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THE CONTROL OF A LUNAR TRANSPORT MACHINE
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of Technology**

Atlanta, Georgia 30332



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THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

ME 4182
MECHANICAL DESIGN ENGINEERING
NASA/UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

Man-Machine Interface
for the Control of
a Lunar Transport Machine

August 25, 1987

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ABSTRACT

This report describes a proposed first generation human interface control panel which will be used to control SKITTER, a three-legged lunar walking machine. Under development at Georgia Tech, SKITTER will be a multi-purpose, un-manned vehicle capable of preparing a sight for the proposed lunar base in advance of the arrival of men. This walking machine will be able to accept modular special purpose tools, such as a crane, a core sampling drill, and a digging device, among others.

Our project was concerned with the design of a human interface which could be used, from earth, to control the movements of SKITTER on the lunar surface. Our control panel is currently concerned only with moving SKITTER, not with controlling the special purpose attachments since the design of such attachments is still far from complete. We have also made preliminary inquiries into necessary modifications required to adapt our panel to boun a shirt-sleeve lunar environment, and to a mobile unit which could be used by a man in a space-suit at a lunar work site.

SKITTER CONTROL PANEL

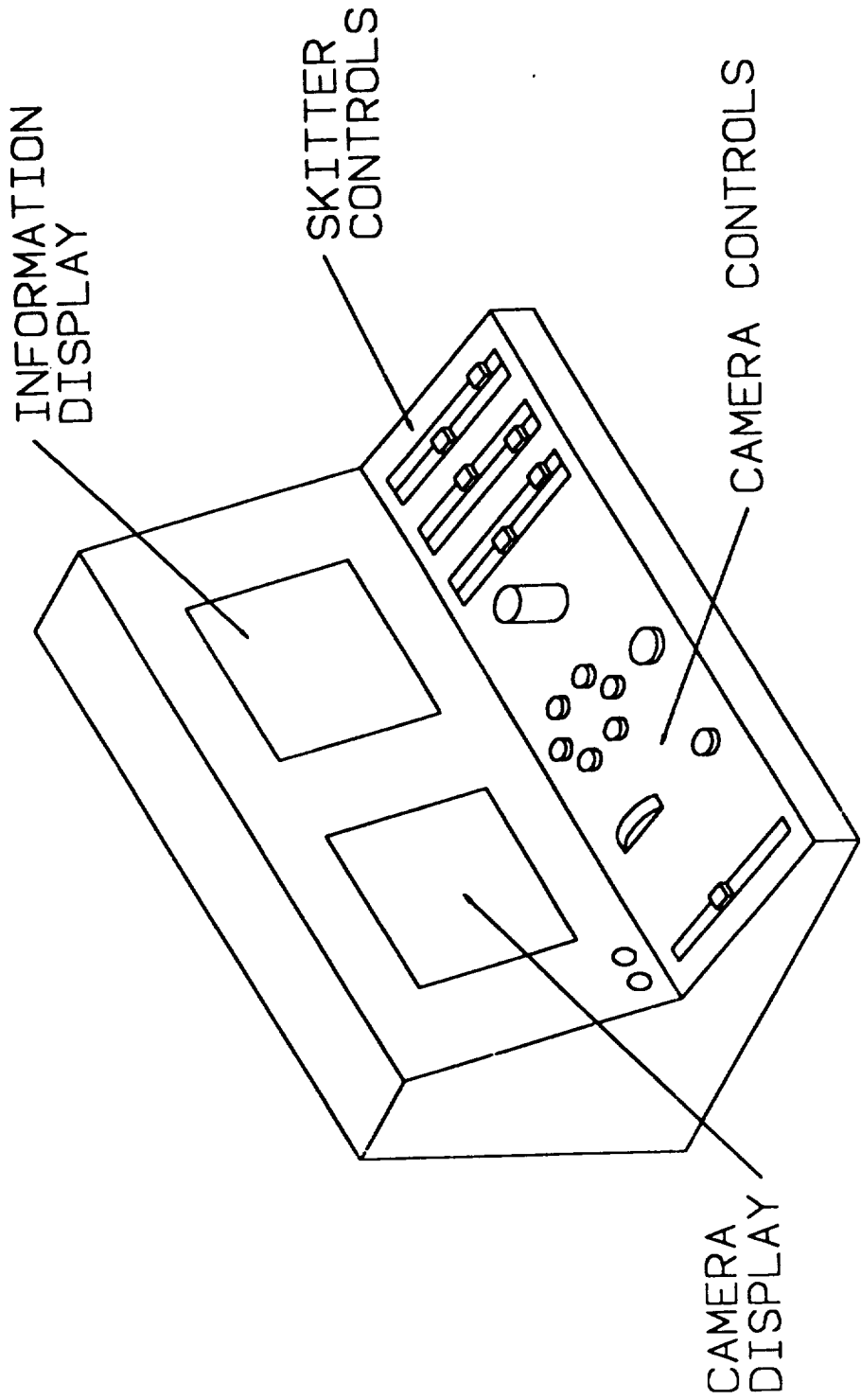


fig. 1

INTRODUCTION

Any new machine which must be operated by people must have a control system that acknowledges the limitations of people, because

the man is already designed and in quantity production. He is difficult to modify and expensive to adapt. The machine designer has a clean sheet of paper. He can design his side of the interface to be a perfect match to long established man. He should study man's design to determine the optimum extent of the interface - what should be in it and what should be "under the floorboards" i.e. automated. (16)

With this in mind, a first generation control interface has been designed for SKITTER. The design is limited to the human interface of the Earth based control system. Suggestions have also been made for further design on related subjects, including a lunar base unit, a lunar portable unit, communications, and the SKITTER interpreter. Established Human Factors techniques were used as a basis for the design decisions, however due to the nature of this project verification of the design was not possible. For that, a simulator of the final control panel will need to be constructed and tested. This report describes the design of the control panel and outlines some of the related topics.

DESIGN OVERVIEW

According to a NATO study on human factors aspects of aircraft accidents and incidents,

the significant errors we humans make can be attributed to one or more of the following:

- 1) failure or inability to collect sufficient information
- 2) failure or inability to correctly interpret this information
- 3) our liability to confusion (16)

Our design team has attempted to determine what information is necessary to make decisions, when the information is necessary, and in what format it is the least confusing. Giving the decisions to the machine is also a possible source of confusion, so input devices were chosen to minimize this confusion. Another factor complicating the design is the time lag caused by the distance between the control console on Earth and the robot on the moon.

I. DEFINITION OF FORWARD

SKITTER does not have an inherently forward direction. However, people think in relation to a forward, therefore a forward had to be defined for the operator. Since SKITTER can walk in six directions, six possible forward directions exist. The operator chooses one of the possible "forwards" by selecting a camera and pointing it in the desired direction.

II. INFORMATION GIVEN TO THE OPERATOR

Since the visual information channel has the widest bandwidth, it was decided to channel most information through the visual channel. Some information occurs naturally in visual

form, and some needs to be converted. SKITTER's surroundings are primarily visual, so we decided that cameras/screens would be a good method of transmitting this information to the operator. SKITTER's position and velocity can easily be represented visually. SKITTER's internal status is not primarily visual, and must be translated into words and numbers, which take longer for an operator to process and can be more confusing. To insulate the operator from extraneous information, while making that information available when needed, we chose to organize it in a hierarchy of levels. Only the level of information that the operator needs at the time is displayed. Since we cannot predict what the operator will need at any one time, the choice of levels is front panel selectable.

Two display screens are used, one for camera reception and one for SKITTER's status. The status screen shows the alphanumeric information and a line drawing of SKITTER, which serves as a predictor display. A predictor display is used since there is a long (approximately six second) time lag between sending a command and receiving the effects of the command due to the distance to the moon and back.

III. INFORMATION OBTAINED FROM THE OPERATOR

To minimize the possibility of confusion, input devices that are analogous to the controlled function were chosen for the input devices from the operator to the control console. Control devices are rated according to their order of control: zero order or position controllers, first order or velocity

controllers, second order or acceleration controllers, and so on. The lower order the controller, the easier it is to use, so all devices should be controlled by the lowest order consistent with the nature of the device. Devices with a limited range of motion should be position, devices with a maximum and minimum speed should usually be velocity, etc. The direction of motion of the controller should be consistent with the direction of the controlled device. The controls should be grouped in logical units, with like items together and close to the related display.

We have divided the controls into camera control and SKITTER control. The camera controls are on the left side, SKITTER motion controls in the center, and SKITTER's individual actuator controls on the right side. The camera controls include focus, zoom, tilt, rotate, and camera select. The main motion control is a joystick with three mode buttons (walk, squat, and tilt) on the top. The actuator controls are slide controls, one for each of SKITTER's six actuators (see fig. 1).

CONTROL PANEL DESIGN

I. HANDLING THE TIME LAG

Due to the fact that the moon is roughly a quarter of a million miles from earth, the time needed for a signal to make the round trip (earth-moon-earth) is roughly six seconds. Part of this lag is due to the fact that the signal does not always travel in a straight line from earth to moon, but instead may be routed through a number of satellites around earth before going to the moon or arriving back on earth.

This lag makes real-time control of SKITTER impossible. There are two things we have done to minimize the effects of the time lag on the operator's performance: 1) use of position controls whenever possible; and 2) use of a predictor display.

The use of position controls is important because the operator can use them without being forced to make use of the video display (which exhibits the time lag). For instance, if the operator wants to rotate the active camera 35 degrees he simply turns a scaled dial on the control panel until it reads 35 degrees more than it did. A signal is sent to SKITTER's computer which causes it to initiate a feedback loop that carries out the command with no further operator interference. If the camera rotate control was a velocity control, the situation would be much more difficult for the operator. The operator would have to move the control to start the camera rotating, then turn it off and wait six seconds to see how far it had moved. This process

would have to be repeated until the camera was at the correct angle. We designed the panel so that all of the camera controls are position controls.

Unfortunately, it was not possible to use position controls for the main SKITTER functions: walking, squatting and tilting. We used velocity controls. In order to minimize the time effects for the operator, we decided to make use of a predictor display. Our predictor is a simulated real-time display which shows the operator what should be happening as a result of his control movements.

It was beyond the scope of our project to attempt to design the hardware and software to make this possible. However, in theory, it is not a difficult concept. Every time the joystick is moved, it creates a signal which will cause the intended action by SKITTER. The computer in the control panel, which interprets the joystick motion and generates the proper command for SKITTER, can use this information to generate a picture of what SKITTER should do when it receives the command three seconds later. For instance, when the joystick is used to give a "walk" command to SKITTER, the computer sends out the desired new positions of SKITTER's actuators to perform a step. Knowing SKITTER's physical dimensions and the positions of the actuators, the geometry of SKITTER can be calculated. The results of the calculations can then be used to create a graphic representation of SKITTER on the screen.

The problems associated with designing this predictor display are:

- 1) the selection of an arithmetic processor which can perform the geometry calculations fast enough to allow real-time display.
- 2) the selection and programming of an image processor which can generate and animate the image of SKITTER in real-time.

II. CAMERA CONTROLS

The following camera functions should be controllable by the control panel:

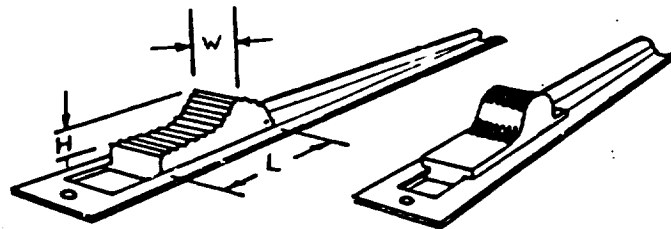
1. Zoom (Visual magnification)
2. Tilt (360 degrees about a horizontal axis)
3. Focus
4. Rotate (60 degrees about a vertical axis)

Two important design criteria were followed in choosing controls for these functions. First, the direction of movement of the control must be related to the resulting change of motion by the camera. Second, position controls should be used whenever possible to decrease the effects of the time lag. All specifications were chosen to fall within military standards and current human factors recommendations.

A. Zoom (Visual Magnification)

There are two controls suitable for this function: lever and slide. The lever increases risk of accidental movement. The low profile slide provides an adequate model of functional motion which is nearly free from unintentional operation. For additional protection, the slide should have viscous or inertial resistance (10 to 40 oz.). The slide should provide continuous control and a scale should be engraved beside the slide knob.

which corresponds to discrete zoom factors (1x, 2x, 3x,). The neutral position, 1x, should be at the end closest to the operator. Movement away from the operator corresponds to "zoom in". Serrations on the top of the knob will facilitate better operation. See figure 2 for dimensions.



Serrated

$H = 1/4$

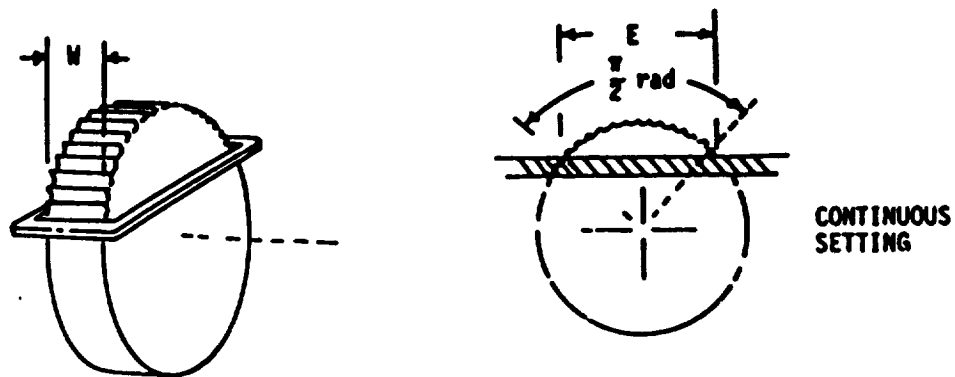
Knurled

$L = 1$ $W = 1/8$ to 1
(Inches)

Figure 2.

B. Tilt

The thumbwheel is a model of the tilt function which can be rotated 360 degrees. It's low profile and a recommended resistance of 12 oz. will guard against inadvertent input. Twelve angles of tilt (0,30,60,...,330) should be marked on the rim of the wheel with light detents at each of the corresponding positions. The wheel is a continuous control and the detents provide an indication of specific angles of tilt. Rotation of the wheel away from the operator will cause the camera, in neutral position, to tilt toward the ground. Angle indications increase with rotation away from operator. See figure 3 for dimensions.

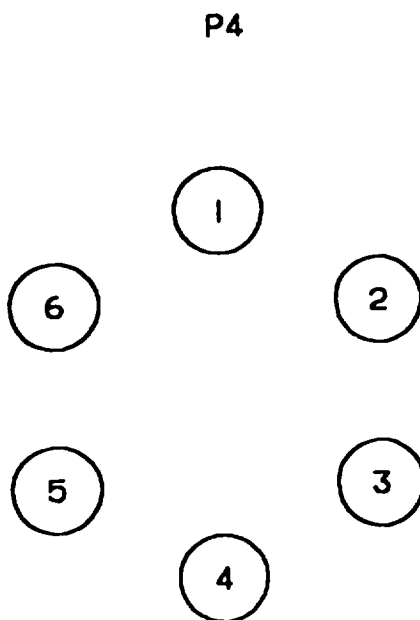
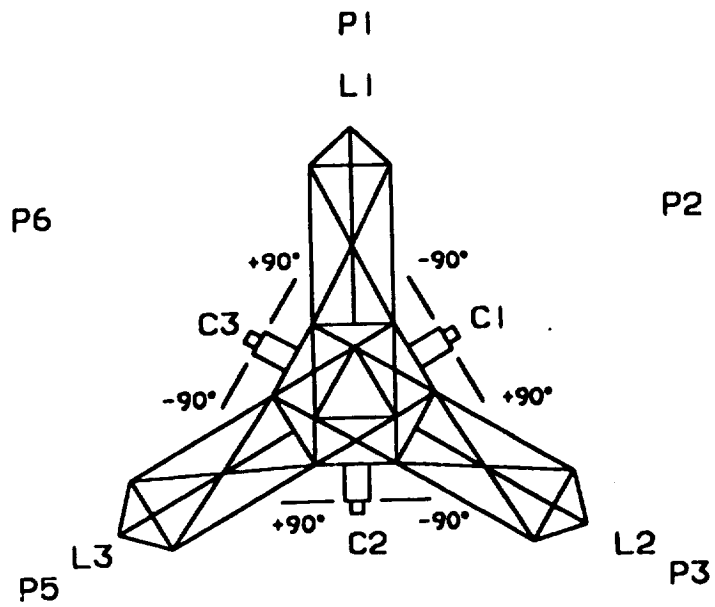


$E = 1 \text{ to } 4 \quad W = 1/8 \text{ to } 7/8$
(Inches)

Figure 3.

C. Focus

The camera will be equipped with automatic focus but should include a manual override. This function requires a high degree of accuracy and will, therefore, be controlled by a continuous control knob. Serrations around the edge and a resistance (3 to 10 oz.) will provide ease of operation. A scale should be engraved on the panel and associated with the image distance (1/4 in. between markings). Clockwise movement increase the focusing distance and light detents mark the specific positions of each number. See figure 4 for dimensions.



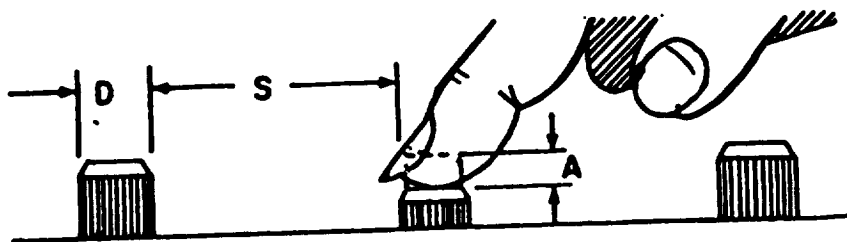
CONTROL PANEL CAMERA POSITION BUTTONS
(AS SEEN BY OPERATOR)

Figure 5.

to indicate it's activation. Depressing button #1 illuminates it and locates the camera on the "front" closest to the camera's current position. Depressing button #2 will illuminate it and locate the camera to the "front" which is 60 degrees from the "front" closest to the current camera position. Once the new camera direction is displayed on the monitor, button #2 is deactivated and button #1 is illuminated, indicating a new "front" is now established.

