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TECHNICAL NOTE 4171

SOME GROUND MEASUREMENTS OF THE FORCES APPLIED BY PILOTS TO A SIDE-LOCATED AIRCRAFT CONTROLLER

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SOME GROUND MEASUREMENTS OF THE FORCES APPLIED BY PILOTS TO A SIDE-LOCATED AIRCRAFT CONTROLLER

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SUMMARY

Ground tests have been made to determine pilots' force capabilities on a proposed side-located aircraft controller, located at one side of the cockpit and situated so the pilot's arm may be supported. The axes of the controller are in a plane through the center of the pilot's forearm to minimize the effects of acceleration forces.

Results indicate a neutral position for the controller at 8° to the right and 15° forward of the vertical. The ability of the pilots to apply forces in both directions at various angles of roll and pitch indicated a usable range for the controller. At the limits of deflection suggested for the controller, the torque capability in the direction of increasing deflection was approximately one-half the maximum value. The range of deflection for roll control was $\pm 45^{\circ}$ from the neutral point. The range of deflection for longitudinal control was $\pm 22\frac{1}{2}^{\circ}$ from the neutral point. Pilots participating in the tests indicated forces that they considered desirable for operation of the side-located controller. This operational torque for the controller is from 10 to 26 inch-pounds in roll and from 15 to 36 inch-pounds in pitch. The pilot's arm should be extended slightly forward of a 90° elbow angle. In the range of deflection proposed for the controller, the relationship between maximum torque (applied in the direction to increase the deflection) and controller deflection is linear, with the torque decreasing in the direction of rotation.

INTRODUCTION

Future high-speed airplanes may require additional and more complex control equipment in the cockpit that must either be operated or monitored by the pilot. Any control system that overtaxes the pilot is undesirable. The ease of the piloting task must be maintained at a reasonable level. Thus, in order to add new piloting tasks, existing tasks must either be

simplified or made automatic. In order to add new equipment to the cockpit, it seems reasonable that existing equipment must be moved or redesigned.

A modification from the standard control arrangement which has been considered is the use of a side-located controller instead of the conventional center stick. Such a controller is located at one side of the cockpit and situated so that the pilot's arm can be supported; thus, the effects of acceleration on control accuracy are reduced. The space in the center of the cockpit could be used for other equipment, such as radar displays. Little information exists as to what configurations or operating ranges are suitable for proposed side-located controllers. The range of control deflections, the operational and maximum force levels, and the control suitability associated with this type of controller are desired.

Reference 1, which presents data on the conventional center control stick, is an example of the type of information required for side-located controllers. Reference 2 furnishes a partial insight on operating ranges and maximum forces pertinent to roll control but gives no information on longitudinal control forces. Additional papers, such as references 3 and 4, deal with grip configurations and general strength, respectively, with no correlation to the present problem.

This paper presents a limited amount of data on pilots' force capabilities obtained in ground tests of a side-located controller. Data were obtained from 11 subjects, referred to as pilots in the present paper. Five were research pilots who had had some experience with side-located controllers, and six were research engineers, four of whom had pilot ratings. Forces were measured in both roll and pitch. The optimum neutral position, as well as the range of deflections of the hand grip in both roll and pitch, was established.

APPARATUS AND TESTS

The apparatus utilized to obtain data for this paper consisted of an aircraft seat and a grip-type handle attached to a shaft which was restrained at the other end by a torque wrench. The roll configuration is shown in figure 1(a). The torque wrench was positioned on a sector at 15° intervals up to $\pm 90^{\circ}$ deflection. Torques were recorded in both directions for each grip position. By rotating the shaft and the sector 90°, as shown in figure 1(b), tests could also be made in pitch.

For each pilot the chair was adjusted so that the back and arm rests were comfortable and correctly alined with the control grip. The right arm was used for all tests. Two different arm positions were employed to

determine how they would affect the pilot's force capability. In one position the upper arm was normal to the arm rest and formed an angle of 90° at the elbow. In the second position the arm was extended so that the included angle between the upper arm and forearm was approximately 130°. Throughout this paper these arm positions are referred to as the 90° and 130° arm positions. The arm rest was horizontal and the subjects were instructed to maintain the same erect position for all tests.

For roll measurements the shaft attached to the grip was alined with the axis of the subject's forearm. Thus, the arm and shaft rolled about the same axis. Rolling torque was recorded at 15° intervals through ±90° of grip position. Roll data presented in this paper were obtained with the hand grip in a vertical plane. In addition, roll forces were recorded for 7 of the 11 pilots with the hand grip tilted forward and rearward of the vertical to determine the effect on maximum force capability.

For pitch measurements, the axis of the shaft was normal to the pilot's wrist approximately at the point where the wrist joins the hand. Torque was recorded at 15° intervals from 30° in a pull-up direction to 60° in a push-down direction.

The pilots were instructed to apply the following three force levels to the controller in both roll and pitch:

(1) Operational force level - the force that the pilots deemed comfortable for continuous control maneuvers, such as instrument or formation flight

(2) Maximum operational force level - the force that the pilots would accept for short periods of time and which would apply to any maneuver requiring maximum control capability

(3) Maximum force level - the maximum force that the pilot could exert at each position of the grip

The operational torque levels (1) and (2) were arbitrarily chosen by the pilots as desirable working levels, whereas maximum torque was a measure of physical ability. Applied forces were noted immediately upon application and again 5 seconds later. A force level that could be sustained for 5 seconds was used for the data of this investigation.

For each test the operational force level was measured first in order to perserve the pilots' feel at the lower torque levels since maximum torque was investigated as the final phase of each test. Also, in order to avoid faulty data due to the tiring effects of prolonged tests, four tests were scheduled on four separate days for the two arm positions in roll and the two arm positions in pitch.

Physical dimensions pertinent to these tests, as well as limits of deflection in roll and pitch, were recorded for each pilot. These are presented in table I. Distance A is measured from the center of the shoulder to the center of the hand for the 90° and 130° arm positions and for the arm extended at 180° elbow angle. Distance B is measured from the top of the arm to the arm rest for the 90° and 130° arm positions. Ability to rotate the unrestrained controller right and left in roll and forward and rearward in pitch was measured in degrees for the 90° and 130° arm positions.

