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An Overview of Space Shuttle Anthropometry and Biomechanics Research with Emphasis on STS/Mir Recumbent Seat System Design

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ABSTRACT

The Anthropometry and Biomechanics Laboratory (ABL) at the Johnson Space Center conducts multi-disciplinary research focusing on maximizing astronaut intravehicular (IVA) and extravehicular (EVA) capabilities to provide the most effective work conditions for manned space flight and exploration missions. Biomechanics involves the measurement and modeling of the strength characteristics of the human body. Current research for the Space Shuttle Program includes the measurement of torque wrench capability during weightlessness, optimization of foot restraint and hand hold placement, measurement of the strength and dexterity of the pressure gloved hand to improve glove design, quantification of the ability to move and manipulate heavy masses (6672 N or 1500 lb) in weightlessness, and verification of the capability of EVA crewmembers to perform Hubble Space Telescope repair tasks.

Anthropometry is the measurement and modeling of the dimensions of the human body. Current research for the Space Shuttle Program includes the measurement of 14 anthropometric parameters of every astronaut candidate, identification of EVA finger entrapment hazards by measuring the dimensions of the gloved hand, definition of flight deck reach envelopes during launch and landing accelerations, and measurement of anthropometric design parameters for the recumbent seat system required for the Shuttle/Mir mission (STS-71, Spacelab M) scheduled for June 1995.

INTRODUCTION

The Anthropometry and Biomechanics Laboratory (ABL) at the Johnson Space Center conducts multi-disciplinary research focusing on maximizing astronaut intravehicular activities (IVA) and extravehicular activities (EVA) capabilities. This research is conducted to provide the most effective work conditions for manned space flight and exploration missions. The ABL performs research in two areas: anthropometry and biomechanics. Biomechanics is the measurement and modeling of the strength characteristics of the human body, while anthropometry is the measurement and modeling of the dimensions of the human body. An overview of the current research directions will be presented along with an example (Shuttle/Mir recumbent seat system design) of the how the human factors product is used in practice.

BIOMECHANICS

In altered-gravity environments, such as the "weightlessness" of low earth orbit, crew capabilities are dramatically different from what they are in the one-gravity environment on Earth. The ABL performs tests to measure and model human strength capabilities in weightlessness. In addition to the laboratory itself, several different simulation facilities are used to conduct investigations. These facilities include the Precision Air Bearing Floor and the Weightless Environment Training Facility at the Johnson Space Center, as well as the KC-135 zero-gravity research aircraft based at Ellington Field, Houston, TX.

A recent test was conducted on the KC-135 to measure torque wrench capabilities of subjects while in prototype intravehicular activity (IVA) foot restraints[1]. The KC-135 provides brief periods of zero-gravity (25 to 30 seconds) while flying parabolic profiles. The test set-up utilized a prototype foot restraint with an adjustable pitch angle. The test subject, wearing socks, was allowed to adjust a 3.8 cm (1.5 in) wide foot loop to a comfortable tension. The subject was then directed to apply torques to an instrumented task board with a torque wrench. Instead of torque, the applied forces were reported, allowing the designer or mission planner to select the appropriate tool length required to generate the necessary torque to complete the task. The forces measured were highly dependent on the direction of effort. When applying force in an up or down direction, the subject was able to position his/her body to use the large muscle masses in the legs to generate large forces. These forces were on the order of 467 N (105 lb) in the down direction and approximately 663 N (140 lb) in the up direction. Forces to the left and right of the subject averaged about 356 N (80 lb) to the left and 400 N (90 lb) to the right, while forces toward (such as pulling an object) and away (such as pushing an object) were about 289 N (65 lb) towards and 356 N (80 lb) away, respectively.

In addition to tasks requiring strength inside the crew compartment of the Shuttle, crewmembers must perform numerous physical tasks while EVA. Occasionally, portable foot restraints are not available to react applied forces and torques. In this situation, crewmembers must use only one hand to counteract the forces and torques of the tool hand. During another study carried out on the KC-135 in which EVA suited subjects applied torques with a 25 cm (10 in) tool handle and used only a single hand restraint, the torques measured were on the order of 70 to 80 N-m (52 to 59 ft-lb) in zero-gravity[2].

One of the keys to a successful EVA is adequate hand function. The hand serves as a multi-purpose end effector required to perform a variety of tasks ranging from holding on to free floating satellites to using EVA tools. Measurements of grasp breakaway forces, which simulate holding a satellite by hand with an EVA handrail, found crewmembers capable of exerting grasp forces in excess of 1000 N (225 lb)[3]. Results from the hand grasp breakaway test indicated that the right hand is generally stronger than the left, and female grip strength is typically 50 percent of male grip strength. Further tests, evaluating barehanded versus gloved hand performance, found the following results: wearing an EVA glove reduces grip capability by 50 percent regardless of gender, performance decreases with increasing pressure, and pinch strength is unaffected by wearing an EVA glove[4].

Manipulation of large masses is another task often required of the crewmember. This task is required in the IVA environment due to the need to move instrumentation racks about the crew compartment on Space Station Freedom. To measure the forces and torques required when manipulating a Space Station IVA rack, a test was conducted on the Precision Air Bearing Floor at Johnson Space Center[5]. This test used a heavy rack mock-up weighing 6672 N (1500 lb) with an instrumented handrail. The results indicated forces of less than 11 N (8 lb) and torques of less than 3.4 N-m (2.5 ft-lb) were required to manipulate the rack.

