LANGLEY WORKING PAPER

MINIMUM CONTROL-INPUT MEASUREMENTS OF A FOOT-CONTROLLED SPACE MANEUVERING UNIT WITH AND WITHOUT AN A-6L PRESSURE SUIT

By Donald R. Riley and Amos A. Spady, Jr.

Langley Research Center Hampton, Virginia

This paper is given limited distribution and is subject to possible incorporation in a formal NASA report.

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SPACE MANEUVERING UNIT WITH AND WITHOUT
AN A-6L PRESSURE SUIT

Prepared by

Donald R. Riley

Amos A. Spady, Jr.

Approved by William H. Phillips
Chief, Flight Dynamics and Control Division

Approved for distribution by G. B. Graves
Director for Electronics

LANGLEY RESEARCH CENTER
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INTRODUCTION

Several experiments on astronaut maneuvering systems for extravehicular activity (EVA) will be carried out in the orbital workshop during the Skylab space flights in the early 1970's. One such experiment, designated as T020, is concerned with a Foot-Controlled Maneuvering Unit (FCMU). This unit provides a propulsion system which the astronaut controls by foot and leg motions (see also ref. 1).

In support of the flight project, a number of ground-based simulations have been developed. Although space suit operations can be carried out in most of these facilities, regular simulator operations are in a shirt-sleeve environment. It is desirable therefore, to obtain some indication of how a pressure suit might affect the results obtained in such simulations.

The purpose of the present paper is to present the results of a brief study using three test subjects on some effects of the A-6L pressure suit on the operation of typical FCMU foot controllers. Minimum control input was selected as the parameter to be examined on the basis of earlier tests. (Note that the tests herein were conducted subsequent to those of reference 2.) Because of the exploratory nature of the tests only a limited number of
measurements were made. Data with and without the A-6L pressure suit are presented and compared. Two different sets of force-deflection characteristics for the foot controllers were used during the tests and measurements with each are included. Although the results are primarily of interest to the FCMU flight project, it is believed the information may be of use for other applications.

SYMBOLS

The symbols used for the present study are defined as follows:

\[ T_1, T_2, T_3, T_4 \] thrusters used for pitch and yaw control

\[ T_5, T_6, T_7, T_8 \] thrusters used for roll and translation control

\[ X_B, Y_B, Z_B \] right-handed system of body axes with origin located at center of gravity and with \( Z_B \) axis parallel to subject's spine

c.g. center of gravity of man and FCMU combination

\[ \alpha_s \] angle between principal axis and body \( Z_B \) axis, deg

\[ \delta \] thruster-block cant angle, deg

\[ \delta_F \] foot-controller deflection due to up-down movement of foot-leg combination, in.

\[ \delta_T \] foot-controller deflection due to movement of foot about ankle joint, designated as toe movements, in.

VEHICLE DESCRIPTION

A front and sideview sketch of an astronaut on a hypothetical FCMU employing the thruster arrangement proposed for the Skylab flight experiment is presented in figure 1. The unit fastens rigidly about the waist and places a group of four thrusters outboard of each foot. Leg and foot movements are used to control the firing of the various thrusters. Two foot controllers are employed, each of which transmits firing commands
only to the adjacent thruster quad. The backpack shown in figure 1 contains the life support system and is not a part of the maneuvering unit illustrated.

The mode of control for the FCMU is on-off acceleration command. This control mode requires the astronaut to fire the thrusters to start or stop a motion. Because of the thruster locations, the thrusters must be fired in pairs to properly maneuver the FCMU. Thus, the coordinated use of both foot controllers is required. Figure 2 itemizes the eight maneuvers available, the corresponding thrusters that must be fired, and the controller deflection logic used in this particular study to activate the thrusters.

APPARATUS

The foot-controller mockup located at the Martin Marietta Corporation, Denver Division, was used for the present tests (see fig. 3). The apparatus consisted primarily of a set of specially designed foot controllers rigidly mounted to the end of a long table. The test subject was thus positioned horizontally to minimize the effects of gravity on the operation of the foot controllers. Two straps were used to secure each foot to the pedal mechanism. In addition, leg straps with suspension cables attached to the ceiling were employed to support the weight of the legs. An adjustable seat was used to position the test subjects on the mockup and restraining straps eliminated possible sliding motions on the table. The mockup could be used in either a shirt-sleeve or pressure-suited condition.