The standard deviation of the forces applied by the 11 pilots at each grip position was calculated by the relation

$$\sigma = \sqrt{\frac{\sum (y - \bar{y})^2}{N - 1}}$$

where y is the measured data, $\bar{y}$ is the mean of measured data, and N is the number of values at a grip position.

The pilots were not aware of their torque outputs during any phase of the tests. The torque wrench was calibrated prior to the tests to insure accuracy.

RESULTS AND DISCUSSION

Force Levels and Operating Range of Controller

As Determined by Tests

Results of force measurements in roll were averaged for the 11 pilots and are presented in figure 2. The force level suggested by the pilots as operational in roll was between 10 and 12 inch-pounds in the direction of displacement for grip positions between approximately 45° left and 60° right. For this same range of grip positions the maximum operational torques in the direction of the displacement were between 20 and 26 inch-pounds. Thus roll torque determined from the tests was in the range between 10 and 26 inch-pounds. The average sustained maximum capability in roll was 86 inch-pounds, and an individual high was 172 inch-pounds.

Since the maximum force level varies over a greater range than the other force levels, the curves of maximum roll torque shown in figure 2(c) show the trend of forces clearly as the grip is rotated from side to side.

By shifting the origin of figure 2(c) 8° to the right, the roll torques are made symmetrical about the new origin. This suggests that a neutral position for the controller (where the average maximum force capabilities for both directions of roll are equal) should be 8° to the right of the vertical. At this location the average maximum roll torque that could be sustained was 70 inch-pounds for either right or left roll. As the hand was rotated to either side of this neutral position, force capability in the direction of rotation decreased linearly while that opposing the rotation increased.

By moving from this new origin approximately 45° to the right or left in roll, the force ability in the direction of roll was reduced to one-half the maximum value, while the force ability opposing the rotation increased 20 percent. This suggests that a suitable range of operation for the controller is $\pm 45^{\circ}$ from 8° right of the vertical.

Pitch data are presented in figure 3. For the range of grip positions between $37\frac{1}{2}^{\circ}$ forward and $7\frac{1}{2}^{\circ}$ rearward of the vertical, the operational force level is between approximately 15 and 21 inch-pounds and the maximum operational force level (applied in the direction to increase the deflection) is between approximately 28 and 36 inch-pounds. Thus, pitch torque determined from the tests was in the range between 15 and 36 inch-pounds. The maximum value of the average maximum force level is approximately 130 inch-pounds, whereas an individual torque of 185 inch-pounds was recorded during the tests. It may be seen that forces for pitch and roll are comparable for this type of control, whereas pitch force capabilities for the center control stick are much greater than roll force capabilities.

By the same reasoning used in determining the range of the controller in roll, figure 3(c) indicates a neutral position for the hand grip at 15° forward of the vertical in pitch. A suitable range of operation in pitch for the side-located controller is approximately $22\frac{1}{2}^{\circ}$ either forward or rearward of the 15° neutral point.

Roll tests were made with the hand grip tilted forward and rearward of the vertical to investigate the coupling effects of the hand position which would be required in a climbing or diving turn. As long as the plane of roll torque was within the pitch range of $\pm 22\frac{1}{2}^{\circ}$ from the neutral, the force capability in roll compared favorably with that obtained with the stick in a vertical plane.

Similar results were obtained in pitch with the grip in various positions to the right and left of the vertical. There was little loss of potential in pitch as long as the grip remained within the range recommended for roll operation.

Deviations in Data

Standard deviations were calculated for the forces in the direction of the displacement and in the direction opposite the displacement for the 90° and the 130° arm positions. These calculations resulted in four standard deviation curves, and, since these were about the same for the four cases, the standard deviation curves shown in figures 2 and 3 are the average of these four cases.

The average standard deviation of the maximum force capabilities of the 11 pilots was approximately 15 inch-pounds for roll and 30 inch-pounds for pitch. (See figs. 2(c) and 3(c).) The maximum deviation was approximately 20 inch-pounds for roll and 40 inch-pounds for pitch.

The maximum operational force level is important in determining a torque at which the controller will command full deflections of the control surfaces. Results of the tests show agreeable consistency in the pilots' choice of an acceptable maximum operational torque. The average standard deviation for this level was approximately 8 inch-pounds for roll and 12 inch-pounds for pitch, or approximately one-half that at maximum effort. (See figs. 2(b) and 3(b).)

The average standard deviation of the operational force level was only about 5 inch-pounds for roll and 10 inch-pounds for pitch. (See figs. 2(a) and 3(a).)

There were no appreciable deviations in the pilot's arbitrary expression of operational or maximum operational levels of torque from one test to another. The maximum force capability of an individual did vary to some degree between tests, as would be expected. Nevertheless, the deviation in maximum physical capability was in no consistent direction and was no more erratic between tests than during a test.

Effect of Arm Position

Results of present tests indicate that any arm position in the range between an elbow angle of 90° and 130° would effect comparable results in either a pitch or roll maneuver when a side-located controller is used. Any slight advantage realized for one arm position with the grip at one end of the range becomes a slight advantage for the other arm position when the grip is at the opposite end of the range. This is evident in the pull-up curves of figure 3(c), where the 90° arm position is stronger than the 130° arm position when the grip is in a push-down position, and the reverse is true when the grip is in a pull-up position. A similar effect is shown by the push-down curves. The slight crossover of advantage attributable to moving the arm from the 90° position to the 130° position indicates that at some intermediate position between 90° and 130° the advantage differential would be minimized or eliminated.

Correlation Between Pitch Configuration Tested and a Configuration With Shaft Axis Through Center of Grip

The controller configuration utilized to record pitching torque for this paper rotated about an axis through the point where the pilot's wrist joins the hand. This indicated a $2\frac{1}{2}$-inch moment arm from the axis of the pitch pivot to the hand grip. (See fig. 1(b).) In order to determine the effect of this $2\frac{1}{2}$-inch moment arm on maximum force capability and hand movement, additional tests were made with the pitch axis through the grip.

