Muscle Preflight Value Requirements

Monitoring crewmember performance readiness is an important task in human spaceflight missions which includes ensuring crewmembers meet the physical strength criteria. To successfully complete in-flight and post-flight nominal task crewmembers must meet NASA-STD-3001 Volume 1 [V1 4023] Pre-Mission Muscle Strength and Function.

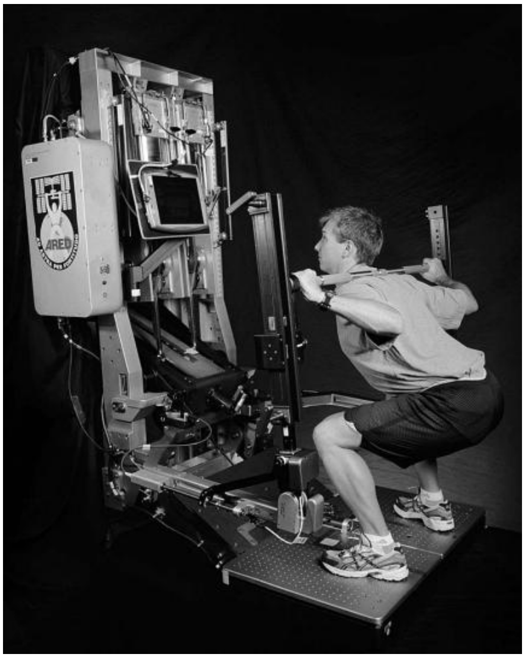
[V1 4023] Pre-mission muscle strength and function shall meet or exceed the values in Table 4.6-1—Pre-Mission Muscle Strength.

Crew must maintain muscle strength in order to safely and effectively perform critical tasks such as:
- Open/Close Hatches
- Incapacitated crew rescue
- Performance in suits during an EVA
- Ambulation (potentially with supplies)
- Hill Climb

Table 4.6-1– Pre-Mission Muscle Strength

	Minimum	Microgravity EVAs*	Extraterresrial Surface EVAs**	Unaided Terrestrial Egress***
Deadlift	1.0 x Body Weight	1.3 x Body Weight	1.6 x Body Weight	1.3 x Body Weight
Bench Press	0.7 x Body Weight	0.8 x Body Weight	1.0 x Body Weight	0.7 x Body Weight

The NASA-STD-3001 pre-flight strength requirement measures strength with two exercises: deadlift (DL) and bench press (BP) which are used to represent lower body strength and upper body strength, respectively. The benefits of using such exercises are that they are location-independent and can be performed in any exercise setting, with the exception of microgravity environments. For ISS crewmembers, isometric mid-thigh pull (IMTP) and isometric bench press (IBP) are the lower and upper body exercise protocols used to measure crewmember strength across their mission, but these exercises are location specific requiring specialized equipment. With concerns that a large percent of crew are not meeting the pre-flight strength requirement but are still able to complete in-mission tasks, a reanalysis of data was completed to ensure the requirements accurately represent mission tasks and crew ability. Data pulled from the SPRINT study was used to correlate IBP vs. BP (English et al., 2020). That correlation was then used to identify the BP lift mass in kg per body weight (BW) in kg. Data pulled from an already correlated IMTP vs. 1 rep max (RM) DL was used to identify the DL mass in kg per BW in kg (De Witt et al., 2018). This technical bulletin further outlines the calculation guidance for extraterrestrial EVA.



Demonstration of the Advanced Resistive Exercise Device (ARED)
Source: NASA

Methodology Overview

1. Identify Mission-Critical Strength Demands

- The FMT study threshold data was used to determine the minimum strength needed to perform mission critical tasks.

2. Convert Task Thresholds Into Predictive Strength Values

- Used SPRINT data to develop regression (IBP → BP) to translate upper body thresholds to predicted bench press loads.
- Used De Witt correlation (IMTP → DL) to convert lower-body thresholds into deadlift loads.

3. Normalize Requirements to Body Weight (BW)

- Thresholds forces multiplied by individuals' BW to calculate required BP and DL values.

4. Integrate Suit Mass (S) and Gravity (G)

- Final equations incorporate mission configuration parameters to predict lift requirements for Earth, Lunar, Martian, or microgravity and suit weight.

