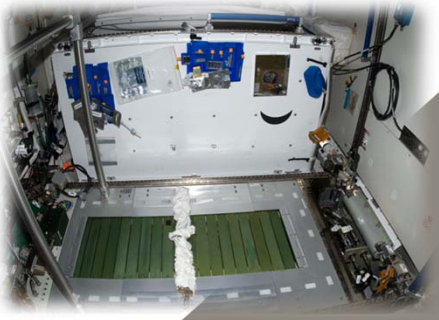

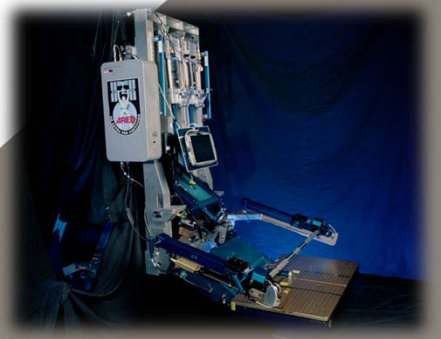

# PORTABLE LOAD MEASUREMENT DEVICE FOR USE DURING ARED EXERCISE ON ISS

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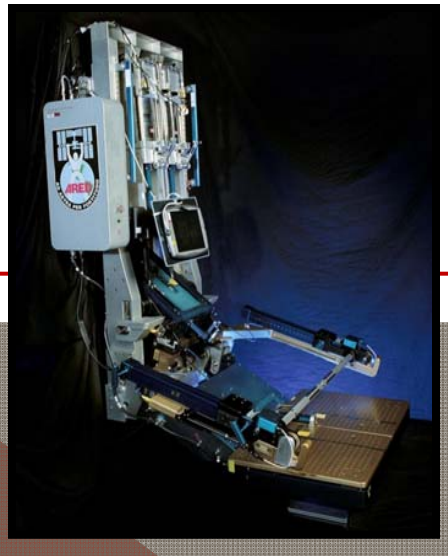
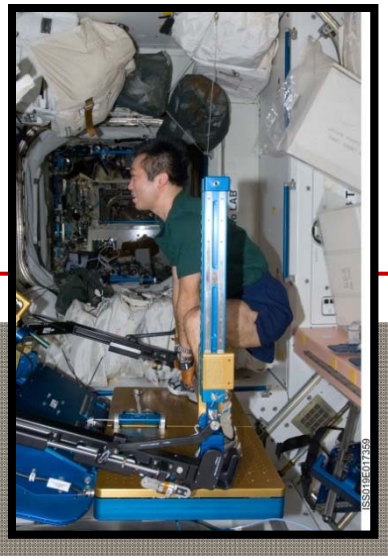
[3]National Space Biomedical Research Institute Summer Student
[4]Universities Space Research Association

# BACKGROUND

- The Advanced Resistive Exercise Device (ARED) was installed on ISS in 2009.
- ARED provides up to 600 lb resistive loads, and accommodates ~40 different exercises.
- Reliable and accurate exercise data has not been available since installation.
- Crewmembers fill out spreadsheets and manually record exercise data.
  - Manual logs are not historically as accurate as direct measurement.
- XSENS ForceShoes™ are the first COTS portable load monitoring device (PLMD) to offer high accuracy (~2%), ground reaction force measurements.
- PLMDs are not as widely used on the ground, but are favorable technology option when considering future exploration needs.



