NASA Technical Paper 3511

Geometry and Gravity Influences on Strength Capability

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December 1994

This publication is available from the NASA Center for AeroSpace Information,
800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934 (301) 621-0390.

ACKNOWLEDGMENTS

This study, supported by Contract No. NAS9-17900 from the National Aeronautics and Space Administration, was conducted in conjunction with the Anthropometry and Biomechanics Laboratory at the Johnson Space Center in Houston, Texas. We would like to thank Ralph Wemhoff for his assistance in preparing the equipment for the experiment and also Ken Demel, Mark Stuart, and Sudhakar Rajulu for their review of the manuscript.

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INTRODUCTION

Background

Strength, defined as the capability of an individual to produce an external force, is one of the most important determining characteristics of human performance. Knowledge of strength capabilities of a group of individuals can be applied to designing equipment and workplaces, planning procedures and tasks, and training individuals. In the manned space program, with the high risk and cost associated with spaceflight, information pertaining to human performance is of high importance to ensure mission success and safety.

Knowledge of human strength capabilities in weightlessness is of interest within many areas of NASA, including workplace design, tool development, and mission planning. The weightless environment of space places the human body in a completely different context. Astronauts perform a variety of manual tasks while in orbit. Their ability to perform these tasks is partly determined by the strength capability required to complete a particular task. Thus an important step in task planning, development, and evaluation is to determine the ability of the humans performing that task. This can be accomplished by utilizing quantitative techniques to develop a database of human strength capabilities in weightlessness. Furthermore, knowing strength characteristics beforehand, equipment and tools can be built to optimize the operators' performance.

There are many ways of studying human strength. From a basic science perspective, accessing individual muscle tension noninvasively is possible but difficult (Komi, 1988). Isolated joint strength is the total net torque that can be generated by all the muscles crossing a specific joint in one direction of rotation. This is useful in analytical modeling of more complex motions (Pandya et al., 1992). Also, it can be used as a tool for drawing comparisons between conditions such as different subject populations (Rajulu and Klute, 1994) and tasks performed with or without a spacesuit (Wilmington et al., 1994). Strength can also be looked at from a purely applied standpoint, for example in evaluating the amount of force individuals can produce in performing a specific, complex task or sequence of tasks (Rajulu et al., 1994). Thus there is a spectrum of methods for evaluating strength, from basic research to applied engineering. This study examined strength in performing a simple task, specifically, using a tool to apply a torque to a fixture.

Many factors affect how much output an individual can produce: the type and characteristics of the tool used, the location and orientation of the force application, and the position of the operator. In weightlessness there are additional factors such as whether a spacesuit is worn, and the type, location, and orientation of foot restraints and handrails. It is of interest to determine the effect of each of these characteristics on strength, especially in microgravity.

Some of these factors that influence strength production have been studied previously. Poliner et al. (1993) performed a generic examination of the loads produced by individuals performing maximal efforts with a torquing tool. They looked at the effects of orientation and direction of rotation of the tool on strength effectiveness. The subjects in this study produced a range of approximately 400 to 725 N of force, depending on the orientation of the tool and the direction of effort. The maximum force was produced when the tool was pushed in an upward direction.

Wilmington et al. (1994) looked at the influence of foot restraint pitch angle and direction of force application on the loads produced on a tool. Pitch angle was not seen to influence force production. The direction of force application, however, did influence production with the greatest forces produced when the operator was performing an upward effort. The mean force values ranged from approximately 300 to 700 N. Both of these investigations looked at a wide range of tool orientations and directions of effort. However, many factors were not investigated, including the location of the task relative to the operator as well as the data from conducting the task in Earth's gravity.

Purpose

This study examined the strength of individuals performing a torquing task as a function of gravity and geometry of the task relative to the person's body. Specifically, the purpose was to determine

- the maximum amount of torque individuals can produce while performing a representative task
- how the location of a task relative to the operator influences strength
- how the orientation of the task and tool influences strength
- if influences are different in 1 g and 0 g

It was anticipated that all of these factors would influence the amount of torque that individuals could produce.

METHODS

Apparatus

A general purpose test stand was equipped for this study (fig. 1). The stand was approximately 183 cm (72 in) tall, 91 cm (36 in) wide, and 137 cm (54 in) long in an "L" shape. Positioned at the work location of the test stand were three custom built multinode torque application fixtures (TAF), each with five 1.11 cm (7/16 in) hex fittings oriented along three orthogonal axes (fig. 2). The TAFs were located at heights of 114.3 cm , 138.4 cm, and 162.6 cm (45, 54.5, and 64 in) from the base, displaced 16.5 cm (6.5 in) to the right of the midline. Fittings extended 19.1 cm (7.5 in) from the base of the TAF.

