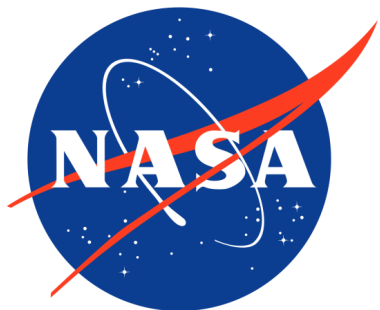




Modeling Spacesuit-Human Interaction for Injury Risk Identification

Garima Gupta

Aegis Aerospace Inc., Houston, TX

Linh Vu

Aegis Aerospace Inc., Houston, TX

Han Kim, PhD

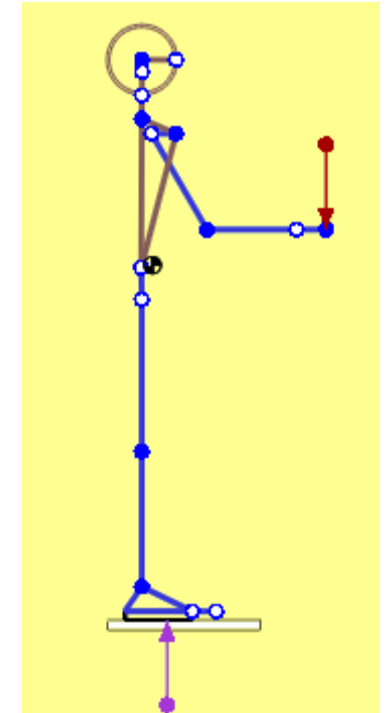
Leidos Inc., Houston, TX

Sudhakar Rajulu, PhD

NASA Johnson Space Center, Houston, TX

Background – Static Human Strength Modeling

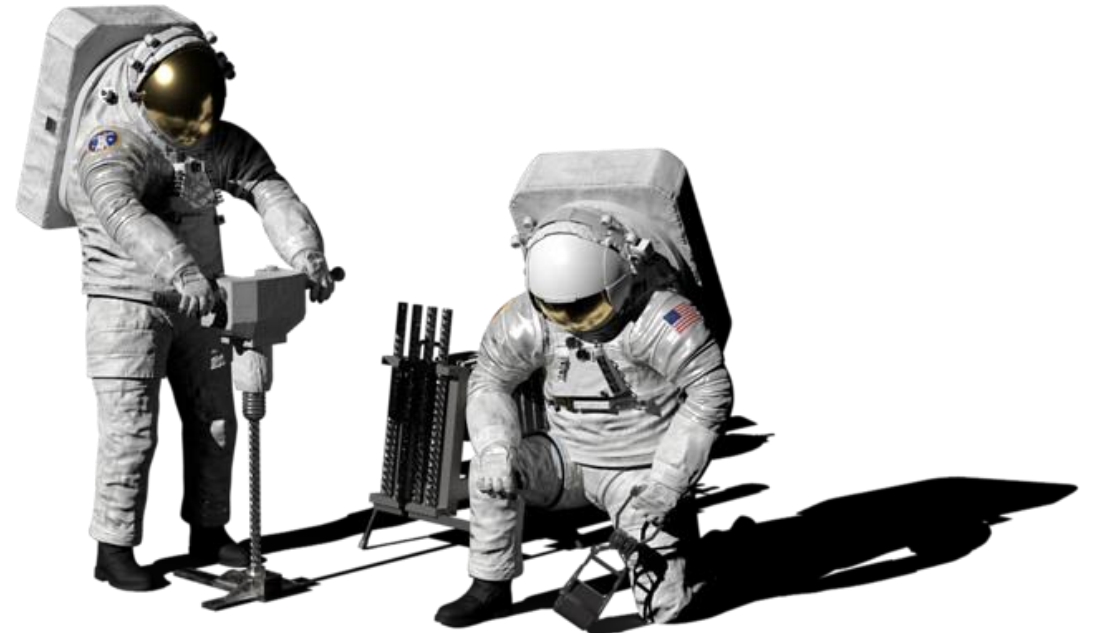
- Human strength modeling is an essential tool to evaluate injury risk and performance capabilities and limitations
- Existing human body strength modeling software can predict joint forces, torques, and population strength capacity
- Can use joint torques to understand task feasibility and as a metric to compare relative injury risk across tasks
 - Other metrics that can be used to evaluate injury risk include task duration, repetition, speed, fatigue, etc.