At deflections near the 15° neutral point for pitch, the hand-centered axis produced slightly higher maximum pitching torque. Near the extremities of the range of deflection, however, the opposite was true, and the axis through the wrist-hand juncture produced higher torque. With the forearm stationary, the effective advantage of the wrist axis extended through a greater range of deflections in pitch. In addition, translatory force could be imparted to the grip with the wrist axis by lifting or pushing down on the grip, and this force increases the torque of pure rotation at maximum deflection. Since the advantages offered at maximum deflection are more important, it is believed that the wrist-axis configuration used for these tests is superior.

Need for Additional Tests

Data presented herein relate to a single configuration of proposed side-located aircraft controllers. Further testing and development of this and other configurations are necessary. Simulation of acceleration forces and the vertical and horizontal variation of roll and pitch axes of the controller, respectively, are examples of possible future studies associated with this type of aircraft controller.

CONCLUSIONS

Ground tests to determine pilots' force capabilities, when a side-located aircraft controller is used, have led to the following conclusions:

1. The force capabilities of the pilots tested indicate that the neutral position for the side-located controller should be 8° clockwise and 15° forward of the vertical.

2. The grip positions where torque capability in the direction of rotation is approximately one-half the maximum value suggest usable limits of deflection for the controller at $\pm 45^{\circ}$ from the neutral position in roll and $\pm 22\frac{1}{2}^{\circ}$ from the neutral position in pitch.

3. Pilots participating in the tests concluded that the torque associated with the operation of the controller should be from 10 to 26 inch-pounds in roll and from 15 to 36 inch-pounds in pitch.

4. The pilot's arm should be slightly extended so as to form an angle between the upper arm and forearm of between 90° and 130°.

5. In the range of deflection proposed for the controller, the relationship between maximum torque (applied in the direction to increase the deflection) and controller deflection is linear, with the torque decreasing in the direction of rotation.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 29, 1957.

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1. Gough, M. N., and Beard, A. P.: Limitations of the Pilot in Applying Forces to Airplane Controls. NACA TN 550, 1936.

2. Darcus, H. D.: The Maximum Torques Developed in Pronation and Supination of the Right Hand. Jour. Anatomy, vol. 85, Jan. 1951, pp. 55-67.

3. Daniels, Gilbert S., and Hertzberg, H. T. E.: Applied Anthropometry of the Hand. American Jour. Physical Anthropology, vol. 10, no. 2, June 1952, pp. 209-215.

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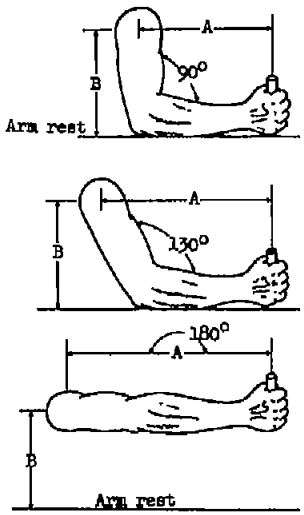
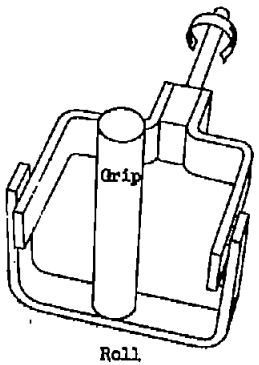
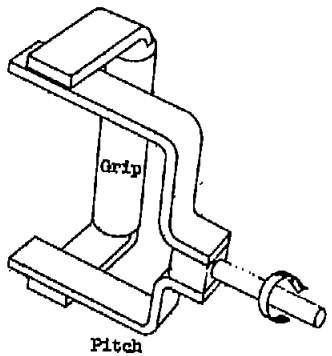
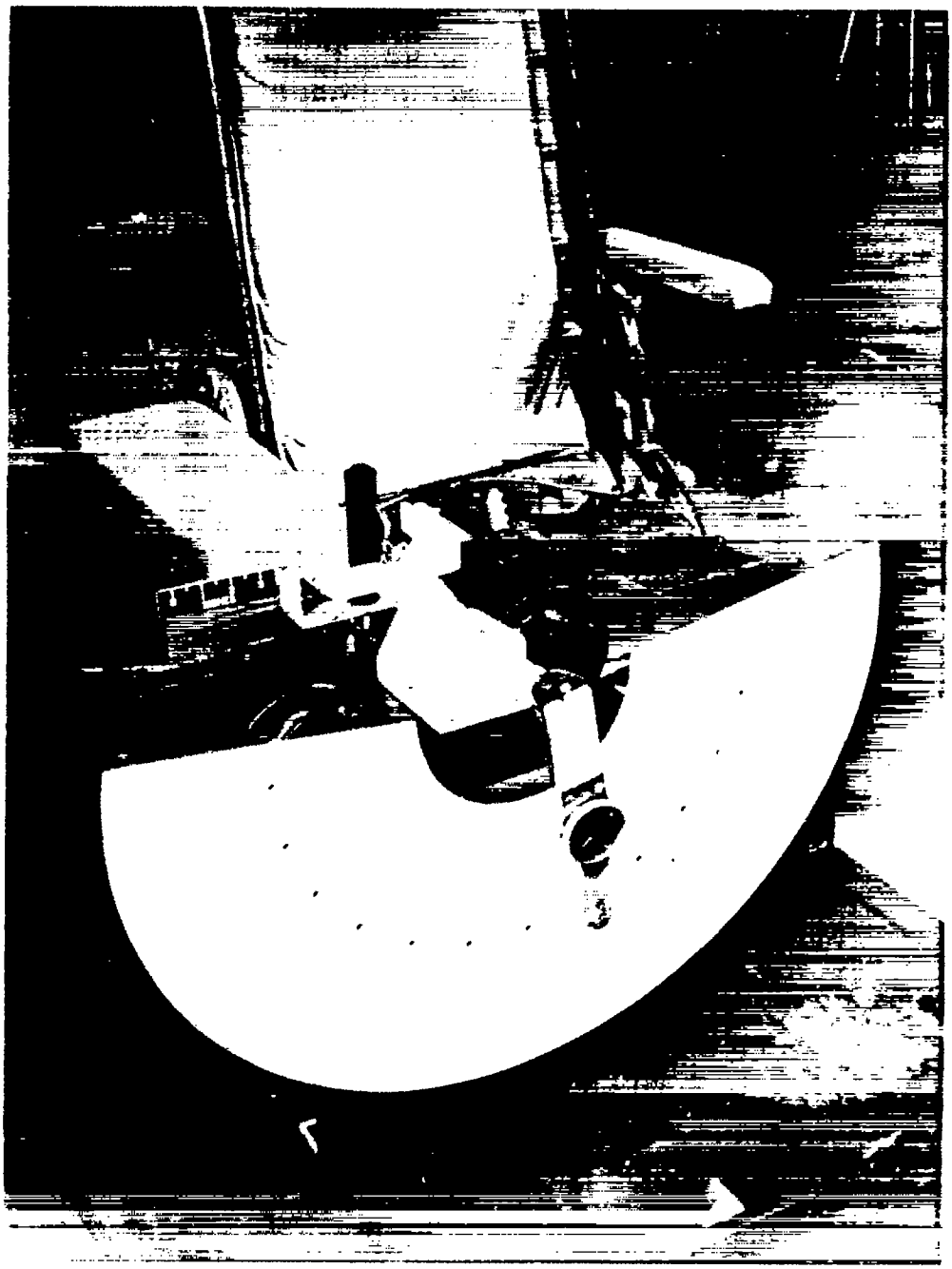
TABLE I.- PHYSICAL DIMENSIONS AND MAXIMUM DEFLECTION CAPABILITIES OF THE PILOTS PERFORMING TESTS