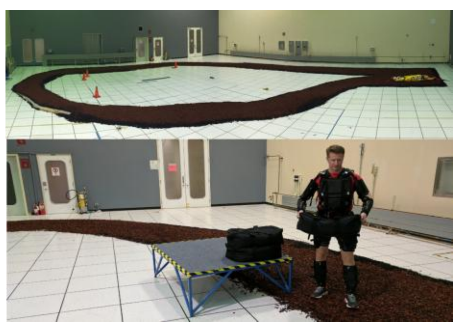
Background

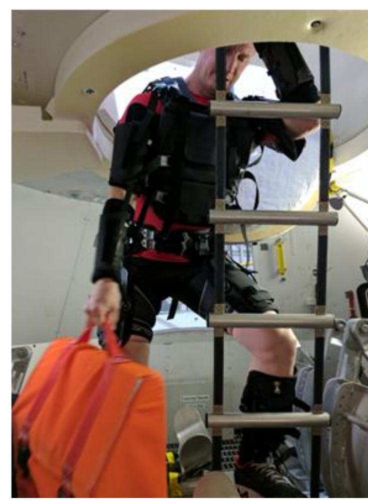
Fitness for Mission Task (FMT) Study

The FMT- Muscle Strength Approach focused on identifying minimal thresholds for achieving acceptable performance of different task (Ryder et al., 2019). The results of this study were presented as threshold data that was further used in a correlation calculation. The following task were used in the FMT testing to stimulate different mission phases:

Nominal

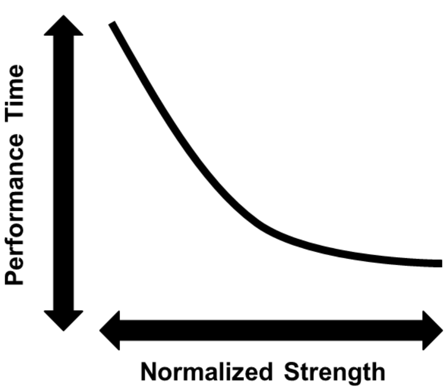
- Ambulation and Supply Transfer
  - 1.5 km walk on a 50 m rubber mulch track
  - Transfer 30 bags between platforms 5 m apart (10.9 kg each)
- Hill Climb and Descent for communications antenna deployment
  - Climb hill (1000 m and 40 m incline) with a 4.5 kg bar
  - Return (no bar)





Contingency Tasks

- Unaided Top Hatch Capsule Egress
- Incapacitated Crewmember Rescue
  - Move 75 kg rescue dummy onto a rescue sled
  - Drag 50 m

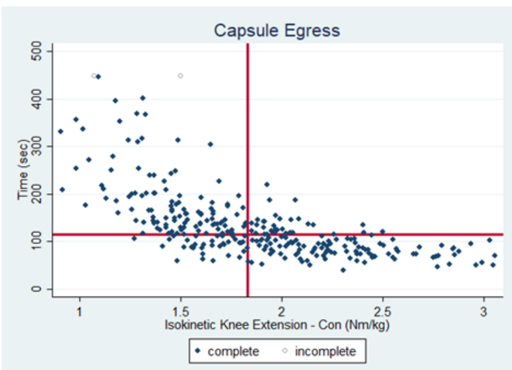


- Mockup selected tasks
- Perform baseline measurements of strength
- Perform tasks under different loaded conditions
- Plot *normalized* strength versus performance time
- Identify strength thresholds

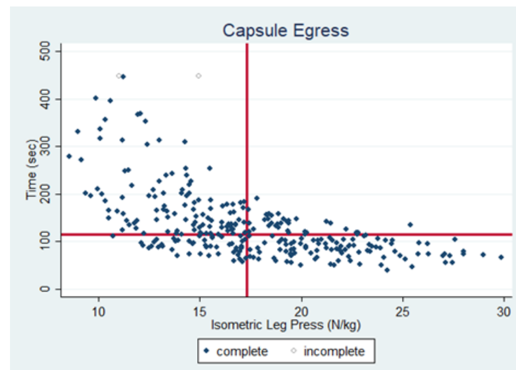
FMT Study Results

The results of the study yielded a threshold curve time (sec) vs. strength, the median performance is indicated by the red line and each task yielded similar values. The capsule egress threshold number was used because it represents one of the most physically demanding and critical tasks astronauts must perform. Capsule egress is a vital emergency procedure that requires significant muscle strength and coordination. By using this threshold, we ensure that the muscle strength requirements are robust enough to cover a wide range of essential tasks, including those that are less demanding. This approach provides a comprehensive safety margin, ensuring astronauts are well-prepared for various mission scenarios.