1. Pushbuttons

Each of the six pushbuttons should be round, momentary contact switches with an illuminated, concave cap. Displacement should be 1/8 in. to 1/4 in. and resistance 10 oz. to 20 oz. It is best to use a button with a raised rim as a guard to accidental activation. A button which provides a "click" should be used to give additional feedback that the button has been activated. See figure 6 for dimensions.



$$D = 1/2 \text{ to } 1 \quad A = 1/8 \text{ to } 1/4$$

(Inches)

Figure 6.

III. SKITTER AND PANEL POWER SWITCHES

The power switches are round, illuminated, latching switches located on the lower left corner of the monitor. The depressed position is the "on" position, indicated by an illuminated, red light. The SKITTER power switch activates skitter's main power supply. The panel power switch activates control panel power. Both switches should follow the same criteria as the rotate buttons.

IV. MANUAL ACTUATOR CONTROLS

Individual control of each femur and tibia can be achieved with slide controls. They should follow the same criteria as the zoom slide (see figure 2) with a few exceptions. The knobs of the femur slides (#1,#3,#5) should be black with serrated tops while the tibia knobs (#2,#4,#6) should be red with knurled tops. Scale markings should be associated with the actual distance the actuator moves. In order to determine which leg corresponds to each pair of slides, the operator must consult the information display.

V. LAYOUT

All labels should be above controls. Use the following labels: ZOOM, TILT, FOCUS, ROTATE, SKITTER POWER, PANEL POWER, FEMUR, TIBIA. Label heights may range from $5/100$ in. to $2/10$ in. while scale markings may range from $16/100$ in. to $31/100$ in. It is best to place knobs close to the operator for accurate operation. The actuator controls are placed on the right of the control panel because of infrequent use and because they are related to the joystick. See figure 7 for control spacing. Our control panel will have a 2 inch margin around it's edge. Military standards dictate the use of black or gray controls while the first two colors listed for special coding are red and green.

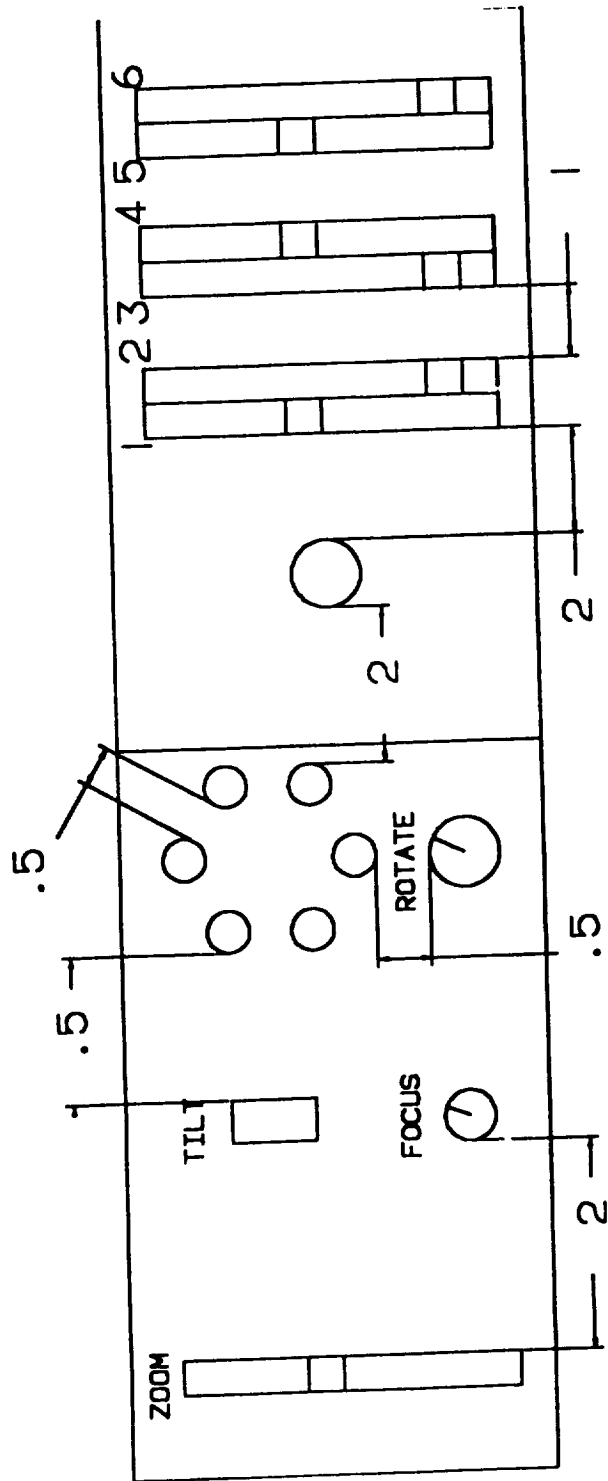


Figure 7.

MINIMUM SPACINGS (IN)

VI. INFORMATION DISPLAY DESIGN

While operating SKITTER, there is a certain amount of information which the user will need beyond what is presented on the camera display. Likewise, the computer which controls SKITTER will require information which cannot be relayed through the joystick and the other manual controls. The Information Display will serve as a two-way communication device to exchange data between SKITTER and the operator. The display will contain messages on error conditions, a motion predictor, important physical parameters, and touch-screen capability for user input. There are four basic types of information displays, Data entry screens, Inquiry screens, Interactive screens, and Menu screens (7). Data entry screens are designed to collect large amounts of information from the user. Inquiry screens display the contents of a certain computer file, which the user cannot change. Interactive screens are those through which the computer and the operator exchange information one idea at a time in a free-form manner. Menu screens permit the user to pick from a number of alternatives. The SKITTER information display can be considered a combination of Inquiry and Menu screens. After defining the type of screen to be designed, the system inputs and outputs need to be defined. The inputs and outputs necessary for the operation of SKITTER and the screen number on which they will appear are listed below.

OUTPUTS

- 1 Location of SKITTER
- 1 Maximum actuator force feedback
- 2 Temperature extremes
- 2 Power plant status
- 2 Radiation dosage
- 3 All actuators force feedback
- 3 Actuator parameter (e.g. hydraulic pressure)
- 4 Camera lighting
- 4 Camera aperture
- all Error conditions
- all Motion predictor: distance traveled
compass heading
ground clearance
tilt angle

INPUTS

- all Choose screen
- all Flip camera image
- all Joystick/manual control switch
- all Adjust camera lighting
- 4 Adjust camera aperture
- 4 Return distance traveled on motion predictor to zero

Screen number one contains only the information necessary for the normal operation of SKITTER. This is done to avoid overloading the operator with information that is less often used. The remaining screens contain other types of data which the operator can use in special situations. The screens are designed so that the operator does not have to reference one screen in order to interpret the contents of another.

A. Touch Screen Key Size

Beaton and Weiman (3) found that when touch key screens have a minimum key size of 10 mm high by 20 mm wide, user errors decreased dramatically compared with smaller size keys. When using these minimum sizes, a vertical spacing of 10 mm and a horizontal spacing of 10 mm is recommended. All touch controls on this display will observe this minimum sizing. According to Galitz (7), good display design both reduces the number of human errors and decreases human and machine processing time. The most common fault in display design is

design inconsistency. Therefore, the different screens which appear on the information display must have consistent layouts. Increasing design consistency will reduce the number of learning requirements, allowing the operator to easily achieve and maintain a high level of performance.

B. Physical Screen Layout

The natural tendency for a person reading a screen is to start in the upper left hand corner and move clockwise around the screen. Since it is most important that the operator be notified of error situations quickly, the error messages will appear across the top of the screen. The next most important piece of information is the motion predictor display, which will be placed on the right hand side of the screen. It is important that areas which will appear on all screens always be in the same location. Therefore, the flip camera and joystick/manual switches will always be located in the lower left hand portion of the screen. The choose screen button is located in the upper right hand corner. The left hand side of the screen is reserved for the menu-specific pieces of information, such as SKITTER's location. An example of this layout can be seen in figures 8 through 14.

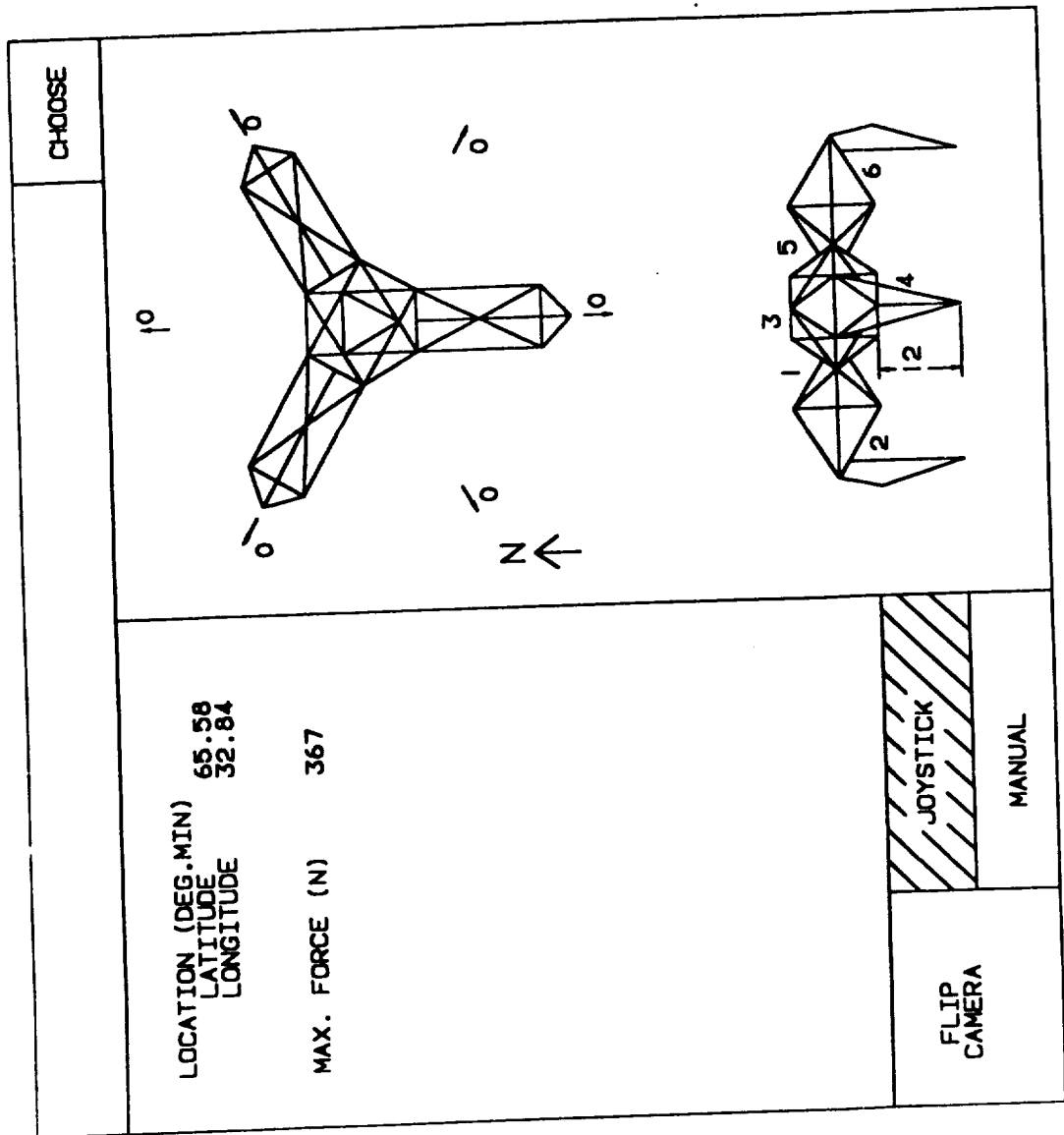


Figure 8.

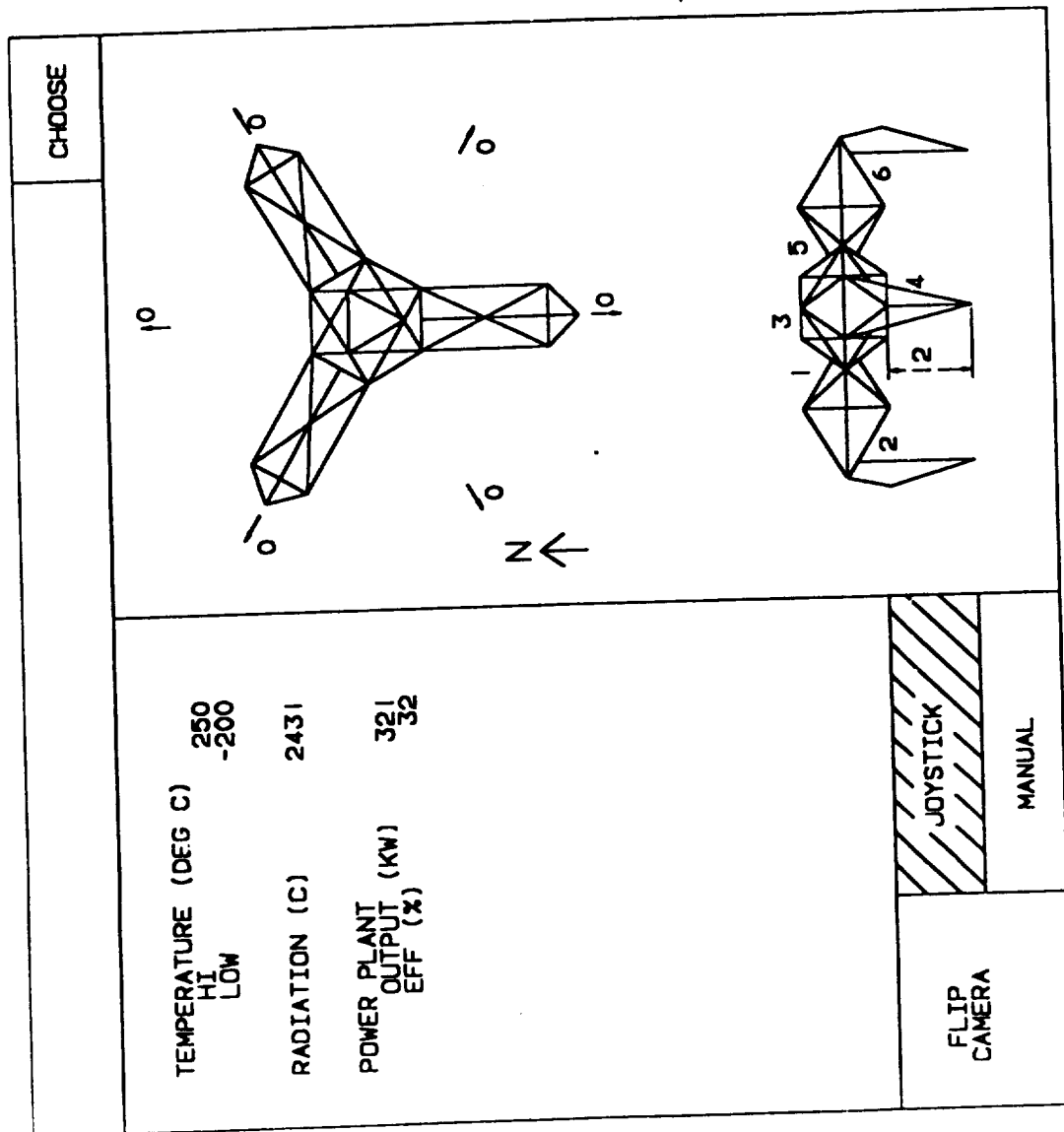


Figure 9.

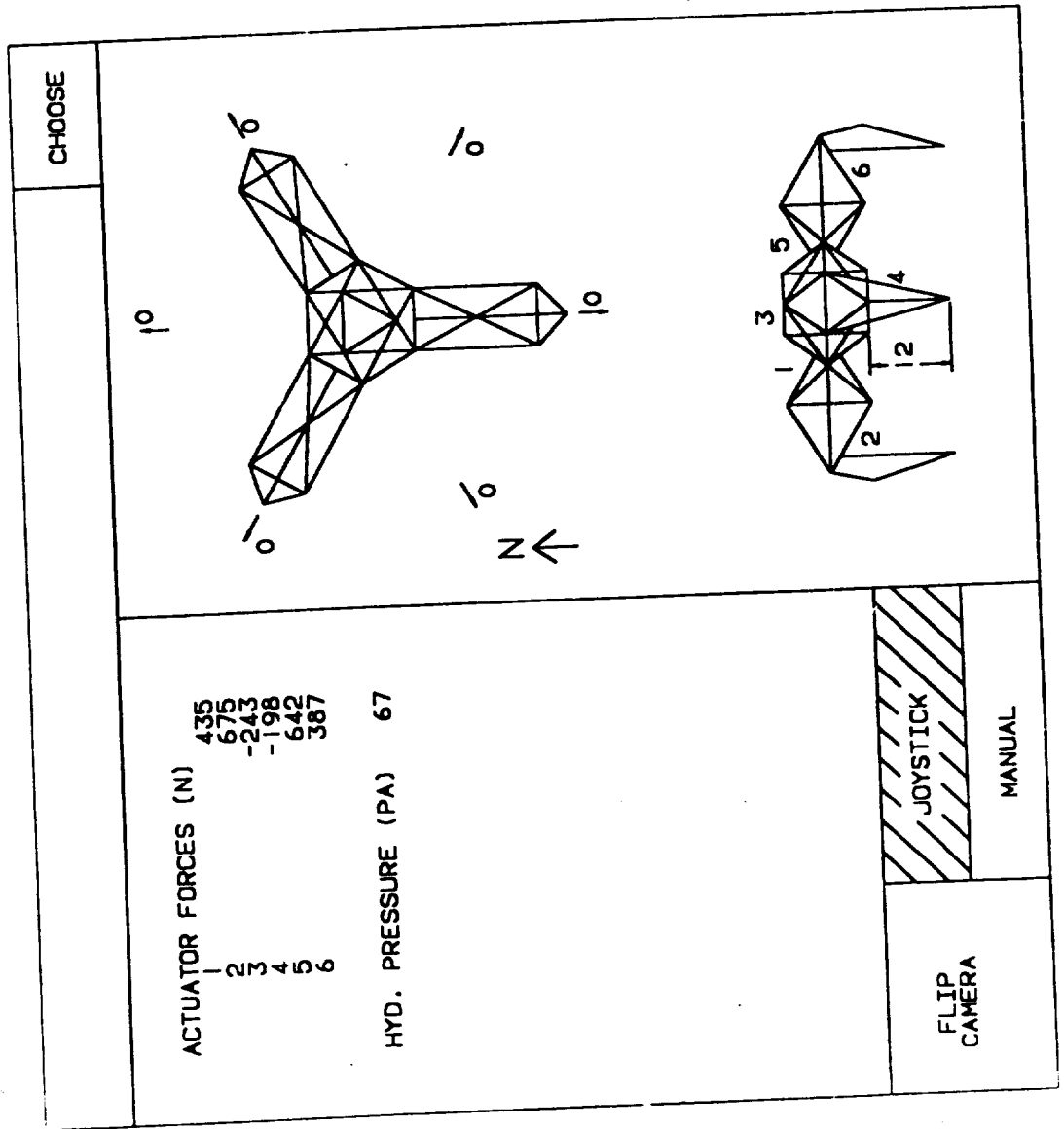


Figure 10.