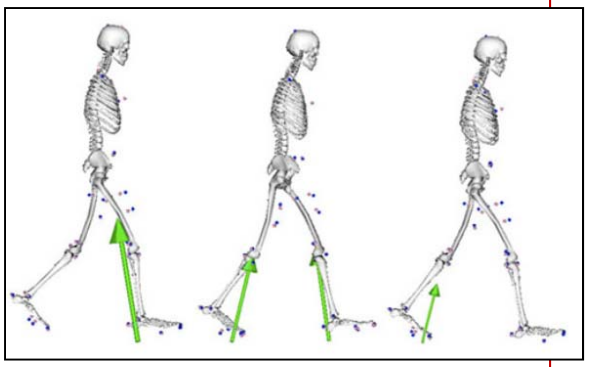


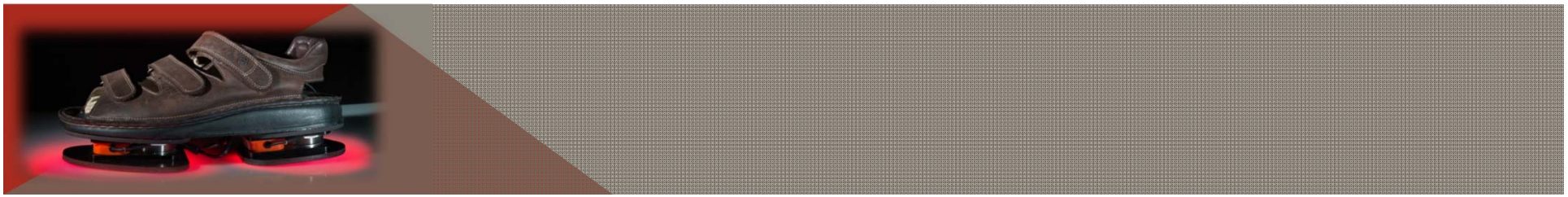
# XSENS FORCE SHOE

- Each Force Shoe is instrumented with:
  - Two six degrees-of-freedom (6-DOF) tri-axial force (Fx,y: ±130 $lb_{force}$, Fz: ±260 $lb_{force}$), and torque (Tx,y,z: ±177 lb-in ) sensors.
  - Two XSENS MTx sensors that measure tri-axial acceleration (± 180 $m/s^2$ ) and inertial parameters (± 1200 deg/s)
- Powered by 4 AA-batteries
- Communication via Bluetooth or serial USB cable
- Shoes weigh ~2.5 lb each, and are ~1.5 inches tall

# BENEFITS TO RESEARCH

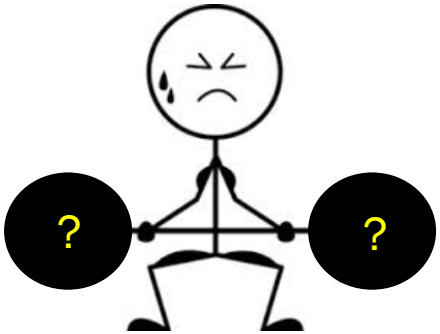
- The better the tools, the better the science
- ARED design requirement states that load measurements must be accurate within ± 1%. Center of pressure should be measured within ± 0.5 cm.
  - Errors of ±0.5cm and ±1.0cm in CoP calculation result in errors (7% and 14%, respectively) in joint torque calculations [McCaw & DeVita, J. Biomech, 1995] and is compounded during biomechanical analysis.
- Bone responds positively to an accumulation of mechanical input (ground reaction forces).
  - Overestimating GRF could reduce training benefits to crewmembers.
  - Underestimating GRF could result in unnecessary discomfort and physical exertion.





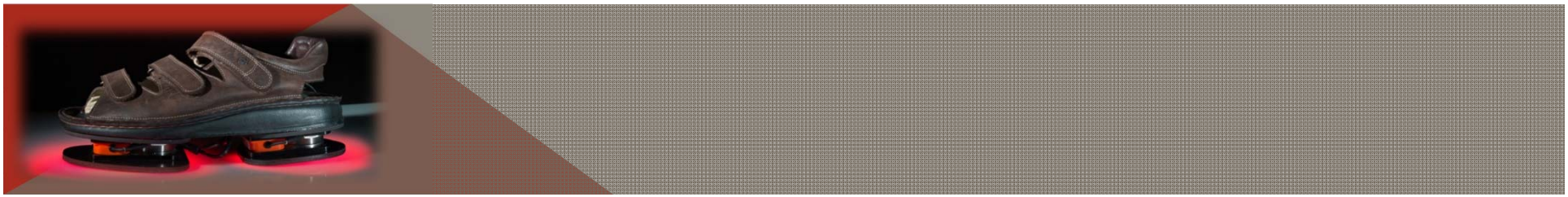
# WHY WE NEED ACCURATE MEASUREMENT

- Safety



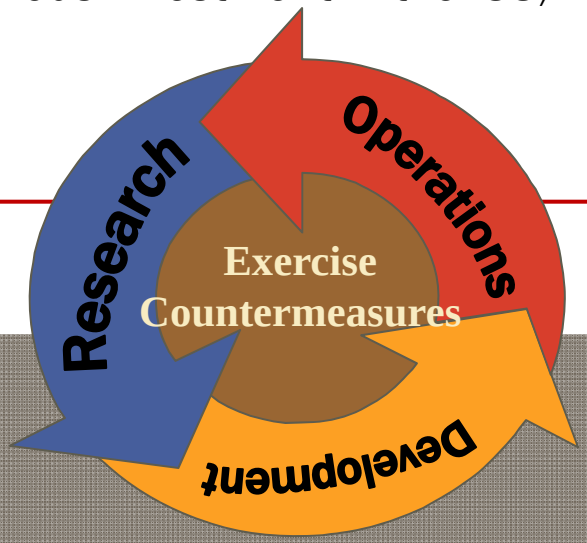

| Rx (lbs) | ± | 1% | 5% | 10% |
|---|---|---|---|---|
| 200 | - | 198 | 190 | 180 |
| | + | 202 | 210 | 220 |
| 300 | - | 297 | 285 | 270 |
| | + | 303 | 315 | 330 |
| 400 | - | 396 | 380 | 360 |
| | + | 404 | 420 | 440 |
| 500 | - | 495 | 475 | 450 |
| | + | 505 | 525 | 550 |
| 600 | - | 594 | 570 | 540 |
| | + | 606 | 630 | 660 |

- ARED can deliver up to 600 lb exercise loads.
- Original ARED calibration curves believed to be erroneous  up to ~10% .
- Can lead to inefficient prescriptions when Rx is underestimated for safety. *It is best to take out the guess work!*



