

Measuring xEMU Loads Through Shoulder Straps

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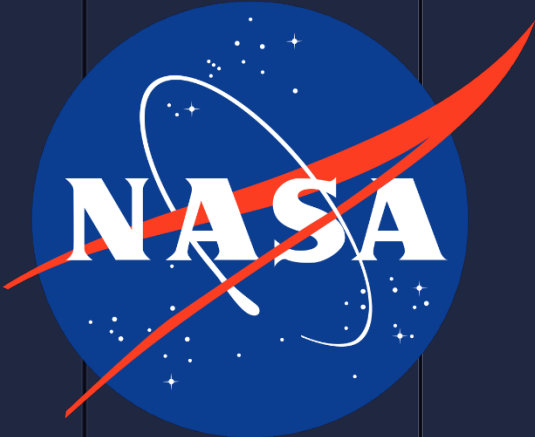


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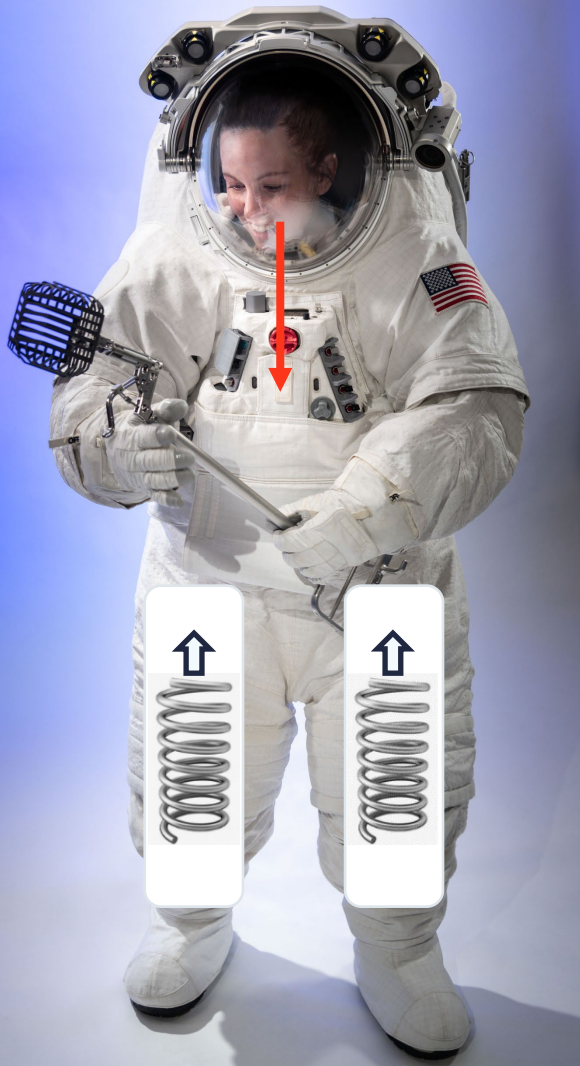


Agenda

- Background
- Hardware
- Test Set-up
- Results
- Discussion
- Forward Work







Theory:

- When pressurized, the suit's legs form air columns that act like springs that hold the suit up

Hypotheses:

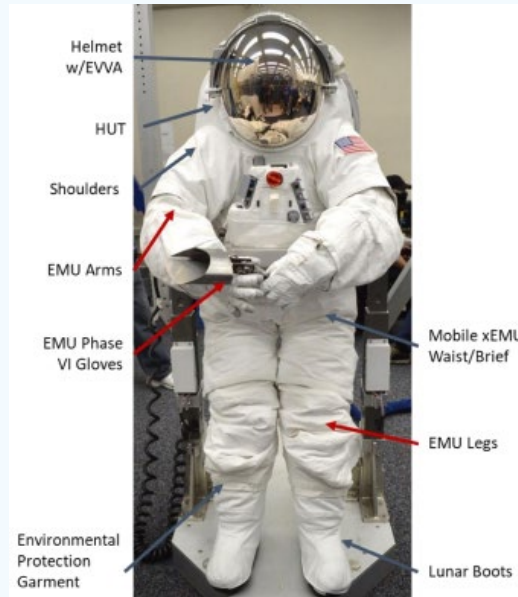
- Weight of the system – suit offload = load carried by the subject
- Suit offload should be highest when joints are aligned (i.e., standing)

Designed and built a system to test this hypothesis.