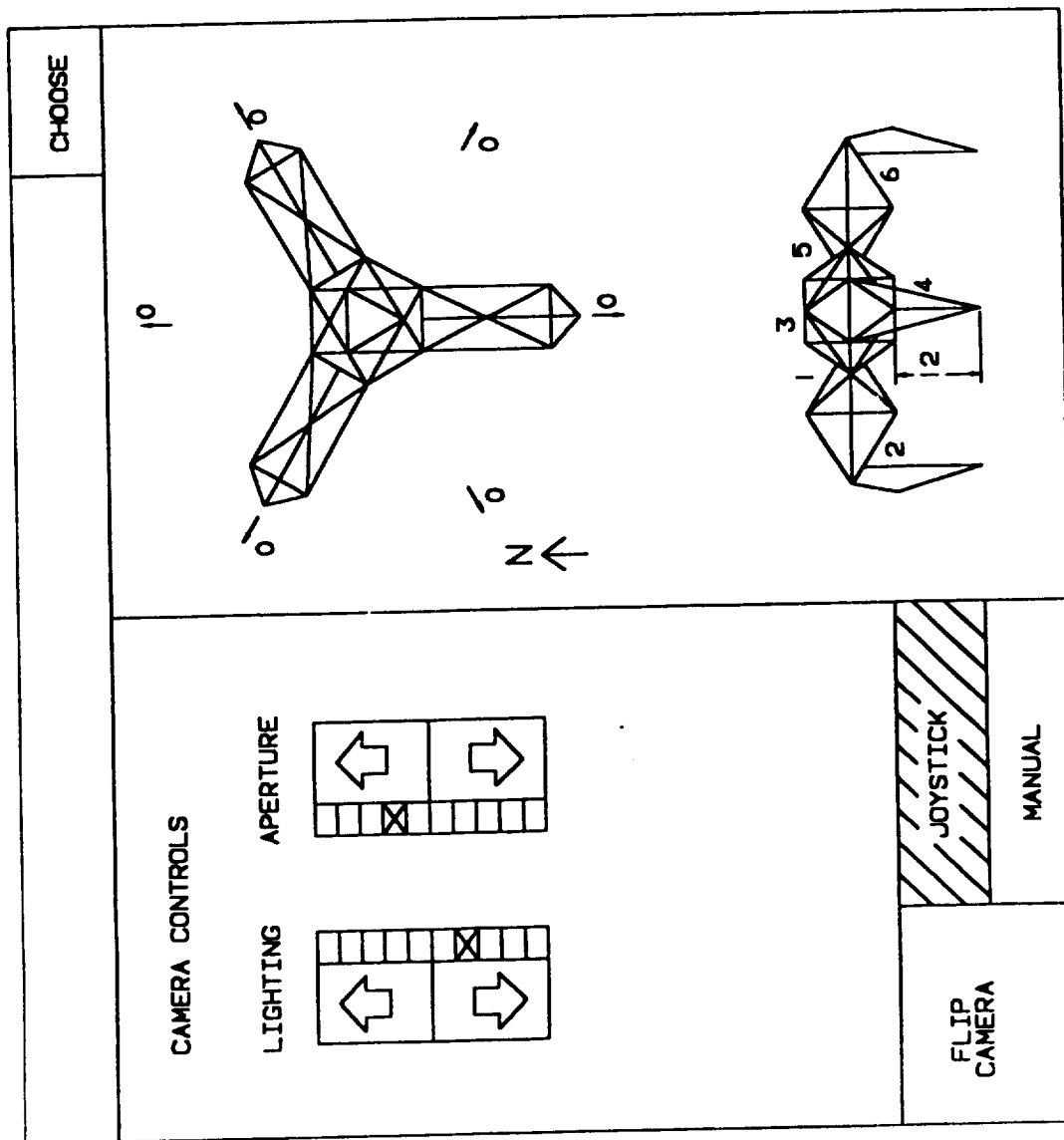


Figure 11.

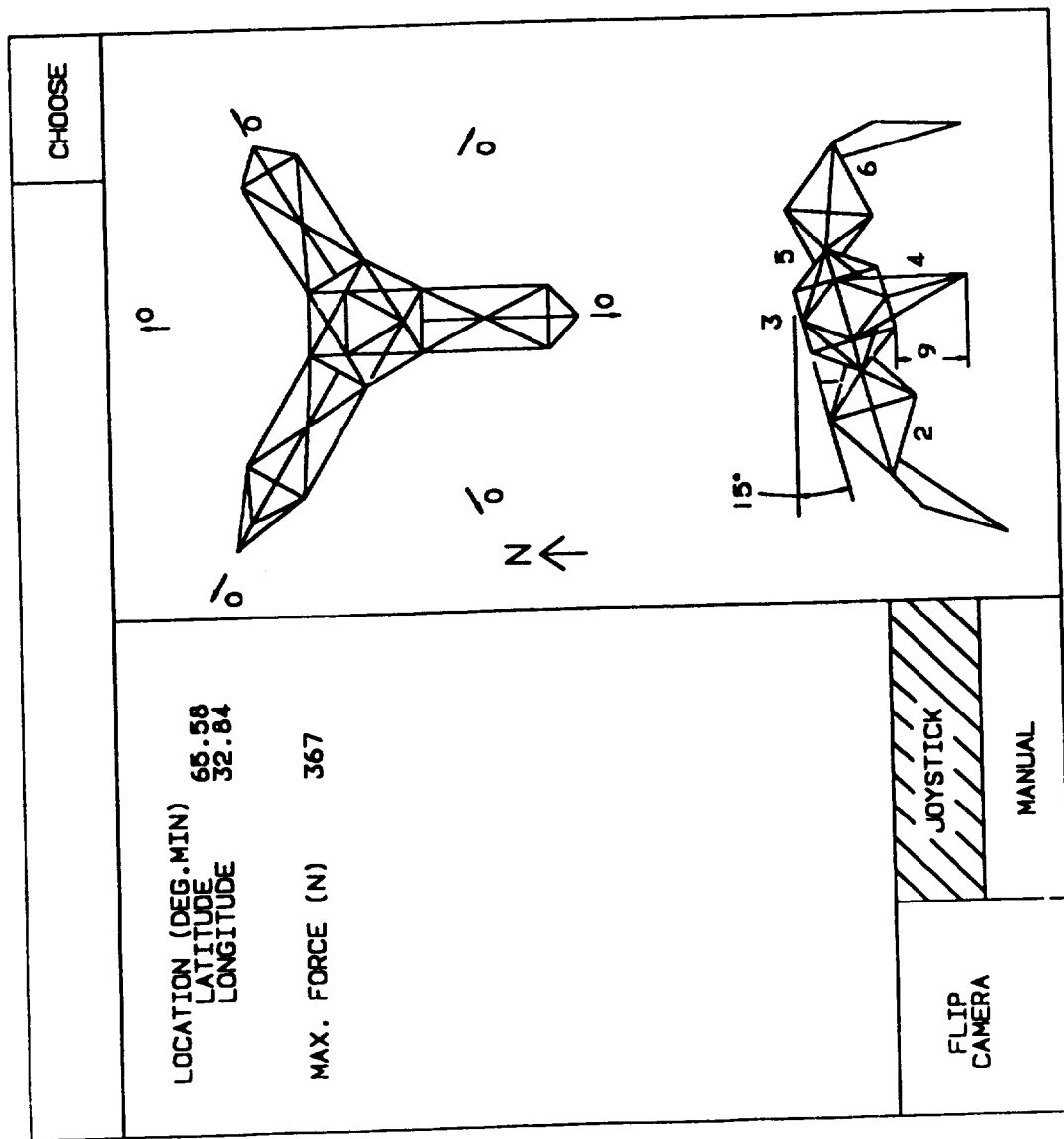


Figure 12.

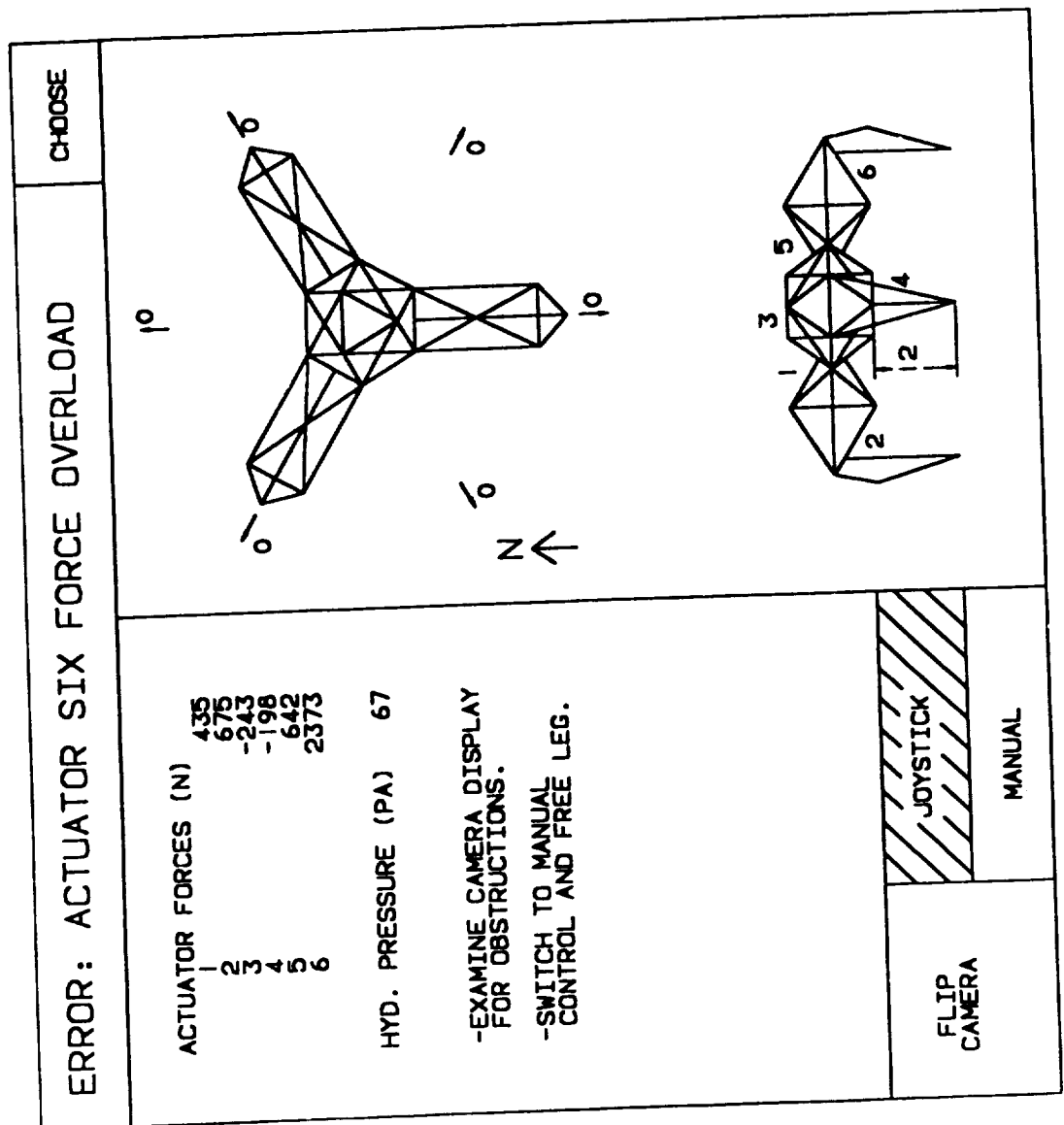


Figure 13.

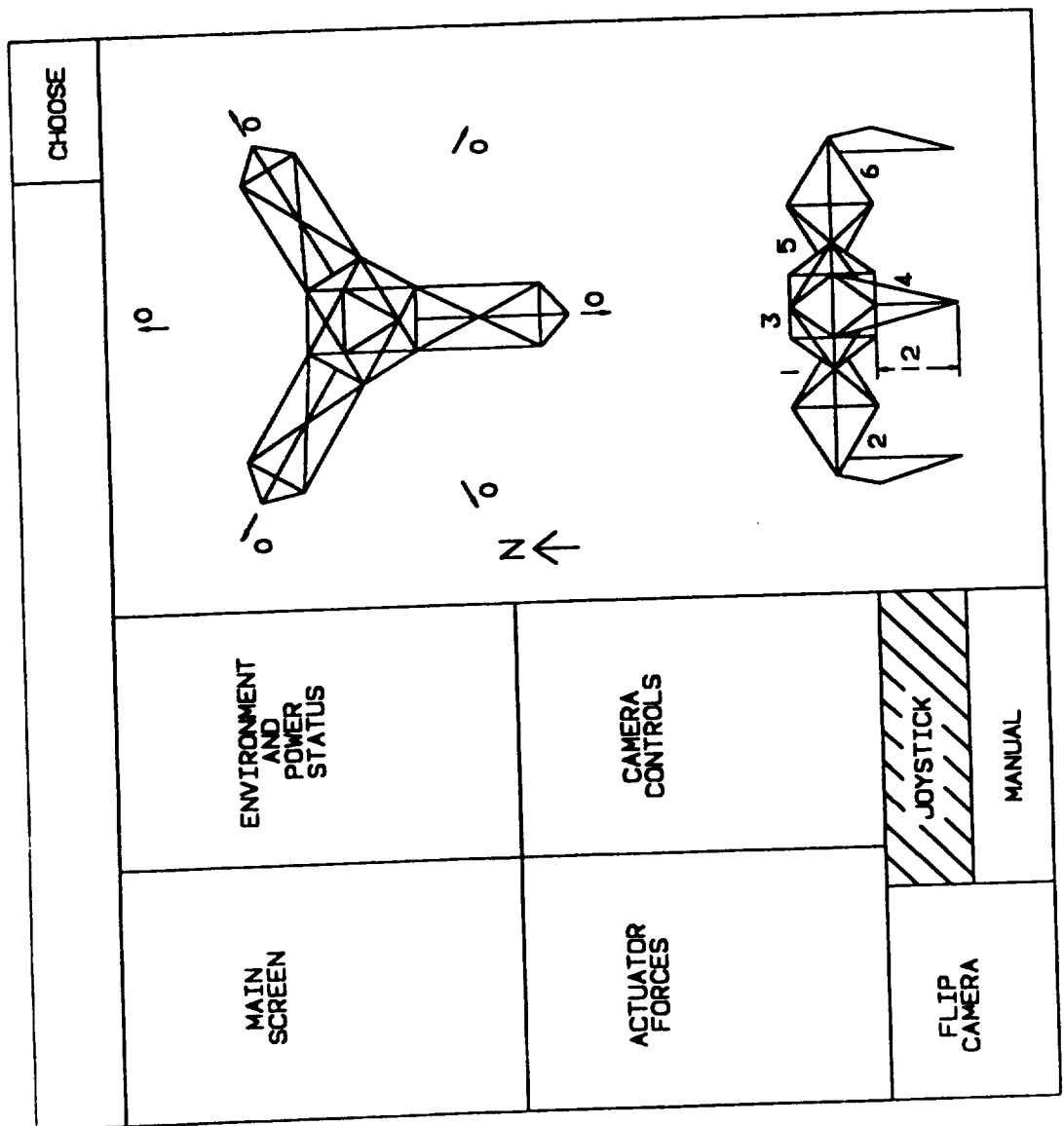


Figure 14.

A color display will be used so that pieces of information can be visually grouped by their type and level of importance. When an error message appears, it will blink between white and red. The motion predictor display will be white and purple while it is being used, and green when it is not. The choose screen, flip camera and joystick/manual buttons will be displayed in blue with white letters. Yellow cross-hashing will be used to indicate whether SKITTER is being controlled manually or with the joystick. The information block on the left hand side of the screen will display orange headings and yellow data. The screen background will normally be black.

The data contained in the information block on the left hand portion of the screen will be arranged so that the operator may easily interpret its contents. The alignment of the headings and the data are recommended by Galitz (7) to promote ease of interpretation (see figures 8 through 10). Touch key controls will be used for the camera settings (see figure 11).

C. Screen Operation

Now that the physical layout of the screen has been established, the actual operation of the screen must be considered. There are certain unique characteristics of SKITTER operation which must be considered in the design of the information display. Perhaps the most important of these is the time delay for earth based operation. This is accounted for in the operation of the motion predictor display and the

joystick/manual control switch. Another area of concern is the definition of how a forward push on the joystick relates to the actual motion of SKITTER. This is also taken into account in the motion predictor.

Since there is no absolute knowledge of the real world of the future, the motion predictor display must be abstract in nature (5). However, it must still give the operator a general idea of the consequences of his actions. The operator must first be able to understand the meaning behind the physical orientation of the predictor model. In order to facilitate this understanding, the following requirements are established.

- There will be two views, a top view and a side view, since all the necessary information cannot be represented in one view.
- Gravity always points straight down on the screen.
- Predictor model rotates so that camera view is straight up on screen, except when the joystick is in "tilt" mode. Then the model rotates so that the tilt angle is normal to the screen.

The motion predictor will also contain numerical data. The following requirements are established concerning this data.