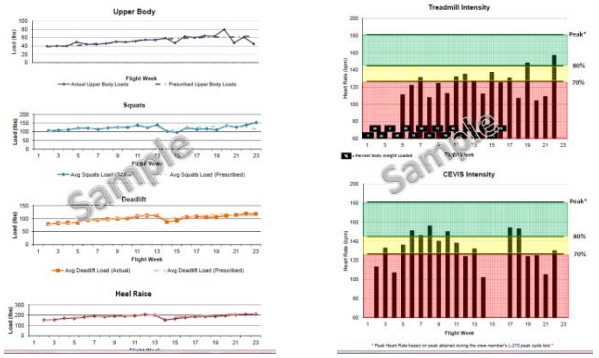
# LOSS OF DATA IS A LOSS OF RESEARCH

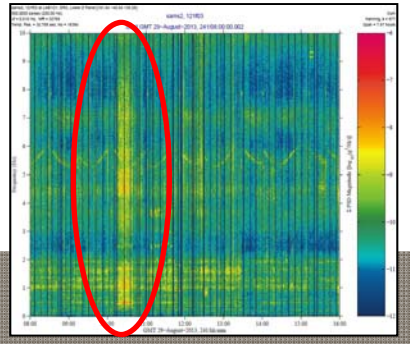
- Researchers are forced to accept increased risk of erroneous/incomplete exercise log data which limits interpretation of results outcomes.
- Risk of promoting a poor countermeasure protocol or not promoting a promising one with large uncertainty in the data.
- May prolong research to reach statistical conclusions (higher cost, longer schedules).
- Uncertainty in the data limits the ability to close HRP Gaps and mitigate Risks.
- Cannot write effective requirements documents for next gen exercise hardware.
- Cannot send our crews off on long duration exploration missions with any confidence that we know how to best protect them.
- Lost opportunity to learn after enormous investment in the ISS, HRP funded science, CMS hardware updates.
- Research informs operations.

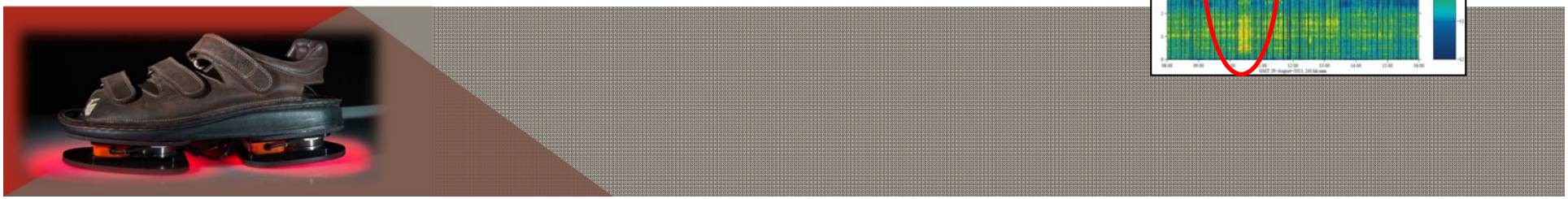


# EXERCISE DATA SUPPORTS MANY GROUPS

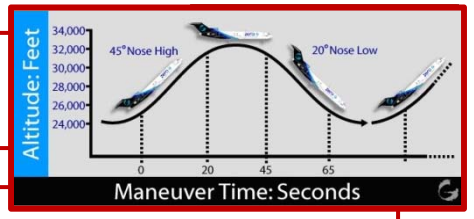
- Fulfill medical requirements.
- CMS Engineering troubleshoots hardware life cycles and anomalies.
- ISS structures group analyze impact to station structure.
- Enhance existing hardware, and inform future device requirements and design.
- Research: SPRINT, VO2 Max, Treadmill Kinematics, ARED Kinematics.





# GROUND & PARABOLIC FLIGHT TESTS




## Controlled ground evaluation

| Test Stand Load | Flight | | Ground | |
|---|---|---|---|---|
| | mean (±SD) | spread | mean (±SD) | spread |
| Average % of Target (Fz, ±SD) | 91.8% (±1.5) | 90.4 – 94.4% | 102.8% (±0.9) | 100.2 – 104.3% |
| Average % of Target (Fx,y,z, ±SD) | 105.0% (±1.8) | 102.4 – 107.8% | 104.5% (±1.2) | 102.6 – 107.7% |
| | N=6 | | N=51 | |

## Parabolic Flight

| Bungee Load | Flight Day 2 | | Flight Day 4* | |
|---|---|---|---|---|
| | mean (±SD) | spread | mean (±SD) | spread |
| Average % of Target (Fz, ±SD) | 99.3% (±2.8) | 94.6 – 101.7% | 89.4% (±0.2) | 89.2 – 89.6% |
| Average % of Target (Fx,y,z, ±SD) | 103.7% (±1.9) | 101.8 – 106.6% | 92.8% (±1.3) | 91.8 – 94.2% |
| | N=5 | | N=3 | |

