

Functional Mobility Testing: A Novel Method to Create Suit Design Requirements

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ABSTRACT

This study was performed to aid in the creation of design requirements for the next generation of space suits that more accurately describe the level of mobility necessary for a suited crewmember through the use of an innovative methodology utilizing functional mobility. A novel method was utilized involving the collection of kinematic data while 20 subjects (10 male, 10 female) performed pertinent functional tasks that will be required of a suited crewmember during various phases of a lunar mission. These tasks were selected based on relevance and criticality from a larger list of tasks that may be carried out by the crew. Kinematic data was processed through Vicon BodyBuilder software to calculate joint angles for the ankle, knee, hip, torso, shoulder, elbow, and wrist. Maximum functional mobility was consistently lower than maximum isolated mobility. This study suggests that conventional methods for establishing design requirements for human-systems interfaces based on maximal isolated joint capabilities may overestimate the required mobility. Additionally, this method provides a valuable means of evaluating systems created from these requirements by comparing the mobility available in a new spacesuit, or the mobility required to use a new piece of hardware, to this newly established database of functional mobility.

INTRODUCTION

Across all fields of human-system interface design it is vital to possess a sound methodology dictating the constraints on the system based on the capabilities of the human user. These limitations may be based on strength, mobility, dexterity, cognitive ability, or combinations thereof. Data collected in an isolated environment to determine, for example, maximal strength or maximal range of motion would be adequate for establishing "not-to-exceed" type design limitations; however, these restraints on the system may be excessive over what is basically needed. Resources may

be saved by having a technique to determine the minimum measurements a system must accommodate.

This paper specifically deals with the creation of a novel methodology for establishing mobility requirements for a new generation of space suit design concepts. Historically, the Space Shuttle and the International Space Station vehicle and space hardware design requirements documents such as the Man-Systems Integration Standards [1] and International Space Station Flight Crew Integration Standard [2] explicitly stated that the designers should strive to provide the maximum joint range of motion capabilities exhibited by a minimally clothed human subject. In the course of developing the Human-Systems Integration Requirements (HSIR) [3] for the new space exploration initiative (Constellation), an effort was made to redefine the mobility requirements in the interest of safety and cost. Systems designed for human space exploration can receive compounded gains from simplified designs that are both less expensive to produce and lighter; thereby cheaper to launch.

This paper shows a method for quantifying functional mobility that produces range of motion requirements that are generally less extreme than subjects' maximum isolated mobility. A list of all functional tasks a suited crewmember on a lunar mission was likely to perform was generated. Minimally clothed subjects performed these functional tasks as well as isolated tasks designed to maximize their ranges of motion. This paper discusses a process of modal analysis that was used to parse the data to provide single values for each joint movement. Additionally, the study discusses solutions to other problems commonly occurring in biomechanical investigations. Results found in these analyses are chiefly useful to space agency applications; however, the methodology developed for these tests could prove helpful in any industry that requires quantitative biomechanical and anthropometric constraints to be

applied in designing equipment that interfaces with humans.

The use of functional measurements in generating requirements is a novel development in space suit design. Previous efforts to develop requirements included calculating 5th and 95th percentile isolated ranges of motion for a pool of male and female subjects [1]. This may create confusion for designers, because this method provides four values (5th and 95th percentile for both males and females) but includes no explanation of which is the appropriate value for use in design. These requirements are also restricted to isolated motions, which may be simpler to quantify but do not provide functional information. Maximum isolated ranges of motion (ROM) merely represent the mobility of a subset of the population. Measuring functional mobility provides a set of range of motion requirements that more accurately represent necessary levels of mobility to complete functional tasks.

This paper details the methodology utilized for the creation of mobility requirements for the next generation of space suits for a return mission to the Moon. The list of functional tasks and its development are explained. Novel methods of video motion capture and statistical analyses of the data are presented.