- There will be six "distance traveled" readouts. Each readout corresponds to the displacement in one of SKITTER's possible directions of motion.
- The "distance traveled" readouts return to zero when the body center in the top view is pressed. When the joystick is moved, a displacement is predicted using dynamic modeling and is displayed in white.
- The compass heading will rotate according to the rotation of the motion predictor model.
- The "ground clearance" is the distance from the bottom of SKITTER's body to the mean relative heights of its feet.

-The tilt angle will only appear when the joystick is in the "tilt" mode. The tilt angle is defined as the angle of SKITTER's body relative to the normal gravity plane (see figure 14).

-Once the actual parameters (displacement, body rotation and tilt) resulting from the operator's actions are fed back from SKITTER, their values (distance traveled, compass heading and tilt angle) are displayed in purple.

-Actuators will be numbered top to bottom and left to right.

The time delay for earth based operation also poses a problem when the operator is switching from joystick to manual control. The positions of the slide controls must correspond to the actual positions of the actuators before the operator can begin manual control. When the operator chooses manual control, the yellow cross-hashing will blink until the servo motors in the slide controls have placed them in the correct positions. Then, the operator can begin manual operation after the cross-hashing has stopped blinking.

D. Menu Selection

Menu selection is done by pressing the "choose" button in the upper right hand corner. The operator then selects from the choices that appear in the information block (see figure 13). Since the information block is about 200 mm by 120 mm, the maximum number of menu choices per screen is forty. Multiple menu choice screens can be employed if the operator's needs expand beyond this. If there is an error message appearing in the top portion of the screen, pressing the choose button will automatically call the relevant screen, along with a recommended course of action.

VII. CONTROL STICK

In order to determine what type of control stick(s) to use as a remote input device for SKITTER, it is important to first define the types of distinct SKITTER motions which need to be controlled. These motions are defined as follows:

- (1) translational motion--walking in any one of six directions (either one or two legs forward)
- (2) rotation--turning SKITTER
- (3) squatting--controls the height of SKITTER's body
- (4) tilt--designates a tilt angle for SKITTER's body

The first two types of motion (translation and rotation) need to be controllable simultaneously to allow easy SKITTER maneuvering. Thus these two motions are grouped together into the joystick mode called "walk". The other two modes are "squat" and "tilt". These three modes are mutually exclusive. As is done in the Harrier aircraft, these motions can easily be controlled by one multifunction control stick system.

There are two types of control stick systems that could be utilized in the SKITTER control panel: a two-lever system (as in a bulldozer); or one multi-axis joystick. Essex Corporation's studies have shown that the multi-axis joystick has a slightly higher operating efficiency, especially in situations with high work loads (18). In addition, the single joystick movements are more consistent with the related movements of SKITTER, which is a criteria specified in MIL-STD--1472c (21). This leads to the choice of a single multi-axis joystick for the SKITTER control system.

A. Joystick Requirements

The joystick must have movement in three axes in order to control the translation (x,y) and rotation (z) of SKITTER. In addition, it should have three function select buttons to allow the operator to direct the walk, squat, and tilt modes. The walk button (most commonly used) should be identifiable tactually to allow for blind operation. The military standard MIL-STD--1472c specifies that for precision type applications a displacement-type joystick should be used with light springs for a return-to-center (resistance no higher than 2 lb.). The grip should be a hand fitted grip with a diameter of approximately 2" and a shaft length of between 4.3" and 7.1".

B. Existing Joystick Recommendation

Through research in the Georgia Tech Library, we have found a vendor--Measurement Systems, Inc.(MSI)--which manufactures a joystick that will meet the above requirements. Essex used two models of MSI joysticks for their teleoperator research, and found them to perform satisfactorily (18).

MSI manufactures a 3-axis displacement-type joystick with three push-button switches for thumb operation and a trigger (Model #544, See Appendix B). The trigger should be removed from the control grip for our application. In addition, the pushbuttons must be labeled (walk, squat, tilt) from left to right, with a raised dimple on the "walk" button for tactile location (see figure 15).

PROPOSED JOYSTICK

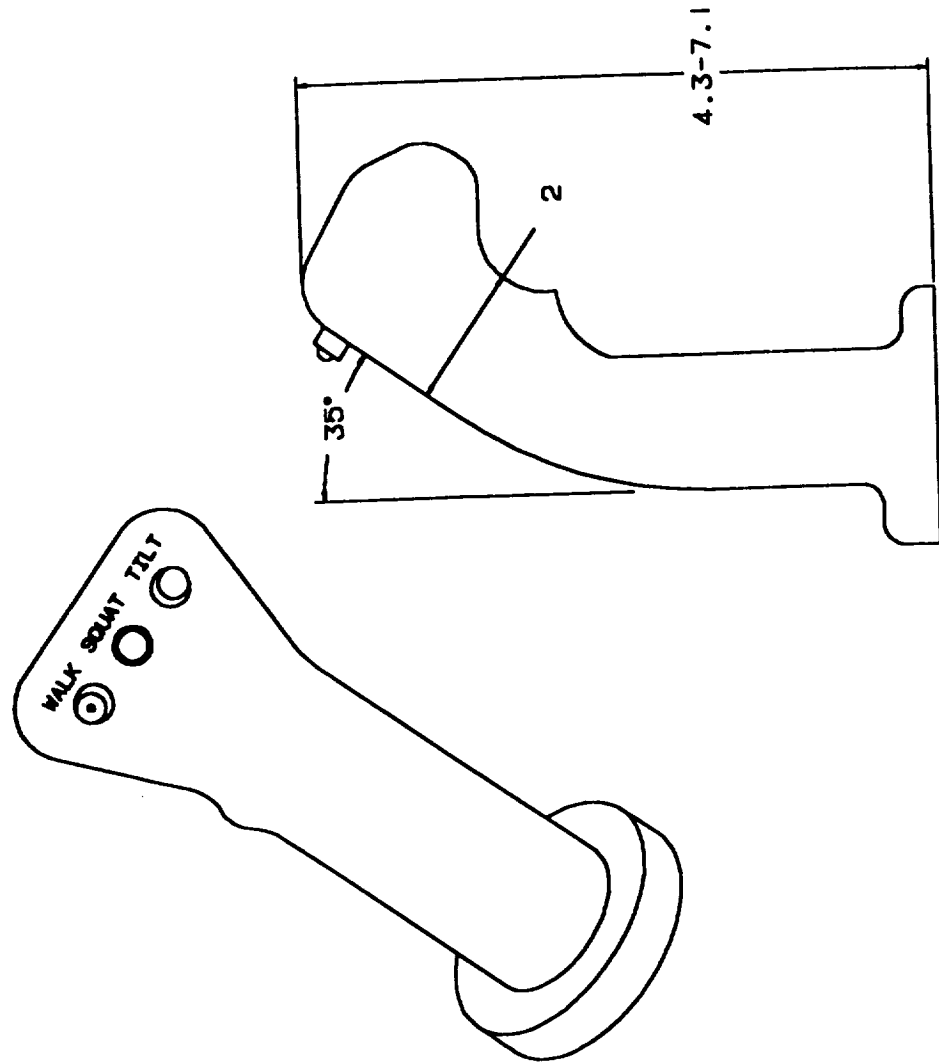


Figure 15.

C. Joystick operation

The joystick has three modes of operation; walk, squat, and tilt. These modes are selected by pressing the thumb operated button on the joystick that corresponds a particular mode. A mode is deactivated by pressing the activated mode's button a second time or by pressing one of the other mode buttons. The following list describes how the joystick operates in each of these modes.

1. Walk

In this mode the joystick controls the translational and rotational movements of SKITTER. When the joystick is pushed away from the operator, SKITTER will walk in a forward direction as defined by the activated camera. By moving the joystick towards the operator, SKITTER will move in the opposite direction of the currently activated camera. This defines two of SKITTER's walking modes: forward and backward. In addition, by moving the joystick at an angle of 60 degrees from either the forward or backward position, one of the other four walking orientations can be obtained (see figure 16a).

To rotate SKITTER, the joystick is rotated about the vertical axis. If the joystick is rotated clockwise, SKITTER will rotated clockwise at a rate proportional to the "twist" of the joystick.

For both rotational and translational joystick control, a particular joystick position corresponds to velocity control of SKITTER.

2. Squat

When the joystick is in the squat mode, the height of SKITTER's body, relative to the ground, is controlled by the joystick. If the operator pushes the joystick away, SKITTER will lower or squat. When the operator pulls the joystick, SKITTER will increase its body height or stand up (see figure 16b). In this mode, the joystick corresponds to a velocity control of SKITTER.

3. Tilt

The tilt mode controls the angle of SKITTER's body relative to the horizontal and the currently activated camera. SKITTER will tilt in the same direction that the joystick is angled, with the currently active camera referenced as the "forward" or "away from operator" joystick direction. The operator can tilt SKITTER at any angle relative to the horizontal by tilting the joystick in the desired direction (see figure 16c). Tilt mode is also a velocity control.

JOYSTICK OPERATION

WALK:
(TRANSLATION AND
ROTATION)

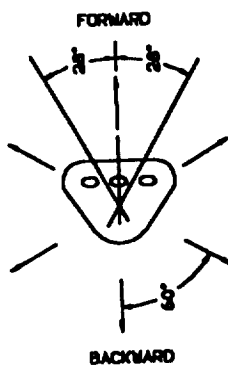


Figure 16a.

SQUAT:

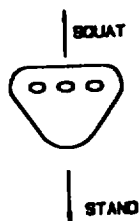


Figure 16b.

TILT:

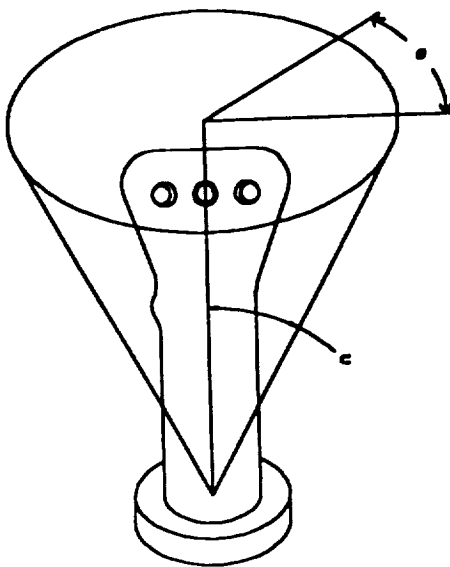
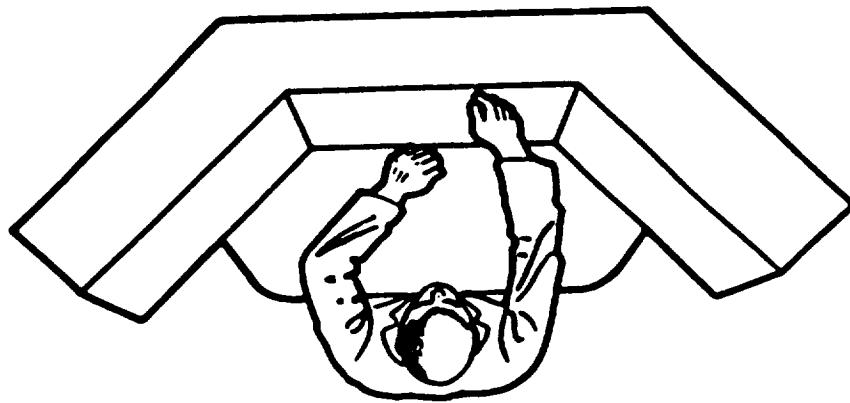


Figure 16c.

VIII. CONTROL PANEL CONSOLE

A flat-surface, segmented, wrap-around console should be provided, in order to place all controls within the reach of the 5th percentile operator (see figure 17). This means that the most distant controls will be no farther than 67.7 inches. We have assumed that the controls will be mounted in an existing console or in a custom made console which will incorporate our suggested controls and controls for other SKITTER attachments. Military standards limit the width of the central segment, containing SKITTER and camera controls, to a value not exceeding 44 inches.



EXAMPLE OF HORIZONTAL WRAP-AROUND CONSOLE

Figure 17.

RELATED TOPICS

The following section describes topics which are related to our control panel design that we were not able to design thoroughly ourselves due to the broad scope of our project. The topics to be treated in this section are error analysis, feedback sensors on SKITTER, a movement memory, the internal workings of the control panel, cameras and lighting, suggestions on how to make our unit portable, and radio communications with SKITTER.

I. ERROR ANALYSIS

There is always possibility for error in a variety of operations. One obvious source of error is between the display on the predictor screen, and the actual motion of SKITTER. For instance, using dynamic and geometric modeling, it may be calculated that SKITTER has moved a certain distance. However, SKITTER could skid or slip and thus not travel the distance calculated. This is one reason we need feedback concerning the actual location of SKITTER. Using such feedback would allow corrections to be made to the predictor display. With the time lag, this means that the predictor would never accumulate more than six seconds worth of error. Such location feedback could be accomplished a number of ways, such as navigation from moon satellites, fixed surface beacons, or gyroscopes on SKITTER.

Another type of error is when commands are given that could cause SKITTER to exceed its design limitations. An example of this is if a leg became stuck and the operator was trying to free it using the manual actuator controls, he could cause the leg

fail. One way to prevent this is to place strain gauges at various places on SKITTER. These strain gauges would be continuously monitored by the computer and cause an error message to be generated on the predictor screen if the leg stress exceeded a certain limit. Also, SKITTER's on-board computer could have a routine which would stop SKITTER's motion if the stress passed the limit.

At the present time, it is easy to visualize errors that could occur and which apparently cannot be negated by design. For instance, how can designers prevent an operator from running SKITTER into a trench or off a cliff? There are many ways in which an operator can ruin the best designed equipment. This area certainly needs attention before SKITTER can be used. A project whose objective is to "people proof" SKITTER could easily occupy a full design group for some time.

II. FEEDBACK SENSORS ON SKITTER

Our design requires certain types of feedback from SKITTER.

They are:

- 1) SKITTER's Location
- 2) Individual Actuator Forces
- 3) Temperature (High and Low)
- 4) Power Plant Status
- 5) Radiation Dosage
- 6) Actuator Parameter (e.g. main hydraulic fluid reservoir pressure)
- 7) Frame Stress (at various places on SKITTER)
- 8) Actuator Position
- 9) Camera status (aperture, zoom position)
- 10) Tilt Position

The problem to be solved is the selection of sensors which will accomplish these tasks while staying within the following constraints:

- 1) low weight
- 2) low power usage
- 3) high reliability
- 4) high accuracy
- 5) resistance to extreme environmental conditions.

Location would be determined by navigation instruments, which might include: accelerometers, for linear acceleration, velocity, and position; and gyroscopes, for rate of turn and an inertial reference frame (13)(14). New laser/fiberoptic gyroscopes could be used instead of spun mass gyros leading to a reduction in mass, increased accuracy because of elimination of friction drift, and increased reliability from a reduction of moving parts. Tilt position could be measured by a reference gyro or from a bubble level.

Actuator force feedback sensors will depend on the type of actuators used. If hydraulic actuators are used, pressure sensors could be used. If linear stepper motors are used, then current and voltage sensors could be used. If other type actuators are used, appropriate force feedback sensors would be required.

III. MOVEMENT MEMORY

One feature that would be nice to add to the panel, although not an absolute necessity, is a movement memory. A movement memory would allow the operator to perform a particular set of commands, storing them as they are performed. Then by pressing a

button, he could cause the entire set of commands to be performed again with no further intervention. This would be extremely useful if SKITTER was performing a repetitive task.

The implementation of a system like this would require copious amounts of memory, since virtually all program parameters generated during the operator controlled movement would have to be stored. Also, some type of large capacity permanent storage device would have to be added to the control panel. (e.g. hard disk drive)

IV. THE INTERNAL WORKINGS OF THE CONTROL PANEL

One other project that must be done is the design of the internal components of the control panel. The way the panel works is as follows. When a control is moved, a potentiometer connected to the control will give off a certain voltage. That voltage is sent to an analog/digital converter, where it is converted to a binary number. The binary number then goes to a computer program, which interprets it. On the basis of this interpretation, the program will generate commands for SKITTER and send these commands to a radio for transmission to SKITTER.

To make this possible, a proper A/D converter must be chosen, as well as the main control panel processor. Also, the decision must be made as to how the computer equipment should be divided between the control panel and SKITTER. One criterion for this decision should be the minimization of radio transmission of data. As with other systems, our criteria are weight, power use, reliability, and resistance to the harsh lunar environment.

V. CAMERAS

SKITTER will need cameras in order to provide visual feedback to the operator, and they should be located on SKITTER so that they do not need to be moved independently (as would free standing cameras). The camera should allow the operator to look in any direction. The center of SKITTER's body seems like a good place; however, since the crane will be attached to the top of SKITTER the camera cannot be located there. If the camera is mounted off center, crane will block its view. The camera cannot be mounted on the bottom of SKITTER's body either because the digging attachments would block its view. A track mount on the top of the body was considered because it would enable the camera to point in any direction without its view being blocked. However, lunar dust would collect on the track and get into the bearings with no good way of sealing the dust out. Care would have to be taken when routing the camera cables to prevent tangles and breaks when the camera moves all the way around. These problems suggested another course of action; therefore, we chose to use three cameras. The three camera system will require less movement and fewer joints requiring seals. This should translate into higher camera reliability through simpler movement and higher system reliability through multiple redundancy.

A. Camera Type, Locations, and Orientation

There will be three cameras located on SKITTER's body, mounted at a sixty degree angle to the legs (see fig. 5). Normal orientation for the cameras will be straight out, i.e. perpendicular to SKITTER's vertical axis with the camera's field

Of View (FOV) centerline coincident with a line intersecting SKITTER's vertical axis and the camera. In most past space missions vidicon cameras have been used, however newer CTDs (Charged Transducer Device, either CID or CCD) are preferred, because they are solid state which makes them generally smaller, lighter, and more shock resistant. Solid state cameras also have variable pixel charge time which would allow them to be used under a wider range of lighting conditions than vidicon or fixed exposure time CTD. With variable charge time, it may be possible to eliminate the aperture shutters completely, providing a mechanically simpler system. Whether vidicon or CTD, the cameras should be equipped with zoom lenses.

