

NEXT GENERATION EXERCISE DEVICE (NGED): ADVANCING EXERCISE CAPABILITIES FOR FUTURE SPACE MISSIONS THROUGH BIOMECHANICAL MODELING

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Introduction

- Background:** As space exploration extends to long-duration missions on the Moon and Mars, maintaining astronaut health and fitness becomes increasingly critical.
- The Next Generation Exercise Device (NGED), developed and tested by the HumanWorks Lab at NASA Johnson Space Center (JSC), aims to address this challenge through innovative approaches.
- Objective:** Development and evaluation of a NGED system, focusing on its adaptability to various Moon to Mars mission scenarios, including prospective use in a Lunar Pressurized Rover (LPR).
- To help inform vehicle and system requirements, an exercise volumetric assessment was performed via data collection and biomechanical modeling.



Figure 1. NGED modalities.
a) Tricep extension exercise with a single top-mounted Beyond Power Voltra I system
b) Alternating-hand ski exercise with dual top-mounted Voltra I systems
c) Lat pulldown with dual top-mounted Voltra I systems
d) Fly exercise with dual shoulder-level Voltra I systems
e) Bench press exercise with dual ground-mounted Voltra I systems
f) Reverse-chop exercise with a single ground-mounted Voltra I system

Methods

Table 1: Data Collection Test Matrix (NGED Summer 2024)

#	Exercise/Trial Name	Variation/Description	Handle & Cable Configuration	Beyond Power(s) Position	Total Load Setting (lbf)
1	BenchPress_1	Bench/ground	LB 2C	ground	40-60
2	Thruster_1	Front Squat + Continuous Overhead Press	LB 2C	ground	30-50
3	BackSquat_1	Normal	LB 2C	ground	30-50
4	Deadlift_1	Normal	LB 2C	ground	30-70
5	BentOverRow_1	Normal	LB 2C	ground	40-50
6	BentOverRow_2	Side Cable, Single Handed	SB 1C	ground	10-20
7	KettlebellSwing_1	Normal	SB 1C	ground	15-20
8	ReverseChop_1	Reverse Chop (Dragon slay)	SB 1C	ground	10-15
9	SideBends_1	Alternating sides	2SB 2C	ground	40-70
10	Fly_1	Normal, thumbs up	2SB 2C	shoulder level	20-50
11	LatPulldown_1	Lateral Pulldown sitting on bench	LB 2C	top	40-90
12	TricepExtension_1	Normal	HB 1C	top	20-50
13	WoodChop_1	Chop	SB 1C	top	15-20
14	Ski_1	Parallel (Synchronous), ski ergometer	2SB 2C	top	10-30
15	Ski_2	Alternating (Asynchronous), ski ergometer	2SB 2C	top	10-30
16	SquatJump_1	Front, raise legs	N/A	N/A	(body weight)
17	LungeJump_1	Swap feet in lunge	N/A	N/A	(body weight)