The instrument panel shown in the photographs of figure 3 contained an eight-ball instrument and a series of four lights on either side that indicated
which thruster was firing. For the minimum control-input tests, the information on the eight-ball instrument was ignored. Although omitted herein, pertinent details on how the instrument was driven and used are given in reference 3.

The three pressure suits and associated regulating and monitoring equipment used for these tests were NASA supplied. Two of the pressure suits were the Apollo type A-6L. The third suit was an A-4H type that had been modified to have the A-6L boots and legs. The A-6L suit employs a soft boot with a large amount of foot play that could influence the operation of the FCMU foot controllers. The use of the A-6L suit, therefore, was a primary test requirement because of possible use in the flight experiment. For the present tests a suit pressure gage reading of 3.7 psi was used.

A drawing of the foot-controller mechanism employed for these tests is presented as figure 4. The mechanism permits a foot up-down motion designated as $\delta_P$ that is parallel to the table top and an independent rotation about the ankle joint designated as a toe movement $\delta_T$. Deflection magnitudes are adjustable and a microswitch is activated at the end of controller travel indicative of thruster firing. A variety of springs such as free springs, captured (preloaded) springs and detent springs of different thicknesses and lengths are available for use so that a wide range of force-deflection characteristics can be obtained. Adjustments permit including or omitting a deadband about the neutral position. A number of different force-deflection profiles were examined qualitatively and two configurations were selected for use in taking data. These are designated as initial and preferred configurations and the characteristics are given in figure 5.
TASK DESCRIPTION

Mounted in the mockup, test subjects were requested to manipulate the foot controllers so as to produce the shortest control input. Pitch, yaw, roll, and translation commands (both directions of control) were performed. A given command was selected by the subject and performed a number of times in succession. About ten individual attempts were considered as a group. In some instances two such groups for a given command were performed in sequence. Since the FCMU uses an on-off system of control the information desired was the shortest time interval that the subjects could activate the thrusters. This time interval is referred to herein as minimum control-input.

PARTICIPANTS

Three test subjects took part in these tests. The following table identified and supplies brief background information on each.

<table>
<thead>
<tr>
<th>Test Subject</th>
<th>Individual</th>
<th>Previous FCMU Foot-Controller Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Research Pilot NASA, Langley Research Center</td>
<td>Several hours on Langley FCMU simulation facilities</td>
</tr>
<tr>
<td>B</td>
<td>Engineer NASA, Langley Research Center</td>
<td>Primary test subject on Langley FCMU simulation facilities. Six months continuous exposure to operating foot controllers of various types.</td>
</tr>
<tr>
<td>C</td>
<td>Engineer Martin Marietta Corporation</td>
<td>Limited use of present test equipment. Brief exposure to Langley FCMU simulation facilities.</td>
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</tbody>
</table>
It is worth noting that test subject B herein also participated as subject B in the study of reference 2.

TESTS

The test program carried out can conveniently be divided into two sections: a qualitative session and a quantitative session. The qualitative portion consisted of an evaluation of various force-deflection characteristics by the research pilot and verified by subjects B and C (see Appendix A). The quantitative portion consisted of data recording sessions for minimum control input. Because the Apollo-type pressure suits were available for only a limited time, not all information that was desired was obtained. Those combinations of test subject, shirt-sleeve or pressure suit configuration, and controller characteristics for which quantitative measurements were obtained, are tabulated below:

<table>
<thead>
<tr>
<th>Test Subject</th>
<th>Pressure Suit</th>
<th>Controller Force-Deflection Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Yes</td>
<td>Preferred</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>Initial</td>
</tr>
<tr>
<td>B</td>
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<tr>
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<td>Preferred</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Initial</td>
</tr>
</tbody>
</table>

DATA MEASUREMENT AND REDUCTION

Voltage signals from the micro-switches mounted on the foot controllers were sent to a small table-top analog computer which scaled
the values to represent on-off jet thruster values. These scaled values were then used in a short program to generate the proper inputs for the 8-ball instrument. The on-off thruster signals were also sent to an 8-channel strip recorder. Since the particular FCMU configuration considered herein uses eight thrusters, all channels of the recorder were used, one for each thruster signal. Time history records were obtained for pitch, yaw, roll, and translation commands (both directions). Paper speed of the strip recorder was selected as 50 millimeters per second which permitted reading the time interval of a given input to the nearest .01 seconds.