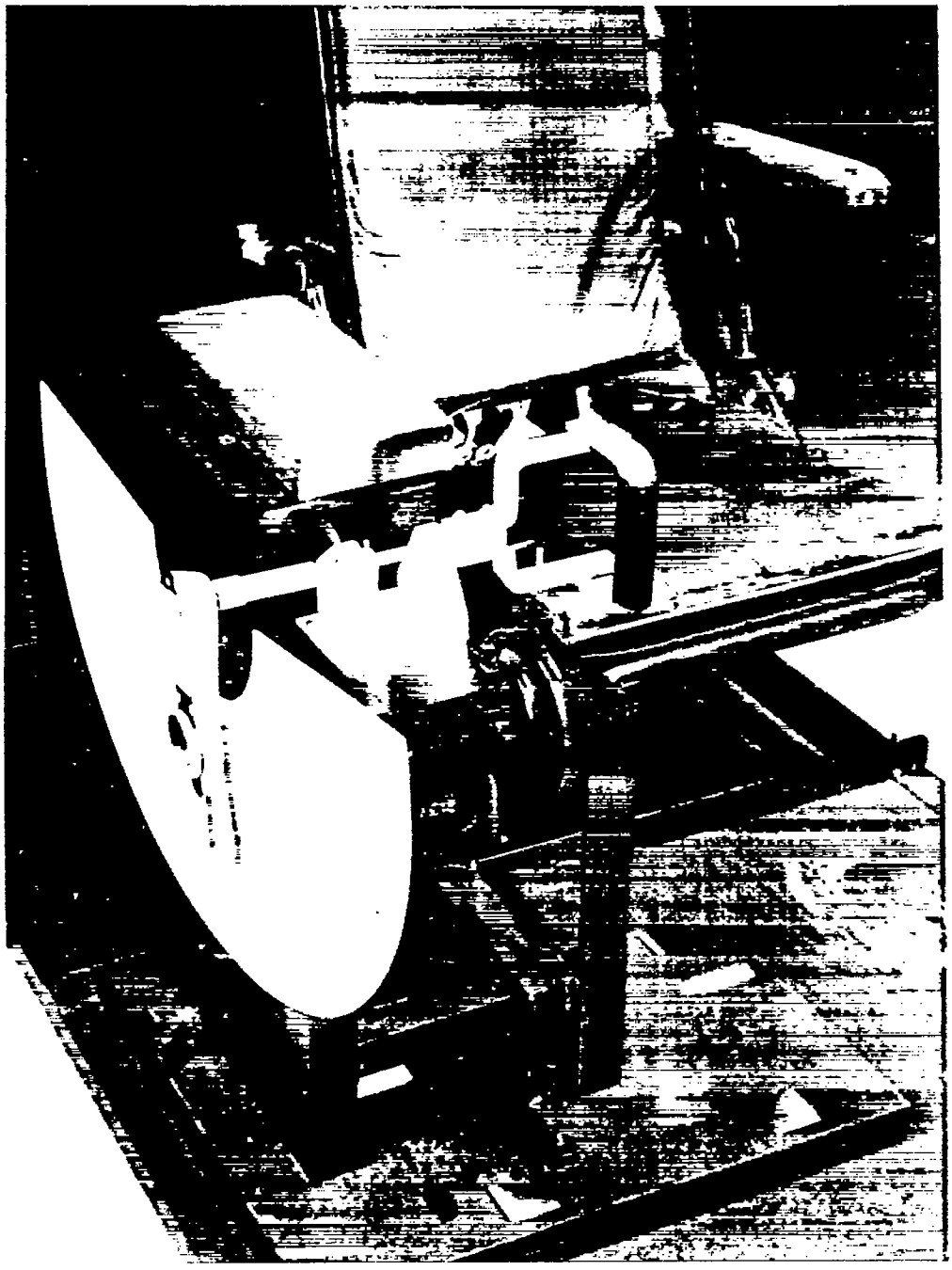


Pilot	Distance A, in.			Distance B, in.		Maximum controller angle (unconstrained), deg							
						Right roll		Left roll		Forward pitch		Rearward pitch	
	Measured at elbow angle of -												
	90°	130°	180°	90°	130°	90°	130°	90°	130°	90°	130°	90°	130°
1	15.00	19.00	26.25	13.00	12.50	105	105	80	75	45	35	30	40
2	11.50	18.00	25.00	12.75	11.50	90	100	90	100	65	70	30	30
3	13.00	18.00	25.00	13.00	12.00	90	90	90	95	55	60	30	35
4	12.00	18.00	25.00	13.00	12.00	85	85	75	80	50	45	30	30
5	14.00	18.50	26.00	13.00	12.50	90	95	90	100	60	65	30	30
6	14.50	18.50	27.00	13.75	13.75	90	100	90	100	75	55	45	40
7	12.50	18.00	25.00	12.75	11.50	90	90	105	105	70	75	30	30
8	13.50	18.50	27.00	13.25	13.00	100	95	100	100	80	75	30	30
9	13.30	18.50	27.00	13.25	13.00	90	90	105	105	45	45	40	40
10	13.00	17.50	27.50	13.75	13.50	90	100	90	105	75	65	55	55
11	14.50	18.75	28.50	13.25	13.75	90	105	90	105	60	75	30	30
Average	13.35	18.30	26.30	13.15	12.63	91.8	96	91.4	97.3	61.8	60.4	34.5	35.0