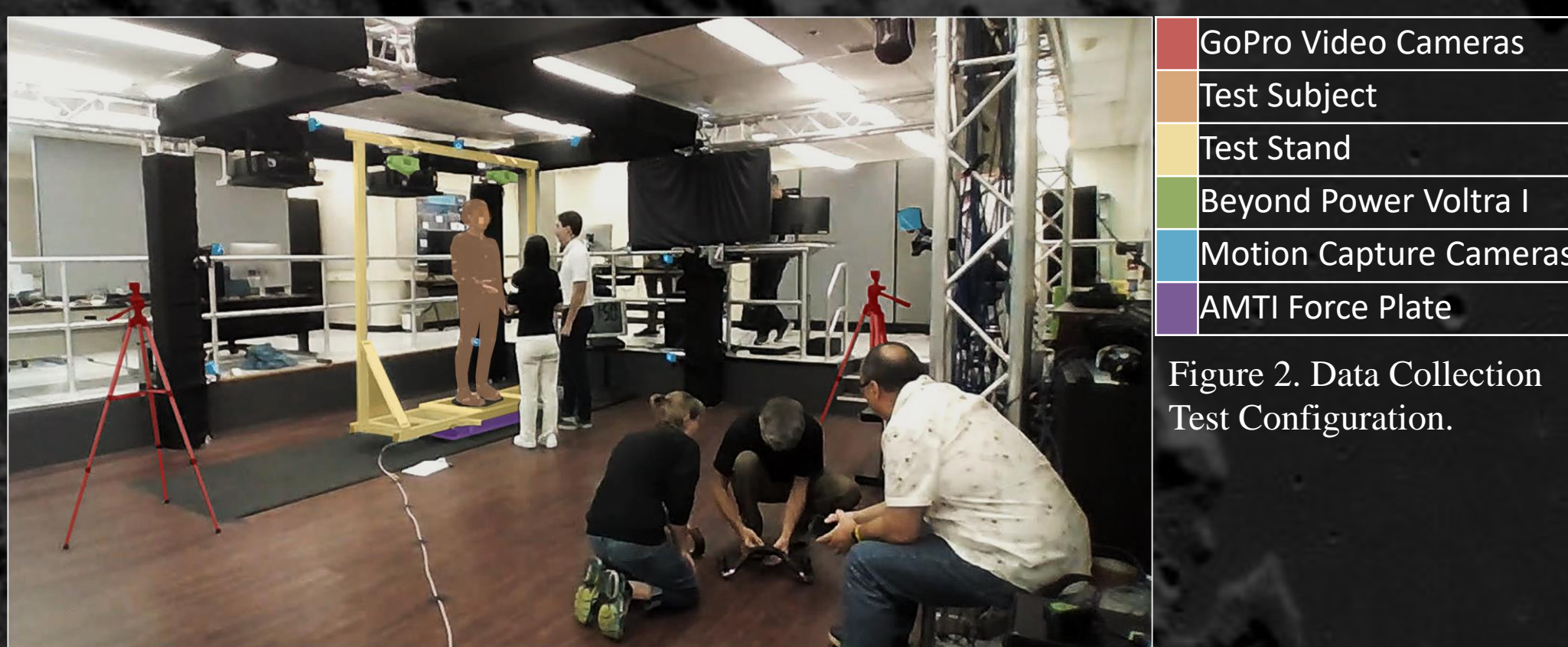


Figure 2. Data Collection Test Configuration.