Human body strength modeling in 3DSSPP software (3D Static Strength Prediction Program v7.1.3)

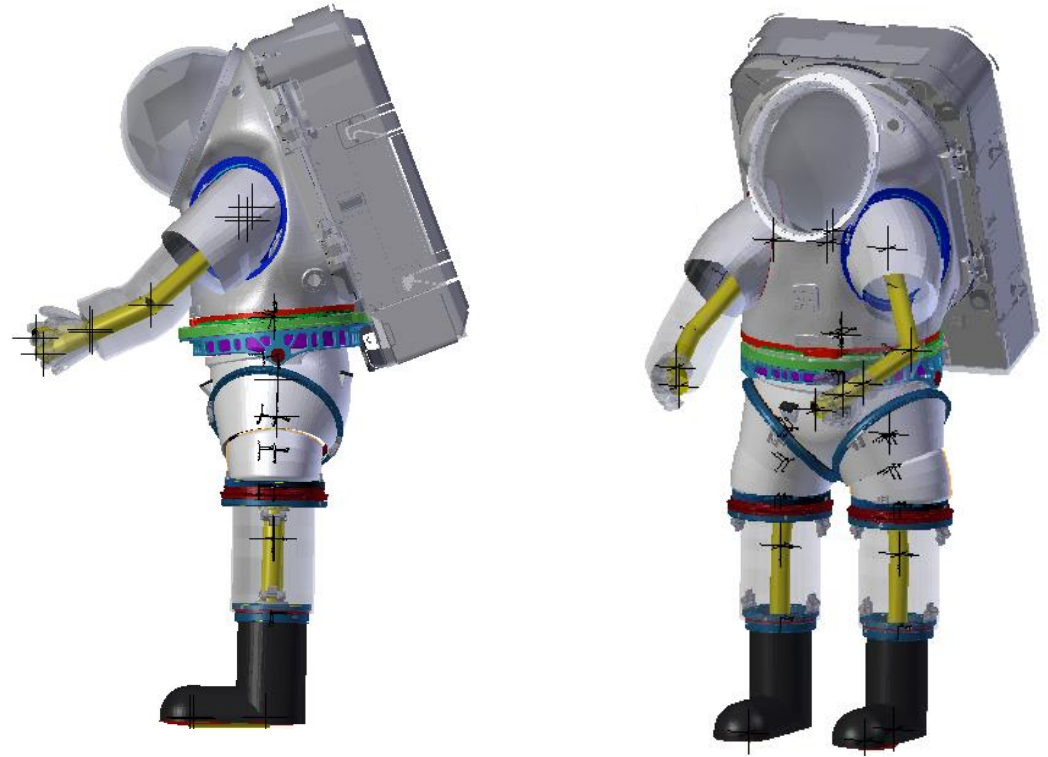
Background – Spacesuit Ergonomics

- Space missions require the use of a spacesuit for protection from the hazardous elements of the space environment
- The spacesuit affects body ergonomics
 - Adds mass
 - Shifts center of mass
 - Introduces mobility/postural restrictions
- Suit weight distribution on body can also change based on anthropometry and suit sizing



Model Description

- Building off current human body strength models, predict joint forces, torques, and population strength capacity for spacesuit-body system
 - Model is based on static postures, does not evaluate dynamic motions



Goal: A proof of concept human-spacesuit exertion model which can be used to provide relative sense of suited exertion feasibility and injury risk

Model Overview

INPUTS

Anthro For Each Body Segment

- Segment mass
- Segment length
- Segment center of mass

Force Vectors Applied to Hands

Suit-Specific Body Posture

- Input body joint angles
- Body position drives suit position, but is adjusted for suit mobility restrictions