B. Camera Movement

The cameras will be able to rotate around their vertical axis (which is parallel to SKITTER's vertical axis) at least 60 degrees in each direction. This will allow the cameras to look forward when SKITTER is walking in the one-leg-forward mode. The cameras will also be able to rotate vertically around their horizontal axis (the line that is tangent to the circle which is centered on and perpendicular to SKITTER's vertical axis) so that SKITTER can look at the ground (for digging implements), look at the sky (for the crane), or look at itself (for status/diagnostics). Vertical rotation should be close to 360 degrees.

C. Camera Mounting Bracket

The mounting bracket for the camera needs two degrees of freedom for the two rotation axes defined. There are several mounting techniques which will satisfy this constraint, and the factors considered in the decision of which to use should include: transport mechanism, control, and feedback; center of mass location (which should be near center of rotation for minimum stresses); camera power supply (routing and flexibility); camera signal return (routing and flexibility); weight; reliability; bearing sealing; and lubrication. A yoke may be the best choice since it can put the center of mass at the center of rotation, movement can be by simple motors, and the cables can be routed inside of hollow forks.

D. Camera Display Stabilization

Since the camera will vibrate when SKITTER walks or moves, the display will shake unacceptably. One method to counteract this shake is to continually move the camera, but this approach requires a complex control system and possibly a large amount of energy. Another method, the one used by the military in tanks, is to process the picture before displaying it to the operator. This method, signal processing, defines a frame inside of the camera picture. The processors filter out the high frequency movements (vibrations) to hold the frame steady, and only the frame is shown on the screen. A disadvantage is that the edges of the picture are thrown away, wasting signal bandwidth.

VI. LIGHTS

The lunar environment does not include the atmosphere which scatters light so evenly on Earth. Consequently, on the moon there are bright (full sunlight) landscapes and deep shadows. Since SKITTER will want to operate in those shadows, it will need to provide its own light. However, since it is not SKITTER that needs the light, but SKITTER's operator, and the operator sees through the cameras, the lights should be mounted on the same brackets as the cameras. The operator should be able to switch the lights off to conserve energy. The could possibly be variable, which would allow shadows to be brightly lit since it is surrounded by blindingly bright sunlight, but would allow the lunar night to be lit less to conserve energy. Another method which could possibly illuminate a shadow during the day is to use mirrors to reflect sunlight into the shadow. This method would conserve energy used by lights, but added system complexity may not be worth the cost.

VII. LUNAR BASE UNIT

The control panel layout can be used as specified, however the console must be designed to withstand the high accelerations and vibrations associated with transporting the panel to the moon. It is also very important to minimize weight in the lunar console because of the transportation costs.

VIII. PORTABLE UNIT

We briefly researched building a portable unit that could be used on-site by an astronaut in a space suit. Our design can be adapted to that environment; however, changes are required.

These changes are necessitated by limitations imposed by the space suit, the hostile environment, and the portability constraint.

A. Space Suit Considerations

The space suit is bulky and unwieldy because it must provide protection from the heat, cold, and radiation. It also has extra weight and size from the life support systems that must be carried. The suit constricts motion which makes most actions difficult and tiring while others are impossible. A tummy pack control panel is not a good idea for a number of reasons. One of these reasons is that there is no feasible place on the current suit design to attach. Also, the current outer suit is held together with velcro, and attaching something to the suit might risk compromising the integrity of the seams. Further, even if a suitable location on the suit could be found, a redesign of the suit would require a redesign of the pack. Also, a tummy pack would change the center of balance for the astronaut. For these reasons we recommend a free standing unit.

Arm motions are almost limited to the area directly in front of the astronaut, and the most comfortable position for a suited astronaut's arms are slightly bent (approximately 45 degrees at the elbows) with the hands about six inches in front of and three inches below the waist. With the shift in posture of a low-g environment, this puts the comfortable hand height well below the optimum height for an Earth based standing console. It also suggests that the surface of the console that the controls are

mounted on should lean away from the astronaut at near the angle of the forearms. The display screens will need to be at a different angle (less vertical) because the screens will be lower and the helmet limits the astronaut's view down. The screens could also possibly be placed higher by moving them farther away from the controls, but the recommendations of Human factors experts is to put the controls and displays as close together as possible.

Leg motions are also restricted, and bending over is very difficult. Kneeling is uncomfortable, so activities should be designed to be done from a standing position. A suggestion in this area is to tether the top of the console to the wrist of the astronaut so that if the console falls over it can be righted without bending. Another suggestion is to make the console legs adjustable and anchorable (to keep the console from being pushed over during operation) from a standing position so that the astronaut does not have to stoop to set it up.

Hand motions are also impaired. According to Dr. Olson (17) of the Georgia Institute of Technology, the gloves give approximately normal motions minus 10 degrees in each direction. It is difficult to move one finger at a time in the glove. Therefore, the grip size of the joystick should be increased and made more ellipsoid in cross section. The shape should be that of the inside of a relaxed hand with the fingers slightly bent. Buttons on the top of the joystick can be used because they are actuated by the thumb. The gloves give very little tactile feedback, so the buttons should be protected from accidental

engagement since the operator may not be aware that one was pressed by accident. The diameters of the knobs and thumbwheels should be increased to accommodate the gloves. The buttons for camera controls should be replaced with touch bars so that more than one finger can be used to engage them.

B. Environmental Considerations

The environmental conditions of the lunar surface also require that modifications be made to our design. The most hostile of these conditions to our design are radiation and temperature. Light and vacuum also must be taken into consideration. The heat, light, and most of the radiation come from the sun.

Radiation attacks the circuits inside the console and the materials which make up the console. Most particulate solar radiation (protons and electrons) is released during solar flares, which currently can be predicted about 45 minutes in advance. Space suits currently do not provide the astronaut with enough protection from this type of radiation, so when a flare is predicted all EVAs (extra vehicular activities) are canceled. Shielding the console with 1/8" of aluminum would enable it to survive flares. Also, rad-hard electrical components should be used for the circuitry. Radiation sensitive polymers and elastomers should not be used on the outside of the console where they will be exposed.

The temperature of the lunar environment varies from about 75 K to 475 K, with the temperature of a white body in full

sunlight stabilizing at approximately 375 K. Temperature gradients this large over a small structure can cause warpage, and this must be accounted for in the design. Also, all materials should be able to function under both temperature extremes. The heat absorbed needs to be disposed of, and the method of choice has been to radiate it into space. Since the console will be portable, with different sides facing the sun at different times, the radiator could be located on the bottom of the console, which will always be in the shade, unless the unit is sitting on highly reflective soil. A method must be chosen to convey the heat from the exposed side and towards the radiator. Current methods involve pumped liquids or heat pipes which rely on the phase change of a metal such as sodium. Either of these methods could be used, although they both add weight. Pumped liquid adds complexity and power requirements. Instead, perhaps the material used for shielding could be designed to conduct the heat effectively.

Light is more of a nuisance to the astronaut than a hazard, however bright sunlight across parts of the face of the console could cause the rest of it to be unable to be seen. Without atmosphere to diffuse the light, the console would be in full sunlight, in a reflection off the space suit, or in deep shadow. Full sunlight would completely wash out the display, and partial sunlight would not allow the astronaut's eyes to dark adapt to allow him to see in the shadows, so direct sunlight should be avoided. To avoid direct sun, an adjustable hood or a small tent that extends from the console could be attached to block the sun.

This shroud should could be made of bleached Gortex or bleached Orthofabric (Teflon outer/Nomex inner), which are both lightweight and currently used in the space program. The shroud must be adjustable so that it will block the sun without blocking the astronaut's view or causing a glare in the astronaut's face. A light source could be placed under the shroud to give even lighting, and the intensity should be adjustable so that the operator can get similar intensities on the worksite and the console. This will help eliminate fatiguing dark/light accommodation each time the astronaut changes views. Also, the display should have a glare filter or coating on it, otherwise, the astronaut will only be able to see a reflection of the suit.

The vacuum must be accounted for when choosing the display itself. Whether using a CRT, electroluminescent display, LCD, LED, or gas plasma, the display must be able to withstand operating in a vacuum and at high temperature gradients. The whole unit must be able to withstand an immediate transition from full vacuum to cabin pressure.

In order to reduce size and weight, the individual actuator controls could be left out of the design. If control of an individual actuator is needed in an operation, the astronaut could radio for it to be done from the lunar base. Also, a

dipole antenna could possibly be built into the tripod legs or a parabolic antenna could be built into the back face. If a parabolic antenna is used, it should have a fairly wide beam path so that aiming would not be critical. With the dipole antenna, aiming is not a concern because dipoles are omnidirectional.

The portable unit's power supply could be a bank of rechargeable batteries since astronauts will not be in the field for extensive periods of time. The batteries could be recharged at the lunar base from the base's power supply.

IX. SIGNAL TRANSMITTER/RECEIVER ON SKITTER

The SKITTER's communication system, which communicates the robot's status and gets instructions, must be designed. The radio's power could be provided by SKITTER's primary power supply, with batteries as a secondary system. In choosing batteries, depth of discharge, life span, capacity, and energy density all need to be considered. The battery charging circuit could contain solar cells or the SKITTER's primary supply, however it seems reasonable to keep the backup system separate from the primary system to increase reliability. Solar power probably would not work as primary SKITTER power because there is not enough surface area on the machine for the required number of cells, and even if there were enough room, solar power would limit SKITTER to working on the day side of the moon.

The radio signal is an important factor to be considered. Bandwidth needs to be minimized due to the limited availability of frequencies. Broadcasting the signals directly from the three

cameras, at a fairly low resolution (such as employed by American TV) would require about 12MHz. By interlacing the camera signals with each other, this bandwidth could probably be reduced, but when all of the other required signals (instrument feedback, command acknowledgment, status, etc.) are added in, the required bandwidth is fairly large. There is a choice of modulation techniques, with the two leading contenders being FM (frequency modulation) and PCM (pulse code modulation). FM is currently used in most satellite communications, but it is more susceptible to noise, and when the signal is amplified, noise is too. PCM is a digital method, and as such allows error checking for noise. For the error checking and possible security codes available in a digital system, PCM should probably be used for commands, instrument readouts, and status reports. Either FM or PCM could be used in broadcasting the camera pictures. Also, if bandwidth must be reduced further, the two rear cameras could broadcast in lower resolution pictures or not be broadcast at all. Since the rear cameras are not a primary source of information, not much utility would be lost.

The toggle from "standby" to "on" modes on SKITTER would be the responsibility of the radio. SKITTER could go into a standby mode, shutting down to conserve power, with only the receiver of the operating, listening for the "wake-up" signal. When that signal is received, the radio would turn on the rest of SKITTER.

Since the moon has no ionosphere to reflect radio waves, communications must be virtually line of sight, and the radio horizon is very close, about two miles (10). Any communications

from a lunar base farther away than this distance would need a repeater of some type. Any signal to or from the Earth while SKITTER was on the other side would be lost. For these reasons, a lunar satellite for communicating with SKITTER seems necessary.

SKITTER's antenna must be in a position that will not interfere with its motions. It also must not interfere with anything that may be attached to SKITTER, such as the crane, the digger, or the drill. It also would be better if it were not an appendage. SKITTER is a construction vehicle, and objects flying from the digger or swinging from the crane might knock the an external antenna off. Parts of the legs could be used as guides for a dipole antenna, an omnidirectional primary or backup antenna. A high gain directional antenna could be mounted inside the body if there is an acceptably shaped space for it. A directional antenna would also need to move to aim at the receiver.

X. COMMAND CHANNEL ARBITRATION SCHEME

The command channel which SKITTER follows must be carefully planned and implemented. With multiple controllers in various space centers on Earth, a controller in the lunar base, and portable units on the lunar surface, multiple command signals could be broadcast. An arbitration scheme must be developed to determine which controller is master so SKITTER does not become confused. Also to be addressed is the case of multiple SKITTERs. All SKITTERs should follow different masters so that a command sent to one robot is not also carried out by another. A third

area to be addressed is security. A method needs to be developed that will allow only authorized stations to control SKITTER. With the current state of technology, people have broken into computer systems and changed files, people have broadcast over the HBO satellite channel interrupting service to HBO's customers, and people have run unauthorized radio stations. We need to insure that SKITTER is not stolen. The military has probably encountered similar problems with their drone aircraft and remote controlled missiles. It is possible that they have classified solutions which could be adapted for use with SKITTER.

SUMMARY

The control panel, or man/machine interface, which we have designed is for the purpose of controlling the lunar multi-purpose walking machine known as SKITTER. Because SKITTER is called upon to carry a variety of tools, its range of motion must be flexible. Besides walking, SKITTER must rotate, squat (change the height of its base with respect to the moon's surface) and tilt (change the angular orientation of its base with respect to the moon's surface). The control panel must not only allow performance of these motions, but also generate feedback so the operator can stay informed about how accurately his intentions are being translated into SKITTER motions.

The result of our project is a control panel with two display screens, one for direct video camera display, and one for display of other feedback information which is selectable by touch screen menus. The control for moving SKITTER is multi-axis joystick, which can regulate the complex motions of walking, rotating, squatting, and tilting of SKITTER through the use of a computer program. Tentative locations for the video cameras mounted on SKITTER have been decided upon, as have control schemes for their use. Also, manual actuator controls which do not require extensive computer support have been provided in order to increase redundancy and flexibility.

Since we were not funded to construct and test our panel, we made extensive use of previous studies in human factors design of controls and displays. Also, the computer program in Appendix A

has not been tested, and as such merely serves a suggested algorithm, rather than a finished, fully debugged control program.

Since our project is a first generation effort, it had a potentially broad scope. We imposed limits on the scope in order to make the project possible in our allotted two and a half months. However, we have defined future peripheral work which needs to be performed for the control panel to become fully operational, and made suggestions concerning the directions such future projects could take.

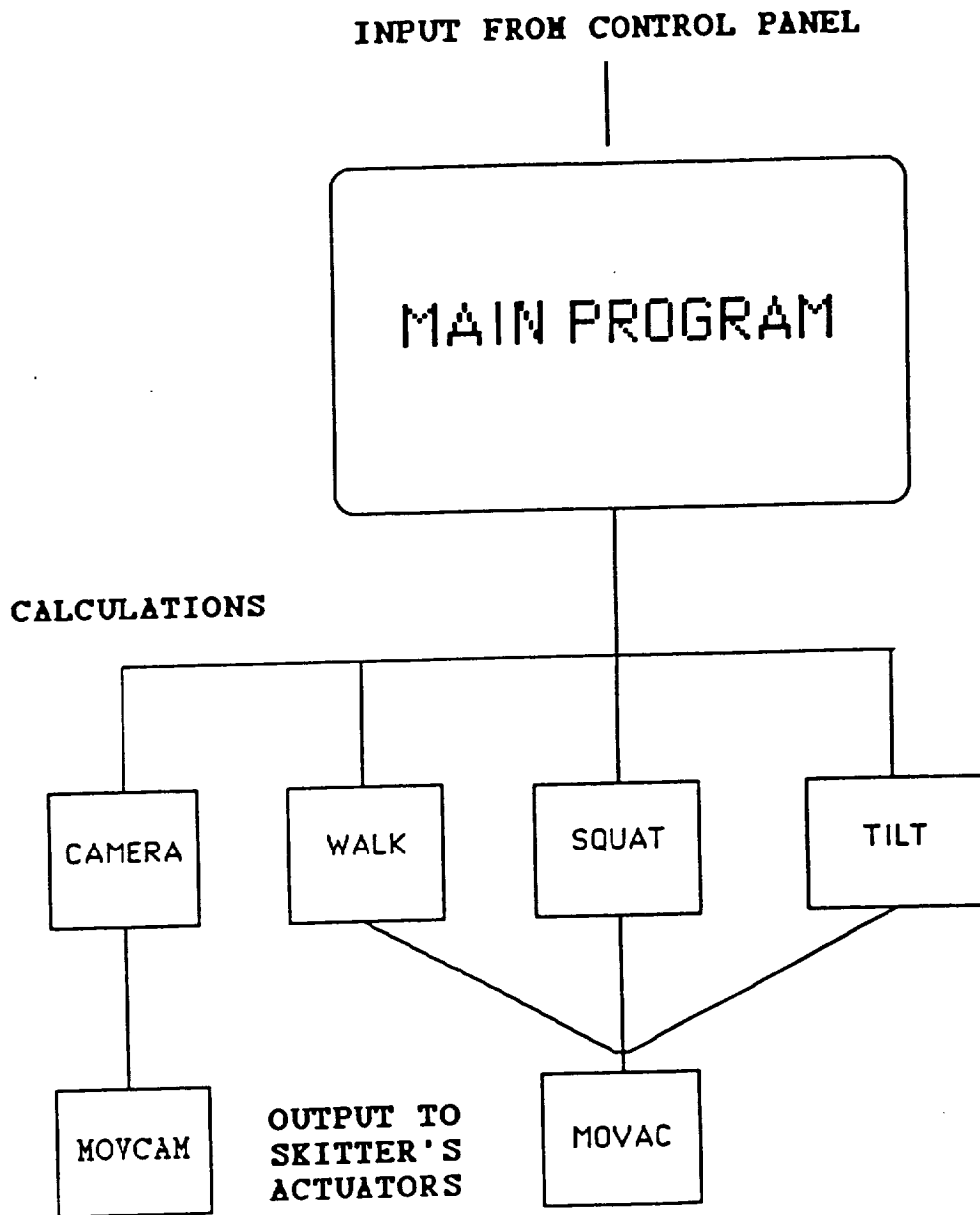
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APPENDIX A

CONTROL PROGRAM



The following program is an outline of a FORTRAN program that could be used to control SKITTER using the control panel being designed by our group. A star at the beginning of a line indicates a comment line. A 'P' at the beginning of a line indicates that the line is psuedo-code, rather than an actual FORTRAN statement. A blank at the beginning of the line indicates operational FORTRAN code.