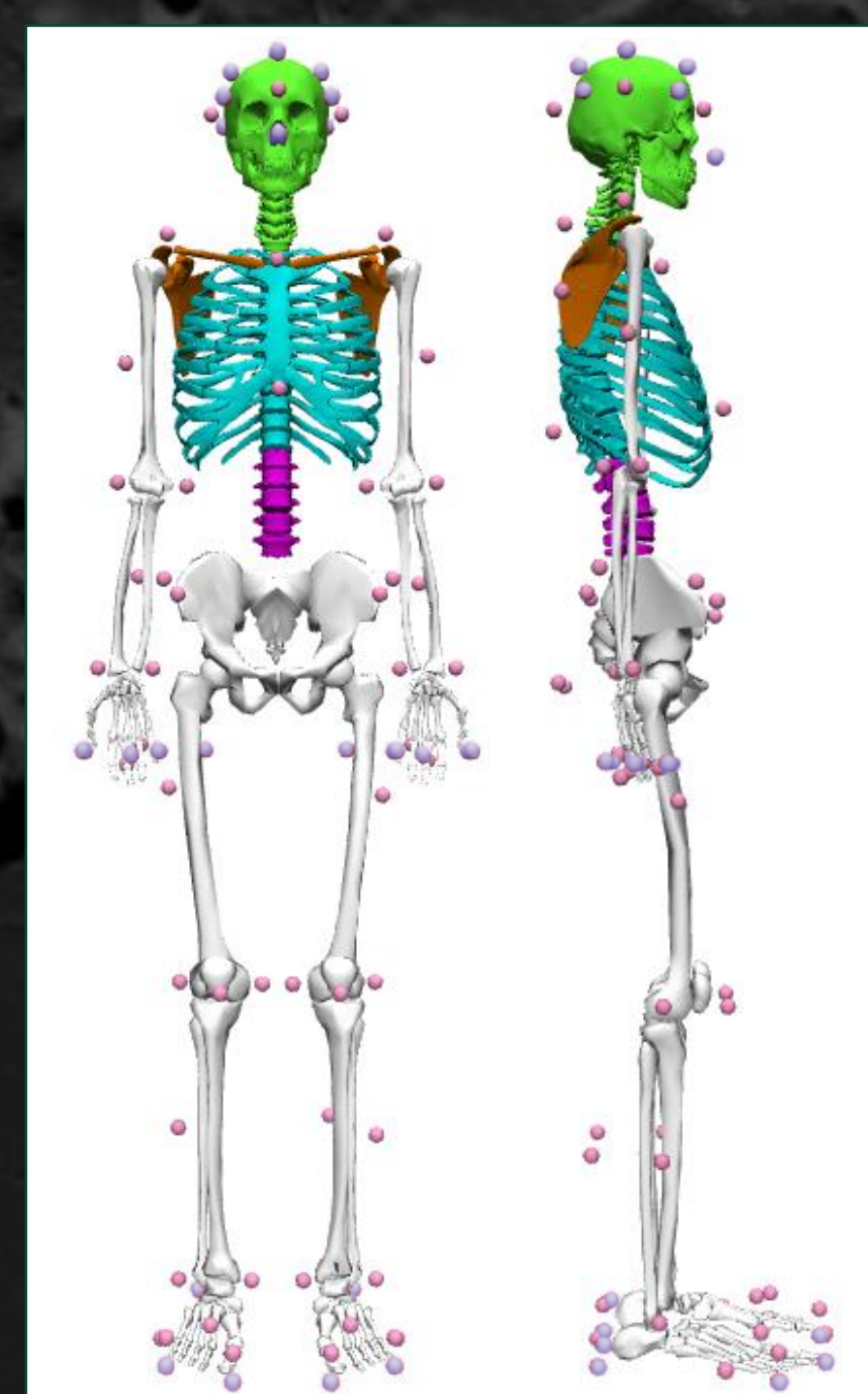


Figure 3. OpenSim model showing all markers used to define the volumetric convex hull.

The collection was performed in JSC's Prototype Immersive Technology (PIT) Lab, utilizing an OptiTrack motion capture system and AMTI force platform, to enable detailed biomechanical analysis via OpenSim [2,3]. Data collection for NGED development was conducted with two motor-driven Beyond Power Voltra I [1] systems and a custom test structure to allow placement of the cable-based devices at different heights (Figure 2).

- Motion capture and force plate data were collected with 3 subjects representing different body types and statures.
- The marker set used was an enhanced version of the full-body Plug-in Gait marker set [4], with additional markers strategically placed for the primary objective of informing exercise volume requirements.
- Subjects performed static poses and at least 8 repetitions of each exercise shown in Table 1.
- Biomechanical modeling and kinematic analysis were conducted using a modified OpenSim Full Body Rajagopal Model [4,5]. (Figure 3)
 - Markers were added to the model for a more comprehensive volumetric analysis. Hardware was excluded.
- Theoretical subject models were also created and scaled to the maximum and minimum body segment anthropometry provided in NASA-STD-3001 [6]. Inverse kinematics was run using isometrically scaled marker trajectories from collected data so that foot motion and postures best represented the source subjects.
- Volumetric convex hulls were generated (in .STL format) based on 95 model marker trajectories and aggregated into geometric assemblies in PTC Creo (Figure 5). OpenSim playback with volumes overlaid were recorded for validation of model marker sets and for understanding of when volumetric limits are reached during a trial motion (Figure 4).