Gravity

Spacesuit Hardware

- Component mass
- Component center of mass

-  Spacesuit Inputs
-  Human Body Inputs

OUTPUTS

Joint Force

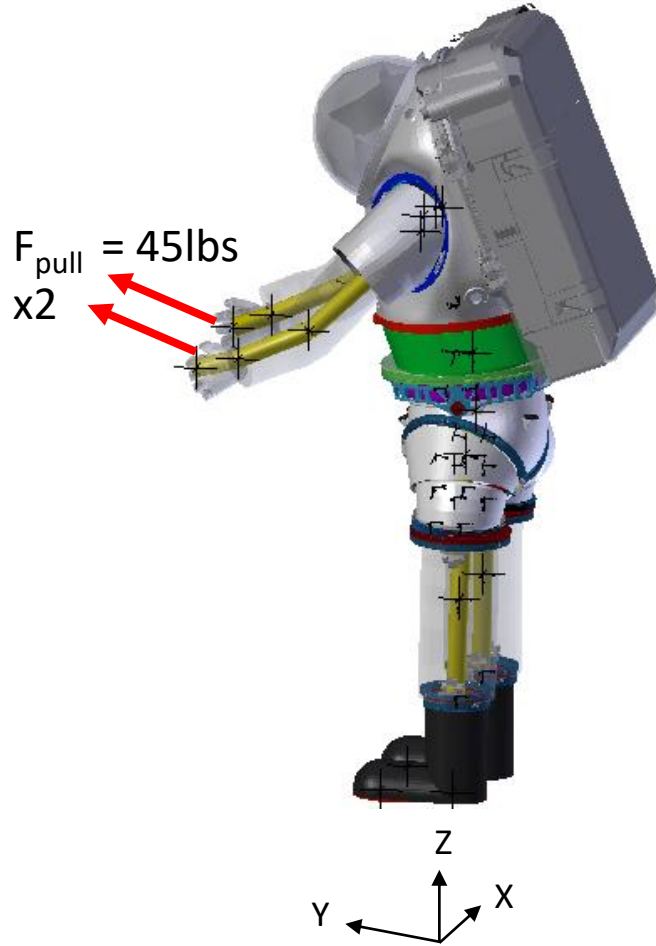
Joint Torque

Population Strength Capacity %

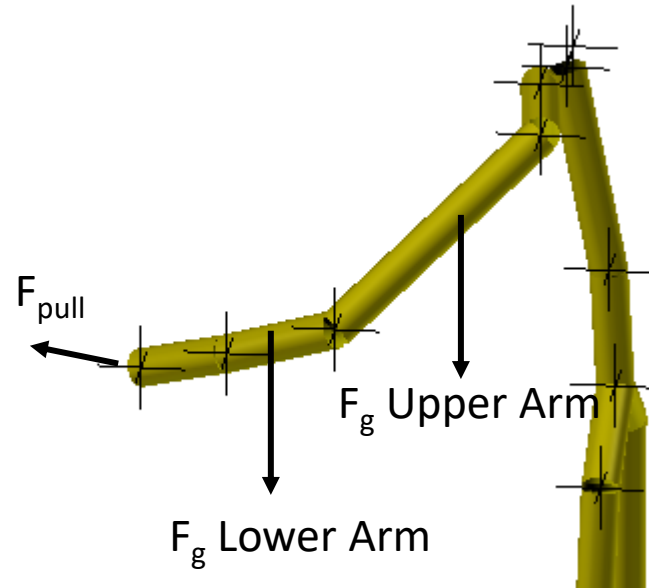
Modeled Test Cases

Anthro	Test Case Description	With Suit?	Body Posture	Input Force Magnitude on Each Hand [lbs]	Input Force Direction	Gravit y
Medium Male	Baseline	Y	Standing waist-height forward reach	45	Pulling	1g
	Remove Suit	N	Standing waist-height forward reach	45	Pulling	1g
	Change Posture	Y	Leaning back, waist-height forward reach	45	Pulling	1g
	Change Force Magnitude	Y	Standing waist-height forward reach	5	Pulling	1g
	Change Force Direction	Y	Standing waist-height forward reach	45	Pushing	1g
Small Female	Baseline	Y	Standing waist-height forward reach	45	Pulling	1g
	Remove Suit	N	Standing waist-height forward reach	45	Pulling	1g
	Change Posture	Y	Leaning back, waist-height forward reach	45	Pulling	1g
	Change Force Magnitude	Y	Standing waist-height forward reach	5	Pulling	1g
	Change Force Direction	Y	Standing waist-height forward reach	45	Pushing	1g