## HILT

| HILT Eval | HILT Evaluation | |
|---|---|---|
| N=25 | mean (±SD) | spread |
| Average % of Target (Fx,y,z, ±SD) | 101.2% (±0.8) | 98.1 – 103.7% |

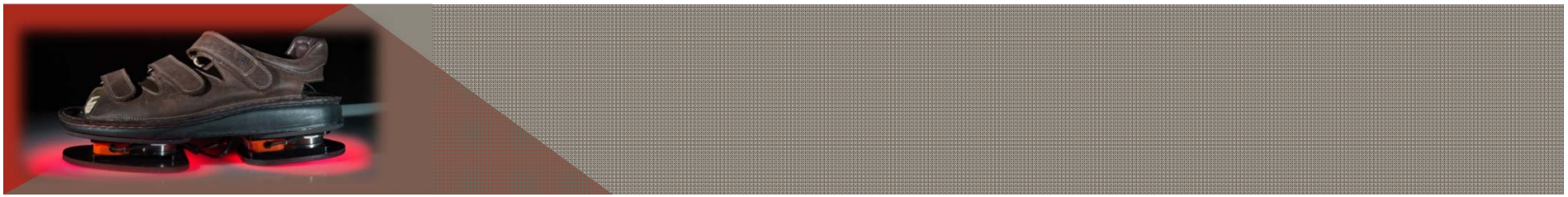
| HILT Eval | Function Checkout | |
|---|---|---|
| N=30 | mean (±SD) | spread |
| Average % of Target (Wireless) | 100.3% (±0.8) | 97.7-101.9% |
| Average % of Target (Wired) | 100.6% (±1) | 98.2-102.7% |

# ISS FORCE SHOE ENGINEERING EVALUATION

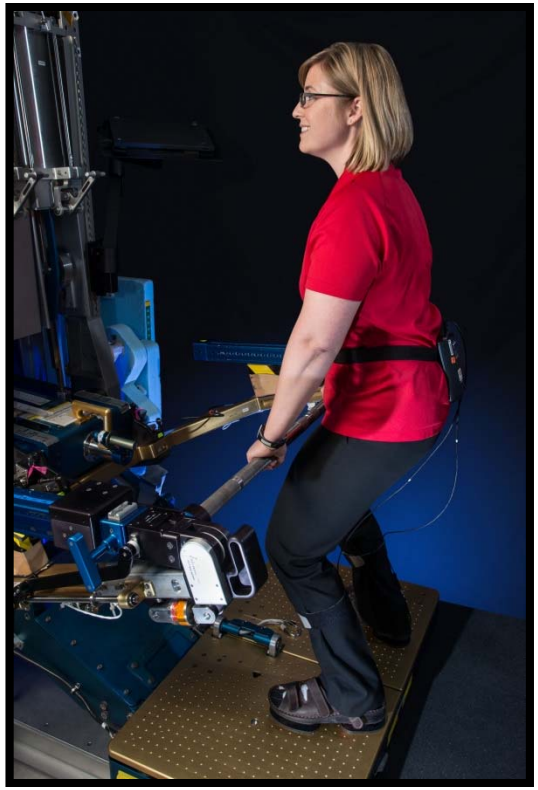
- Hardware arrived to ISS on 39S (May 2014).
  - Wireless receiver will arrive on Orb2 (~July 3rd).
- First data expected by June/July 2014.
- Aims of hardware demonstration:
  - 1: Use the ForceShoes™ as a means to measure static loads on ARED.
  - 2: Collect dynamic data during ARED exercise to aid in the ongoing evaluation of the XSENS ForceShoe™ to support HRP sponsored research.

*Static load data will be collected on the T2 under stationary (non-motorized) conditions, to compare the ForceShoe™ load measure to that recorded by the T2 load sensors.*

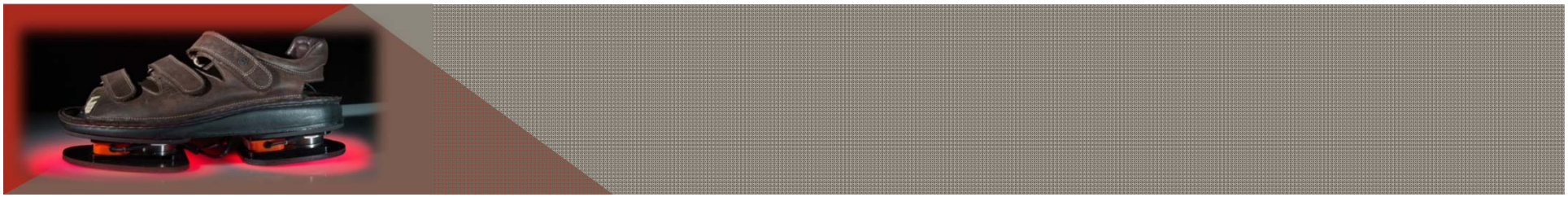
- Inform transition of use for research, and modifications required to next generation PLMD for use as a daily operational tool.