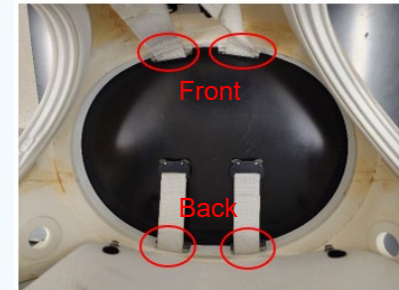
Hardware



- Exploration Pressure Garment System (xPGS) was utilized
- Shoulder straps inside the Hard Upper Torso (HUT) serve multiple purposes:
 - Index the subject's head and shoulders
 - Uniformly distribute the weight of the suit onto subject's upper torso
- Shoulder straps attach in front and rear
 - Length of shoulder straps is determined at a fit check
 - Ideally, 1" below the shoulder bearing but balance head and shoulder position
 - Settings denoted in 1-inch (2.54 cm) increments with red thread



xPGS Suit Subsystem

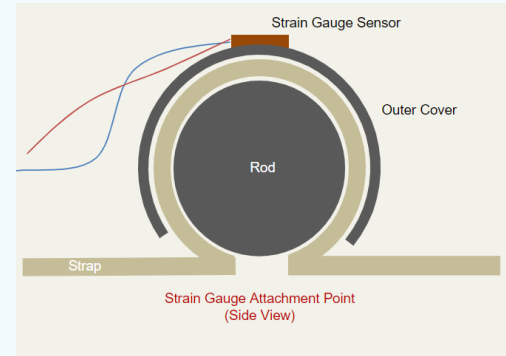
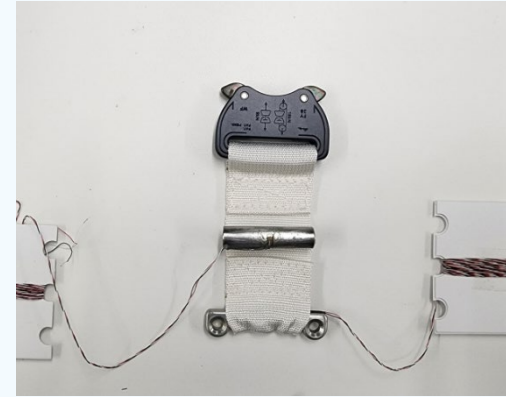


Interior view of the HUT from the top showcasing shoulder strap attachment points (top), shoulder strap sizing (bottom).

Force Sensing System



- Circular Force Brackets (back)
 - Length of the shoulder strap webbing enclosed between a rod and outer cylindrical cover
 - Strain gauge fixed to the circular bracket. A force would cause elongation and deformation to the external cylindrical cover which resulted in change to the resistance of the strain gauge which could be correlated to an applied force.
 - These sensors were attached to transmitters that relayed the load data in real time to a laptop with an external access point
- Shoulder Strap Brackets (front)
 - Strain gauges were placed on the top surfaces of two suit brackets that attached to the interior of the HUT
 - Applied forces to the straps caused these brackets to bend and the resultant changes to the strain gauge resistances were correlated to applied force
- Calibration of both types of sensors gave a curve fit formula to apply to the data logging software to convert voltage to force



Shoulder strap integrated bracket force sensor and circular force sensor (top), circular force sensor side view diagram (bottom).



RF Transmitter, Receiver, and Data Logging Software

- To accurately interpret data during testing, it was important to design a system capable of relaying data wirelessly in real time
 - Used a COTS radio-frequency transmitter, SG-Link-200-OEM by Microstrain
 - One Transmitter per sensor (four total)
 - Each transmitter was powered by a 3.7V rechargeable lithium-ion battery that was placed a 3D printed case inside the HUT
 - COTS receiver, WSDA-200-USB by Microstrain, was used to coordinate the transmission of data between all four nodes and the receiver
 - Receiver was connected to a laptop via USB and was used to configure and setup each of the nodes
- Datalogging software, SensorConnect, used the calibration curve for linear correlation values to convert the strain gauge millivolts outputs to forces

Test Plan



- Objectives
 - Quantify the offloading effects of a pressurized planetary suit
 - Characterize subject-suit interaction based on changes in indexing (i.e., shoulder strap setting)
 - Evaluate the differences in loads between static and dynamic tasks
- Shoulder strap setting
 - “Well-fitted” was determined at subject’s previous fit check as their nominal shoulder strap setting
 - “Tight” and “Loose” is approximately 1-inch from the “well-fitted” baseline