Data reduction was performed by a single individual. Four time intervals were read from a given time history record for each individual control command. These time intervals \( (t_a, t_b, t_c, \text{ and } t_d) \) are illustrated in the following sketch:

A check computation \( (t_a + t_d = t_b + t_c) \) was then performed. Using this method, any individual reading is believed accurate to .01 seconds.
Because a given control command by the astronaut requires the firing of two thrusters, the average of the two inputs \( \frac{t_a + t_b}{2} \) was calculated and is considered herein as minimum control-input.

RESULTS AND DISCUSSION

Presentation of Results

Mean and standard deviation time intervals for minimum control-input were calculated using the measurements taken from the time history records. The data are presented in tabular form in figure 6 for the different commands performed by the three test subjects. Because the amount of data was limited, the number of individual readings used for each of the calculations is also listed. Figures 7, 8, and 9 prepared from this summary chart provide some comparisons showing the effects of test subject differences, force-deflection profiles employed and shirt-sleeve versus pressure suit configurations. Figure 10 presents one test result not summarized in figure 6 showing the effect of task.

For some figures herein, data for opposite control directions are plotted in a displaced format on either side of the vertical line indicating the abscissa designation. Results for both directions of a given command are thus presented together yet distinguishable from one another for comparison. Another technique employed is the use of a dashed envelope about the data so that the impression of the data group as an entity is obtained rather than that of isolated data points. Thus, a quick evaluation of the data group can be obtained visually from the size and placement of the enclosed area.
General Observations

Because the testing time allotted for this exploratory study was limited, not all desirable combinations of test subject and equipment could be examined. In addition, a number of combinations involving force-deflection adjustments in the foot-pedal mechanism were examined only qualitatively. Of the two selected for quantitative measurement, only a limited number of data points were obtained. In most instances, about 20 inputs were recorded for a particular command by a given individual for a specific set of conditions.

Some effort was made in reference 3 to examine a portion of this data using a statistical approach. Only measurements with the pressure suit and the preferred forced-deflection profile were considered. Data for the three test subjects were combined. The analysis attempted was very detailed and considered a number of factors, as for example, differences between the inputs commanded by each foot, whether the signal from the left or right controller occurred first in time, which preceded the other when the pedals were released, etc. The general conclusion obtained from this data examination was that the information available (number of individual measurements and number of subjects used) was too meager to yield statistically significant results.

Because of these difficulties, a broader approach is taken herein than in reference 3 in examining and comparing results. Use is made of the dashed envelope and the data group of commands is considered as an entity. Note that the area is related to the standard deviation and hence the scatter in the data. Visualizing a centerline permits a quick estimate of an average level (average of the 8 mean values). Both the average
level and an impression of the scatter are used as the basis for comparing and evaluating the various combinations tested.

It is of interest to note that one concluding observation reported in reference 3 concerned the use of a sequential test scheme consisting of a series of the same command (in the same direction) performed in succession as employed for these tests. The observation was that the input values commanded for each foot tended to decrease in magnitude in the direction first to last. The initial value is believed to be the more common input experienced and hence the more realistic value for minimum control-input for actual flight conditions.