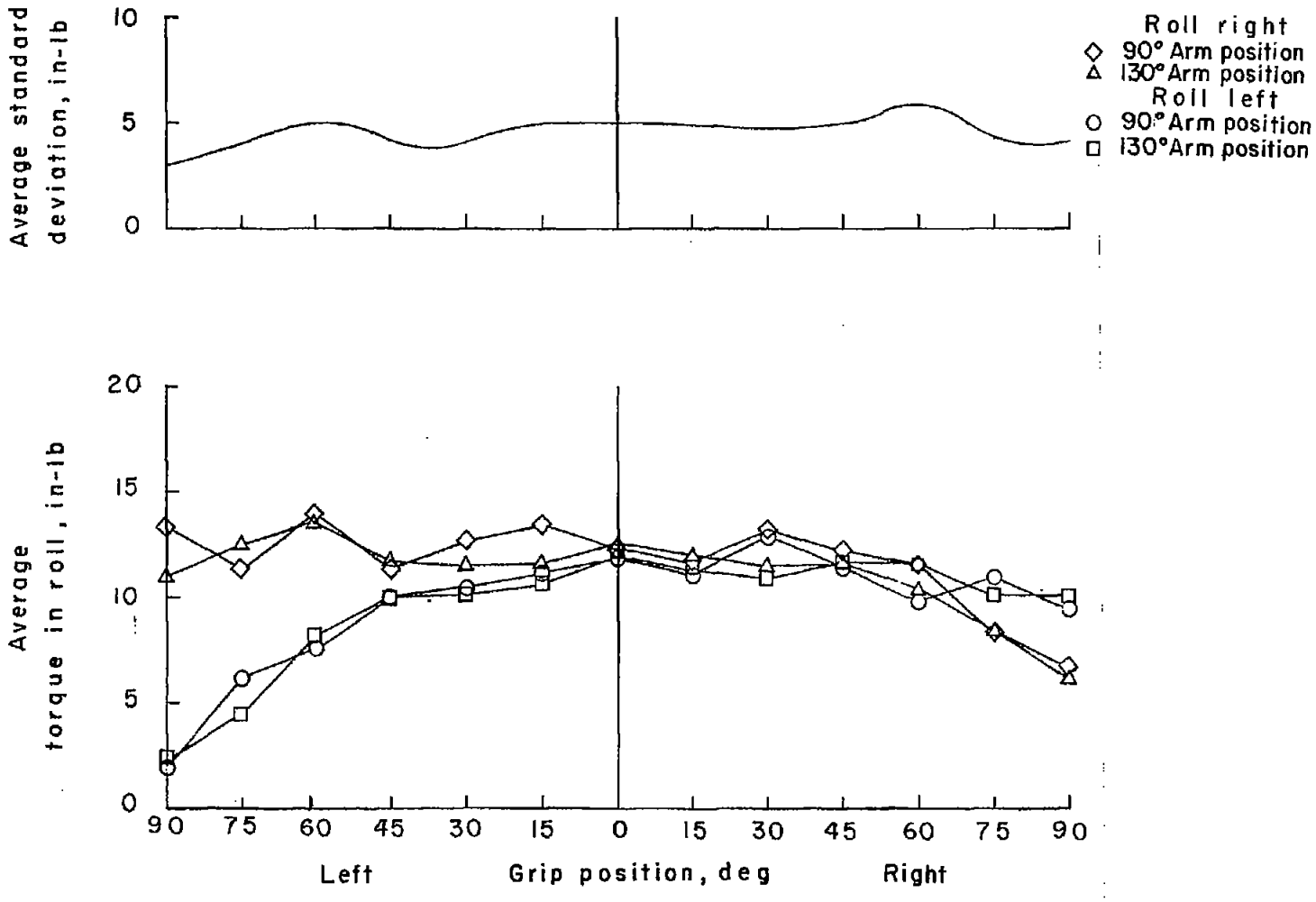
(a) Roll configuration. L-57-1332

Figure 1.- Equipment used to measure forces.