# FORCE SHOES HARDWARE

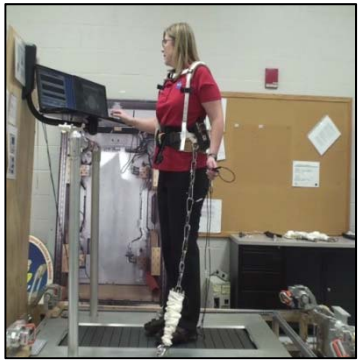



- Launched to ISS May 29th!

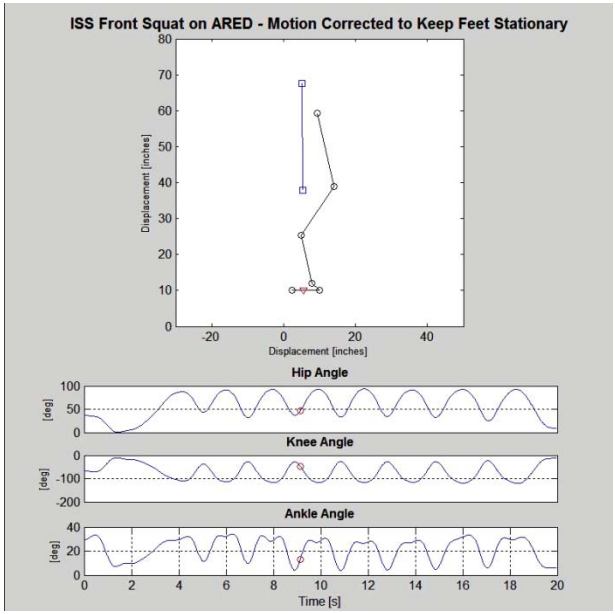


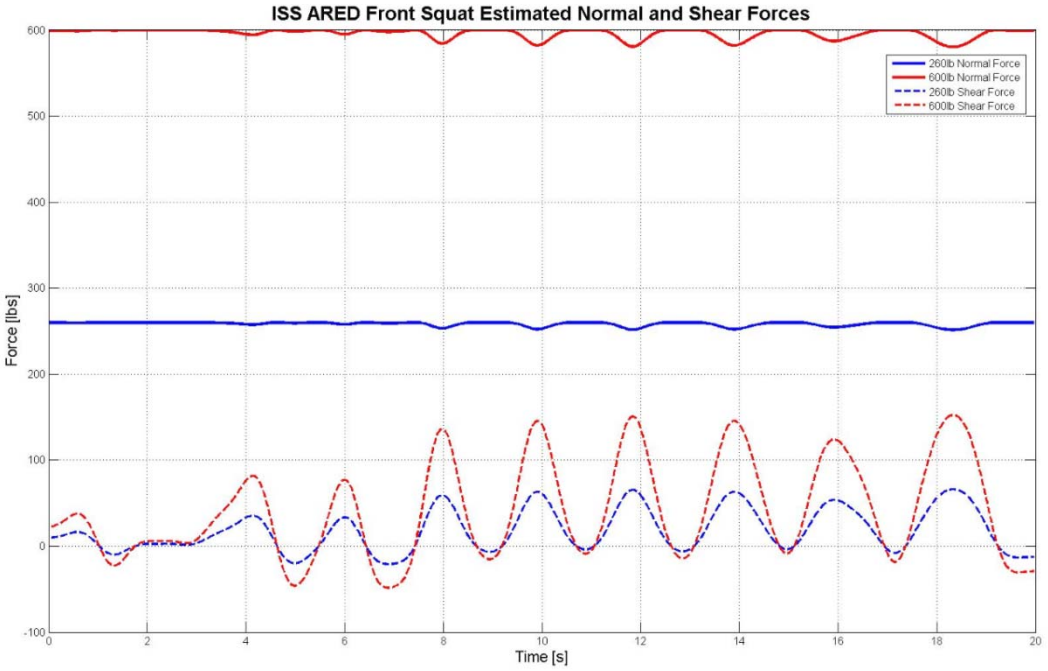
# METHODS & ANALYSIS

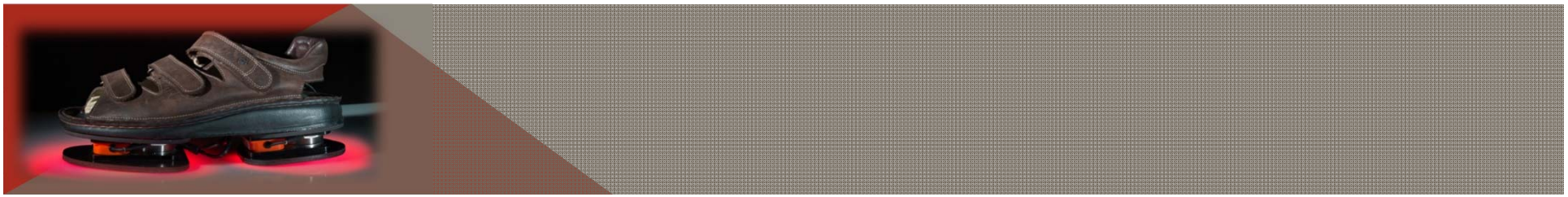
- Each static load measure will be made in triplicate.
  - Up to 6 load levels with treadmill bungees.
  - Up to 20 load increments on ARED.
    - High and low bar static load measures.
  - Squat, deadlift, bicep curls.
- Data will be analyzed for:
  - Repeatability and Accuracy.
  - Tri-axial force components.
- Evaluate range/robustness of Bluetooth communication.