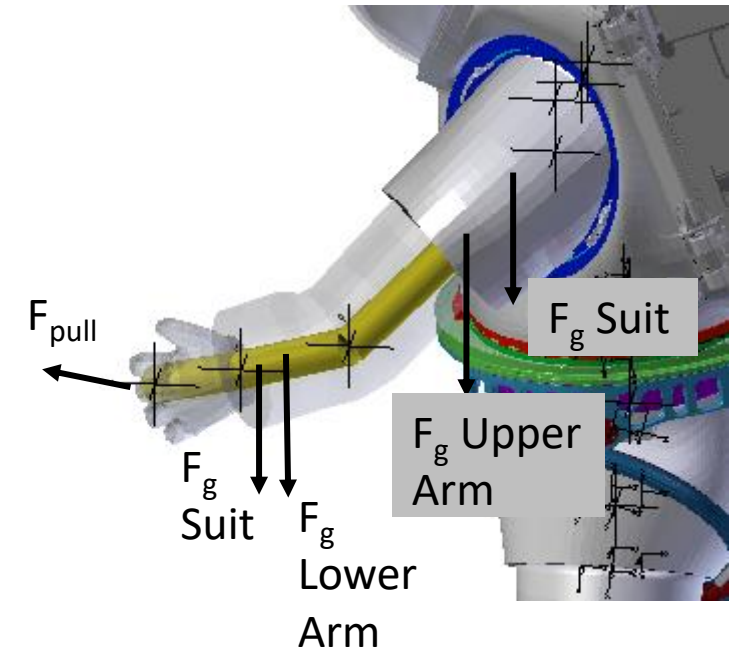
Baseline Case



Human Body Only



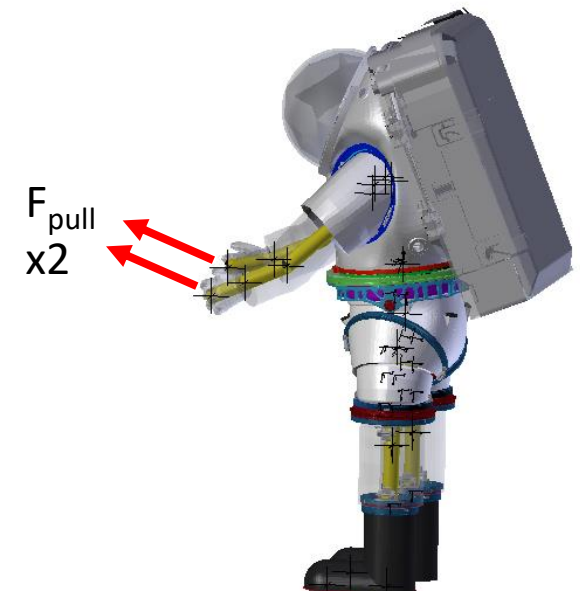
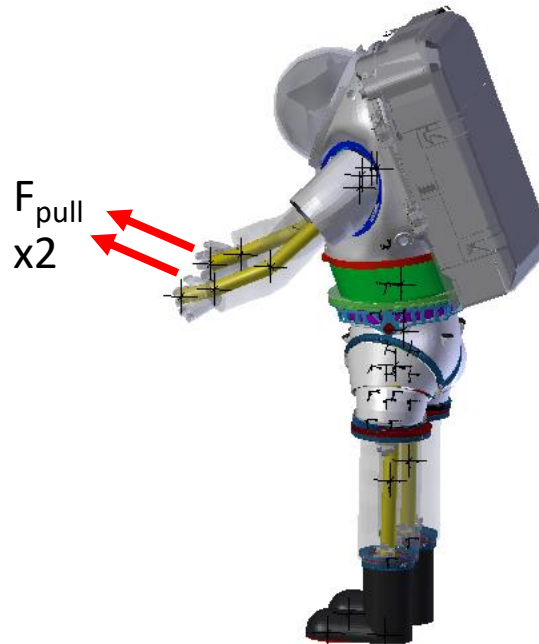
Human and Suit



