A Method for and Issues Associated with the Determination of Space Suit Joint Requirements

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Introduction

- Space suit mobility is critical for performing work efficiently, with less fatigue for longer durations.
- Mobility can be described by joint Range of Motion (ROM) and joint torque.
- NASA has a need to define these for the CSSE to give indications of capability early in a component level design.
- It was decided that the ROM and Torque Values would be attained by two separate methods.

Historical Methods- EMU

The EMU torque requirements were established during the certification process in 1980.

The methodology utilized a "fish scale" for softgoods and a mechanized system for bearings.

The softgoods method included securing the component at one end, positioning it so it moved neutral to gravity, and attaching the fish scale to the other end. Then the joint was pulled by a person through it's ROM.

While this test was advantageous for situations that required simple methods and flexible setup the test lacked repeatability and contained several sources for human error.

Historical Methods-EMU Robot

Following the Space Shuttle development era, resources within NASA and academia continued to investigate more dynamic and repeatable methods for calculating space suit joint torques, ultimately leading to the development of a robotic tester.

A robotic space suit tester was built for the EMU it included:

- 12 hydraulic actuated joints on the right side of the robot.
- Each joint contained a potentiometer and a strain gauge load cell to measure torque.

It collected acceptable torque data for a torque-angle database.

However, due to problems associated with using a hydraulic robot in a suit such as leaking and donning issues, the same robot cannot be used with the other one-of-a-kind prototype suits used by the Space Suit Systems Branch at NASA's Johnson Space Center (JSC)

Recent Efforts-SF Test

The CSSE PGS team collaborated with NASA's Habitability and Human Factors Branch(SF3) to determine a sufficient method to produce torque requirements.

Three methods considered were a revised fish scale method, a manned suit test using Primus RS, and and an unmanned test using actuators on the outside of the suit.

However due to time constraints and the desire to have more precise data the manned test was selected.

Recent Efforts-SF Test

- The manned test utilized the Primus RS™ developed by BTE Technologies.
- The test setup required a manned suit to be attached to the Primus RS™ , the subject then set their own comfortable ROM, then the subject remained passive while the Primus RS™ moved them through the ROM while calculating the torque.
- The data collected by the Primus RS™ was manipulated by the SF3 team to remove the effects of gravity and human influence.

Recent Efforts-SF Test

During the data collection phase, the PGS engineers noted flaws in the data collection system that would ultimately affect the results.

The two major areas of concern were:

1. The inability to collect torque data at the ROM extremes of the suits.

2. The manner in which Primus RSTM forced joints to operate.

Recent Efforts-SF Test

Difficulty during testing:

- Since there were subjects in the suits and they determined that their comfortable ROM was the extreme, ROM torque data was therefore not usually collected.
- The Primus RSTM system, while an accurate measuring device, had limited flexibility in moving the joint through its ROM.
- Several joints were not able to be tested because either the joint would be unsafe to move with a person in the suit or the suit's joint could not be setup in a way for the Primus RSTM to manipulate it.
- Primus RSTM can only manipulate in a strict singular plane, it was difficult or impossible to record several joints accurately because they do not move cleanly within the plane (some joints tend to oscillate as they move through the motion).

Recent Efforts-SF Test

Preliminary data analysis and results varied across subjects and suit types to the degree that no reasonable conclusions could be drawn.

Major contributing factors included:

- Failure to remove gravity and human subject influences from the data during the test and post-test analysis phases.
  - During testing, the body position of the suit was adjusted, where possible, to make the movement of interest parallel to the gravity force vector, but due to the geometry of the suit and the Primus RSTM, this was impossible in most instances.
- Inaccurate weights for individual segments of the suits
  - The suits generally cannot be separated at precise joint centers and several of the suits were not designed for disassembly at all.
- Several key measurements were only estimates.
  - An additional difficulty is the distribution of weight changes as subjects' sizes and dimensions vary.

Several iterations on the post-processing code were conducted to wash out the error.

In the end the test team terminated the project because there was no clear path forward to produce the necessary results within the established time constraints.

Recent Efforts-TEES Test

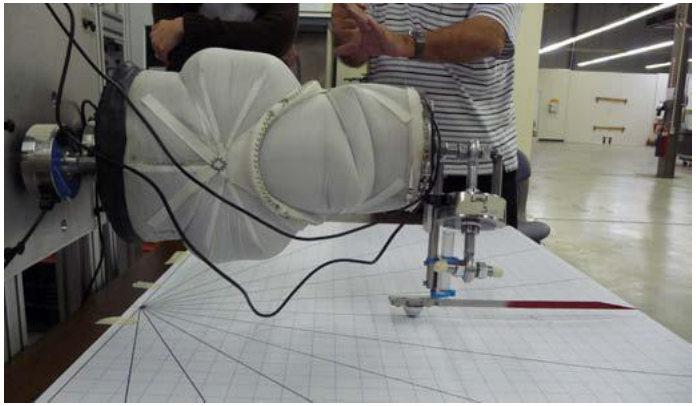
Months after the Primus RSTM torque project was terminated, NASA awarded a delivery order (DO) to Texas Engineering and Experiment Station (TEES) to develop a space suit soft shoulder design.