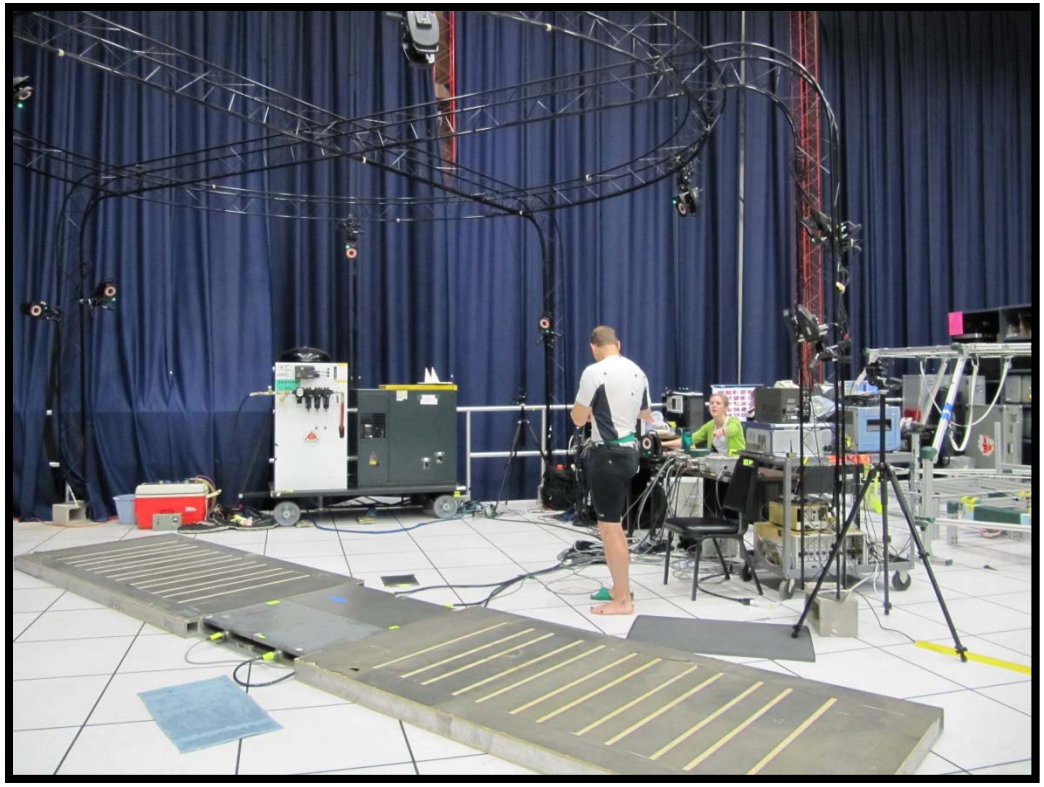
# ESTIMATION OF LOAD DISTRIBUTION



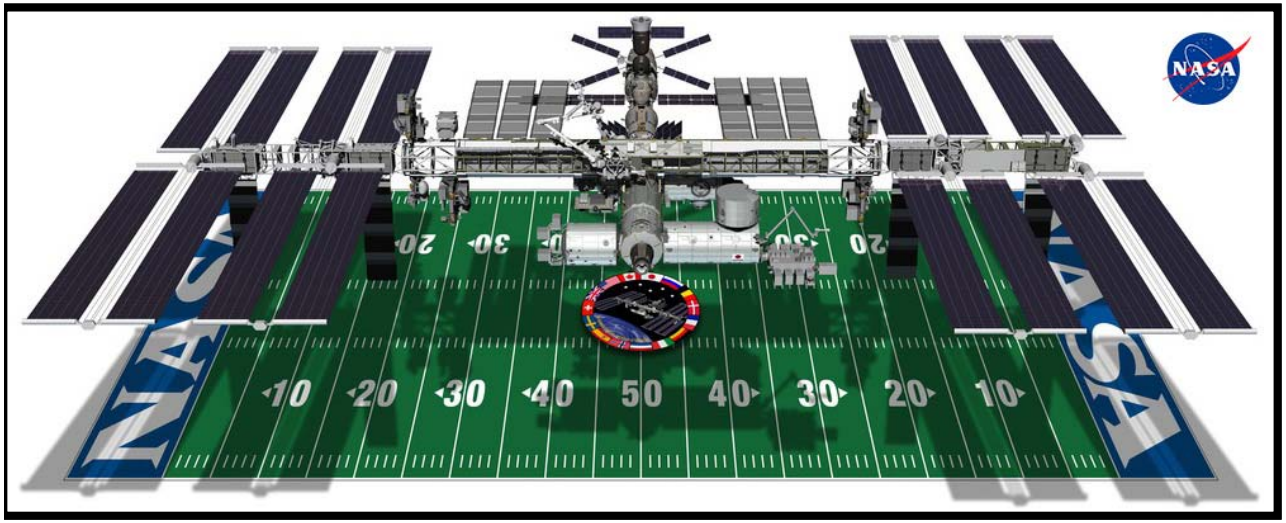
# RESEARCH TAKES SPACE!