FUNCTIONAL TASK LIST

Figure 1 illustrates the procedure used for the development of functional design requirements. After recognizing the need for improved data and determining that utilization of functional mobility requirements are appropriate, the next step is to consider every action that may be performed during the completion of the overall task. A comprehensive list of generic tasks that may be performed during lunar missions was generated. This list was generated based on a review of relevant literature [1, 4] along with reasonable assumptions concerning future lunar missions. An example of a task list organized by mission phase is shown in Table 1. These functional tasks shown represent a partial list of activities considered for motion capture. After the initial list of functional activities was generated, a marker set designed to capture all relevant motion was developed. During this process, consideration was given to which joint angles would possibly be maximized during each functional task.

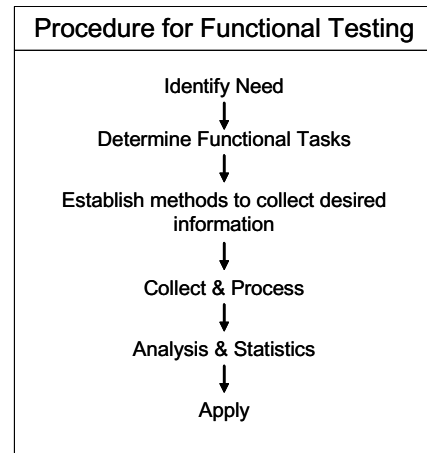


Figure 1: Procedure for Functional Testing

The full list of functional tasks was modified for two primary reasons. First, the list was pared down into a smaller list of major functional tasks to make data collection with a large pool of subjects more manageable while still encompassing the maximum range of joint mobility. Therefore, tasks that were deemed to be either very similar to other, already included tasks, or tasks that were not likely to maximize any single joint's ROM, were eliminated. Second, because motion capture markers were to be placed only on the right side of subjects' bodies (discussed in Data Collection Methods), some tasks were added in order to ensure that asymmetric tasks were fully captured. Examples of redundant tasks include multiple permutations of the usage of various hand tools that are not likely to present substantially different joint angles. Examples of tasks excluded because they were unlikely to maximize joint angles include the use of simple controls such as button pushing or toggle flipping. In addition to these primary reasons, several tasks that were deemed excessively difficult or unsafe to attempt were eliminated, such as a complete fall recovery that may injure the subject and is likely to occlude or shake loose a large number of markers. The breadth of other tasks performed should resolve any gaps left by the exclusion of tasks and still provide for an accurate representation of required mobility.

Table 1: Mission Phases and Preliminary Functional Tasks

Mission Phase	Anticipated Activities	Tasks (Actions Involved in Completing Activities)
Prelaunch	- Don Suit - Ride in Van - Ingress Vehicle - Possible Abort	- Walk - Crawl - Sit - Climb Ramp/Ladder - Adjust Visor/Seatbelt/Controls - Stow Cargo - Emergency Egress/Evacuation - Zip Line
Launch	- Sit - Reach Controls - Adjust Visor	- Sit - Reach Controls - Adjust Visor
IVA	Emergency Scenarios Requiring Suits	- Open Hatch - Manipulate Cargo - Walk - Crawl - Climb Ladder - Seat Ingress/Egress
EVA	- Egress Vehicle - Microgravity Locomotion - Reduced (Martian or Lunar) Gravity Locomotion - Perform Maintenance on Vehicle - Collect Rock/Soil Samples - Deploy Payload/Equipment - Habitat Fabrication - Fall Recovery - Drive Rover - Ingress Vehicle	- Open Hatch - Close Hatch - Walk - Run - Crawl - Kneel - Climb/Descend Ladder - Climb/Descend Ramp - Pull Along Tethers/Handrails - Jump - Fall Recovery - Sit - Activate Foot Pedals - Use Steering Wheel - Touch One or Both Hands to Ground - Lift a Box - Move a Box - Use Tools (Hammer, Wrench, Screwdriver, Shovel, Pick Axe, Drill, Camera, Bolt) - Brush Off Lunar Dust - Adjust Visor
Return/Reentry	- Reentry - Vehicle Egress - Raft Ingress - Emergency Abort	- Ingress Seat - Adjust Seatbelt/Straps - Egress Seat - Egress Vehicle - Ingress Raft - Pull Along Tether - Parachute - Air Slide