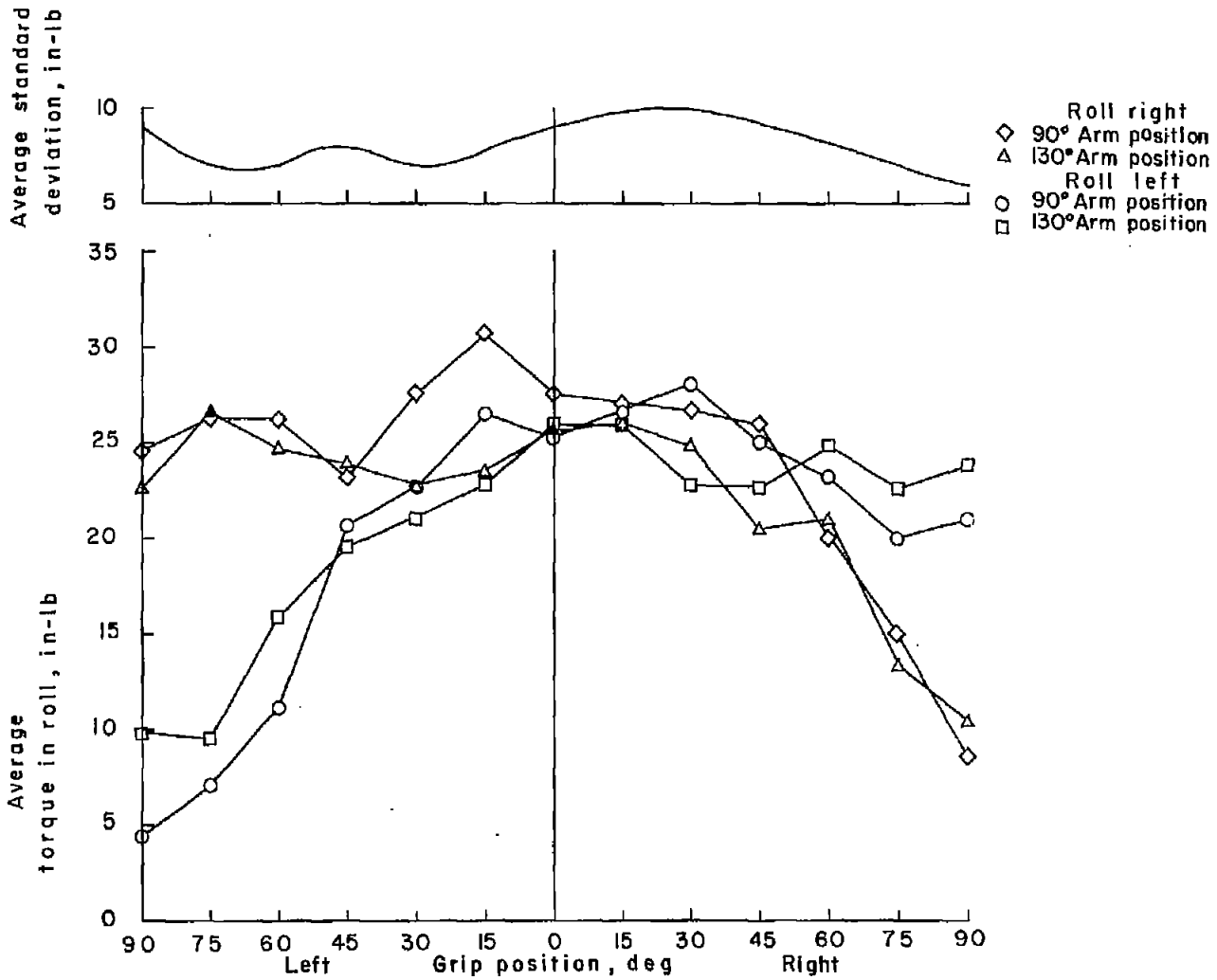
(b) Pitch configuration. L-57-1331

Figure 1.- Concluded.



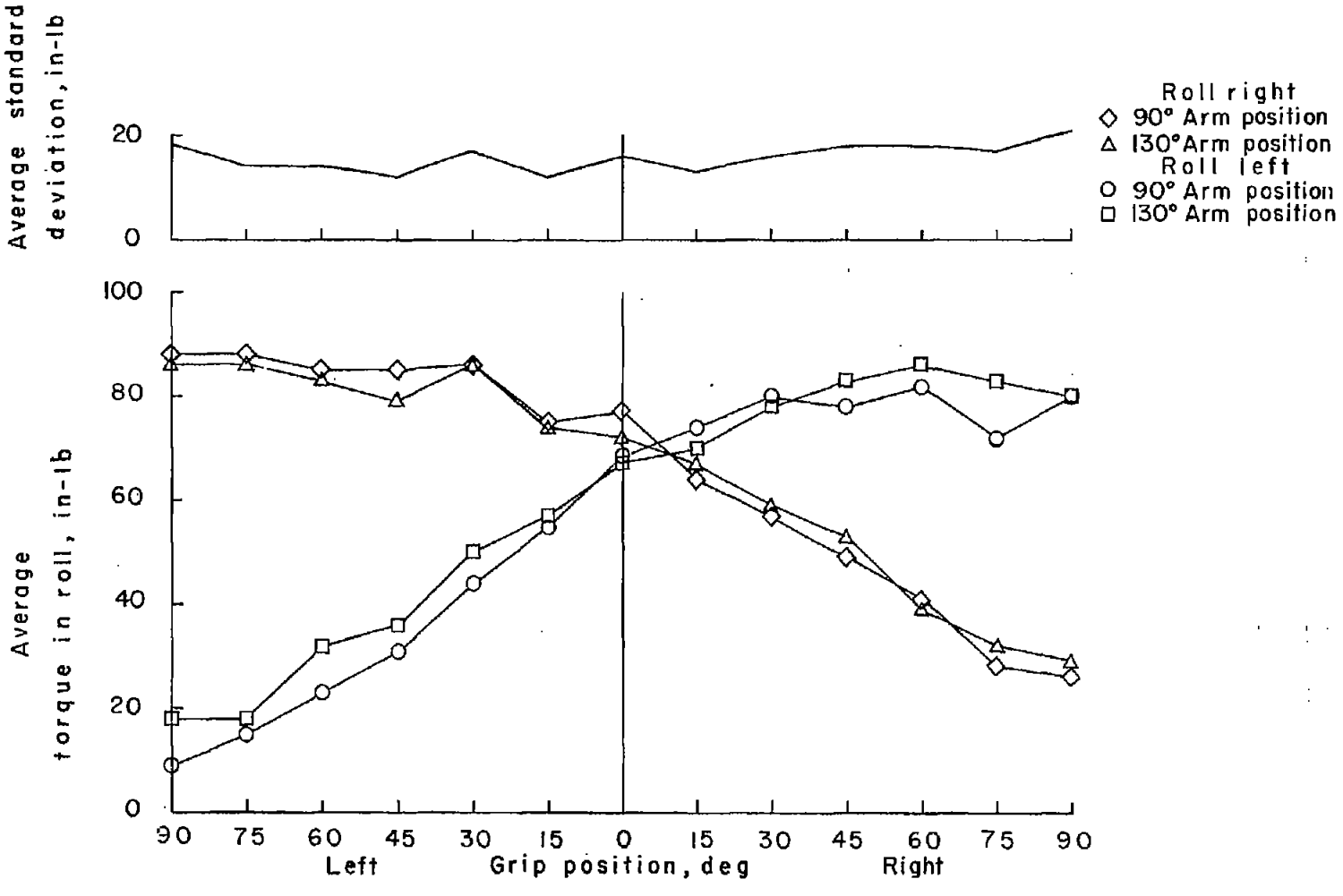
(a) Operational force level.