Shoulder strap sizing: loose (left), well-fitted (middle), and tight (right)

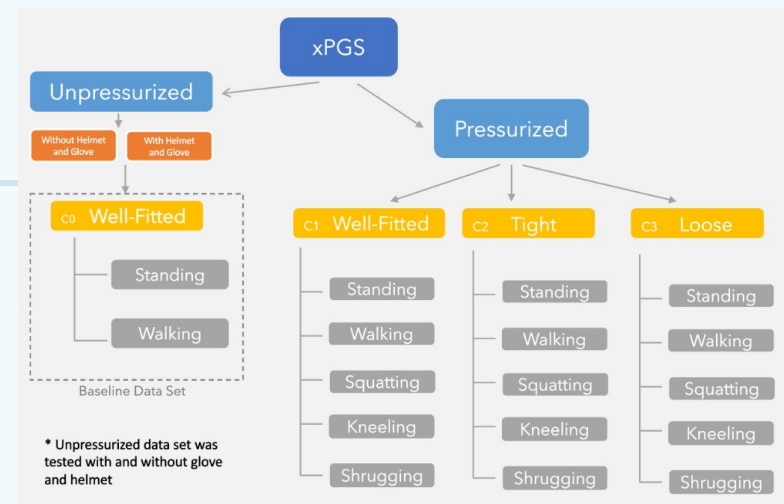
Test Plan

- Unpressurized Configuration

- A baseline data set was collected at vent pressure
 - Vent pressure is ~0.5 psid due to the vent flow (6 ACFM) with the helmet/gloves installed
- Only walking and standing was collected with “well-fitted” shoulder straps

- Pressurized Configuration

- Suit pressurized at 4.3 psid
- Data collected during standing, walking, squatting, kneeling and shrugging tasks
 - Subjects were allowed to use a non-instrumented walking stick and technician support (as needed) for kneeling due to suit weight
- Subjects repeated task set for “well-fitted”, “tight”, and “loose” shoulder strap settings
 - No other changes to sizing evaluated



Task Matrix



Walking (left), Squatting (middle), and Kneeling (right)



Results



- Five subjects participated in the study
 - As a group, the variance in forces were large due to big anthropometric and suit fit differences between the subjects
 - Note: Due to the small sample size and since the comparison of laser scans of the HUT and subjects was not done, statistical analysis was not performed on the data set
- xPGS weighed 174 lbs on average
 - Weight varied depending on subject sizing elements

Results



- Total shoulder force was computed by summing each shoulder's front and back load sensors together and adding the left and right shoulder sums together
 - Averages computed by selected time intervals were the subject's data was stable
 - Peak forces were found by finding highest value within selected interval

Results - Standing



Average total shoulder force data as a function shoulder strap settings while standing

	Pressure Conditions			
	Vent	Nominal		
Subject ID	Nominal Strap Lbs (N)	Loose Strap Lbs (N)	Nominal Strap Lbs (N)	Tight Strap Lbs (N)
S1	167 (744)	22 (98)	50 (220)	70 (310)
S2	205 (910)	85 (378)	120 (535)	168 (748)
S3	190 (843)	79 (352)	99 (441)	154 (683)
S4	132 (586)	34 (153)	77 (344)	125 (555)
S5	110 (491)	61 (269)	50 (224)	75 (333)
AVG	161 (715)	56 (250)	79 (351)	118 (525)
SD	40 (176)	28 (125)	31 (138)	45 (200)

Subject Spacesuit weights

Subject ID	Suit Weight Lbs (Kg)
S1	Was not recorded
S2	183 (83)
S3	168 (76)
S4	172.3 (78.2)
S5	171.2 (77.6)