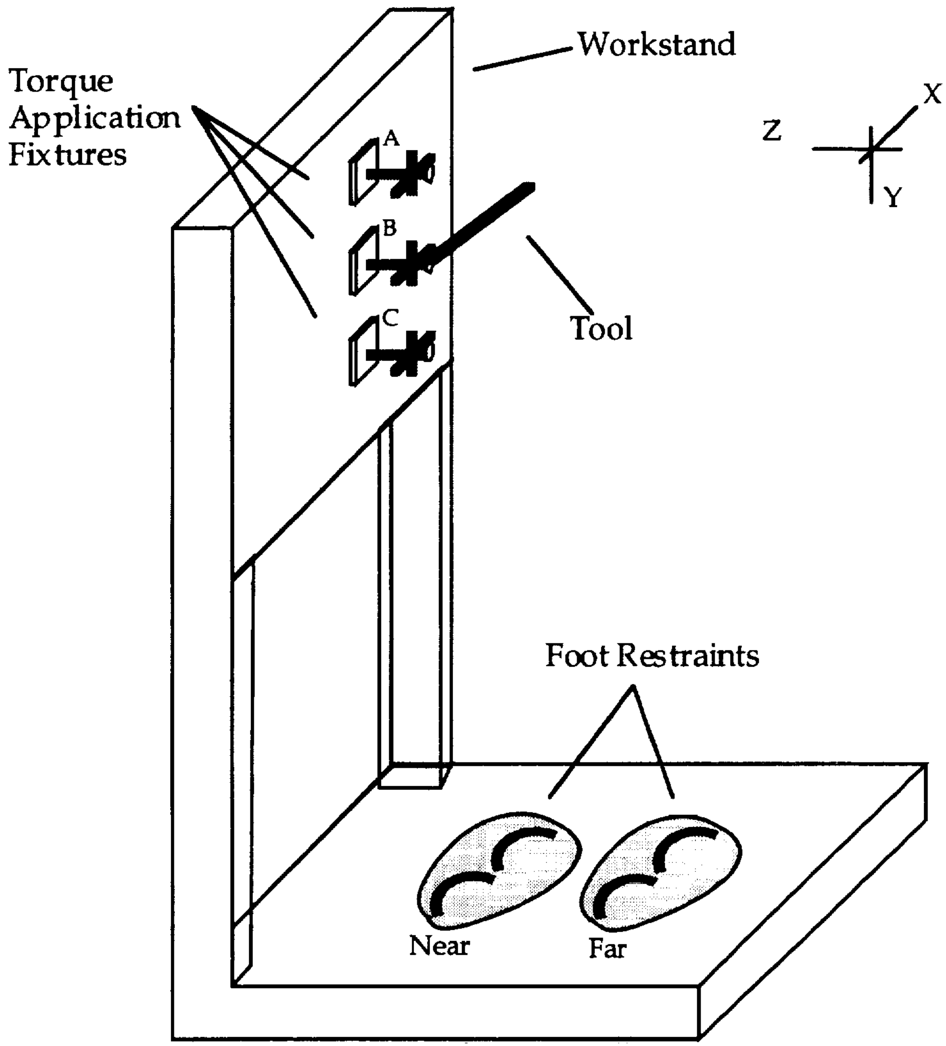

Figure 1. Test apparatus setup.

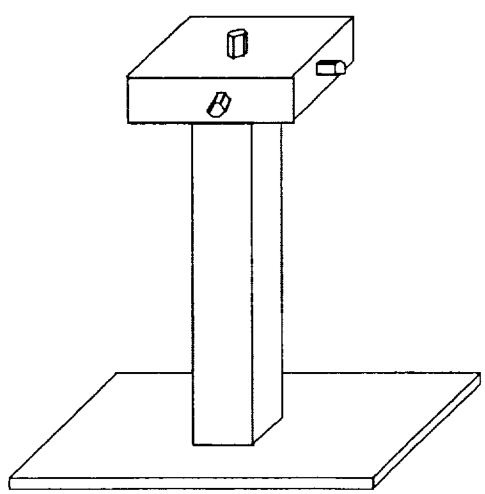

Figure 2. Torque application fixture (TAF).

An instrumented torque wrench (model #1150-200, GSE, Inc., Farmington Hills, MI) was used as the tool in this study. The wrench had a padded handle centered at a distance of 22.86 cm (9 in) from the center of the socket.

Two sets of foot restraints were set up at the base of the test stand. The restraints were similar to the system currently in use on the Space Shuttle. They consisted of loops of cloth held down on the floor surface. They were positioned at distances of 52.7 and 83.2 cm (20.75 and 32.75 in) from the plane of the work surface. On the Shuttle, the crewmembers position the foot restraints wherever they feel they will work best; there are no preset locations. The positions used in this study were felt to represent typical locations that crewmembers may choose.

A global coordinate system was defined (fig. 1) in which the Y-axis was parallel to the longitudinal axis of the subject's body (head to foot), the X-axis corresponded to the mediolateral axis of the subject's body (left to right), and the Z-axis was perpendicular to the coronal plane of the subject's body (back to front).

There were two phases of this project, ground-based (1 g) and weightless (0 g). The 1-g phase was conducted in the Anthropometry and Biomechanics Laboratory at Johnson Space Center. In addition to familiarizing the subjects and test conductors with the procedures in a less critical environment, the ground-based part of the study provided data to serve as a basis of comparison for the 0-g data.

Testing for the 0-g phase was conducted aboard NASA's reduced gravity aircraft, the KC-135, which simulates brief periods of weightlessness. The KC-135 is a modified jet that is capable of flying parabolic arcs with a vertical acceleration equal to the acceleration due to gravity. Thus during the parabola, passengers and equipment within the plane experience virtual 0 g. Each parabola lasts approximately 25 seconds, with a typical flight consisting of 40 parabolas. This experiment was conducted over three flights. The test stand was mounted on the KC-135 aircraft, using six 0.95 cm (3/8 in) bolts. In both test environments, a data acquisition system (Ariel Performance Analysis System) was mounted near the stand. Two video cameras were positioned nearby to record the study.

Subjects

Subjects for this study were male volunteers recruited from the NASA and contractor work force. All subjects passed an Air Force Class III physical and signed an informed consent to be in the study acknowledging their understanding of the procedures and risks. A total of thirteen subjects were tested in 1 g, eight of whom flew on the KC-135 and participated in the 0-g testing.

Experimental Design

This study implemented a randomized block design using the variables of foot restraint location (FRL), task location (TL), tool orientation (TO), and direction of effort (DE).

The two FRLs were identified by Near and Far. Test fixtures were set at three task locations and labeled A-High, B-Mid, and C-Low. For each task location, four tool orientations (TO) were used. These were labeled 'D,' 'E,' 'F,' and 'G.' Figure 3 and table 1 present these orientations and describe the node the socket was placed on and the axis alignment of the tool handle for each of the TOs. Table 1 gives the directions of effort, both in the global coordinate system and relative to the subject's body.