Effects of Anthropometry – Baseline Cases

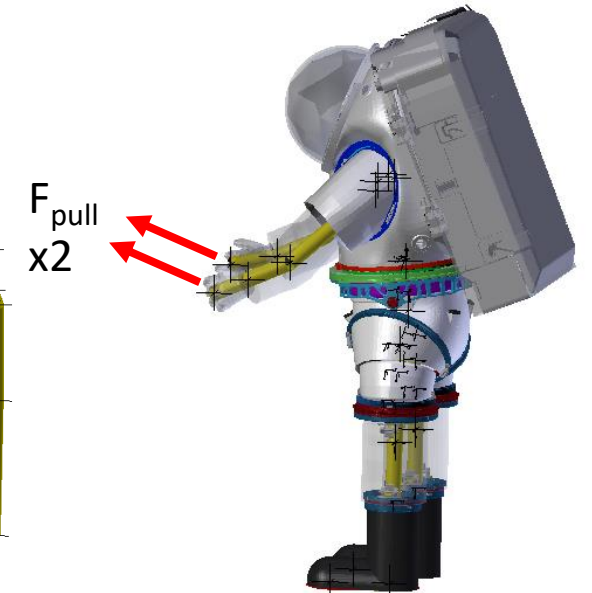
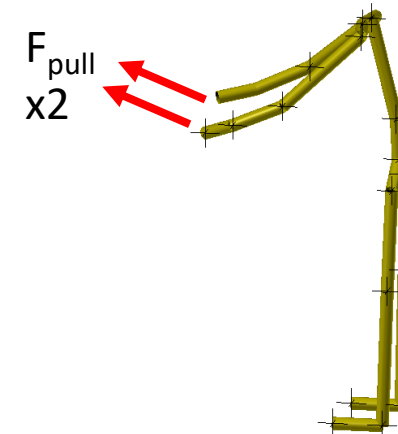
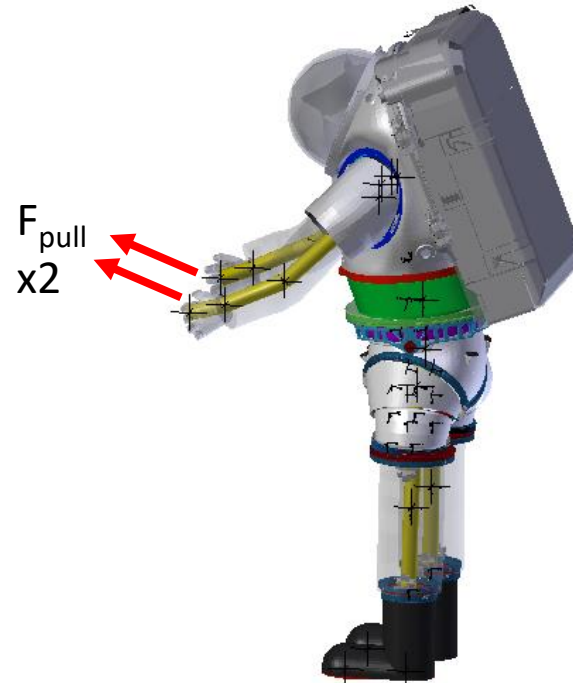
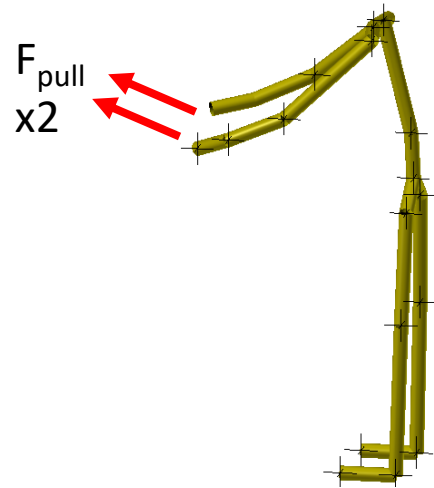
Anthro	Joint	Force X [lb]	Force Y [lb]	Force Z [lb]	Torque X [in-lb]	Torque Y [in-lb]	Torque Z [in-lb]	Population Strength Capacity %
Medium Male	Elbow	0	-45	-12	-232	8	-39	99
	Shoulder	0	-45	-35	-947	-95	169	28
Small Female	Elbow	0	-45	-12	-202	3	-29	92
	Shoulder	0	-45	-35	-870	-94	157	0

- Greater relative impact on small sized female compared to medium sized male
- Due to suit characteristics, greater demands applied to shoulder than elbow