Manipulating large masses is also required in the EVA environment. Manual handling of the Intelsat satellite (STS-49, June 1992) was required to successful capture the satellite. Large mass handling will also be required on the Hubble Space Telescope Service Mission 01 (STS-61, December 1993). Significant operational concerns are inherent with EVA mass handling tasks. Of critical importance to insure safety of the crewmember as well as the integrity of the payload, is to verify that the tasks required are within the crewmember's capability. A mass handling test, which used a mock-up of one of the Hubble's instruments scheduled for replacement, with correct mass and inertia properties, was conducted on the Precision Air Bearing Floor[6]. This test measured the forces and torques required to maintain stable control of the orbital replacement unit (ORU) while performing insertion tasks and operations with the remote manipulator system (RMS). The results found that the amount of force that can be expected during ORU insertion tasks varied from about 18 N to 62 N (4 lb to 14 lb) while the torques varied from 11 N-m to 20 N-m (8 ft-lb to 15 ft-lb). During the RMS operations, the worst case force at the handrail was approximately 222 N (50 lb) during a sudden stop of the RMS when translating at 0.5 m/s (1.5 ft/sec). This test verified that the forces and torques required to perform the task were well within the crewmember's capabilities.

ANTHROPOMETRY

Anthropometry is the measurement and modeling of the dimensions of the human body and includes both static and dynamic measurements. Anthropometric data can be used to size pressure garments, EVA gloves, and flight clothing so appropriate tariffs can be developed to accommodate all crewmembers. Other uses include developing hardware such as exercise equipment, EVA and IVA tools, crew seats, and flight control systems.

The ABL maintains a database of anthropometric measurements from astronauts and astronaut applicants. As part of the astronaut selection process, the ABL measures 14 anthropometric variables from each astronaut applicant. Recently, statistical analyses were performed on the database created over the data collection period from 1985 to 1991[7]. This period includes 473 individuals, 82 of which were selected as astronauts.

An operational concern involving anthropometry during EVA includes the risk of finger entrapment. The potential for such a situation would be a serious safety problem. The ABL conducted a glove box test with series 3000 gloves at 0.624 kPA (4.3 psi) to determine the range of hole sizes that could result in finger entrapment[8]. Based on experimental results, the smallest diameter should be less than 13 mm (0.50 in) and the largest diameter should be greater than 35 mm (1.38 in) in order to eliminate the possibility of finger entrapment during EVA.

Anthropometry is typically static, that is there is no motion. However, certain conditions can require the measurement of anthropometry under dynamic conditions. An example of this is a crewmember's reach envelope and how it changes under various gravitational conditions[9]. Launch profiles create accelerations on the order of three times that of Earth's gravity (3 g's). Certainly, the reach envelope of a crewmember on the flight deck during launch will be different than that experienced in 1 g. Measurement of reach envelopes under various acceleration environments provide designers with the information needed to properly design flight systems which are accessible under flight conditions.

SHUTTLE/MIR RECUMBENT SEAT SYSTEM

Anthropometry is used frequently to design equipment and flight hardware. An example of this process is the anthropometric data required to design the seating system for the Shuttle/Mir mission.

In June of 1995, the Space Shuttle (STS-71, Spacelab-M mission) will rendezvous and dock with the Russian space station Mir[10]. The Space Shuttle will return to a landing site in the U. S. with three crewmembers: a Russian trained U.S. astronaut and two cosmonauts. The primary U. S. scientific goals are to investigate the effects of long-duration space flight on the human body. One of the operational concerns is the level to which the returning Mir crewmembers will be able to withstand the g conditions during the return flight. Because the long stay aboard Mir will cause cardiovascular deconditioning and muscle atrophy, it was proposed that the crew return to Earth in a recumbent position to minimize the effects of these physiological changes.

Returning the crewmembers in a recumbent position requires the design of a new seating system. However, the existing anthropometric data for seat systems is based on measurements taken while the subjects were unsuited and sitting[11]. To insure accuracy, the anthropometric data must be collected when the subjects are wearing a pressurized Launch and Entry Suit (LES) and are lying in a recumbent position.

Additionally, the design of the recumbent seating system must meet the requirements of both 5th percentile Japanese female and 95th percentile American male crewmembers. To accommodate this requirement, a test was conducted where the subjects were measured in the shirtsleeve condition, and then again after donning and pressuring the LES[12]. To account for the spinal elongation which occurs due to the absence of gravity, an additional three percent was added to the spinal measurements[11]. The difference between shirtsleeve and suited measurements, which is representative of the change due to the suit, posture, and pressure can then be added to the existing Man-Systems Integration Standards (MSIS) (NASA-STD-3000) anthropometric data to project the measurements for 5th percentile Japanese female and 95th percentile American male crewmembers[11].

CONCLUSION

Anthropometry and biomechanics research makes up an important component of a successful manned space flight program. The environment of space, so unlike that here on Earth, often requires performance tests in simulation facilities to measure crewmember capabilities. Interaction with mission planners, hardware designers, astronauts, and others is essential in creating a useful human factors product.

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