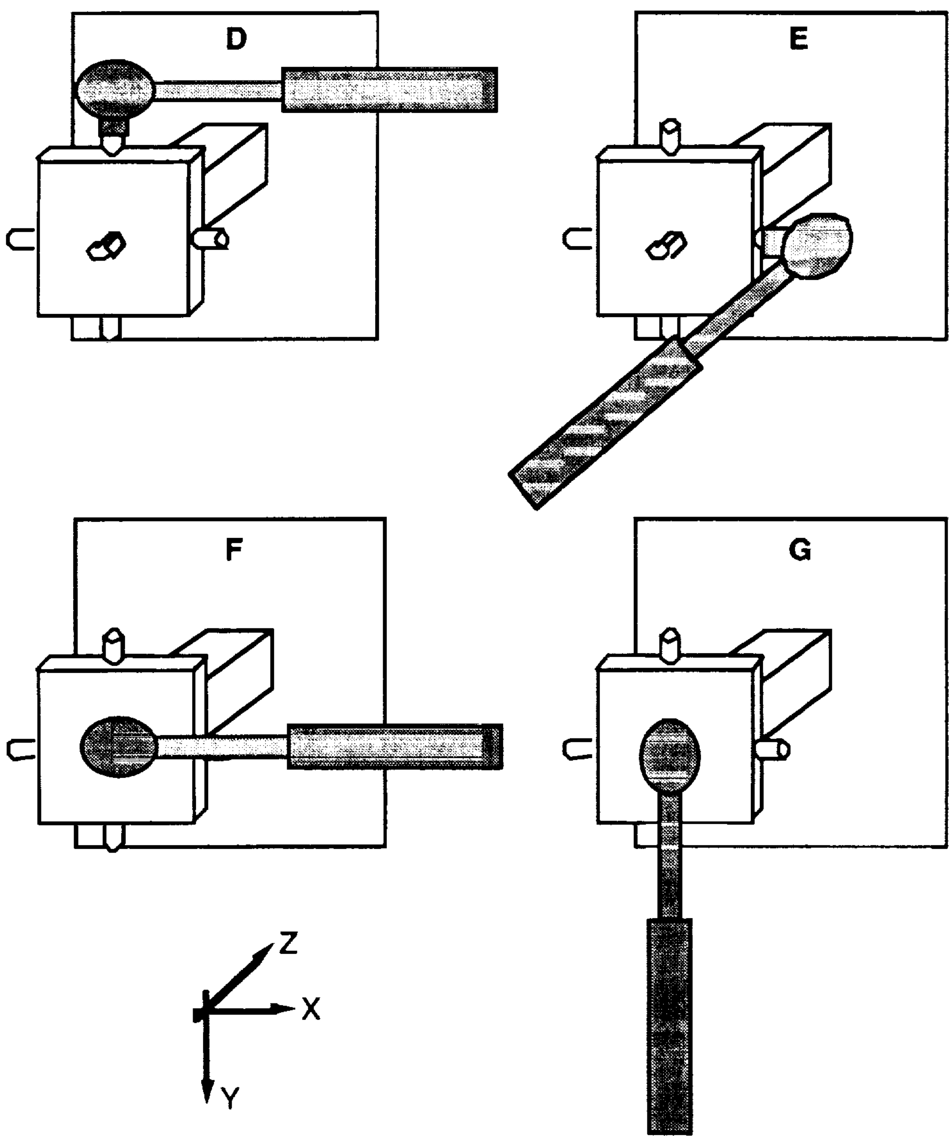

Figure 3. Demonstration of the four tool orientations.

Table 1. Definitions of Tool Orientations

Tool Orientation	TAF Node	Tool Orientation Axis	DIRECTION OF EFFORT (CW/CCW) GCS	Subject
D	-Y	+X	-Z/+Z	towards/away
E	+X	-Z	-Y/+Y	up/down
F	-Z	+X	+Y/-Y	down/up
G	-Z	+Y	-X/+X	left/right

Thus there were 48 conditions to be tested (2 FRL x 3 TL x 4 TO x 2 DE). Each subject performed one trial for each of the 48 conditions. Four trials were performed during each parabola on the KC-135. Conditions were randomized and balanced within each subject's twelve parabolas.

Procedures

Before the onset of 0 g, the subject was reminded of the four trials he would perform. The subject stood with his stocking feet in the specified foot restraint. His left hand grasped the head of the wrench or hung free. With his right hand, he positioned the tool on the designated fitting and in the first orientation for that parabola. He produced a maximal effort on the tool first in one direction (clockwise or counterclockwise) and then in the opposite direction, with a brief pause in between. Next, he repositioned the tool to the second orientation and produced two more maximal efforts in opposite directions. Subjects alternated performing the torquing tasks in sets of six parabolas with a rest between sets to minimize fatigue.

Only the right hand was tested. The left hand was either held free or grasped the tool at the socket head.

Data Collection and Analysis

Torque data were collected from the torque wrench at a rate of 250 Hz for the duration of the 0-g interval and stored on the computer hard disk. Processing of the data involved determining the peak torque during each of the trials.

An analysis of variance (ANOVA) was performed on the data to determine which of the factors (FRL, TL, TO, and DE) had a significant effect on torque production. Post hoc analyses were performed with a significance level of 0.05 to determine what the differences were between conditions.

Of the thirteen subjects in the 1-g study, data were collected from only ten. Complete data were collected from only six of the eight who participated in the 0-g study. Not all of those subjects who produced good data from the 0-g study had data from the 1-g study. A summary of the subjects whose test resulted in good data in each phase is presented in table 2. Because there were complete data from both 0 g and 1 g from only four subjects, each set of data was analyzed separately.

Table 2. Summary of Subjects Whose Tests Resulted in Good Data

1-G DATA GOOD	TESTED IN 0-G	COMPLETE DATA IN 0-G	NUMBER OF SUBJECTS
YES	YES	YES	4
YES	YES	NO	1
YES	NO	--	5
NO	YES	YES	2
NO	YES	NO	1
NO	NO	--	0

RESULTS

Phase 1 - Weightless

Numerical Presentation

Raw results from this study appear in the tables below. Table 3 presents the means of the torque produced by all subjects for each combination of the test conditions. All values are in newtons-meters (Nm); note that 1 Nm is equivalent to 0.737 ft-lb. Since a tool with a 22.9 cm (9 in) moment arm was used, the values in table 3 can be multiplied by 4.37 to obtain the force applied to the tool in N (1 N is equivalent to 0.225 lb). Overall, the average torque produced by these subjects was 67.0 Nm.