Results - Walking



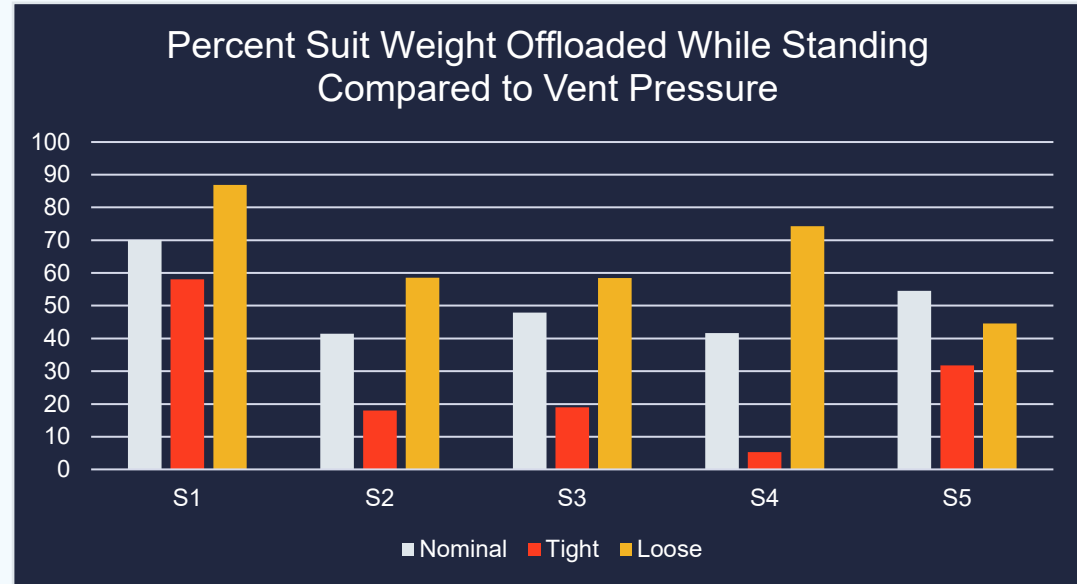
Average total shoulder force for the walking task

	Dynamic Task - Walking			
	Pressure Conditions			
	Vent	Nominal		
Subject ID	Nominal Strap Lbs (N)	Loose Strap Lbs (N)	Nominal Strap Lbs (N)	Tight Strap Lbs (N)
S1	180 (799)	73 (325)	107 (475)	128 (571)
S2	207 (919)	117 (518)	148 (660)	207 (919)
S3	204 (909)	97 (429)	130 (577)	198 (879)
S4	127 (564)	48 (215)	92 (409)	148 (660)
S5	104 (461)	88 (393)	86 (383)	120 (532)
AVG	164 (730)	85 (378)	113 (503)	160 (712)
SD	47 (209)	26 (116)	26 (116)	40 (178)

Discussion: Big Picture



- Measured unpressurized loads were consistently higher than when the suit was pressurized
 - Proving the hypothesis of the suit offload created by the 4.3 psid pressurization
- While pressurized in all tasks, loose shoulder straps usually had the lower loads than well-fitted and tight
- While pressurized in all tasks, tight shoulder straps usually had higher loads than loose and well-fitted



Discussion



- Since the subjects were wearing the same small HUT and short Brief, one of the contributing factors is how well they fit volumetrically inside the spacesuit
 - Potentially not all the load was going through their shoulder straps and was offloaded through other areas of contact
 - Subject 2 and 5 have same shoulder strap length but large differences in Vertical Truck Diameter and Circumferences which might have contributed to differences seen in their data
- A three-dimensional analysis using body scan data and CAD models of the spacesuit could be performed in the future to understand data set more completely

Discussion



- Potential sources of error include:
 - Suit sizing
 - Subject anthropometry and strength differences
 - Variations of the placement of the nominal shoulder strap length
 - Shoulder strap slippage during data collection
 - Subject technique and posture
 - Any technician support given, or support staff used, especially during the kneeling task

Conclusion



- Developed and validated a small portable force sensing system
 - Helps the team understand the forces imparted into the body as a function of suit sizing, posture and tasks
 - Provides quantitative data relative to suit fit and sizing
- Pressurized suit supporting some of its own load has potential implications for decreasing the overall load a subject must support
 - Could be especially important in partial gravity environments where the weight of the suit will be decreased but the pressure offload will remain the same

Forward Work



- Forward work includes
 - Collecting data from more test subjects
 - Increase the durability of the sensor design
 - Including a 3D anthropometric analysis to understand how human-suit interactions are affecting data
 - Testing at different pressures to understand how that affects the offload will help to further validate the design
 - Incorporating into different suit architectures to evaluate different mobility designs
 - Incorporating into different facilities (i.e., NBL or ARGOS) to characterize different 1/6-g simulated environments