Test Subject Differences

Only one direct comparison of results involving the three test subjects is afforded by the data of the summary chart of figure 6. The data are for the pressure suited condition and preferred force-deflection controller configuration. Figure 7 presents this minimum control-input data spaced so as to give an overall impression of test subject performance using the foot controllers. Visually grouping the eight commands as a unit, a general performance impression is obtained that is essentially related to two elements - an average value for the mean of the eight commands and an average value for the one sigma scatter about the mean (average of standard deviation of the eight commands). The smallest values obtained for these two averages would thus be adjudged to be the most desirable. The smallest values were obtained by subject B who also had the most experience with comparable foot controllers. The largest values were obtained by subject C who had the least experience using foot controls. Although subject A's experience with typical FCMU foot controllers is limited, he has accumulated
considerable experience using the feet as primary controllers in other simulations and with other devices. (For example, he was a participant in a number of simulations of the device described in reference 4.)

Effect of Controller Force-Deflection Profile

Figure 8 presents comparisons of minimum control-input data for the two controller force-deflection profiles used in the present study. Two such comparisons are available, one for the most experienced subject using foot controllers (subject B) and one for the least experienced (subject C). Both subjects were in the pressure-suited condition.

Examination of subject B's results show some differences in the scatter of the data between the two configurations, but little change in the average level of the eight commands. The larger scatter was obtained with the initial configuration but only for toe up-down controller movements. Thus, it would appear that subject B with his extensive experience using foot controls could favorably compensate for the differences in controller profiles used for foot movements but was not as consistent in the performance of toe movements. For less experienced subject C, the differences in both scatter and average level between data sets are large emphasizing the effects of force-deflection profile. Of the two data sets, the better performance was obtained with the preferred configuration.

A detailed examination of the initial and preferred profiles, figure 5, show that the preferred configuration employed unsymmetric forces, unsymmetric deflections and used no deadband, whereas the initial configuration had unsymmetric forces, symmetric deflections, and included a deadband. The contribution of each of these adjustments on the foot controller mechanism to the differences shown in the minimum control-input data can not
be assessed due to the limited data obtained. It is believed, however, that the effective presence of a double deadband for the pressure-suited subjects using the initial configuration is a large contributor to the differences shown.

Effect of Pressure Suit

Available comparisons for minimum control-input for test subjects with and without the pressure suit are presented in figure 9. A direct comparison for evaluating suit effects, however, is available only for subject B. His data permit a shirt-sleeve versus pressure suited comparison with all other factors identical. Such a comparison gives the general impression that the presence of the A-6L pressure suit has little or no effect on minimum control input.

For subject A, a different comparison is shown in which the data includes not only pressure suit effects but also the effect of controller force-deflection characteristics. Results for the preferred configuration with the suit are presented adjacent to those for the initial configuration without the suit. A comparison of the two data groups shows a noticeable improvement in foot-motion performance (roll and translation control) for the preferred profile with the suit on. Thus, the better performance with the pressure suit indicates the differences shown are probably due to force-deflection profile effects for this particular subject.

One reason performance degradations were not evident when employing the pressure suit would seem to be due to the small controller deflections employed. The controller characteristics given in figure 5 show both toe
and foot movements were very small. Suit restraints and possible binding effects were thus not encountered. To produce the input command, the controllers must be driven hard against the mechanical stops and then released. In this situation, test subjects are influenced more by the forces encountered than by the small deflections used.

Effect of Control Task

During the test program several sets of data were obtained by one subject (subject A) using only the pitch control in which the task was changed. Instead of performing a series of pitch inputs in the same direction, the test subject was asked to reverse his control direction for each succeeding input. Thus, he would alternately apply a pitch-up command then a pitch-down command, etc. A comparison of the minimum control-input data obtained for the reverse-direction task with similar data for the same-direction task taken at comparable times during the test program is presented as figure 10. The results show magnitudes for the reverse-direction task roughly double those for the same-direction task. Apparently, differences in task can have a large influence on the size of minimum control inputs.