Figure 2.- Roll torque and average standard deviation.



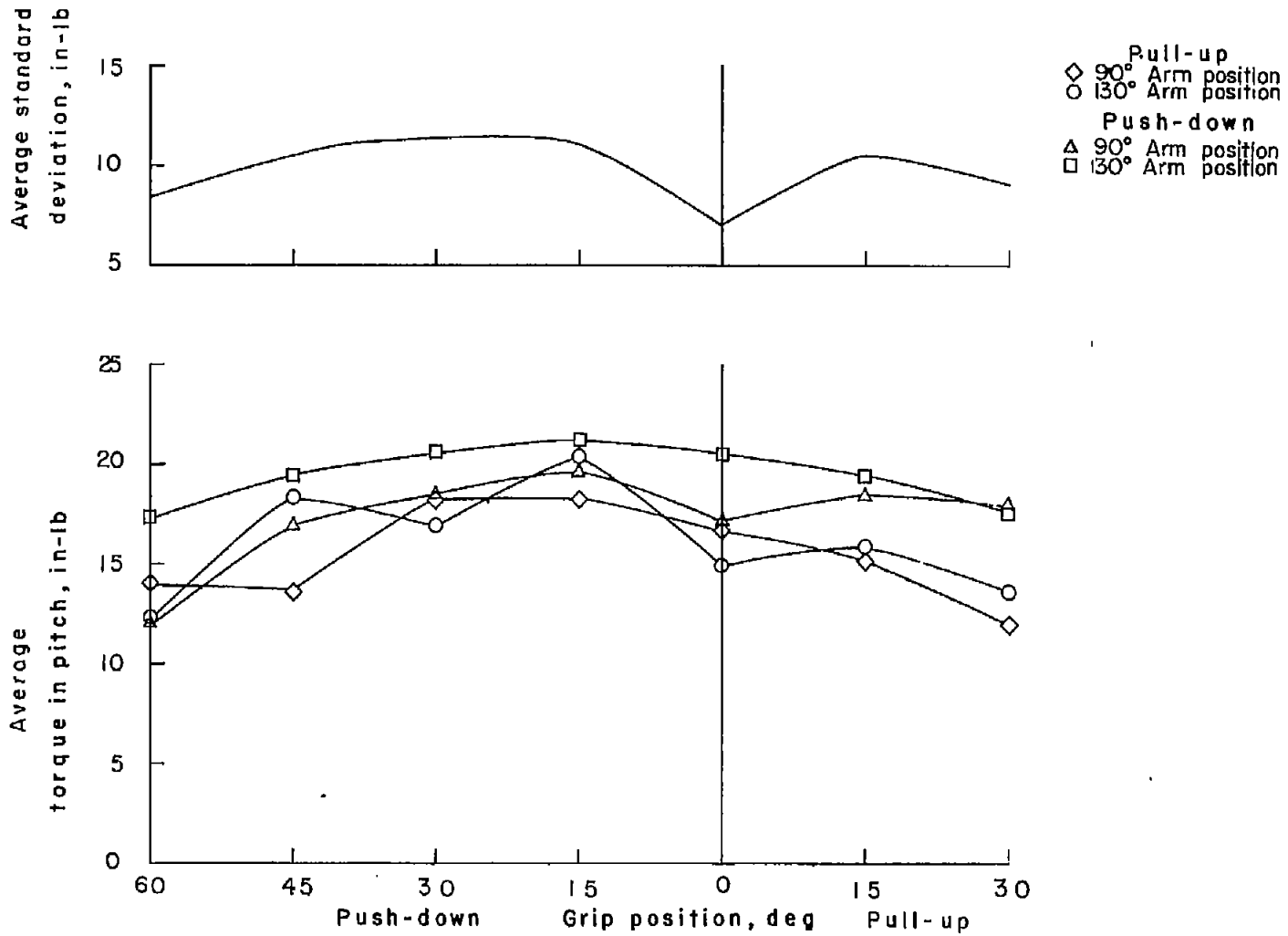
(b) Maximum operational force level.

Figure 2.- Continued.



