will be mounted on the vehicle, the need for some overall control, or management of such matters as space, weight, and power allocation, interfacing, interference, and noise is apparent. Responsibility for monitor these, and some other general problems was assumed by the Systems Coordination group. A vehicle running log was established to provide a record of vehicle operation, and to reduce the possibility that testing of one subsystem might damage another subsystem installed on the vehicle. Field-testing of the vehicle was the responsibility of the Systems group. Two field tests were made, during which the vehicle performed in a generally satisfactory manner.

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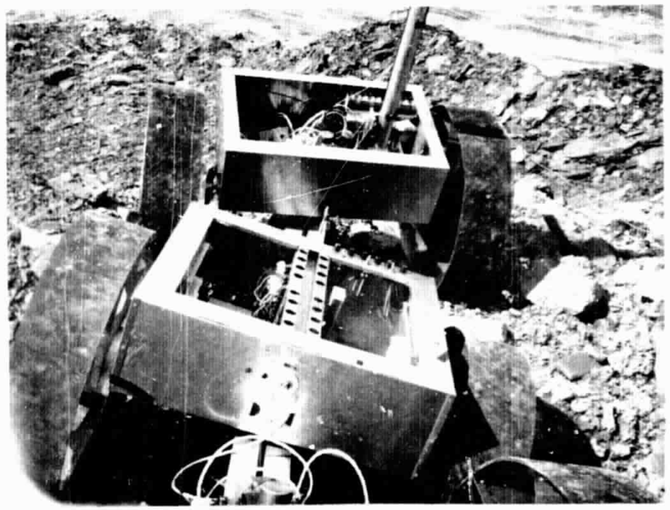
* "Systems Coordination and Control", MRV71-11, Thomas H. McLeod, June 1971.

PICTURE 1

PICTURE 2

PICTURE 3



PICTURE 4

SYSTEMS GROUP: FIELD TESTS

IV. PROJECTIONS OF ACTIVITY FOR THE PERIOD JULY 1, 1971 TO JUNE 30, 1972.

A. Obstacle Detectors. With the present optical efficiency combined with the photodetector ability and laser output, the system is only able to detect white objects at 2 m. The photomultiplier tube dark current has continued to be a limiting process so experiments will be made with solid state photodetectors such as avalanche photodiodes. Development of vertical scanning ability will be attempted so that more information will be available for path decision making. Further testing and minor modifications of the present tactile obstacle sensor will be made. A new concept of extending the front cab in front of the remainder of the vehicle and using the powered front cab as the tactile sensor will be explored.

B. Soil Sampler-Tester. A sampler head has been developed which obtains an adequate sample without moving parts within the head. This head will be more fully tested and the sample removal method developed. Another possibility will be explored - that of having the sampler head removable so that the sampler head becomes the sample container. The soil tester unit will be built and field tested.

C. Short-Range Navigation. A gyro direction finding system will be mounted on the vehicle for operation tests. A mini-computer will be connected to the vehicle by an umbilical cord for navigational control.

D. Communication. Refinements will be made on the communication links developed this year to establish dependable control and data readout from the vehicle.

V. EDUCATIONAL CONSIDERATIONS

Many skills expected of an engineer are not taught in formal courses. For reasons of economy of instructor and student time, most courses are highly structured. This means that material covered in reading assignments and lectures is applied to problems stated in such a manner that the currently studied material can be (and is expected to be) used to obtain the solution. The student is never (or rarely ever) expected to state the problem in a manner in which he can solve it or to state the problem from raw information. The strength of this design project is that the student is expected to state the problem and to find solutions which he or others can realize in working physical devices. One of the shocks experienced by most students is that the physical world does not necessarily obey the relationships derived by simplified theoretical analysis.

Another strength of this project is the opportunity and necessity of oral and visual presentations of ideas to the project monitor. Many an engineer has understood his problem better after he has had to put together a technical presentation of the project. This also applies to these student engineers. They further learn to organize their thinking for the presentation. They also learn to consider their audience for if a point is not clear the monitor is sure to ask for clarification on the spot.

The final review held jointly with the design group from Rensselaer Polytechnic Institute was attended by representatives from various governmental agencies and industries active in aerospace research. This full-scale presentation is an excellent capstone to the design efforts of the students. The presence of this group on campus serves to build interest among students not yet associated with the project and is part of the growing interest of students in the work being done.

The following students have participated in the program during this period. All have received the degrees sought except for Mr. Vincent who transferred to another degree program and Mr. Cole who accepted an offer from a new federal environmental laboratory in February when it was indicated that the offer would probably not be extended until June.

Thomas P. Armour	M. Eng. (Elec.)
William W. Blakeslee	M. Eng. (Mech.)
Frederic S. Boericke, III	M. Eng. (Elec.)
Christopher J. Campbell	M. Eng. (Mech.)
Jean M. Canaguier	M. Eng. (Elec.)
Clifford E. Cole	Left program in February to accept Federal Employment
Edward M. Cutler, Jr.	M. Eng. (Mech.)
Walter Dowell	M. Eng. (Elec.)
Daniel J. Fellman	M. Eng. (Elec.)
Philip J. Goldman	B.S.
Steven N. Goodspeed	M. Eng. (Elec.)
Jeffrey A. Haber	M. Eng. (Elec.)
Lawrence Hellings	M. Eng. (Elec.)
Alan Huang	M. Eng. (Elec.)
Paul J. Kampas	M. Eng. (Elec.)
William M. Lee, Jr.	M. Eng. (Elec.)
Alan B. Livingstone	B.S.
Thomas H. McLeod	M. Eng. (Elec.)
Thomas F. Nix	M. Eng. (Elec.)
Deane C. Osborne	M. Eng. (Elec.)
Alan L. Schweitzer	M. Eng. (Elec.)
Ronald J. Vincent	Transferred to Master of Science program
Lawrence A. Wojcik	M. Eng. (Mech.)
Robert J. Haluga	M. Eng. (Mech.)