Table 3. Numerical Results from 0-g Experiment - Average of All Subjects' Data

	Direction of Effort		FRL=Near			FRL=Far		
TO	Relative	Absolute	High	Mid	Low	High	Mid	Low
D	CW	towards	48.8	58.4	55.2	61.8	61.5	60.2
D	CCW	away	45.2	58.2	55.8	61.4	59.5	68.4
E	CW	up	66.4	107.0	86.9	64.5	91.5	83.5
E	CCW	down	73.9	77.3	78.0	79.7	79.3	70.4
F	CW	down	78.9	73.1	79.4	73.9	69.8	64.5
F	CCW	up	73.1	94.8	63.8	59.2	80.7	68.7
G	CW	left	61.3	65.4	62.4	66.1	74.9	65.7
G	CCW	right	43.8	47.1	52.2	47.7	53.8	44.1

Graphical Presentation

These data are repeated graphically in figure 4. Each graph presents the data from one of the three task locations. Each combination of tool orientation and direction of effort is shown. The statistical analyses revealed that there were no differences due to the foot restraint location. Thus for these graphs, the data from the two foot restraint locations were combined. Error bars indicate ±1 standard deviation from the mean. Note that the scales on the torque axis are not the same on all graphs. Refer to figure 3 for a display of each of the tool orientations.

Statistics

An analysis of variance (ANOVA) was performed on these torque data with the independent variables of foot restraint location (FRL), task location (TL), tool orientation (TO), and direction of effort (DE). A summary table from the ANOVA is given below.

Table 4. Results from Analysis of Variance of Torque Data from the 0-g Study

	DF	Sum of Squares	Mean Square	F-Value	P-Value
TL	2	4800.5	2400.2	4.544	.0114
TO	3	32588.4	10862.8	20.563	<.0001
TL * TO	6	2272.2	378.7	.717	.6363
DE	1	3052.5	3052.5	5.778	.0169
TL * DE	2	83.6	41.8	.079	.9239
TO * DE	3	4620.7	1540.2	2.916	.0346
TL * TO * DE	6	6770.4	1128.4	2.136	.0494
FRL	1	3.3	3.3	.006	.9367
TL * FRL	2	299.3	149.6	.283	.7535
TO * FRL	3	3239.5	1079.8	2.044	.1079
TL * TO * FRL	6	1016.4	169.4	.321	.9259
DE * FRL	1	31.9	31.9	.060	.8060
TL * DE * FRL	2	32.8	16.4	.031	.9694
TO * DE * FRL	3	405.6	135.2	.256	.8571
TL * TO * DE * FRL	6	1591.2	265.2	.502	.8067
Residual	288	152140.9	528.3		

The torque produced was significantly influenced by the variables of task location (TL), tool orientation (TO), and direction of effort (DE) as well as the interactions of TO*DE and TL*TO*DE. The foot restraint location had no effect on the torque produced. Post hoc analyses were performed to see how each of these variables affected torque production. The results of these are presented in figures 5 and 6.