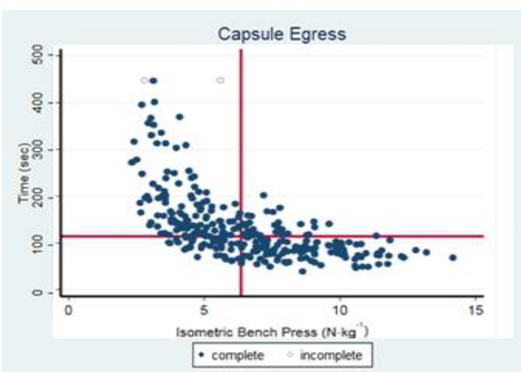
Isokinetic KE



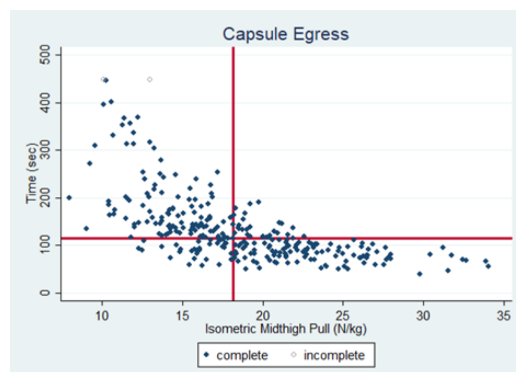
Isometric LP



Isokinetic BP



Isometric MTP



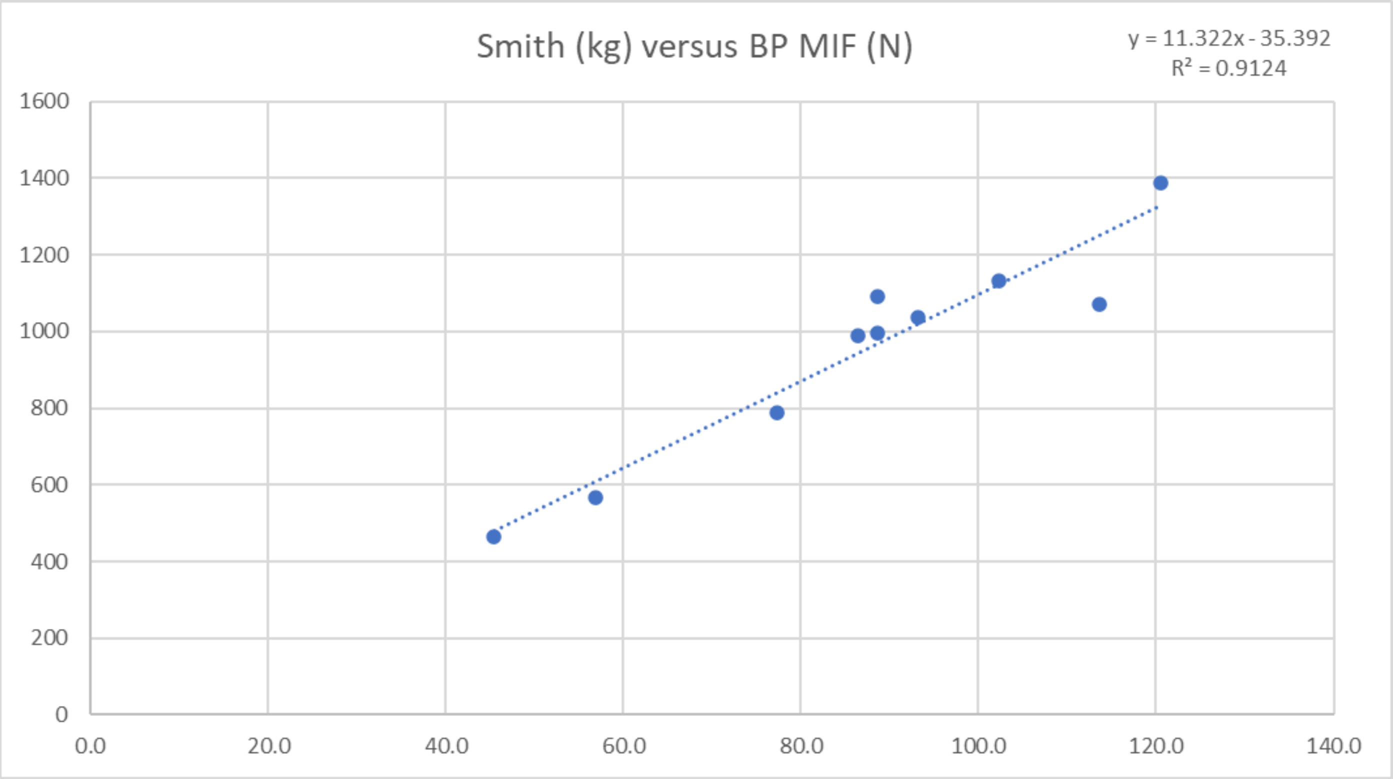
Muscle Strength Threshold Derived from Simulated Missions Tasks