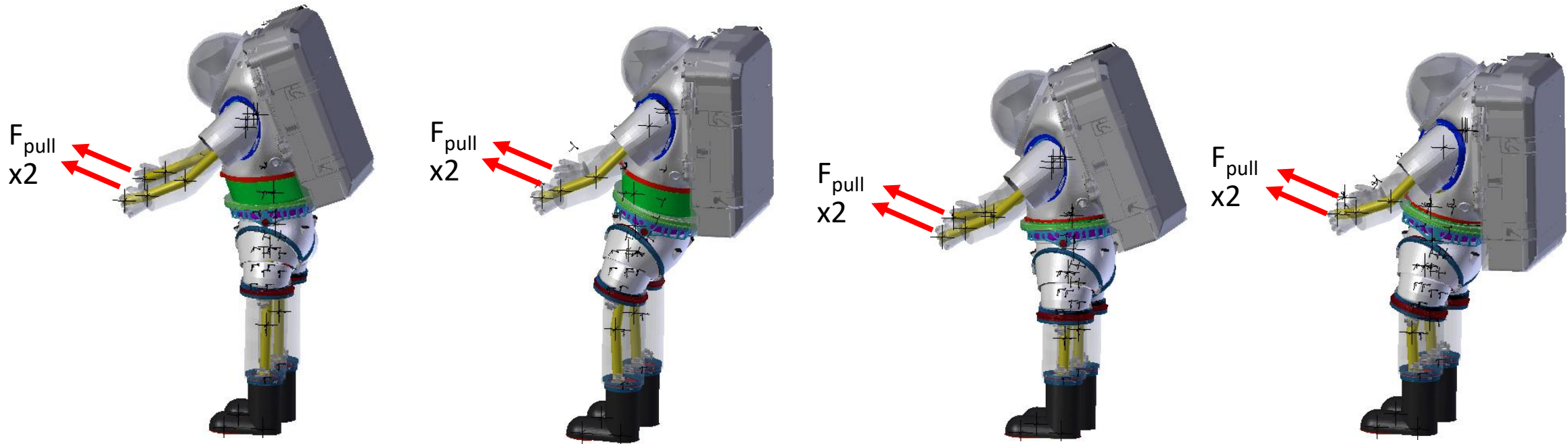
Effects of Suit

Joint	Joint Torque Magnitude (in-lb)			
	Male (no suit)	Male (with suit)	Female (no suit)	Female (with suit)
Elbow	30	235	11	204
Shoulder	423	967	392	889