PROGRAM SKITTER

*
* August 21, 1987
* for ME 4182 - Senior Design Project
*

* Main program including joystick interpreter
*

* Variable list: MODE - indicates what mode the joystick is in, where:
* MODE = 0 for deactivated
* MODE = 1 for walking
* MODE = 2 for squatting
* MODE = 3 for tilting
*

* STIKMAG - contains how far the joystick is from center
* position. The values which this variable can
* have will be determined by the number of
* discrete voltage levels which can be output
* from the joystick.
*

* STIKANG - contains the angular direction at which the
* stick has been moved from center position. This
* variable can have the values of:
* 0 = forward
* 60 = 60 degrees clockwise from zero
* 120 = 120 " " " "
* 180 = 180 " " " "
* 240 = 240 " " " "
* 300 = 300 " " " "
*

* Note: these are the only six directions in
* which our joystick can move.
*

* STIKTWS - contains the angle at which the joystick
* handgrip has been twisted through. This
* control is for making SKITTER rotate. This
* variable's values will be determined by the
* number of discrete voltage levels available
* from the joystick handgrip potentiometer.
*

* FRONT - which of the six positions of SKITTER that is
* currently defined as the forward direction
* of SKITTER for the purpose of walking. FRONT
* can have a value of 1 to 6. Postions 1,3, and 5
* are the three legs. Positions 2,4, and 6 are the
* three positions halfway between the legs.
*

* Declare Variables
*

INTEGER MODE, STIKMAG, STIKANG, STIKTWS, FRONT

P 10 CHECK STATUS OF MODE BUTTONS
P IF (WALK BUTTON IS DEPRESSED) MODE = 1
P IF (SQUAT BUTTON IS DEPRESSED) MODE = 2
P IF (TILT BUTTON IS DEPRESSED) MODE = 3
P IF (NO BUTTON IS DEPRESSED) MODE = 0

* Get the coded values of the joystick position, convert to integers,
* and assign the values to the proper integer variables.

P GET VALUE OF JOYSTICK POSITION
P ASSIGN VALUE TO STIKMAG
P GET VALUE OF JOYSTICK ANGLE
P ASSIGN VALUE TO STIKANG

IF (MODE .EQ. 0) THEN
CALL CAMERA (FRONT)
GOTO 10
ENDIF

IF (MODE .EQ. 1) THEN
CALL WALK (STIKMAG, STIKANG, FRONT)
IF (STIKMAG .EQ. 0) THEN
CALL ROTATE (STIKTWS)
ENDIF
ENDIF

IF (MODE .EQ. 2) THEN
CALL SQUAT (STIKMAG, STIKANG)
ENDIF

IF (MODE .EQ. 3) THEN
CALL TILT (STIKMAG, STIKANG, FRONT)
ENDIF
GOTO 10
END

SUBROUTINE CAMERA (FRONT)

* This subroutine retrieves signals from the camera controls on
* the main control panel, decides what those signals mean, and
* then moves the cameras accordingly. Also, this routine defines
* which of the six possible forward positions is currently defined
* as forward.

* All of the camera controls: the rotation dial, the zoom slide,
* the tilt thumbwheel, and the six buttons, are all position
* controls. The reason for this is to decrease the effects of
* the time lag upon the operator.

* Variable list: ROTCON - current value of the rotary camera control
* which adjusts camera rotary direction.
* This variable can have values which range
* from -90 (degrees ccw of perpendicular as
* seen from a top view) to 0 (perpendicular
* to SKITTER's body) to +90 (same as -90
* except camera lens is facing opposite
* direction.

* TLTCN - current value of the thumbwheel control which
* adjusts camera tilt. This variable has values
* from 0 to 360 degrees in which 0 is parallel
* to SKITTER's body (not necessarily parallel to
* the moon's surface.) If the camera is facing
* directly upwards, TLTCN has a value of +90,
* and so on.

*
*
*
*
*
*
*
*
*
*
*
*
*
*
*
*

ZOMCON - current value of the slide control that adjusts the camera's zoom lens. This variable will have values ranging from 0 to 20, where 0 indicates widest angle view (least zoom power) , and 20 is maximum zoom (minumum field of vision).

CAMPOS - current rotary direction (in degrees) that the active camera is pointing. This variable's value range is the same as ROTCON.

FRONT - same as FRONT which is defined in main program.

BUTTONn - logical variables that tell whether each button has been activated.

ONMCAM - tells which camera is currently active (1, 2, or 3).

*
*
*
*
*
*
*
*

check the six camera position buttons. Depending on which one has been most recently depressed, turn on the appropriate camera. The buttons are numbered 1 through 6, where button #1 is the physically "topmost" of the six. Button #2 is 60 degrees clockwise of button #1, and so on.

The cameras are numbered 1 through 3. Camera #1 is clockwise from leg #1 and so on.

P
P
P

CHECK SIX CAMERA BUTTONS
WHICHEVER OF THE SIX WAS DEPRESSED SET BUTTONn = .YES.
SET ALL OTHER BUTTONn = .NO.

```

IF (ONCAM = 1) THEN
  IF (CAMPOS = 0) THEN
    IF (BUTTON1) THEN
      FRONT = 2
      GOTO 17
    ENDIF
    IF (BUTTON2) THEN
      ONCAM = 1
      CAMPOS = 60
      FRONT = 3
      GOTO 17
    ENDIF
    IF (BUTTON3) THEN
      ONCAM = 2
      CAMPOS = 0
      FRONT = 4
      GOTO 17
    ENDIF
    IF (BUTTON4) THEN
      ONCAM = 3
      CAMPOS = -60
      FRONT = 5
      GOTO 17
    ENDIF
    IF (BUTTON5) THEN
      ONCAM = 3
      CAMPOS = 0
      FRONT = 6
      GOTO 17

```

S

```

ENDIF
IF (BUTTON6) THEN
  ONCAM = 1
  CAMPOS = -60
  FRONT = 1
  GOTO 17
ENDIF
ENDIF
ENDIF
IF (CAMPOS = 60) THEN
  IF (BUTTON1) THEN
    ONCAM = 2
    CAMPOS = -60
    FRONT = 3
    GOTO 17
  ENDIF
  IF (BUTTON2) THEN
    ONCAM = 2
    CAMPOS = 0
    FRONT = 4
    GOTO 17
  ENDIF
  IF (BUTTON3) THEN
    ONCAM = 3
    CAMPOS = -60
    FRONT = 5
    GOTO 17
  ENDIF
  IF (BUTTON4) THEN
    ONCAM = 3
    CAMPOS = 0
    FRONT = 6
    GOTO 17
  ENDIF
  IF (BUTTON5) THEN
    ONCAM = 1
    CAMPOS = -60
    FRONT = 1
    GOTO 17
  ENDIF
  IF (BUTTON6) THEN
    ONCAM = 1
    CAMPOS = 0
    FRONT = 2
    GOTO 17
  ENDIF
ENDIF
ENDIF
IF (CAMPOS = -60) THEN
  IF (BUTTON1) THEN
    ONCAM = 3
    CAMPOS = 60
    FRONT = 1
    GOTO 17
  ENDIF
  IF (BUTTON2) THEN
    ONCAM = 1
    CAMPOS = 0
    FRONT = 2
    GOTO 17
  ENDIF
  IF (BUTTON3) THEN
    ONCAM = 2
    CAMPOS = -60
    FRONT = 3
    GOTO 17
  ENDIF
  IF (BUTTON4) THEN

```

```

        ONCAM = 2
        CAMPOS = 0
        FRONT = 4
        GOTO 17
    ENDIF
    IF (BUTTON5) THEN
        ONCAM = 3
        CAMPOS = -60
        FRONT = 5
        GOTO 17
    ENDIF
    IF (BUTTON6) THEN
        ONCAM = 3
        CAMPOS = 0
        FRONT = 6
        GOTO 17
    ENDIF
ENDIF
ENDIF
ENDIF

```

```

IF (ONCAM = 2) THEN
.
.
.
ENDIF
IF (ONCAM = 3) THEN
.
.
.
ENDIF

```

```

17  BUTTON1 = .NO.
    BUTTON2 = .NO.
    BUTTON3 = .NO.
    BUTTON4 = .NO.
    BUTTON5 = .NO.
    BUTTON6 = .NO.

```

```

CALL MOVCAM (CAMPOS,..)

```

* Rather than rehashing the code, a statement of the rule is better.
 * The direction of the active camera is always the front of SKITTER.
 * This direction always corresponds to button #1. Thus if the operator
 * wants to move the front of SKITTER 60 degrees to his right, he hits
 * the button that is 60 degrees to the right of button #1 (button #2).
 * If this new front position is along a leg, the camera to the right of
 * the leg moves until it is parallel to that leg, thus giving the
 * operator vision in the direction he is walking.

* There is one special case. If one of the legs is defined as front, the
 * camera to the right of the leg (which incidentally has the same number
 * as the leg itself) is active. By pushing button #1, the active camera
 * becomes the camera to the left of the leg. This camera is
 * automatically pointed in the proper direction, which is parallel to
 * the leg defined as front.

* check status of camera controls and send desired values of
 * camera parameters to the machine language subroutine MOVCAM.

```

P 20  GET VALUE OF ROTARY CONTROL
P      ASSIGN VALUE TO VARIABLE ROTCON
P      GET VALUE OF THUMBWHEEL CONTROL
P      ASSIGN VALUE TO VARIABLE TLTCON

```

```

P   GET VALUE OF ZOOM CONTROL
P   ASSIGN VALUE TO VARIABLE ZOMCON

CALL MOVCAM(ROTCOM, TLTCOM, ZOMCON)
RETURN
END

```

SUBROUTINE MOVCAM(ROTAT, TILT, ZOOM)

```

*   This subroutine contains the commands that will actuate
*   servo motors to rotate, tilt and zoom the camera. Since
*   all the controls are position controls, this subroutine
*   merely sends the values to a processor which is presumed
*   capable of actuating motors until the desired positions
*   are achieved. In other words, the processor that controls
*   the motors has built in (possibly hard-wired) commands which
*   act as a feedback loop for the camera control motors.

```

```

*   Variable List: ROTATE - indicates the desired position to which the
*                   camera is to be moved. This is actually a
*                   dummy argument, which will receive its value
*                   from either ROTCOM or CAMPOS, the corresponding
*                   variables in SUBROUTINE CAMERA.
*
*                   TILT  - dummy argument which corresponds to the
*                   variable TLTCOM in SUBROUTINE CAMERA.
*
*                   ZOOM  - dummy argument which corresponds to the
*                   variable ZOMCON in SUBROUTINE CAMERA.

```

```

P   SEND VALUE OF ROTAT TO PROCESSOR
P   SEND VALUE OF TILT TO PROCESSOR
P   SEND VALUE OF ZOOM TO PROCESSOR
RETURN
END

```

SUBROUTINE WALK(SIZE, DIRECT, FRONT)

```

*   This subroutine is a collection of the calls to the actuator movement
*   subroutine "SUBROUTINE MOVAC" which are required for SKITTER to
*   take exactly one full step.
*
*   The data in the data files will have to be determined
*   by experiment. During this experimentation, SKITTER must
*   always be walking with leg #1 defined as the front.

```

```

*   The data files are loaded into the 3-dimensional array WAKPOS
*   when the program is initialized. WAKPOS contains, in sequence,
*   all the actuator movements needed to make one step.
*
*
*
*
*
*   Variable List: WAKPOS(actuator #, sequence #, gait) - This
*   array contains all the actuator positions for
*   each of the six actuators which are needed to take
*   one step forward and one step backward. The first
*   subscript tells which actuator the data is for, the
*   second subscript is the sequence in which the data
*   will be transmitted to SKITTER, and the third is the
*   gait SKITTER will use (1-leg-1st or 2-legs-1st).
*   Thus this array has the dimensions (6 x 'n' x 2)
*   where 'n' is the number of calls which must be made
*   to SUBROUTINE MOVAC to complete one SKITTER step.
*
*   SIZE - this variable contains both the direction of
*   SKITTER's step and the size of the step. If
*   SIZE is positive then the joystick has been
*   pushed forward and SKITTER is moving forward.
*   If SIZE is negative, then the joystick has been
*   pulled back toward the operator and SKITTER is
*   taking a backward step. The magnitude of SIZE
*   indicates how far the joystick has been pushed
*   or pulled.
*
*   GAIT - this variable has a value of either 1 or 2.
*   It is used as an array subscript
*   so that the proper data is accessed from the
*   array depending on whether SKITTER is using
*   the one-leg-forward gait or the two-legs-forward
*   gait.
*
*   DIRECT - This variable corresponds to STIKANG of the main
*   program.
*
*
*   POSACn - these variables are the desired position of each
*   actuator which is to be sent to SUBROUTINE MOVAC.
*
*   I      - loop counter variable
*
*
*   declare variables
*   INTEGER SIZE, GAIT, WAKPOS(6,N,2), I
*   IMPLICIT INTEGER(P)
*
*   decide whether skitter wants to walk forward or backward.
*
*   IF ((FRONT .EQ. 1 .OR FRONT .EQ. 3 .OR FRONT .EQ. 5) .AND. (DIRECT .EQ.
* C 0 .OR DIRECT .EQ. 120 .OR DIRECT .EQ. 240)) THEN
*     GAIT = 1
*   ELSE
*     GAIT = 2
*   ENDIF
*
*   Message and send all the data to SUBROUTINE MOVAC for the completion
*   of one step. 'N' is a number that will be determined by experiment.
*
*   DO 50, I = 1, N

```


* correct for the fact that any of SKITTER's three legs could
 * currently be defined as the forward direction. At the same time
 * multiply each position by SIZE so that it will take the properly
 * intended step size.
 * If position #1 or #2 is the forward direction then just send out
 * the numbers as they are.

```

    IF (FRONT .EQ. 1 .OR. FRONT .EQ. 2) THEN
      POSAC1 = WAKPOS(1,N,GAIT) * SIZE
      POSAC2 = WAKPOS(2,N,GAIT) * SIZE
      POSAC3 = WAKPOS(3,N,GAIT) * SIZE
      POSAC4 = WAKPOS(4,N,GAIT) * SIZE
      POSAC5 = WAKPOS(5,N,GAIT) * SIZE
      POSAC6 = WAKPOS(6,N,GAIT) * SIZE
    ENDIF
  
```

* if position #3 or #4 is front then rotate all values one
 * position clockwise

```

    IF (FRONT .EQ. 3 .OR. FRONT .EQ. 4) THEN
      POSAC1 = WAKPOS(5,N,GAIT) * SIZE
      POSAC2 = WAKPOS(6,N,GAIT) * SIZE
      POSAC3 = WAKPOS(1,N,GAIT) * SIZE
      POSAC4 = WAKPOS(2,N,GAIT) * SIZE
      + POSAC5 = WAKPOS(3,N,GAIT) * SIZE
      POSAC6 = WAKPOS(4,N,GAIT) * SIZE
    ENDIF
  
```

* if position #5 or #6 is front then rotate all values one position
 * counter-clockwise.

```

    IF (FRONT .EQ. 5 .OR. FRONT .EQ. 6) THEN
      POSAC1 = WAKPOS(3,N,GAIT) * SIZE
      POSAC2 = WAKPOS(4,N,GAIT) * SIZE
      POSAC3 = WAKPOS(5,N,GAIT) * SIZE
      POSAC4 = WAKPOS(6,N,GAIT) * SIZE
      POSAC5 = WAKPOS(1,N,GAIT) * SIZE
      POSAC6 = WAKPOS(2,N,GAIT) * SIZE
    ENDIF
  
```

* send the actuator positions to SUBROUTINE MOVAC to cause motion

```

    CALL MOVAC(POSAC1, POSAC2, POSAC3, POSAC4, POSAC5, POSAC6)
  
```

50 CONTINUE

```

    RETURN
    END
  
```

SUBROUTINE ROTATE (TWIST)

* This subroutine is very similar to subroutine WALK in the way it works.
 * Very simply, an array hold all the actuator positions necessary to make
 * one rotary step. This array is sent, one row at a time, to SUBROUTINE
 * MOVAC, which causes the actuator motions to be carried out.

* Variable List - ROTPOS(actuator #, sequence #, direction)
 * - This array serves an identical function to

the array WAKPOS in SUBROUTINE WALK.

*
*
*
*
*
*
*
*
*
*

TWIST - corresponds to STIKTWS in the main program. If positive, then SKITTER rotates clockwise. If negative, SKITTER rotates ccw. TWIST also gives the magnitude of the step used.

DIR - If TWIST is positive DIR is 1. If TWIST is negative DIR is 2. DIR acts as a subscript of the array ROTPOS. It serves a similar function as GAIT in SUBROUTINE WALK.

POSAC(6) - same as the POSACn variables in SUBROUTINE WALK

```
IF (TWIST .GT. 1) THEN
  DIR = 1
ELSE
  DIR = 2
  TWIST = TWIST * (-1)
ENDIF

DO 100, I = 1, N
  DO 101, J = 1, 6
    POSAC(J) = ROTPOS(J,N,DIR) * TWIST
101  CONTINUE
100  CALL MOVAC(POSAC(1),POSAC(2),POSAC(3),POSAC(4),POSAC(5),POSAC(6))
    CONTINUE

RETURN
END
```

SUBROUTINE SQUAT(STIKMAG,STIKANG)

* This routine adjusts the height of SKITTER's base above the ground.
* Variable List - STIKMAG,STIKANG - same as defined in main program.

* POSAC(N) - same as in subroutine ROTATE

* if the joystick has not been moved either directly forward or directly
* backward then execute no movements at all.

```
IF (STIKANG .NE. 0 AND STIKANG .NE. 180) THEN
  RETURN
ENDIF
```

P GET ALL CURRENT ACTUATOR POSITIONS AND STORE IN ARRAY POSAC(N)

```
DO 120 J = 1, 6
  POSAC(N) = POSAC(N) + STICKMAG
120 CONTINUE

CALL MOVAC(POSAC(1),POSAC(2),POSAC(3),POSAC(4),POSAC(5),POSAC(6))

RETURN
END
```

SUBROUTINE TILT(STIKMAG,STIKANG,FRONT)

* This subroutine performs the necessary calls to SUBROUTINE MOVAC to
 * allow SKITTER's base to assume any angle with respect to the moon's
 * surface. Using geometry and actuator position feedback, it should be
 * possible to calculate the necessary actuator positions to tilt SKITTER.
 * These actuator positions could then be sent to SUBROUTINE MOVAC for
 * execution.

P CALCULATE NECESSARY ACTUATOR POSITIONS AND STORE IN ARRAY POSAC(N)
 CALL MOVAC(POSAC(1),POSAC(2),POSAC(3),POSAC(4),POSAC(5),POSAC(6))
 RETURN
 END

SUBROUTINE MOVAC(POSAC1, POSAC2, POSAC3, POSAC4, POSAC5, POSAC6)

* This subroutine assumes that each of the six hydraulic actuators
 * on SKITTER has a certain finite number of positions to which it
 * can move. Each actuator has its own processor which will accept
 * the value of POSACn and then independently move the actuator to
 * the desired position. Sending a value of -1 would cause the
 * actuator to remain in its present position.