Test (Muscle strength)	Egress	Rescue	Ambulation	Hill Climb
Isokinetic Knee Extension (Nm/kg)	1.83	1.83	1.83	1.86
Mid-Thigh Pull (N/kg)	18.12	18.20	18.36	18.53
Leg Press Strength (N/kg)	17.36	17.30	17.51	17.65
Bench Press Strength (N/kg)	6.40	6.39	6.57	6.67

Isometric Bench Press and Bench Press Correlation

The SPRINT Study used 9 crewmembers on the ISS, 8 males and 1 female, to test whether a high intensity, low volume protocol (SPRINT protocol) could maintain cardiovascular fitness and musculoskeletal strength as effectively as the ISS protocol (low intensity, high volume). The SPRINT protocol included aerobic training and resistance training that emphasized fewer, heavier load reps to simulate strength training. Data was further taken from this study to identify the correlation between bench press (BP) and IBP. The limitations of this study include a low population number and low female representation in the population pool.

The BP 1 RM and the IBP 1 RM was found for each subject and plotted. A linear regression analysis was performed.



BP and IBP Equation

Using the FMT thresholds, IBP vs. BP regression and different suit mass and gravity, developed these equations for both BP and IBP:

$$BP = 0.088324 * (6.4 * (BW + S) * G + 35)$$
$$IBP = (BW + S) * 6.4 * G$$

BW = Body Weight in kg
S = Suit Mass in kg
G = Gravity*
*NOTE: Use value 1 for Earth

Example Calculations using a 75kg crewmember for each mission task:

Minimum (no suit)
BP= 0.088324 x (6.4 x 75 kg x 1 + 35)
BP = 46 kg

IBP = (75 kg) x 6.4 x 1
IBP = 480 N

Extraterrestrial EVA (using Apollo EMU 83 kg)

Lunar

BP = 0.088324 x (6.4 x (75 kg + 83 kg) x 1/6 + 35)
BP = 18 kg

IBP = (75 kg + 83 kg) x 6.4 x 1/6
IBP = 169 N

Martian

BP = 0.088324 x (6.4 x (75 kg + 83 kg) x 3/8 + 35)
BP = 37 kg

IBP = (75 kg + 83 kg) x 6.4 x 3/8
IBP = 379 N

Extraterrestrial EVA (using high mass suit 200 kg)

Lunar

BP = 0.088324 x (6.4 x (75 kg + 200 kg) x 1/6 + 35)
BP = 29 kg

IBP = (75 kg + 200 kg) x 6.4 x 1/6
IBP = 293 N

Martian

BP = 0.088324 x (6.4 x (75 kg + 200 kg) x 3/8 + 35)
BP = 61 kg

IBP = (75 kg + 200 kg) x 6.4 x 3/8
IBP = 660 N

Isometric Mid-Thigh Pull and Deadlift Correlation using De Witt et al. (2018)

To determine the relationship between an Isometric Midthigh Pull (IMTP) versus a 1 RM deadlift, De Witt et al., (2018) tested 9 adults (5 male and 4 female) under 2 sessions. Each session they performed IMTP and conventional 1 RM deadlift. The findings found that there was a strong correlation between IMTP and Deadlift 1 RM (R = 0.88, p ≤ 0.05).