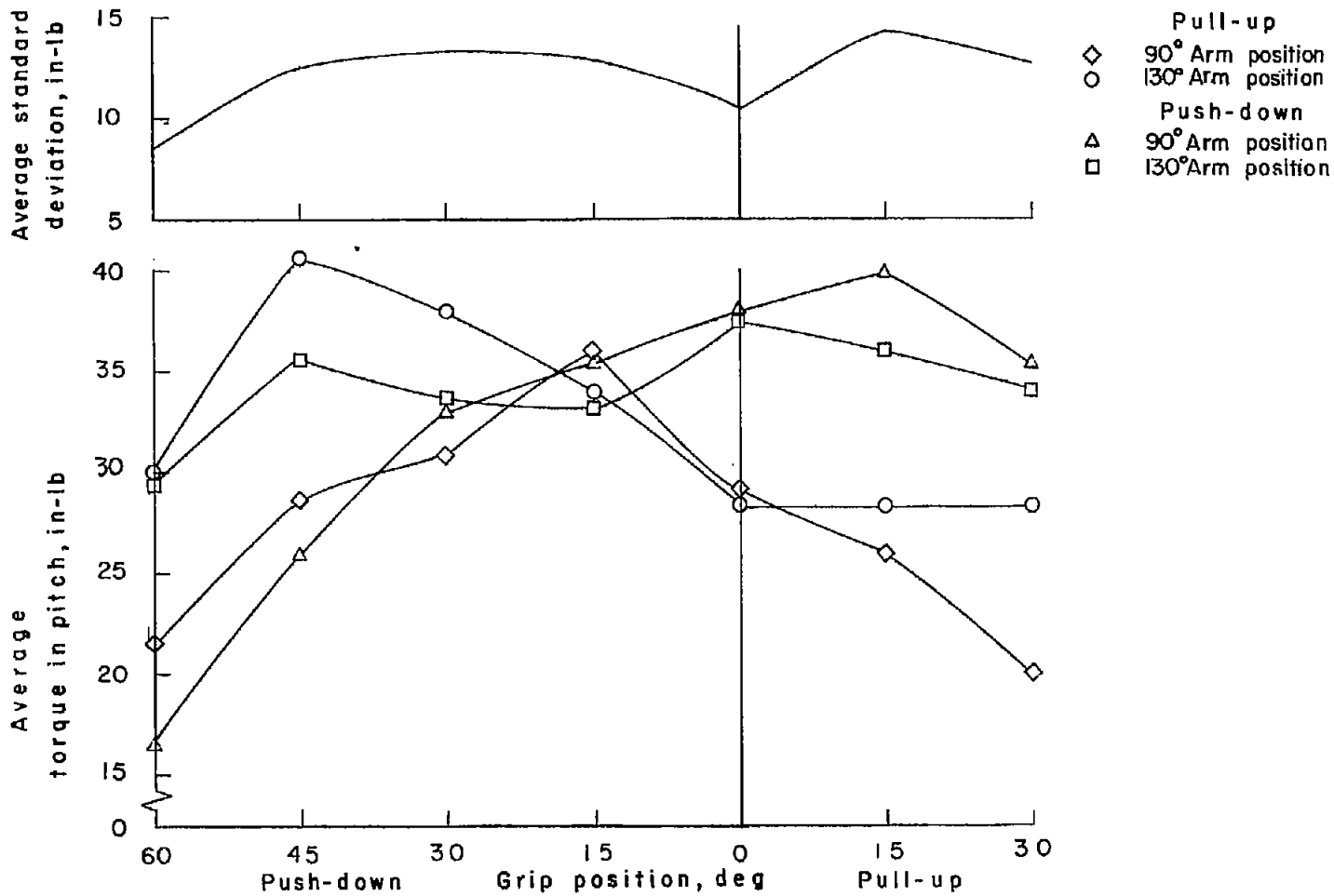
(c) Maximum force level.

Figure 2.- Concluded.



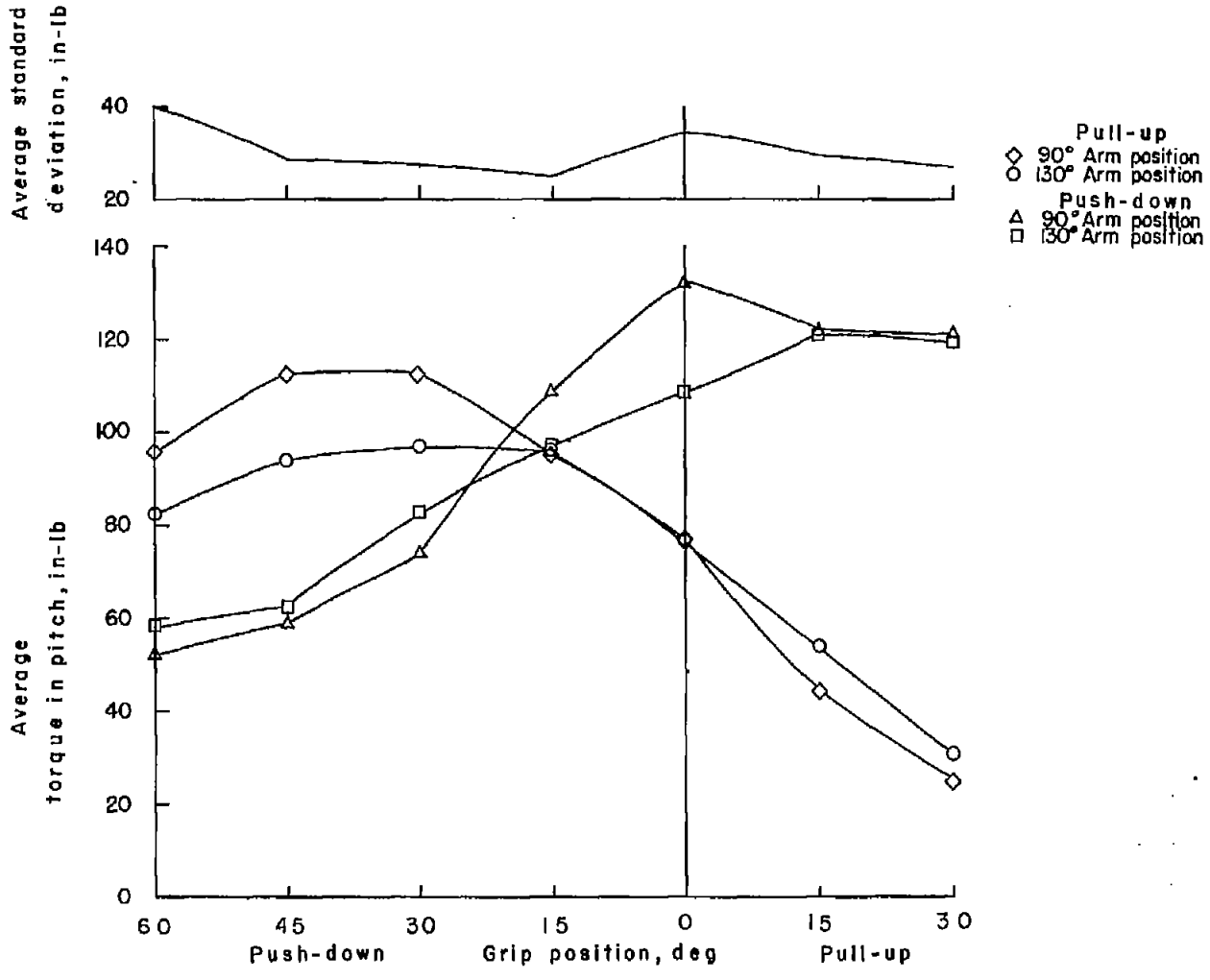
(a) Operational force level.

Figure 3.- Pitch torque and average standard deviation.



(b) Maximum operational force level.

Figure 3.- Continued.



(c) Maximum force level.

Figure 3.- Concluded.

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