It is also of interest to note that task differences invalidate a direct comparison of the results for the eight different commands presented herein with those of reference 2. Such a comparison was attempted. However, it was soon apparent that considerably smaller mean-value magnitudes were obtained for the minimum control-inputs herein. Although there are a number of differences in the foot pedals and other apparatus used in the two studies, the smaller magnitudes occur primarily because of the sequential test scheme used herein as opposed to the technique of making an input in each of the eight possible commands before recycling as used in reference 2.
CONCLUDING REMARKS

Three test subject, one a NASA Research Pilot, were participants in a brief exploratory study of the effects of the Apollo-type pressure suit (A-6L) on the operation of typical FCMU foot controllers. Minimum control-input was selected as the quantitative parameter to be examined and summary data of these measurements are presented. Because the A-6L pressure suits were available for only a short time, the number of tests that could be performed were limited. Observations based on these few results indicate that the presence of the pressure suit had little effect on minimum control input probably because of the small controller deflections employed. Differences in the magnitude of minimum control-inputs were evident due to differences in (1) the controller force-deflection characteristics used, (2) the test technique employed to obtain the data and (3) test subject ability apparently related to the amount of experience using foot controllers. Although the results presented were not on a good statistical foundation, they do provide an indication of some factors affecting minimum control-input magnitudes. The test data were obtained primarily for use with the Foot-Controlled-Maneuvering-Unit, however, the results may be of use for other applications.
APPENDIX A

Qualitative Evaluation

Part of the testing time of this exploratory study was spent evaluating qualitatively a number of different foot-controller force-deflection profiles. Test subject judgements were made after using the controllers to arrest various linear and angular rates displayed on the 8-ball indicator. Thrust values remained unchanged during these tests so that a comparative assessment of performance using different force-deflection profiles could be obtained from successive flights. The purpose of this qualitative evaluation was two-fold:

a. To obtain a force-deflection profile for the FCMU acceptable for astronaut use in the A-6L pressure suit.

b. To re-examine and hopefully verify the evaluation of reference 2 (performed by subject B in shirt-sleeves) using a NASA Research Pilot (subject A) in the A-6L pressure suit.

The force-deflection profiles examined involved the use of both free and captured springs, with or without detent springs and with or without a deadband about the neutral position. The evaluation of the various configurations by the research pilot was similar to the assessment made by subject B in reference 2. In addition, a discussion of these particular results along with comments on the advantages and disadvantages of the various profiles is given in reference 3. For these reasons a detailed discussion of the results is not presented herein.

Briefly however, the evaluation indicated a centering problem in the use of free springs and a coordination difficulty in achieving simultaneous inputs with detent springs. The use of these spring systems should probably be avoided for FCMU applications. Controllers using captured springs
with a deadband about the neutral position appear suitable for shirt-sleeve operations. For pressure suit operations, however, the use of captured springs without a deadband is desirable simply because the A-6L suit has a loose boot arrangement that effectively builds in a deadband. This latter combination was selected by the research pilot as the preferred configuration and consequently is so labeled herein.

A number of the configurations examined by the research pilot were also examined by subjects B and C in pressure suits. They concurred in the profile shape selected by subject A as the preferred configuration for use with the A-6L suit. Some individual preferences, however, as to the most desirable force and deflection magnitudes were evident. For these three subjects, a foot-pedal mechanism providing ±25 percent adjustment in the magnitude of both the force and deflection shown in figure 5 would include the desired settings of each. Desirable features of the preferred profile worth itemizing are: (1) the elimination of the deadband about the neutral position, (2) the use of captured springs that provide positive centering and elimination of unintentional inputs, and (3) the incorporation of unsymmetrical forces and deflections indicative of the ease of pressing the toes and feet downward rather than lifting them.

It is worth noting that the force-deflection profile labeled herein as initial configuration (figure 5) was selected for a shirt-sleeve condition by subject B as a starting point for the evaluation study. Only a few other profiles were examined without the pressure suit. The major effort in obtaining an evaluation was concentrated on the pressure suit condition. Because of the limited testing time available minimum control-input measurements were obtained for only two profiles, the initial and preferred.
REFERENCES