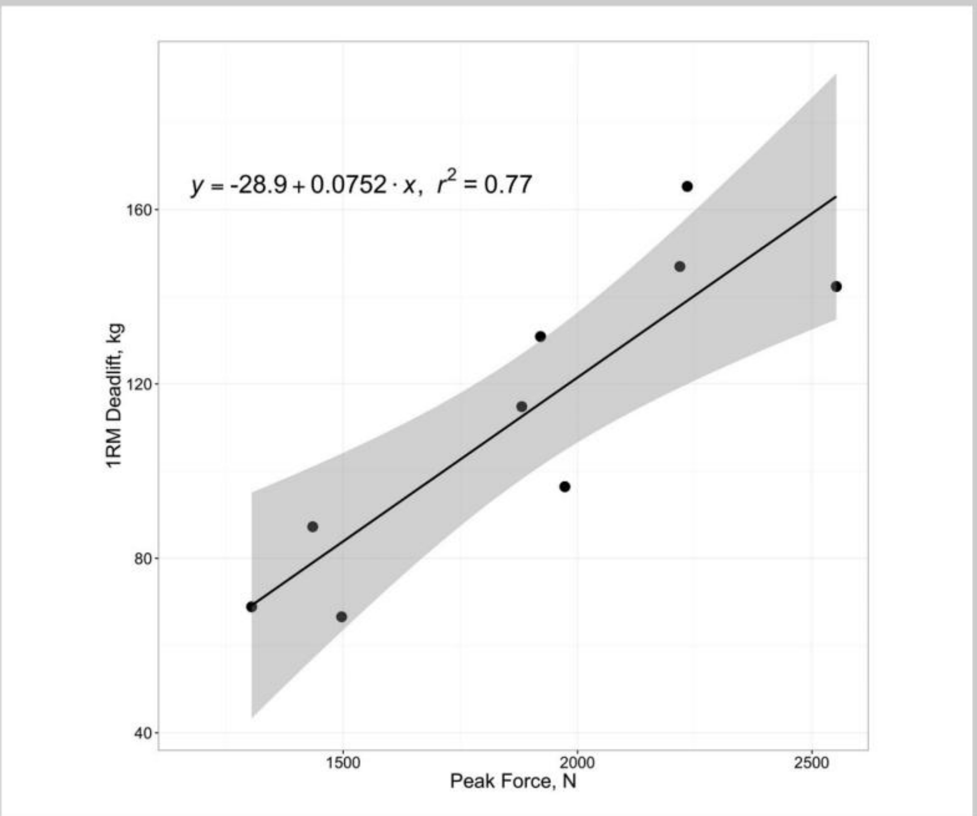


Figure 2. Relationship between maximum isometric midthigh pull peak force and deadlift one repetition maximum (1RM).

DL and IMTP Equation

Using the FMT thresholds, DL vs. IMTP regression from De Witt et al. (2018), and different suit mass and gravity, these equations were developed for both DL and IMTP:

$$DL = 1.3626 * (BW + S) * G - 28.9$$

$$IMTP = (BW + S) * 18.12 * G$$

BW = Body Weight in kg
S = Suit Mass in kg
G = Gravity*
*NOTE: Use value 1 for Earth

Example Calculations using a 75 kg crewmember for each mission task

Minimum (no suit)

DL= 1.3626 x (75 kg) x 1 – 28.9
DL = 73 kg

IMTP = (75 kg) x 18.12 x 1
IMTP = 1359 N

Extraterrestrial EVA (using Apollo EMU 83 kg)

Lunar

DL = 1.3626 x (75 kg + 83 kg) x 1/6 – 28.9
DL = 7 kg

IMTP = (75 kg + 83 kg) x 18.12 x 1/6
IMTP = 477 N

Martian

DL= 1.3626 x (75 kg + 83 kg) x 3/8 – 28.9
DL = 52 kg

IMTP = (75 kg + 83 kg) x 18.12 x 3/8
IMTP = 1074 N

Extraterrestrial EVA (using high mass suit 200 kg)