SPACE DEMANDS INNOVATION!

# TO THE MOON, MARS & BEYOND!

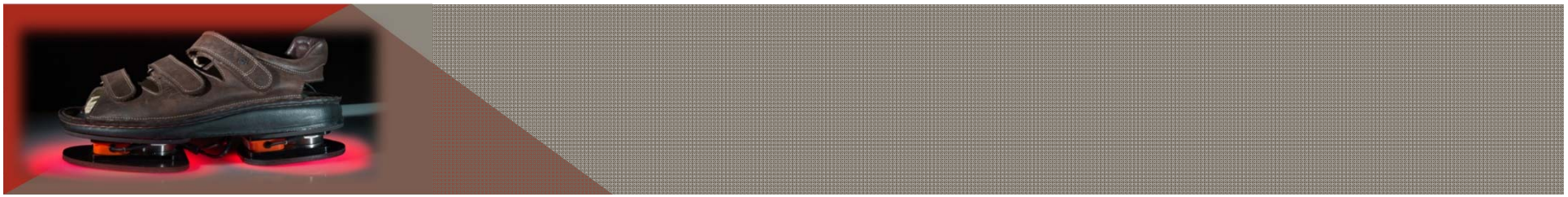
International Space Station




Habitable Volume: 15,000 $Ft^3$

Orion Capsule

Habitable Volume: 316 $Ft^3$



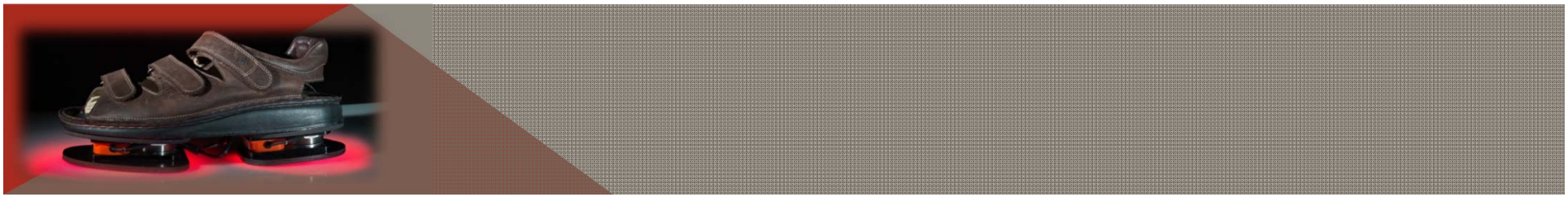
# PORTABLE LOAD MONITORING DEVICES

XSENS
ForceShoe™

Nike+
Hyperworkout Shoe

JSC Robotics Team:
X1/X2 Force Shoe

Aurora Flight Systems:
*Enhanced Dynamic Load Sensors* –
Phase II SBIR

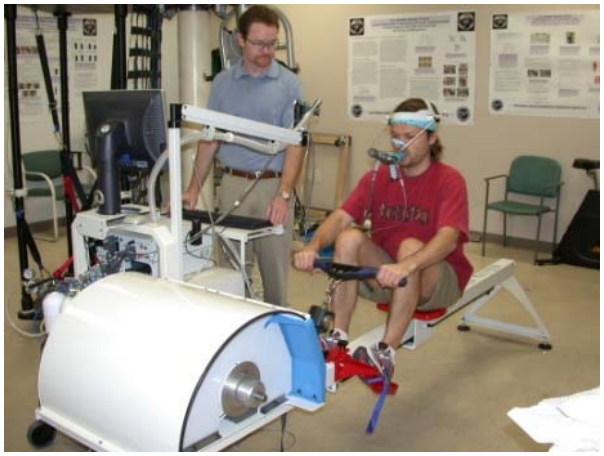



# ADVANCED EXERCISE CONCEPTS

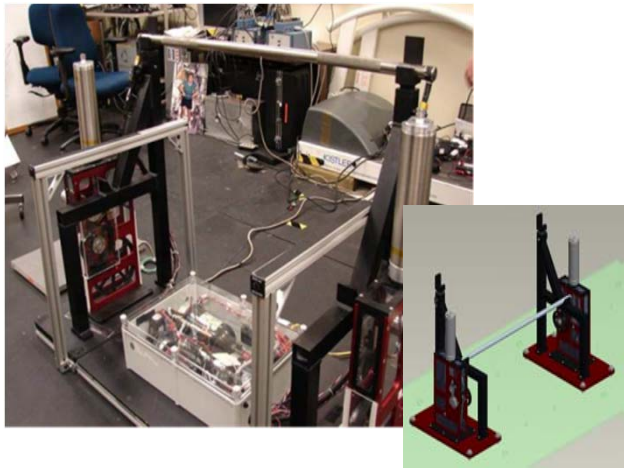
**Design requirements:** small footprint, low power usage, resistance and aerobic capabilities in one device…*highly effective*.