Results

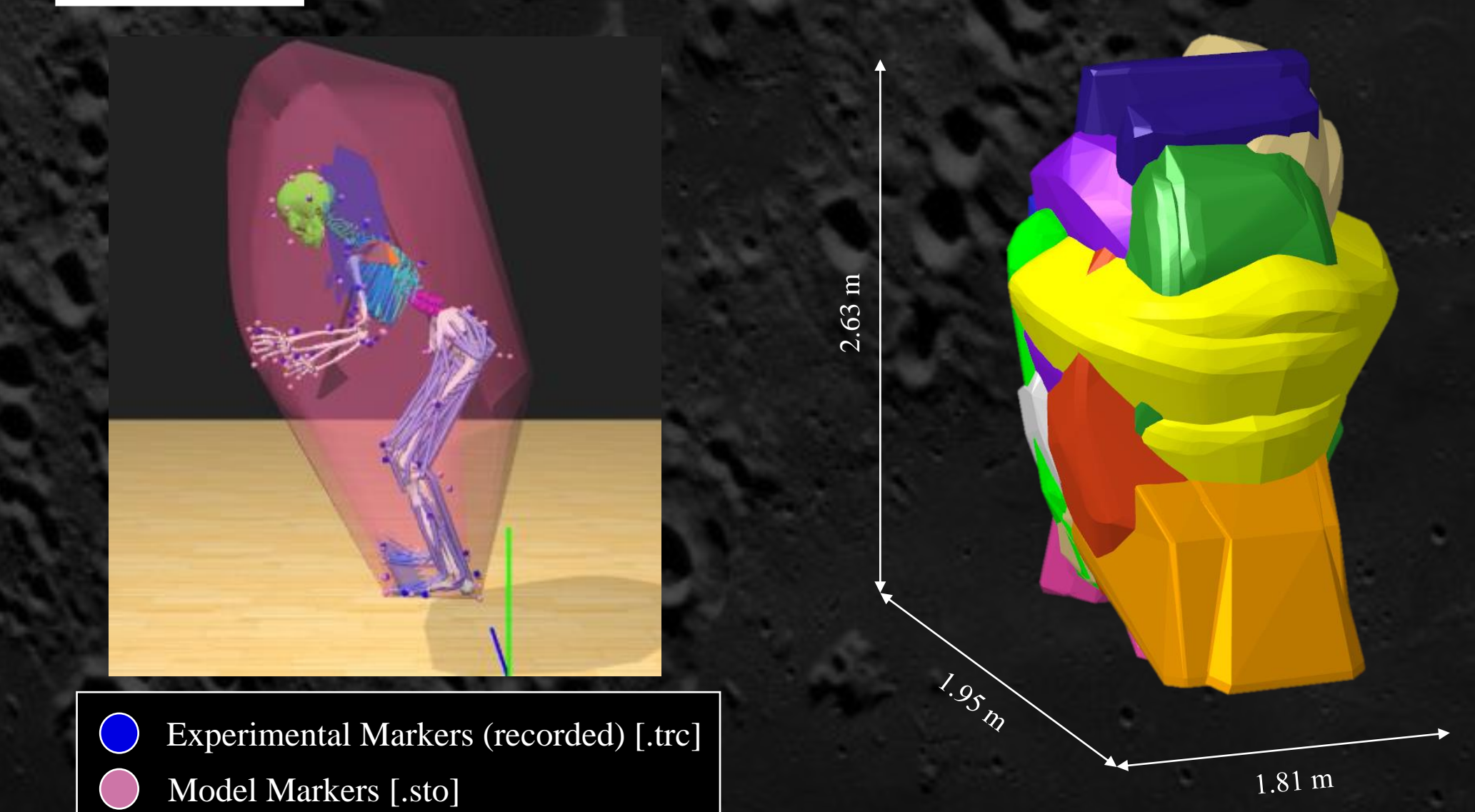


Figure 4. Example of OpenSim model with volume overlay.



Figure 5. Aggregate of exercise volumes across all subjects, with default placements representative of relative data collection configurations.

Table 2: Maximum dimensions across all subjects and trials (volume used, independent of relative offsets during collection).

Exercise	Depth (m)	Height (m)	Width (m)	Volume (m ³)
Back Squat	0.89	1.97	1.04	0.85
Bench Press	1.67 (S35 SMax)	1.33	1.19	1.08
Bent Over Row	1.03	1.84	1.02	0.70
Deadlift	1.04	2.00	0.90	0.73
Fly	1.37	1.94	1.76 (S34 SMax)	1.54
Kettlebell Swing	0.75	1.99	1.32	0.80
Lat Pulldown	1.31	1.98	1.20	1.03
Lunge Jump	1.07	2.04	1.37	1.21
Reverse Chop	1.26	2.36	1.31	1.57
Side Bends	0.58	1.96	1.20	0.67
Ski	1.37	2.16	1.15	1.85 (S34 SMax)
Squat Jumps	0.96	2.02	0.84	0.63
Thruster	1.00	2.39 (S34 SMax)	1.14	1.27
Triceps Extension	0.76	1.93	0.80	0.50
Wood Chop	1.15	2.11	1.39	1.40

Note: While S35 was the tallest test subject, the theoretical subject with maximum stature (SMax) based on S34 set more of the max dimensions due to kinematics with greater limb range of motion and straighter postures.