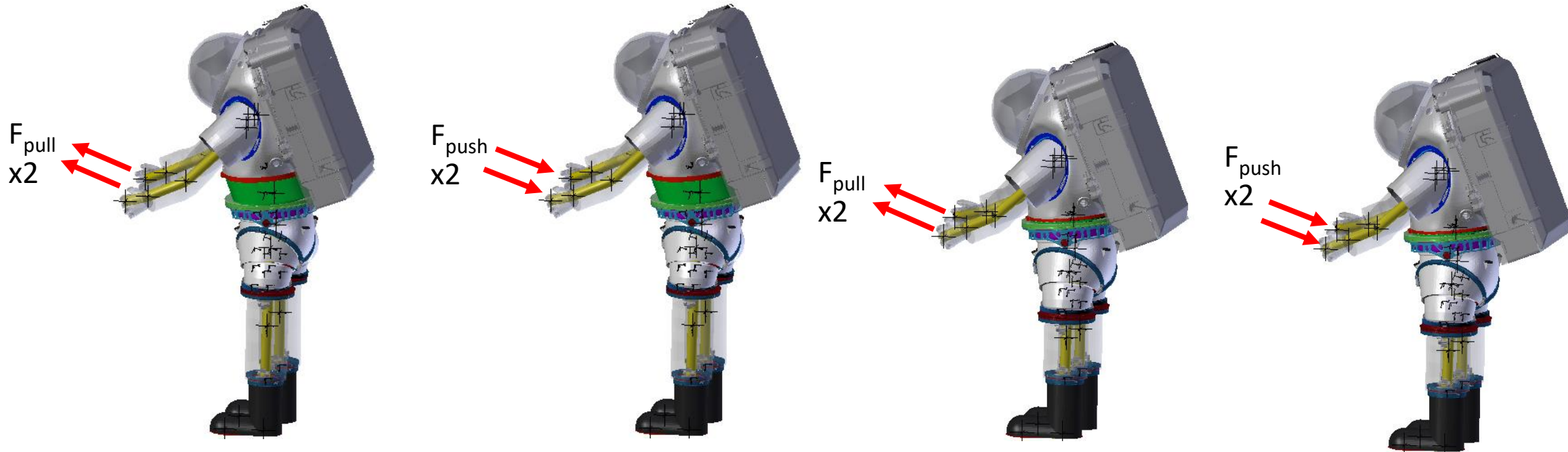
Effects of Posture

Joint	Joint Torque Magnitude (in-lb)			
	Male – Upright Pull Back	Male – Leaning Pull Back	Female – Upright Pull Back	Female – Leaning Pull Back
Elbow	235	244	204	200
Shoulder	967	130	889	220

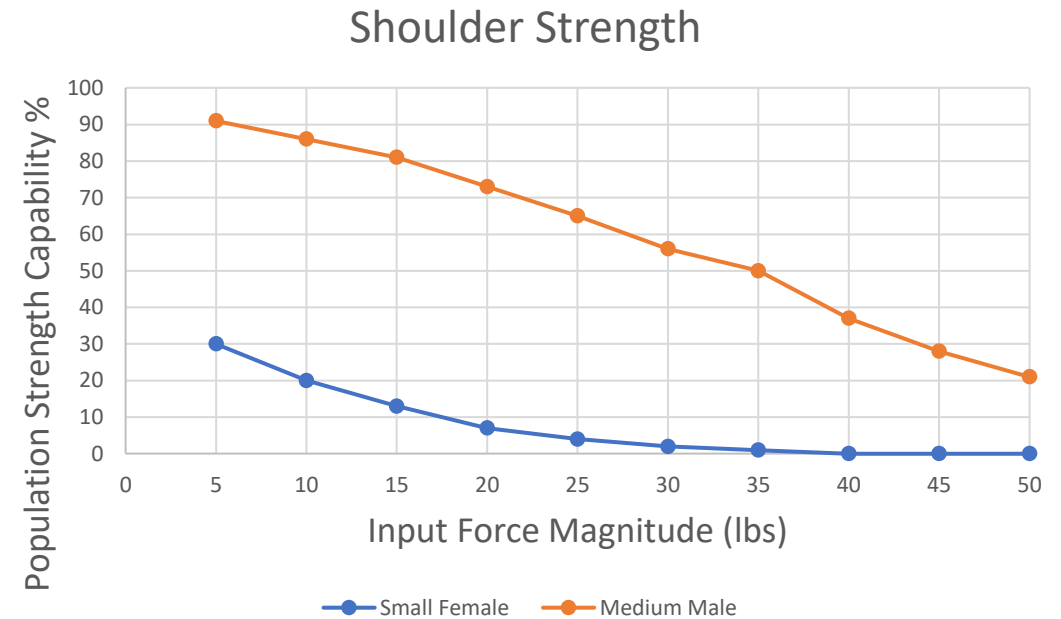
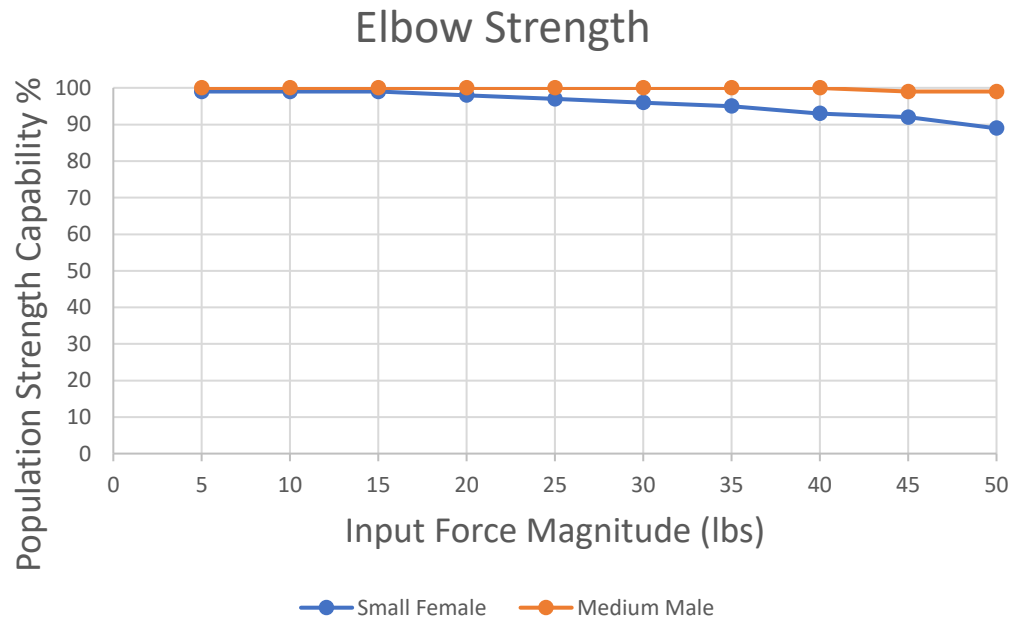