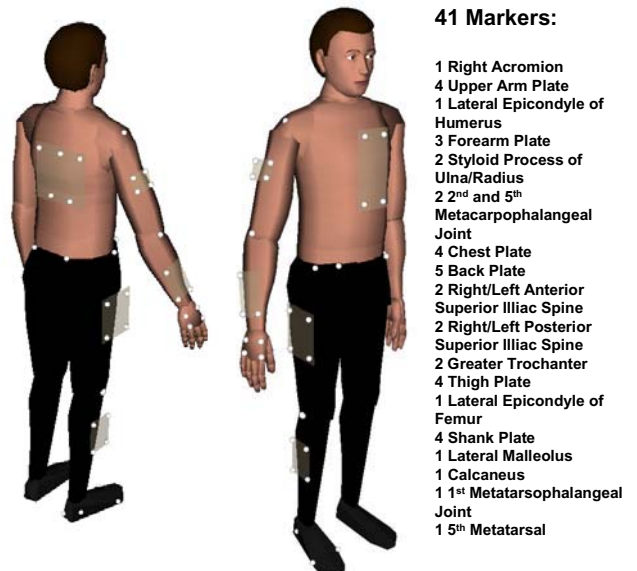


Figure 2: Retroreflective Marker Set & Anatomical Landmarks

Subjects

For this test, 20 healthy subjects were used, 10 males and 10 females, with the only disqualifying factors being that subjects must be healthy enough to perform the tasks and be free of any major joint pathologies that might restrict range of motion.

Collection Sessions

A chief concern during video motion capture is the ability to collect data truly representative of the tasks being performed. To this end, subjects were asked to wear skin-tight clothing for the duration of the test to enable optimal placement of the retroreflective markers. Once subjects were instrumented with 41 markers, a single laser scan using a Vitus Smart 3D Full Body Scanner (Weisbaden, Germany) was also taken of the subjects to allow for extraction of any desired anthropometry at a later date. The subjects then performed 49 functional tasks while data was collected for each trial. Some of these trials were repetitive to accommodate high frequency of marker occlusions or to allow for symmetry, since markers were only placed on limbs on the right side of the body. Subjects were instructed before each trial concerning the task they would be performing next. If issues occurred such as a marker falling off, the trial was repeated. After functional data was collected, isolated mobility data was collected as subjects maximized principal motions of each major joint about every axis sequentially. The data was intended to enable quantification of the amount of mobility required to perform all functional tasks as a fraction of total mobility available, and also to compare average population ROM to accepted values from literature.

JOINT ANGLE CALCULATIONS

Joint angles were calculated by assigning a coordinate frame to every major body segment and comparing the

DATA COLLECTION METHODS

A novel approach to the quantification of required mobility was used in this test. This procedure included collection of both functional and isolated ROMs using a unique set of rigid marker plates. Joint angles were calculated for every major joint of each subject throughout all functional and isolated tasks.

DATA COLLECTION

All data was collected over a three-month period in the Anthropometry and Biomechanics Facility at NASA's Johnson Space Center. Kinematic data was recorded at 200 Hz with a Vicon 612/SV (Oxford Metrics, Oxford, UK) passive video-based motion analysis system containing 10 cameras. Forty-one retroreflective markers were placed on the subject (see Figure 2), with at least three points per major body segment to enable the calculation of major joint angles. A variety of items were used during the performance of the functional tasks. These props included a hammer, an empty box, non-rolling desk chairs, a safety ladder, a recumbent seat, and a Primus RS (BTE Technologies, Hanover, Maryland) system. The Primus RS system is typically used for rehabilitative therapy, but its functionally oriented design makes it a simple replacement for a large array of props and mockups.