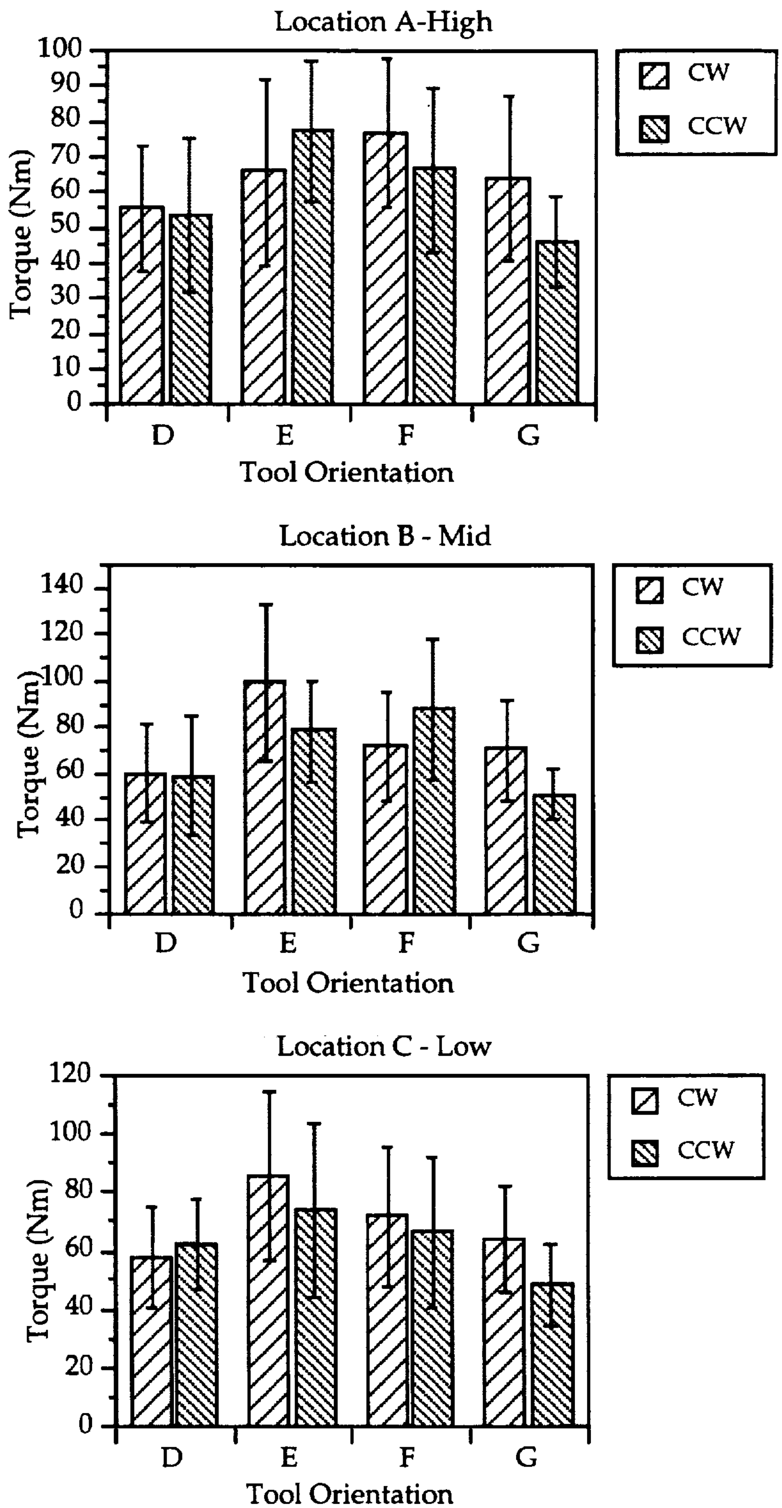

Figure 4. Raw data for the three task locations.

Effect of Location

Figure 5 presents the data averaged over all trials for each of the three task locations. There was a significant difference in the torque produced at locations A (62.9 Nm) and B (72.0 Nm). Location C (66.2 Nm) did not differ from the other two.

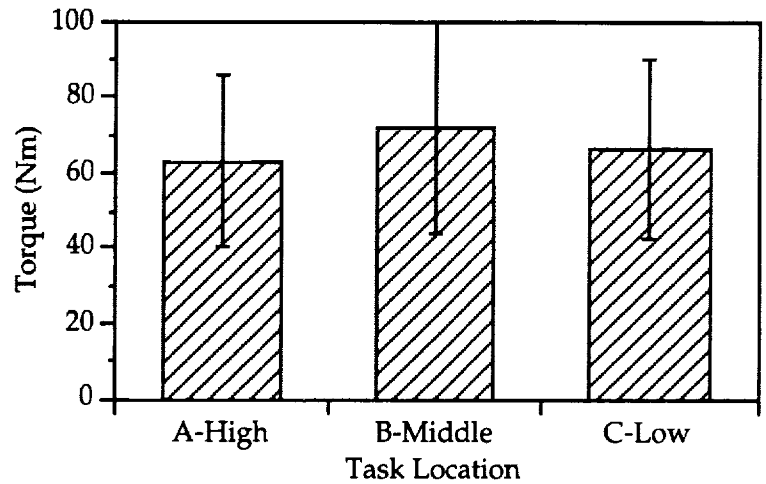

Figure 5. Effect of task location on torque produced in 0 g.

Effect of Orientation and Direction

Table 5 and figure 6 present the effects of tool orientation and direction of effort on torque production. Orientations E and F were seen to be significantly greater than orientations D and G. Taken as a whole, clockwise rotations were significantly greater than counterclockwise ones. The greatest clockwise/counterclockwise difference was seen with orientations G and E. Refer to table 2 and figure 3 to relate these DE to directions relative to the subject.

Table 5. Effects of Tool Orientation and Direction of Effort on Torque Production

Tool Orientation	Direction of Effort CW	CCW	avg
D	57.6	58.1	57.9
E	83.3	76.4	79.8
F	73.3	73.4	73.3
G	66.0	48.1	57.0
avg	70.0	64.0	

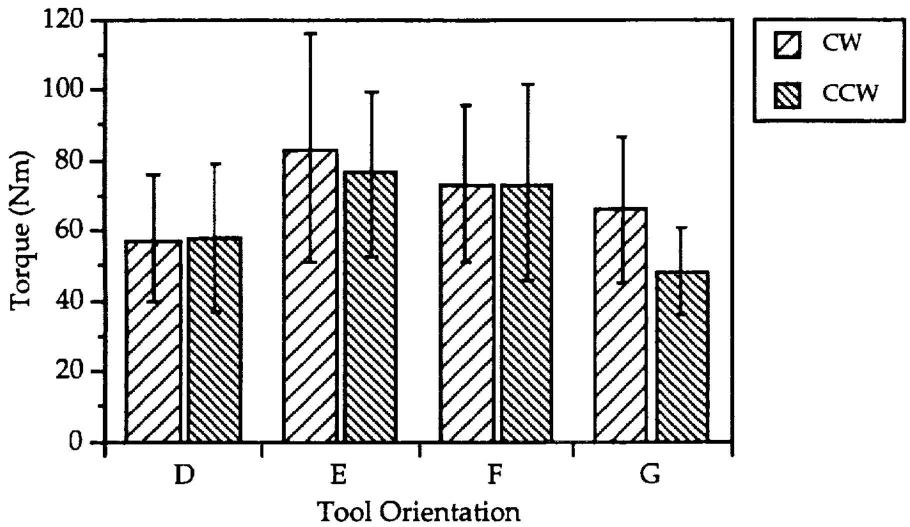

Figure 6. Torque produced as a function of tool orientation and direction of effort.

Phase II - Ground-Based

Numerical Presentation

The results from the ground-based part of this study appear in table 6. It presents the means of the torque produced by all subjects who participated in this experiment for each combination of the test conditions. All values are in Nm. Note that 1 Nm is equivalent to 1.36 ft-lb. Overall, the average torque produced by these subjects was 82.1 Nm.

Table 6. Numerical Results from the Ground-Based Experiment - Average of All Subjects' Data

	Direction of Effort		FRL=Near			FRL=Far		
TO	Relative	Absolute	High	Mid	Low	High	Mid	Low
D	CW	towards	86.6	90.0	90.4	90.1	98.2	99.5
D	CCW	away	65.6	73.4	76.2	74.6	90.7	77.8
E	CW	up	79.7	109.0	88.8	71.3	87.6	81.0
E	CCW	down	87.6	91.3	99.5	91.1	80.7	90.5
F	CW	down	81.6	99.0	92.1	77.9	83.4	86.3
F	CCW	up	78.7	101.0	73.9	70.8	88.7	80.2
G	CW	left	82.3	92.2	74.3	72.7	85.0	65.7
G	CCW	right	76.6	63.6	68.2	63.9	58.4	55.1

Graphical Presentation

These data are repeated graphically in figure 7. Each graph presents the data from one of the FRL/TL combinations. Each combination of tool orientation and direction of effort is shown. Error bars indicate ±1 standard deviation from the mean. Note that the scales on the torque axis are not the same on all graphs. Refer to figure 3 for a display of each of the tool orientations.