Lunar

DL = 1.3626 x (75 kg + 200 kg) x 1/6 – 28.9
DL = 34 kg

IMTP = (75 kg + 200 kg) x 18.12 x 1/6
IMTP = 831 N

Martian

DL = 1.3626 x (75 kg + 200 kg) x 3/8 – 28.9
DL = 112 kg

IMTP = (75 kg + 200 kg) x 18.12 x 3/8
IMTP = 1869 N

Strength Deconditioning Consideration

While strength deconditioning is variable and influenced by different components such as flight duration, form of exercise, and individual factors, for the purpose of this technical bulletin, no representative value was used to standardize calculations in the deadlift column. Future mission application may benefit from adjusting to mission specific deconditioning values as more targeted data becomes available. Reference NASA OCHMO-TB-031 Exercise Overview for additional information.

Strength & Bone Standards • Maintain 80% of pre-flight muscle strength • Maintain 95% of pre-flight hip and spine and 90% femoral beck bone mineral density						
Exercise Type & Mission Duration	**Exercise Session Frequency**	**Exercise Session Duration**	**Equipment/Hardware**	**Hardware Capabilities**	**Crew Usage**	**Physiological Decrements**
Very Short Duration (<10 days)[1]	No Exercise	No exercise	Shuttle Treadmill only, no resistive exercise	**Load Capacity:** max 220lbs	N/A	Muscle strength loss: -12% to 1-19% in upper leg -3% to -10% in lower leg -2% to -23% in back < 1.5% BMD loss
Short Duration (up to 14 days)[1]	3 days/week	Variable	Shuttle Treadmill only, no resistive exercise	**Load Capacity:** max 220lbs	Continuous and intervale exercise training at 60-85% of pre-flight VO_{2MAX}	Muscle strength loss -2% to -9% in upper leg -5% to +12% in lower leg -15% to -38% in back < 1.5% BMD loss
Long Duration (180+ days)[2]	6-7 days/week	60 minutes/session	ISS Advanced resistive exercise device (ARED)	**600lb. Load capability** <u>Critical Exercises:</u> • Rowing • Squat Press • Squat • Deadlift • Shoulder raise <u>Additional Exercises:</u> • Kneeling chop • Bell swing • Leg abduction • Leg flexion	**Bench Press:** Average 44 repetitions; load range 98-153lbs **Squat:** Average 189 days; load range 150-223lbs **Heel Raise:** Average 207 repetitions; load range 198-293lbs. **Deadlift:** Average 230 repetitions; load range 156-215lbs.	Average: -1% loss of upper body strength; 9% loss of lower body strength Range: -1% to -3% loss of upper body strength; -4 to -12% loss of lower body strength Average: -0.5 to 1.0% BMD loss per month Range: -2.1% to -8.5% BMD loss Range: -2.1% to -8.5% BMD loss

From: NASA OCHMO-TB-031 Exercise Overview

Reference List

Ryder JW, Fullmer P, Buxton RE, Crowell JB, Goetchius E, Bekdash O, De Witt JK, Hwang EY, Feiveson A, English KL, Ploutz-Snyder LL. A novel approach for establishing fitness standards for occupational task performance. Eur J Appl Physiol. 2019 Jul;119(7):1633-1648. doi: 10.1007/s00421-019-04152-3. Epub 2019 May 8. PMID: 31069517.

De Witt JK, English KL, Crowell JB, Kalogera KL, Guilliams ME, Nieschwitz BE, Hanson AM, Ploutz-Snyder LL. Isometric Midthigh Pull Reliability and Relationship to Deadlift One Repetition Maximum. J Strength Cond Res. 2018 Feb;32(2):528-533. doi: 10.1519/JSC.0000000000001605. PMID: 27548797.

English, K.L., Downs, M., Goetchius, E. et al. High intensity training during spaceflight: results from the NASA Sprint Study. npj Microgravity 6, 21 (2020). https://doi.org/10.1038/s41526-020-00111-x