* Clearly, this is the most important section of the entire program
 * since all the complex SKITTER movements (WALK, TILT, SQUAT, etc.)
 * will be composed of numerous calls to this subroutine.

* One of the important things that must be worked out is how the
 * position values are actually sent to each processor, and how each
 * processor uses this value to make the actuator attain the desired
 * position. Certainly this requires each processor to receive
 * position feedback from each actuator.

* Variable List: POSACn - The position to which actuator 'n' is to
 * be moved. The odd numbers are femur
 * actuators. The even numbers are tibia
 * actuators.

* Declare variables

IMPLICIT INTEGER(P)

P SEND VALUE POSAC1 TO PROCESSOR #1
 P SEND VALUE POSAC2 TO PROCESSOR #2
 P SEND VALUE POSAC3 TO PROCESSOR #3
 P SEND VALUE POSAC4 TO PROCESSOR #4
 P SEND VALUE POSAC5 TO PROCESSOR #5
 P SEND VALUE POSAC6 TO PROCESSOR #6

RETURN
 END

APPENDIX B

JOYSTICK DATA SHEET

ORIGINAL PAGE OF POOR QUALITY

Heavy Duty, Displacement, Hand Operated

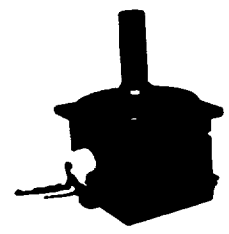
Two and Three Axis Capability

Selection of Joystick Handles and Hand Grip Styles

These controls provide two and three axis operation with a rugged, full gimbal construction providing smooth operation. The full scale output voltage is 100% of the applied voltage. Units incorporate a neoprene boot seal for resistance to severe environmental conditions and utilize precision, center tapped ± 28 angle potentiometers. The direct coupling of the handle and the shaft of the potentiometer without the use of gears or linkages means the backlash is reduced to a minimum.

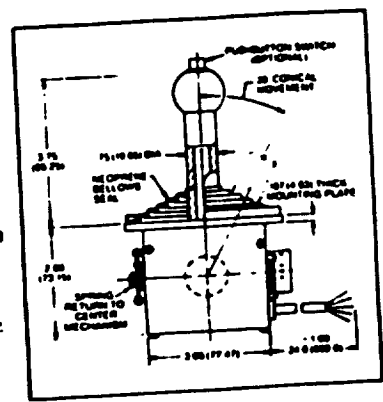
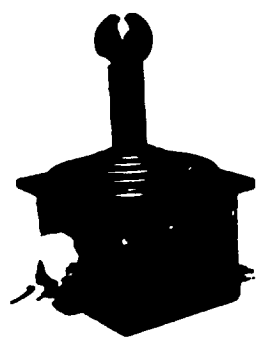
Rugged, Gimbal Movement

Environmentally Sealed Construction



Model 541 Z Three Axis Control

The same as Model 541 except that the handle knob is replaced by a 5K ohm potentiometer (not center tapped) which is spring return-to-center.



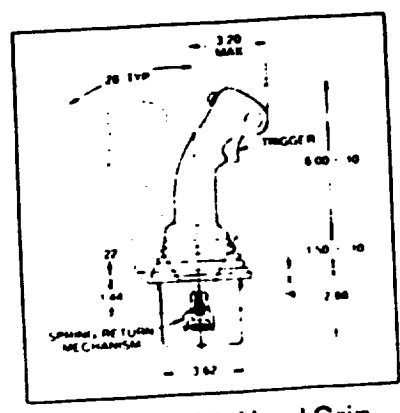
Model 542-G903 Two Axis Hand Grip Control

This rugged, gimbal movement model features high forces, a special cast aluminum enclosure and construction to provide spray resistance under high pressure conditions. Auxiliary functions are performed by an array of switches including finger operated push buttons, a trigger switch with a guard and a bar switch in the grip handle. This model includes long life potentiometers and full scale output force of 70 pounds.



Model 541 Gimbal Joystick

A two axis displacement control for severe environments. Full gimbal construction operates very smoothly with as low as 1 pound force applied to the joystick. This model is available as Model 541 P which includes a push button switch at top of the handle.



Model 544 Three Axis Control

Provides X and Y control by conventional motion of the control grip. Rotational control is easily obtained by rotation of the control grip. All three axes are spring return-to-center. Potentiometers are 5K center tapped. Watt conductive plastic. The control grip includes trigger and three push button switches for thumb operation.



Model 542 Two Axis Joystick with Hand Grip

Provides a handle grip to provide several additional switch functions. The joystick on this unit is smooth gimbal construction as in the Model 541. Trigger switch and three push buttons with two optional standard for optional "see page 3" and "see page 4" Grip Controls.

Model 544-G308 Three Axis Control

A special version of Model 544. It includes a trigger switch and three push buttons with two optional standard for optional "see page 3" and "see page 4" Grip Controls.



Optional Controls for Grips

The following are some of the optional controls that may be incorporated in various control grips. They provide a vast variety of switch and thumb operated controls for maximum design flexibility.

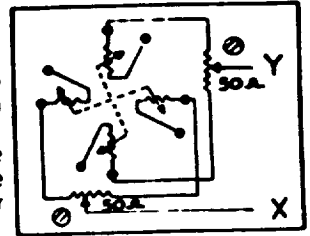


Miniature Thumb Operated Force Type Joystick

Models 465, 467, 469 and 470 offer a variety of available features. See Page 4 for details or ask for our Miniature Joystick Catalog.

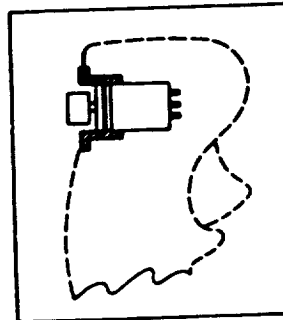
Joystick Balance Pots P/N 682545

These may be required to adjust the null voltage level on Model 465 miniature joystick. Two multi-turn pots can be mounted in a cavity on the grip for external screw driver adjustment.



Push Button Switch P/N 701683 and 701796

Available in momentary (P/N 701683) or alternate action (P/N 701796) with ratings of 5 amps, 28 VDC resistive. Meets MIL-S-8805.



Recessed Mounting Adapter P/N 022026

For use with Model 465 thumb operated joystick. The adapter lowers the thumb knob about .25 inches into the grip shell. This provides for more comfortable operation and protects the joystick from inadvertent actuation.

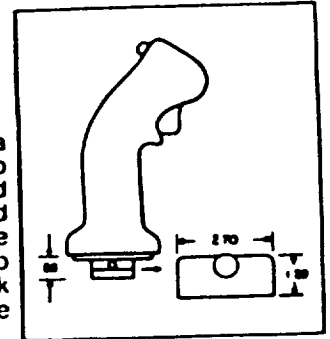


Slide Switch P/N 705807

Is rated at 4 amps, 28 VDC resistive and is available in single or double pole, two or three position momentary or maintained action.

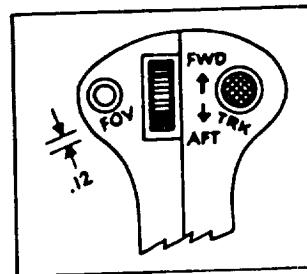
Quick Disconnect Adapter P/N 021119 and Mounting Block P/N 1235

These attachments provide a quick means of using a grip control alternately mounted to a console or operated remotely on a retractable cable. A knurled thumb screw on the mounting block secures the grip to console when desired.



Rocker Trim Switch Model 580

Is single pole, double throw double break, snap action. Rated at 5 amps, 28 VDC inductive. Meets MIL-S-8805.



Engraving

Standard engraving is Groton in high V cut and filled with white paint. Typical number of characters and locations are shown on sketch.

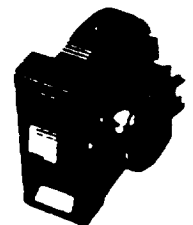


Model 465P

This miniature joystick has a special case and knob design to provide maximum protection to the centerizer beam from accidental mechanical damage. This unit, with the appropriate trim pots, is designed to provide a null voltage level of 0.000 ± 0.005 VDC. The joystick is available in two versions: Model 465P-1, which has a single throw, and Model 465P-2, which has a double throw.

Thumbwheel Control P/N 682412

This control is operated by a knurled thumb wheel which is mounted on the joystick. The wheel is available in two versions: Model 682412-1, which has a single throw, and Model 682412-2, which has a double throw.



APPENDIX C

PROBLEM STATEMENT

Design of a Man-Machine Interface for the Control of a Lunar Transport Machine

by Richard Ashley
Loring Bacon
Tim Carlton
Mark May
Jimmy Moore
Dennis Peek

Group #3
Summer Quarter, 1987
ME 4182

The goal of this project is the design of an operator control panel for the lunar walking machine known as the SKITTER. Specific objectives are: 1) the physical design and layout of the control panel; 2) the selection of feedback necessary for both operation and troubleshooting; 3) determining the optimal methods of displaying this feedback; and 4) defining related problems which will form the basis of activity for future design groups.

- We have identified five important constraints on our design:
- 1) SKITTER will be operating at a remote, inaccessible location. No men will be available to correct errors on the spot.
 - 2) There is a six second time lag in the control loop between earth and the moon.
 - 3) The design must be compatible/adaptible to a mobile, spacesuit supported unit.
 - 4) A spacesuit limits the force and range of motion of the operator.
 - 5) The lunar environment is hostile to equipment.
 - Temperature (-280 F to + 260 F)
 - Radiation
 - Dust
 - Lack of atmospheric pressure

The methods available for evaluating our project are limited since we cannot build a working model to test. Therefore we will make use of :

- 1) past research/design done on similar systems;
- 2) evaluation of experts in instrumentation design here on the Tech campus.

APPENDIX D
PROGRESS REPORTS

Group #3

SKITTER CONTROL

Subject : Weekly Report

Date : July 1, 1987

Dennis:

My job, as assigned last week, was to decide what type of feedback would be necessary for an operator to control SKITTER. Under normal operation conditions, vision feedback should be sufficient.

I have spent the last week reading handbooks on human factors in equipment design, which should prove helpful when we actually begin designing gauges, numerical displays, etc.

Mark:

In the last week I have researched industrial standards and stereotypes for control devices, in addition, I have located literature on control design and human factors. I have discussed the human factors issue with a senior I.E. student and have found two Tech Psychology professors, working with Lockheed, who can give further advice. I plan to talk to an I.E. professor about the topic of human factors.

Tim:

I reviewed human factors control theories from my texts, and researched related topics in the library. The related topics included aircraft controls and the lunar environment. I checked with the Textiles office, and Dr. Olson (the man who worked on the space suit) is out of town.

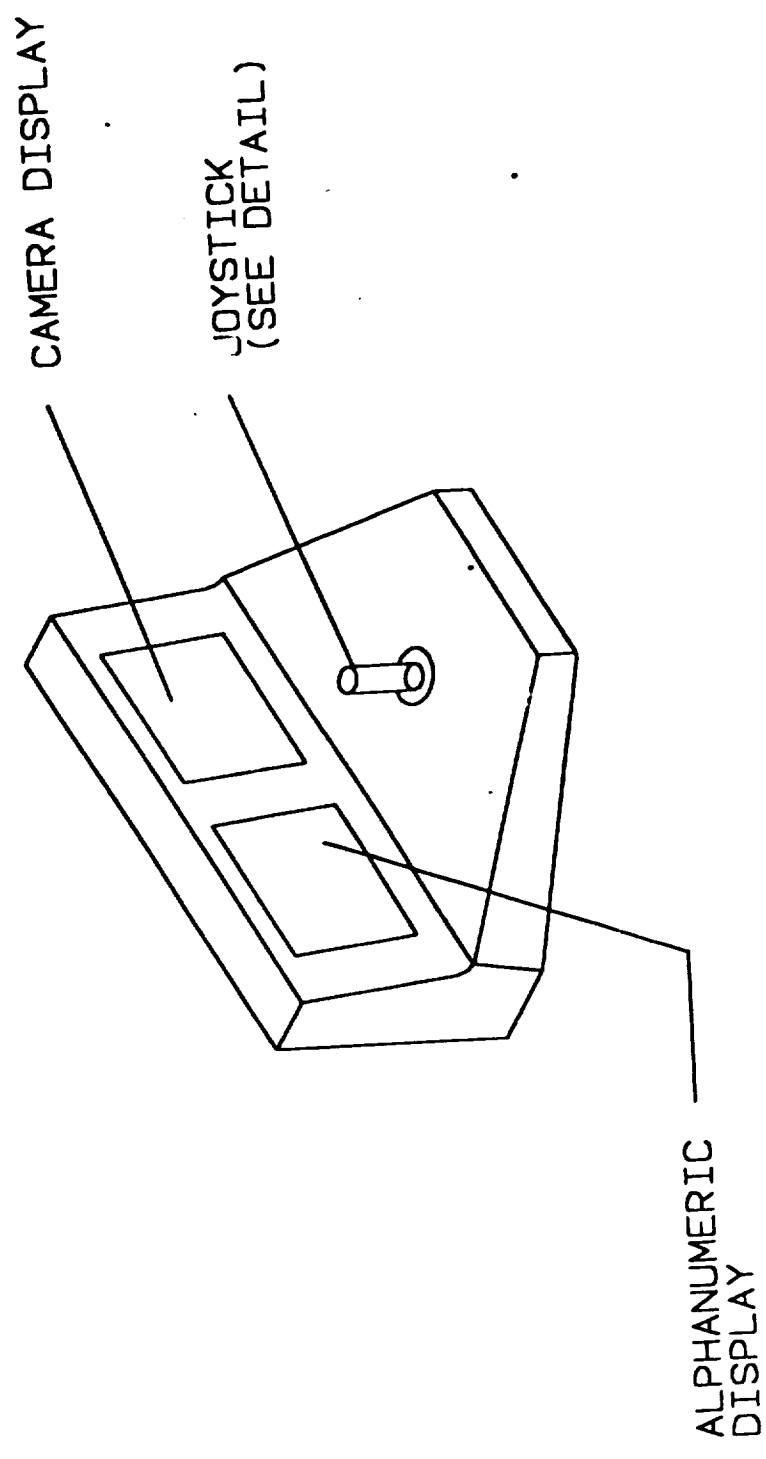
Richard:

My job was to find information on control systems that are currently being used by NASA. I found data on the RMS (Remote Manipulator System), the HPA (Handling and Positioning Aid), and the MMU (Manned Maneuvering Unit) Control systems. The MMU will probably be the most useful example of a control system for our purposes, but I still need to get more information.

Jimmy:

I researched SKITTER to determine its modes of operations and to find information that might aid in the controller design. From the information that I have obtained so far, it is my belief that specifying the acceleration for each actuator will produce the smoothest operation engh.

SKITTER CONTROL PANEL



Group #3

SKITTER CONTROL

Subject : Weekly Report #2

Date : July 8, 1987

Dennis:

I continued working on the problem of what feedback an operator needs for successful operation of SKITTER, and what feedback must be available for trouble shooting from a remote location. Also I have continued working on the weak points of the "Glove Controller" for use by a field operator wearing a spacesuit.

Mark:

I performed additional research in library textbooks on human factors in man machine interfaces.

Jimmy:

I did research on robot remote controller design, time lag, human factors, and possible designs.

Loring:

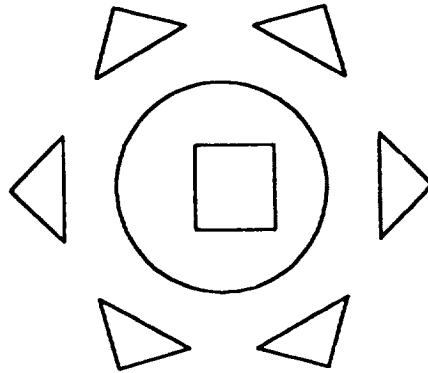
My assignment for this week was to investigate the lunar environment that SKITTER will be exposed too. I researched all the possible constraints that the lunar environment could impose on our control, thus prolonging the life of the moving parts.

Loring:

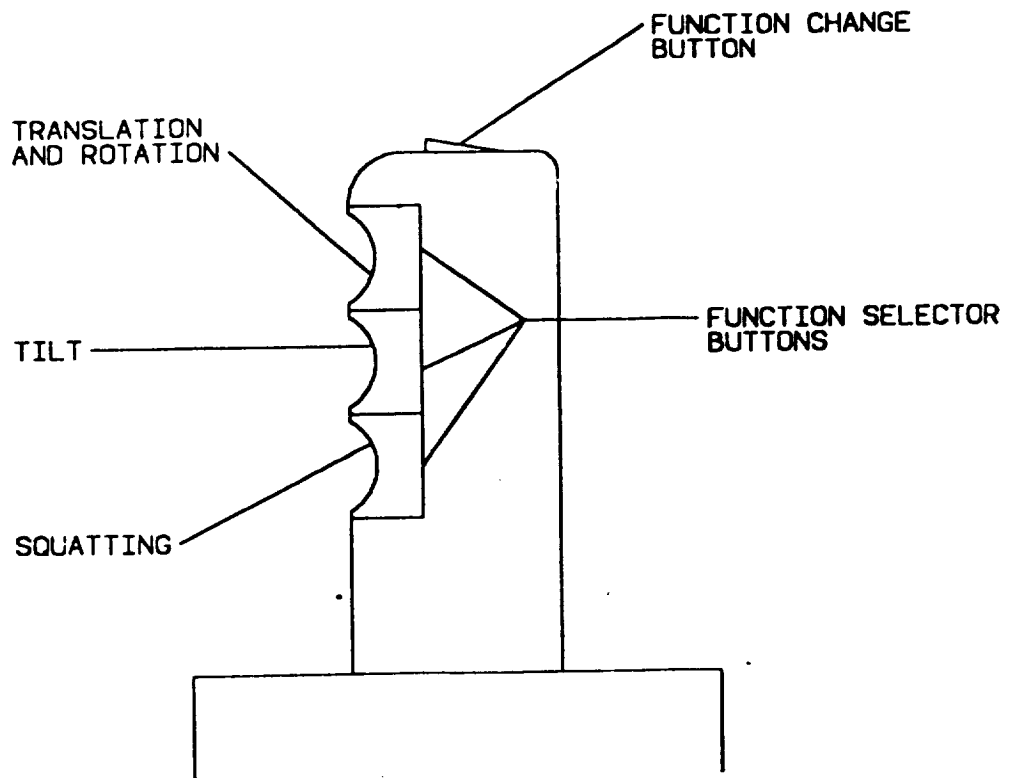
Loring has just joined the group and is in the process of investigating lunar environmental conditions.