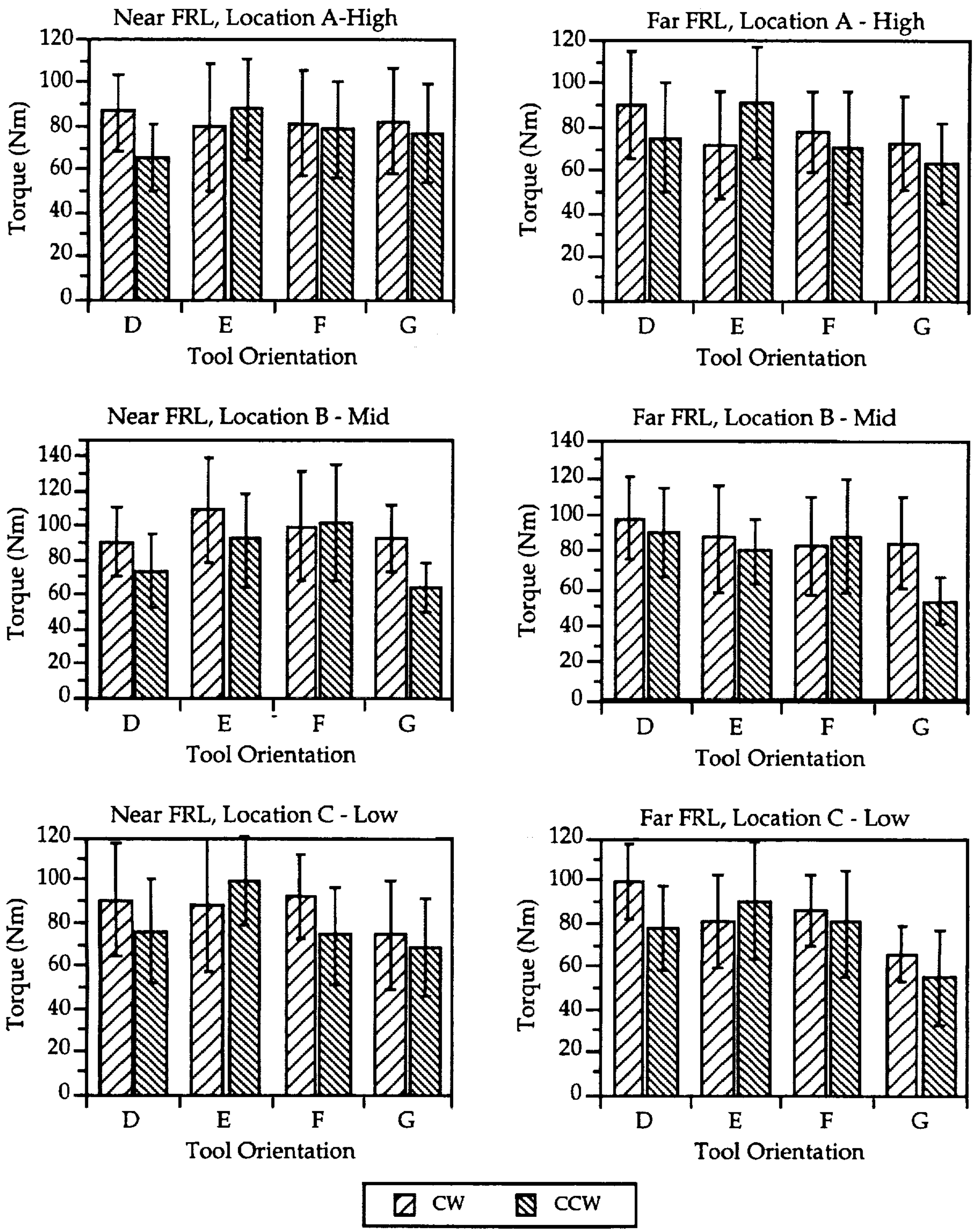

Figure 7. Raw data for the various foot restraint task locations of the ground-based experiment.

Statistics

An analysis of variance (ANOVA) was performed on these torque data with the independent variables of foot restraint location (FRL), task location (TL), tool orientation (TO), and direction of effort (DE). A summary table from the ANOVA is given below.

Table 7. Results from Analysis of Variance of the Torque Data from the Ground-Based Experiment

	DF	Sum of Squares	Mean Square	F-Value	P-Value
TL	2	6411.4	3205.7	5.807	.0032
TO	3	19044.8	6348.3	11.500	<.0001
TL * TO	6	4397.7	732.9	1.328	.2433
DE	1	7159.9	7159.9	12.970	.0004
TL * DE	2	1256.5	628.3	1.138	.3214
TO * DE	3	7819.7	2606.6	4.722	.0030
TL * TO * DE	6	6815.9	1136.0	2.058	.0570
FRL	1	2083.6	2083.6	3.774	.0527
TL * FRL	2	166.7	83.3	.151	.8599
TO * FRL	3	6186.0	2062.0	3.735	.0113
TL * TO * FRL	6	2253.3	375.6	.680	.6656
DE * FRL	1	229.1	229.1	.415	.5198
TL * DE * FRL	2	207.9	103.9	.188	.8284
TO * DE * FRL	3	309.8	103.3	.187	.9052
TL * TO * DE * FRL	6	830.0	138.3	.251	.9590
Residual	430	237369.7	552.0		

2 cases were omitted due to missing values.