Effects of Input Force Direction

Joint	Joint Torque Magnitude (in-lb)			
	Male Pull Back	Male Push Forward	Female Pull Back	Female Push Forward
Elbow	235	149	204	29
Shoulder	967	162	889	183



Effects of Input Force Magnitude



- While holding posture constant, strength capability varies with force magnitude
- In this posture, the shoulder is more sensitive to increased input forces than the elbow
- Reducing load magnitude makes the task more feasible, however, may still not be feasible for many smaller sized people

Test Case Results

Anthro	Test Case Description	With Suit?	Body Posture	Input Force Magnitude on Each Hand [lbs]	Input Force Direction	Gravity	Elbow Torque [in-lbs]	Shoulder Torque [in-lbs]
Medium Male	Baseline	Y	Standing waist-height forward reach	45	Pulling	1g	235	967
	Remove Suit	N	Standing waist-height forward reach	45	Pulling	1g	30	423
	Change Posture	Y	Leaning back, waist-height forward reach	45	Pulling	1g	244	423
	Change Force Magnitude	Y	Standing waist-height forward reach	5	Pulling	1g	109	481
	Change Force Direction	Y	Standing waist-height forward reach	45	Pushing	1g	149	162
Small Female	Baseline	Y	Standing waist-height forward reach	45	Pulling	1g	204	889
	Remove Suit	N	Standing waist-height forward reach	45	Pulling	1g	11	392
	Change Posture	Y	Leaning back, waist-height forward reach	45	Pulling	1g	200	220
	Change Force Magnitude	Y	Standing waist-height forward reach	5	Pulling	1g	112	494
	Change Force Direction	Y	Standing waist-height forward reach	45	Pushing	1g	29	183

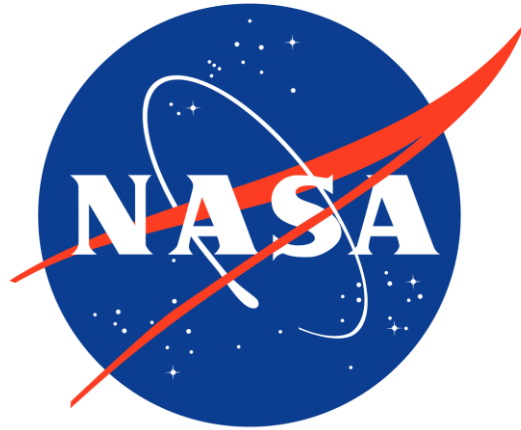
Summary

- Integrated spacesuit mass properties and mobility restrictions with human body strength modeling to create a static suited exertion model
- Characterized suit, anthropometry, posture, and input force effects on joint torques
- The model provides suited strength comparison, which can be used along with other industrial ergonomic considerations such as task duration, speed, repetition, etc. to identify and mitigate suited injury risks

Future Work

- Compare model to testing to verify trends
- Improve suit modeling fidelity by investigating effects of pressurization, suit joint resistance, and partial gravity
 - Pressurization may contribute additional resistance in certain motions
 - Suit joint resistance/limited degrees of freedom may affect predictions
 - Partial gravity may also play a role

Contact Information



Garima Gupta

garima.gupta@nasa.gov

Sudhakar Rajulu PhD

sudhakar.rajulu-1@nasa.gov