As a group we met in order to exchange information, define new questions, and to discuss future actions. We also examined several concepts for SKITTER's control system and we should have one or two concepts finalized by next week.

JOYSTICK DETAIL



(BASE NOT SHOWN)



Group #3

SKITTER CONTROL

Subject : Weekly Report #3

Date : July 14, 1987

Tim: I researched heads-up displays and discussed space suits with Dr. Olson in the textiles department. I also experimented with the APOLLO system.

Jimmy:
-Researched on alpanumeric screen design
-started screen design
-Drawing of the week

Loring:
I continued my research in the lunar environment and its effects on materials.

Mark:
This week I made a preliminary design of camera controls and studied human factors relating specifically to these controls.

Dennis:
I came up with a preliminary design for camera controls which were vastly improved by Mark. I also came up with a concept for individual actuator controls. Group discussion resulted in improvements in this concept and a tentative design. I have started on my main task of defining the jobs that will eventually be carried out by future design groups. (Jobs outside the scope of our project.)

Richard:
I researched joysticks in order to find an existing model that we can adapt to our control panel (which is my main task)

Group:
We split up our project into 4 tasks and assigned each group member to a task. We also identified specific responsibilities and areas that each task should cover.

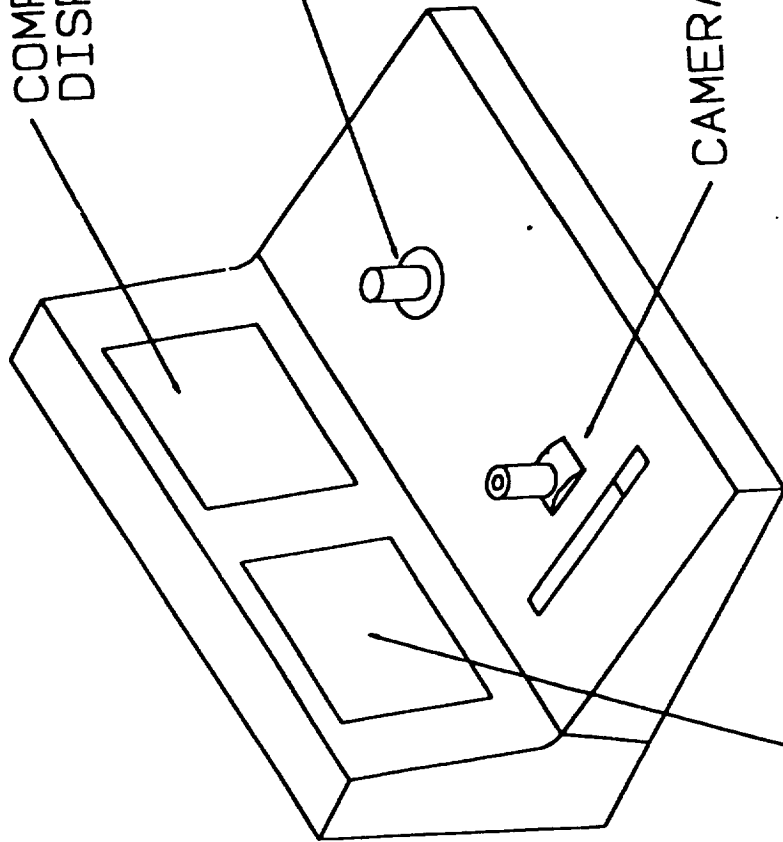
SKITTER CONTROL PANEL

COMPUTER
DISPLAY

JOYSTICK

CAMERA CONTROLS

CAMERA DISPLAY



Group #3

SKITTER CONTROL

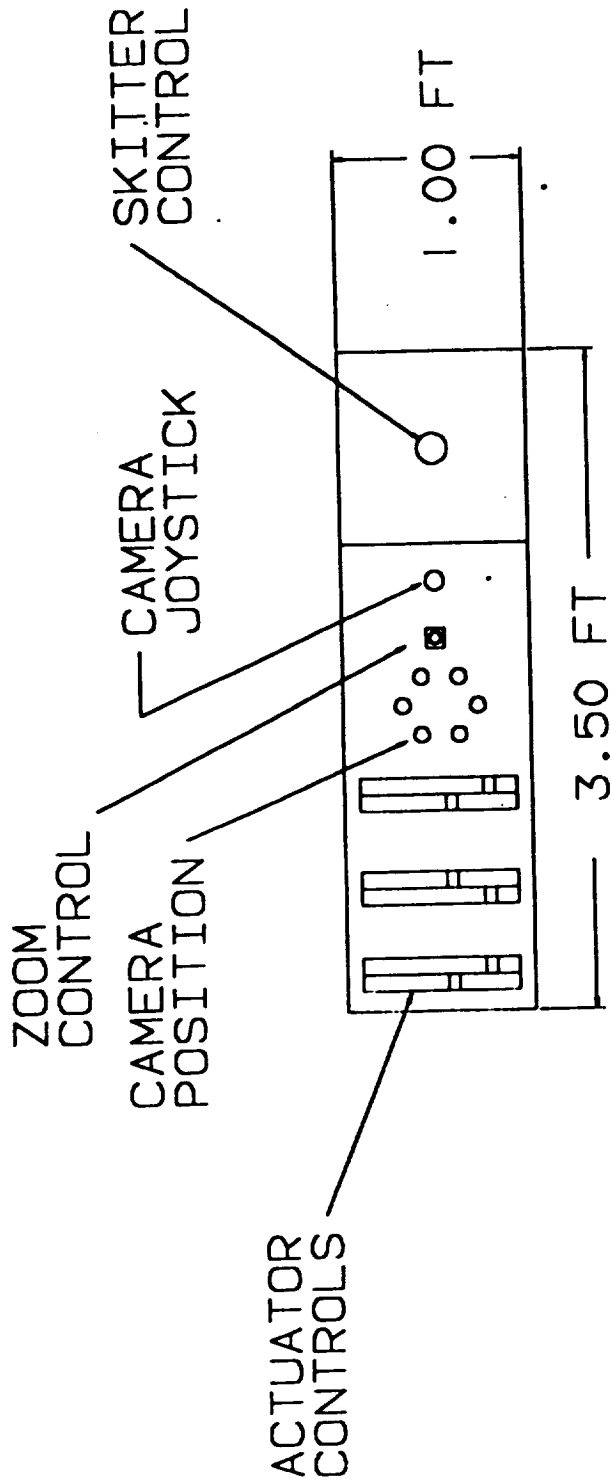
Subject : Weekly Report #4

Date : July 22, 1987

Group:

Each member of the group continued working on the previous week's assignment.

SKITTER CONTROL PANEL
TOP VIEW



Group #3

SKITTER CONTROL

Subject : Weekly Report #5

Date : July 29, 1987

Tim:
-Worked on the camera mount design
-Made preliminary camera mount drawing

Jimmy:
-Researched on alphanumeric screen design
-Started screen design
-Drawing of the week

Loring:
-Prepared for presentation
-researched vendor catalogs for push-buttons and other components

Mark:
-Researched available camera controls from manufactures which meet human factor limitations and military specifications.

Dennis:
I have been working on a control program for SKITTER. Much of this program is actually psuedo-code, but it will give future design groups an organized approach to solving other problems related to our control panel (i.e. the predictor display, error analysis, etc.)

Richard:
-Found existing joystick from Measurement Systems Inc.
-Made viewgraph for presentation
-Researched NASA documentation for information that might applicable for our project.

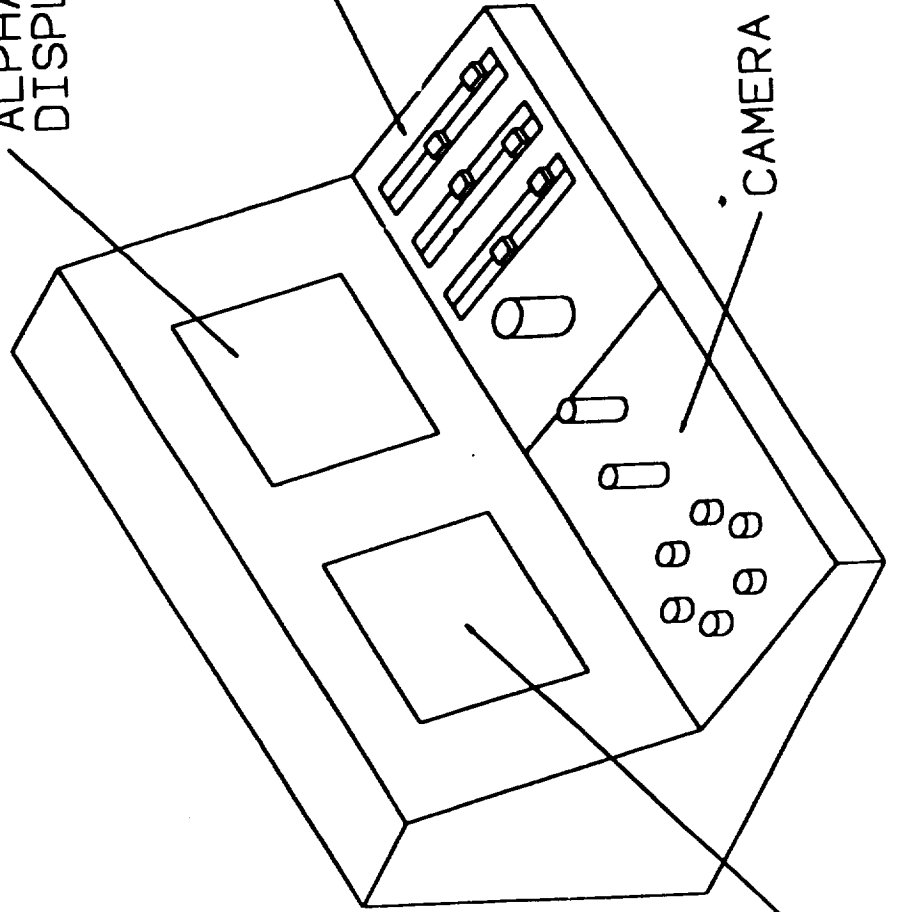
SKITTER CONTROL PANEL

ALPHANUMERIC
DISPLAY

SKITTER
CONTROLS

CAMERA
CONTROLS

CAMERA
DISPLAY



Group #3

SKITTER CONTROL

Subject : Weekly Report #6

Date : Aug. 05, 1987

Tim:
-Worked on the new camera mount design

Jimmy:
-Researched on alphanumeric screen design
-Defined visual predictor display
-Drawing of the week

Loring:
-Researched vendor catalogs and started on preliminary report.

Mark:
-I worked on the new camera controls and researched available controls.

Dennis:
-I have continued working on the control program for SKITTER. Due to a large number of changes we recently made, this job has gone slowly. I have begun writing my part of the report.

Richard:
-Finalized joystick operation
-Researched NASA documentation

Group:
-We redefined the camera controls and the camera mounting scheme.
-We have started on our preliminary report.

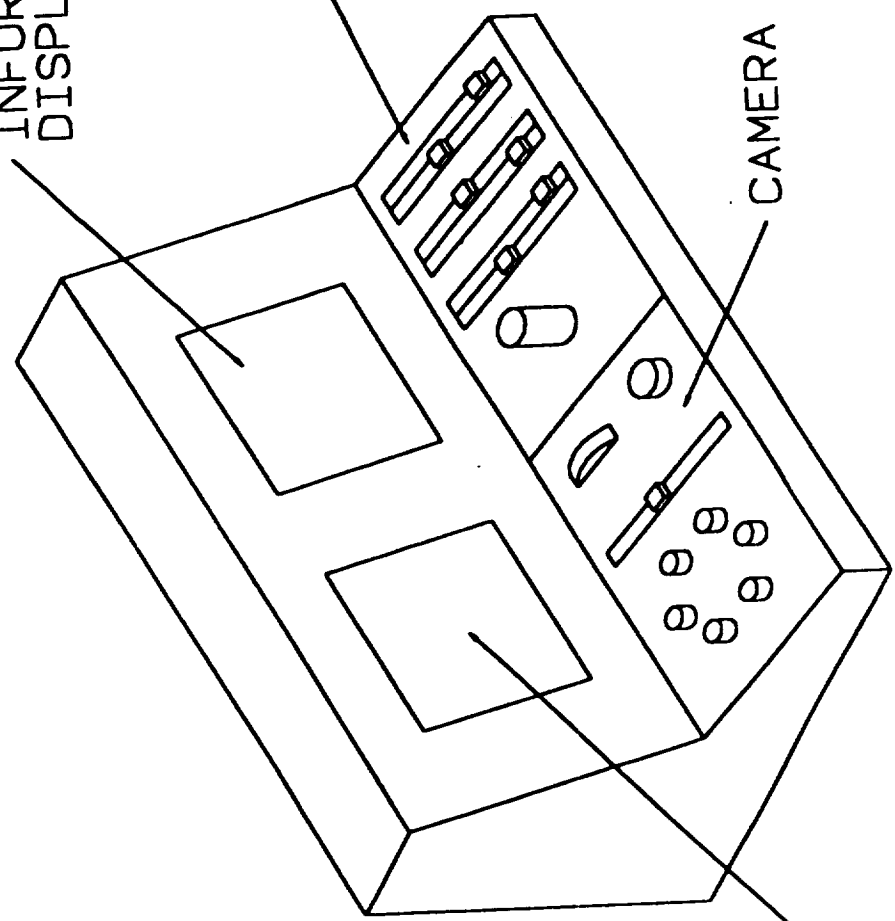
SKITTER CONTROL PANEL

INFORMATION
DISPLAY

SKITTER
CONTROLS

CAMERA CONTROLS

CAMERA
DISPLAY



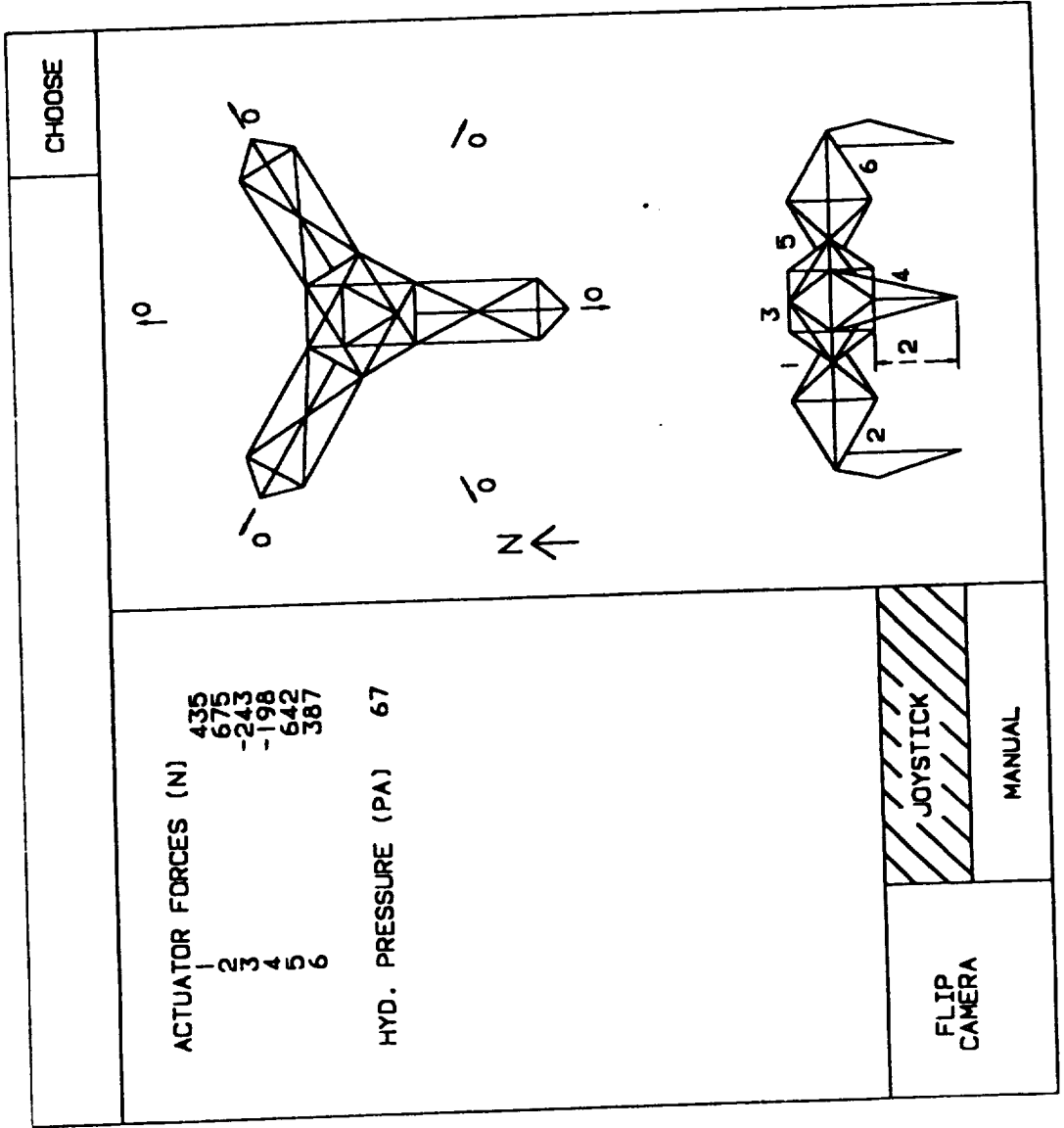
Group #3

SKITTER CONTROL

Subject : Weekly Report #7

Date : Aug. 12, 1987

This week, each member in our group has either started or finished a preliminary report on his assigned area.



Group #3

SKITTER CONTROL

Subject : Weekly Report #8

Date : Aug. 19, 1987

At this point in the quarter, each team member has outlined his own section of the report. Final design decisions have been made and report sections are being individually typed by group members. Our last task will be to combine all report sections and make any adjustments necessary for continuity of the report. Activity during the last week of the quarter will be the same for all group members.

END