The torque produced was seen to be significantly influenced by the variables of task location (TL), tool orientation (TO), and direction of effort (DE) as well as the interactions of TO*DE and TO*FRL. A cutoff of 0.05 was used to determine statistical significance. The effects of FRL and TL*TO*DE were very close to this cutoff. Post hoc analyses were performed to see how each of these variables affected torque production. The results of these are presented in the figures that follow.

Figure 8 presents the data averaged over all trials for each of the three task locations. There was a significant difference in the torque produced at locations A (78.2 Nm) and B (87.0 Nm), and between B and C (81.4 Nm).

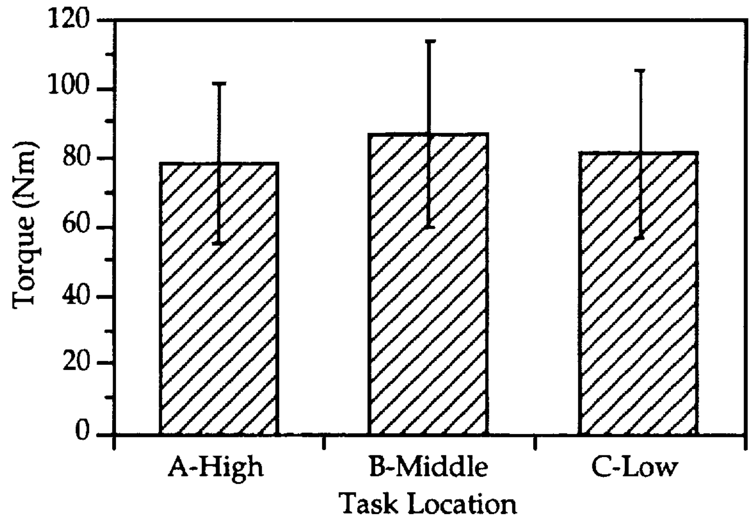

Figure 8. Effect of task location on torque produced in the ground-based study.

Table 8 and figure 9 present the effects of tool orientation and direction of effort on torque production. Orientation G was seen to be significantly less than orientations E, F, and G. Taken as a whole, clockwise rotations were significantly greater than counterclockwise ones. Refer to table 2 and figure 3 to relate these DE to directions relative to the subject.

Table 8. Effects of Tool Orientation and Direction of Effort on Torque Production in the Ground-Based Study

Tool Orientation	Direction of Effort CW	CCW	avg
D	92.5	76.4	84.4
E	86.2	90.1	88.1
F	86.8	82.3	84.5
G	78.7	64.5	71.6
avg	86.0	78.4	

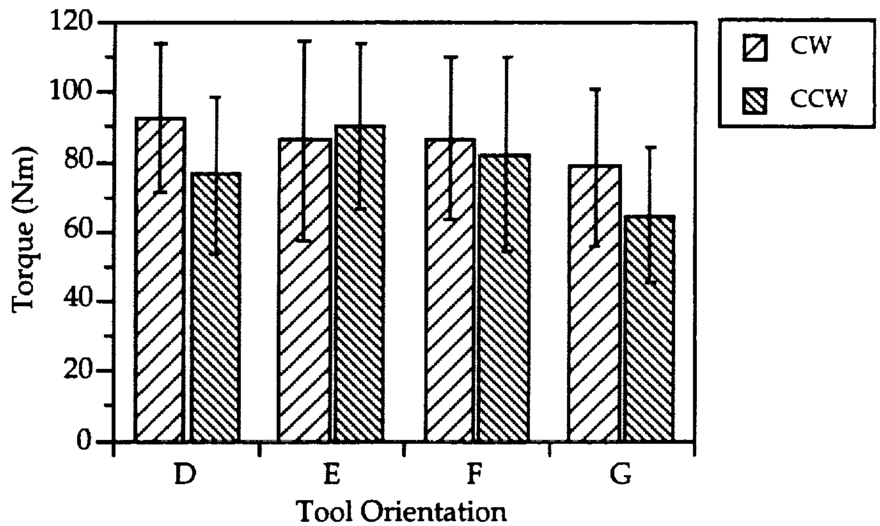

Figure 9. Torque produced as a function of tool orientation and direction of effort for the ground-based study.

DISCUSSION

This study was an examination of the strength of individuals performing a torquing task as a function of gravity and the geometry of the task relative to the person's body. Specifically, the purposes were to determine

- the maximum amount of torque individuals can produce while performing a representative task
- the influence of the location of a task relative to the operator on strength
- how strength is influenced by the orientation of the task and tool
- if influences are different in 1 g and 0 g

In reviewing the results, several things should be pointed out. First, although only one specific task was examined, this task was general enough that much can be learned from it and the data can be generalized to a variety of tasks. The results can be applied to any task in which the operators are producing a force on an object in front of themselves while their feet are held down by foot restraints, for example, moving on ORU. Second, a relatively small number of subjects participated in the study. Thus care must be taken in extending the absolute values of the results to other subject populations such as the astronaut corps.

The instrumented torque wrench used in this study was uni-axial. It measured the moment transmitted to the fixture. Within this discussion, reference is made to the force applied to the tool. However, it must be kept in mind that this refers only to that component of the applied force perpendicular to the tool in the direction of rotation of the tool. Previous studies (Poliner et al., 1993; Wilmington et al., 1994) defined a force effectiveness ratio (FER) as a measure of the amount of a force application that actually goes towards producing a torque in the desired direction. They reported FERs of between 0.65 and 0.97, depending on the direction of effort.

It was seen that the subjects in weightlessness could produce an average of 67 Nm of torque on the tool. This is equivalent to a force of 293 N. In Earth's gravity, the subjects could produce an average of 82 Nm of torque or 359 N of force. Thus in weightlessness, there was a reduction in strength of approximately 18%. It must be noted that different sets of subjects were used for the two tests. Using only the four subjects who provided good data in both experiments gave a reduction of 17%. For every combination of test conditions, the 0-g value was less than the 1-g (compare tables 4 and 7). This information is useful. Access to a microgravity environment is very limited. Knowing the relationship between 1 g and 0 g measurements of a task allows for future testing in 1 g with extension of the results to 0 g.