1. Hewes, Donald E.: A Discussion of Control Systems for Foot Controlled Space Maneuvering Units. LWP-782, August 1969.


Figure 1: Sketch of hypothetical foot-controlled-maneuvering-unit showing thruster arrangement and numbering system.
<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Type</th>
<th>Direction</th>
<th>Thruster operation</th>
<th>Controller Deflection Logic</th>
</tr>
</thead>
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<td>Pitch</td>
<td>Up</td>
<td>$T_1, T_2$</td>
<td>Press toes both feet down</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Down</td>
<td>$T_3, T_4$</td>
<td>Pull toes both feet up</td>
<td></td>
</tr>
<tr>
<td>Yaw</td>
<td>Right</td>
<td>$T_2, T_3$</td>
<td>Press toes left foot down</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pull toes right foot up</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>$T_1, T_4$</td>
<td>Press toes right foot down</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Pull toes left foot up</td>
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<tr>
<td>Roll</td>
<td>Right</td>
<td>$T_6, T_7$</td>
<td>Push left leg down</td>
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<td>Lift right leg up</td>
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<td></td>
<td>Left</td>
<td>$T_5, T_8$</td>
<td>Push right leg down</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lift left leg up</td>
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<tr>
<td>Translation</td>
<td>Down</td>
<td>$T_7, T_8$</td>
<td>Lift both legs up</td>
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<tr>
<td></td>
<td>Up</td>
<td>$T_5, T_6$</td>
<td>Push both legs down</td>
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Figure 2.- Available control maneuvers, thrusters required, and controller deflection logic used.
3. Side view of test subject in AGL pressure suit on test apparatus.

Figure 7: Photographs of test set-up for foot-controller investigation.
c. Over-the-shoulder view of instrument panel.

Figure 3.- concluded.
Figure 4.- Sketch of foot pedal mechanism showing pertinent dimensions in inches.
Figure 5.- Force versus deflection characteristics of two controller configurations for which data was obtained. (Forces were measured 18 1/4 and 25 3/8 inches above the table surface for foot and toe deflections respectively. See figure 4)
### Roll

<table>
<thead>
<tr>
<th>Subject</th>
<th>Press suit</th>
<th>Controller configuration</th>
<th>Right Mean</th>
<th>Std. dev.</th>
<th>Data pts.</th>
<th>Left Mean</th>
<th>Std. dev.</th>
<th>Data pts.</th>
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### Translation

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<th>Controller configuration</th>
<th>Down Mean</th>
<th>Std. dev.</th>
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<th>Up Mean</th>
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### Pitch

<table>
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<th>Press suit</th>
<th>Controller configuration</th>
<th>Up Mean</th>
<th>Std. dev.</th>
<th>Data pts.</th>
<th>Down Mean</th>
<th>Std. dev.</th>
<th>Data pts.</th>
</tr>
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<td>.02</td>
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### Yaw

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Figure 6.- Summary table of the mean and standard deviation results for minimum control-inputs in seconds.
Figure 7.- Comparison of minimum control-input measurements obtained on three test subjects in A6L pressure suit—preferred configuration. (Symbols indicate mean values and terminated lines show standard deviation about the mean.)
<table>
<thead>
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<th>Translation</th>
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<tr>
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<td>Left</td>
<td>Left Up</td>
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Subject B
Number of data points

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<td>20</td>
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</tr>
<tr>
<td>□</td>
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Subject C
Number of data points

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<tbody>
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</tr>
<tr>
<td>□</td>
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</table>

Figure 8: Comparison of minimum control-input data for two controller configurations illustrating the effect of altering foot controller deflections and deadbands as obtained by two pressure-suited test subjects. (Symbols indicate mean values and terminated lines show standard deviation about the mean.)
Figure 9.— Comparison of minimum control-input data showing the effect of the A6L pressure suit for two test subjects. (Symbols indicate mean values and terminated lines show standard deviation about the mean.)
Figure 10: Data comparison showing the effect of control task on minimum control input for pitch as obtained by Subject A without the pressure suit (initial configuration)

<table>
<thead>
<tr>
<th>Task</th>
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<th>Mean Value</th>
<th>Std. Dev.</th>
<th>Data pts</th>
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<td>.11</td>
<td>21</td>
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<tr>
<td>Successive pitch inputs</td>
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<td>.04</td>
<td>18</td>
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<tr>
<td>Successive pitch inputs</td>
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<td>.32</td>
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<tr>
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<td>10</td>
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Note: Filled and unfilled symbols designate sets of data obtained at different times during tests.