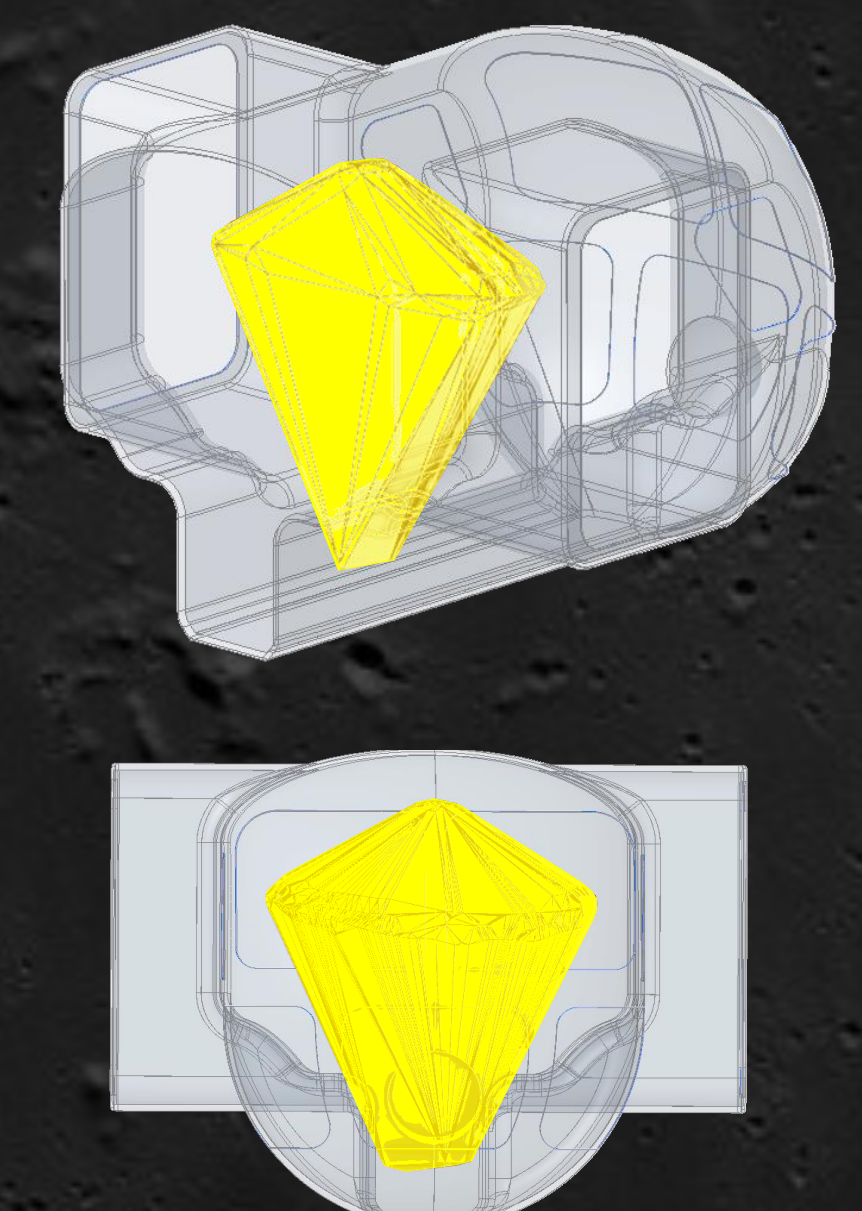


Figure 6. Example of a fly exercise volumetric convex hull compared with a model of the Space Exploration Vehicle.

Conclusions/Recommendations

- These volumetric convex hulls can be placed in models of vehicle designs to assess fit to protect for exercise (Figure 6) as well as to adapt NGED exercise to fit available space.
- Preliminary findings from the collection indicate that the NGED prototype demonstrates significant adaptability across varying user anthropometrics and exercise types.
- The device showed consistent performance in load-bearing exercises, with subjects able to perform exercises effectively while maintaining proper biomechanical form.
- NGED represents a forward-looking advancement in exercise capabilities for future space missions.
- Its versatility in accommodating various exercises and user physiques, coupled with the ability to provide targeted biomechanical loading, makes it a promising approach for maintaining astronaut health during long-duration missions to the Moon and Mars.

Future Work

- Explore less conservative methods of volume generation.
- Inform feasibility of exercise modalities within an LPR design.
- Refine NGED design and optimize its use within the confined spaces of an LPR and other space habitats.
- Develop NGED to assess crew isometric mid-thigh pull force outputs, postural muscle strength, and overall isometric strength.

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