In both 1 g and 0 g, the torque production was seen to be influenced by the vertical location of the task, relative to the subject. In both gravity levels, the middle of the three locations was seen to be the most effective at producing a torque. This location corresponded approximately to shoulder level for these subjects. It should be noted the location of the task was set at absolute positions. An alternative experiment could have set the distances at positions relative to each of the subjects' height (e.g., at 80, 90, and 100% of stature). The subjects tested were all similar in height. Therefore, it is not clear how these results would extend to a population with more diverse body builds and physiques.

The foot restraint location had no significant effect on the torque production in 0 g. In 1 g, there was a 5% difference with the near FRL having a greater torque production. In the 0-g study, if the two subjects with incomplete data sets are excluded from the analysis, a 5% difference (not statistically significant) was also seen with the near FRL being greater than the far one. Interestingly, the subjects reported that it was more difficult to perform the task from the far FRL, and they felt as if they could not produce as much force in that position. Thus it is hypothesized that torque production is influenced by distance of the foot restraints. It would take a larger distance than used in this study, however, to conclusively see this effect.

The orientation of the task and tool was seen to affect the torque production in both 0 g and 1 g. In both gravity environments, the greatest torque was seen when the tool was coming out from the worksite and the subject applied the effort in an up or down direction. In this orientation, the subject could put his body under the tool and use his full body to generate a force. Interestingly, there was not a very large difference between the upward and downward efforts. In this orientation in 0 g, pushing up resulted in 9% more force than pulling down; in 1 g pushing up resulted in 1% less force than pulling down. The second most effective orientation in both gravities was also when the subject could apply force in an up/down direction but with the tool extended to the right from the worksite. The least effective orientation was with the tool extending downward from the worksite, requiring an effort to the left or right. In

0 g, the left-sided effort resulted in 37% less torque production than the right; in 1-g, this difference was 20%. Recall, that the TAFs were displaced to the right of the subject by 16.5 cm.

Two previous projects (Poliner et al., 1993; Wilmington et al., 1994) used a similar task. The study by Wilmington et al. quantified the loads imparted on a foot restraint system as well as the torque that could be produced by the subjects. Their subjects produced between 300 and 650 N of force in the direction of the applied force. They also found that the greatest force could be applied in the down and up directions, with the upward direction being slightly greater than downward. The study by Poliner et al. also found forces of between 400 and 750 N in the direction of the applied force with the greatest in the up/down directions. In both of these two studies, a handrail was set up at the worksite for the left hand to grab. Thus it seems that the absence of the handrail decreased the strength ability by approximately 50%.

It is of interest to apply these results to a suited crewmember performing extra vehicular activity (EVA). Wilmington et al. (1994) are currently looking at the decrement in isolated joint strength as a result of wearing a pressurized EVA suit. Results from that study and this current one can be combined to predict the forces a suited crewmember can produce during a task similar to the one used in this study.

Recommendations/Future Directions

Future testing will further develop the database of human capabilities in weightlessness. We recommend that testing efforts be focused in two areas: first, examining the strength of individuals in a similar manner to this but in a dynamic setting (dynamometers are available to allow for a controlled velocity and positioning of a task); and second, examining fatigue. Most tasks crewmembers perform in weightlessness do not require a maximal effort. It is of interest to determine the duration or the number of repetitions of a submaximal task an individual can perform without becoming fatigued. Another suggestion for future study is to extend the results of this study to a wider range of task parameters such as task locations, tool type, and location of additional hand rails.

CONCLUSIONS

The information from this study can be put to use in several ways. Tasks can be designed based around the strength capabilities and limitations of individuals in weightlessness. Tasks requiring the application of a force to a tool can be planned so that crewmembers can position themselves for the most effective force production and minimal fatigue. Specifically, this study demonstrated that the most effective force production occurred at a task site located approximately at shoulder height. Also, tools can be developed based on the known strength of the tool users. For example, if a large torque is needed to tighten a fastener, a tool can be used with an appropriately long moment arm. Finally, this study documents the differences in strength measurements taken for the same task performed in weightlessness and Earth's gravity.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Dec/94	NASA Technical Paper

4. TITLE AND SUBTITLE

Geometry and Gravity Influences on Strength Capability

5. FUNDING NUMBERS

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Flight Crew Support Division
NASA Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS

S-784

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

TP-3511

11. SUPPLEMENTARY NOTES

*Lockheed Engineering & Sciences Company, Houston, Texas

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unlimited/Publicly Available
Available from the NASA Center for AeroSpace Information
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
(301) 621-0390

Subject category: 54

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Strength, defined as the capability of an individual to produce an external force, is one of the most important determining characteristics of human performance. Knowledge of strength capabilities of a group of individuals can be applied to designing equipment and workplaces, planning procedures and tasks, and training individuals. In the manned space program, with the high risk and cost associated with spaceflight, information pertaining to human performance is important to ensuring mission success and safety.

Knowledge of individuals' strength capabilities in weightlessness is of interest within many areas of NASA, including workplace design, tool development, and mission planning. The weightless environment of space places the human body in a completely different context. Astronauts perform a variety of manual tasks while in orbit. Their ability to perform these tasks is partly determined by their strength capability as demanded by that particular task. Thus, an important step in task planning, development, and evaluation is to determine the ability of the humans performing it. This can be accomplished by utilizing quantitative techniques to develop a database of human strength capabilities in weightlessness. Furthermore, if strength characteristics are known, equipment and tools can be built to optimize the operators' performance.

There is a spectrum of ways of looking at strength, from basic research to applied engineering. This study examined strength in performing a simple task, specifically, using a tool to apply a torque to a fixture.

14. SUBJECT TERMS

Muscular strength, weightlessness, astronaut performance, torque

15. NUMBER OF PAGES

25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std. 239-18
298-102

ORIGINAL PAGE IS
OF POOR QUALITY