TEES was required to verify that pressurized ROM and joint torque requirements had been met.

TEES developed a test rig that the three different soft shoulder prototypes could be attached and their corresponding ROMs and torques measured in three orientations to simulate shoulder adduction/abduction, flexion/extension, and lateral/medial motions.

This test provided some useful ideas and technologies that could be used during a system level test. Such as the use of roller/transfer balls to provide support, and utilizing load cells and angle sensors for precise data collection.

Recent Efforts-TEES Test



TEES Test Setup:

- Three load cells, two on the fixed end test plug and one on the moving ends test plug.
  - This allowed gravity and any other forces to be checked.
  - And provided force data to be converted to torque data.
- An apparatus on the moving end that contained an indicator to help visually confirm the ROM path, as well as a marker to trace the path on grid paper.
- Transfer ball connected to the apparatus provided support to the free-moving end.
  - This helped reduce gravity effects while contributing only a negligible amount of drag.
- Pull handle attached to the load cell.
- DAC system that collected the force and angle data and matched this data with video collected by an overhead camera.
- Video camera to collect ROM angle data to pair with the torque data.

Current Approach

Following inconclusive results of the Primus RS™ testing, the PGS team decided to pursue an unmanned testing approach using a modified fish scale method.

This method uses a load cell to measure the force required to pull a joint though its ROM and a sensor to calculate the translation path.

The unmanned joint torque test will utilize the EMU, ACES, Mark-III, I-Suit, D-Suit, and EM-ACES to investigate the effects of torque on each suit joint.

Two pressures will be used during the test:

- Nominal suit pressure (Varies for each EC5 prototype suit)
- Representative constellation vent pressure. (0.8psi)

Current Approach

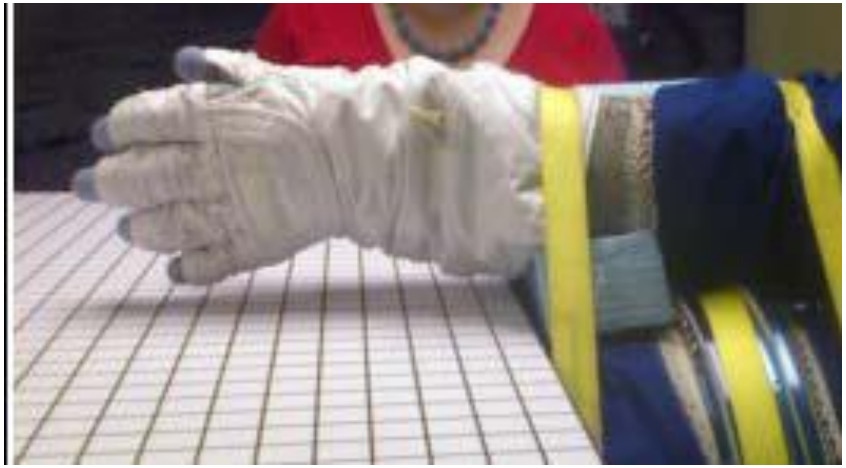
Each test will be configured such that the selected joint is parallel to the floor, thus reducing the effects of gravity.

This test will be repeated for each pressure, suit, and joint.

The following joint movements will be collected if mobility features are present on the suit being tested:

Shoulder Flexion/Extension
Wrist Flexion/Extension
Hip Flexion/Extension
Shoulder Adduction/Abduction
Shoulder External/Internal Rot.
Hip External/ Internal Rotation
Ankle External/Internal Rotation
Trunk Rotation
Torso Flexion/Extension
Wrist Adduction/ Abduction
Wrist Pronation/ Supination

Elbow Flexion/Extension
Knee Flexion/Extension
Ankle Flexion/Extension
Shoulder Medial/ Lateral
Hip Adduction/Abduction



Current Approach

Because this method is still in the pilot testing phase, its effectiveness cannot be stated with any significant degree of certainty.

The test team has focused on learning from previous attempts to measure torque and is incorporating that information into the new test design.

The following are examples of steps taken to improve the data:

- In order to reduce the gravity effects on the suit, the suit joint will be positioned so it is parallel to the floor, making it gravity neutral.
- The test will also be performed "unmanned" to eliminate the influence of a subject.
- Load cells and angle sensors will be used in combination with video angle and measurement analysis to collect data more accurately.

At this stage in pilot testing the major difficulties expected include dealing with joints that move in non-linear motions and reducing the error associated with using a human to pull the load cell.

Conclusion

The need for torque requirements remains unchanged.

There are several unknowns and difficulties that are expected such as:

- Creating component-level torque requirements for the CSSE from existing prototype systems.
- The relationship of torque measurements taken at the system level verses the component level; it is theorized that change in system volume may have an affect.
- No suit possesses the exact build up combination of what is currently envisioned by CSSE designers
- The effectiveness of requirements at predicting the ability of the CSSE to successfully complete mission operations.

However, by benchmarking the entire suite of EC5 suits at a system level it is hoped that valuable torque information can be extracted and converted into component-level requirements. At a minimum the requirements and guidelines should help reduce the number of design changes later in the system's design and fabrication.