*NGRED*

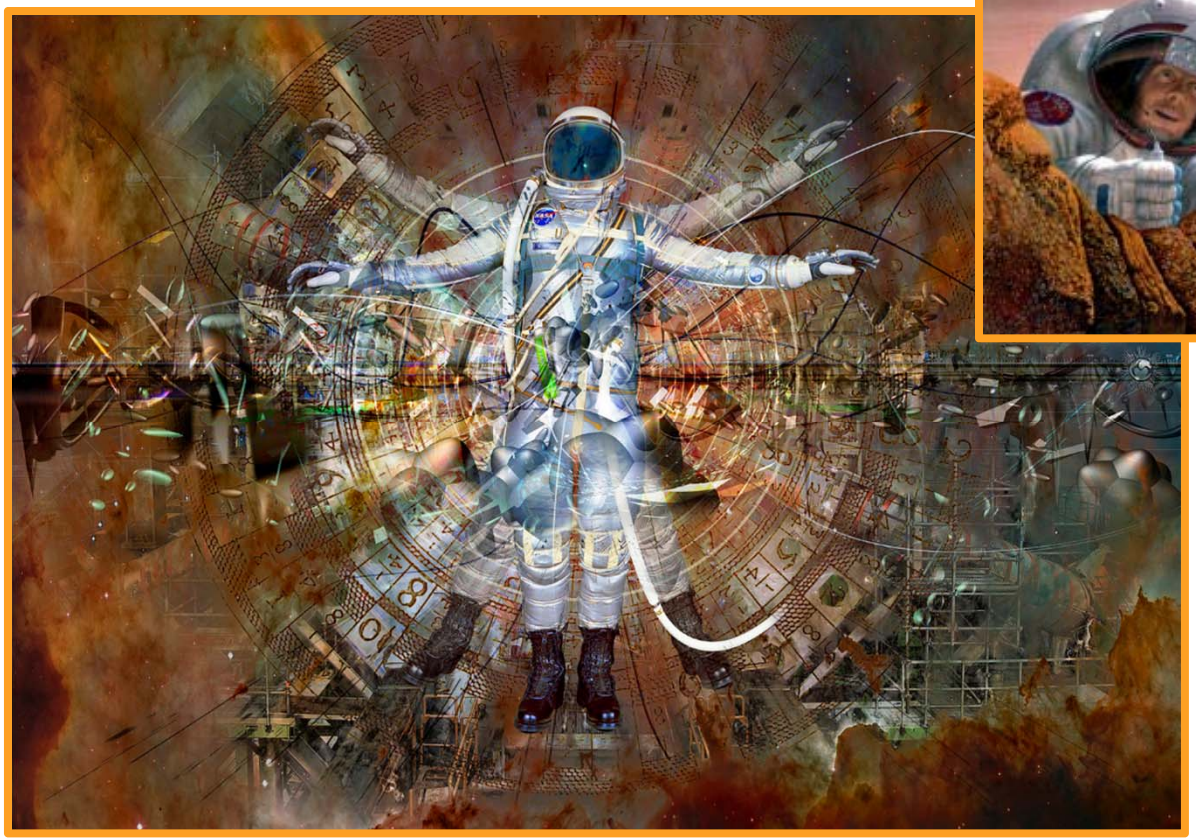
*MMED Flywheel*



*HERO*



# ISS IS A TEST-BED FOR FUTURE EXERCISE HARDWARE DESIGN



## THANKS!

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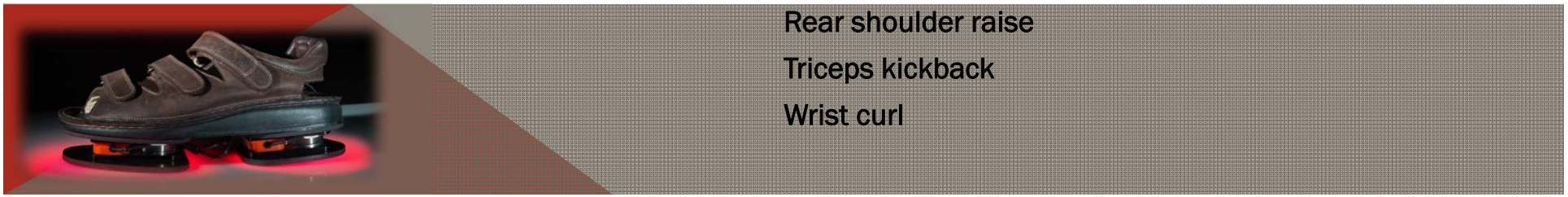
ISS Medical Projects
Alonso Fuentes, Lockheed Martin
David Sehrt, Lockheed Martin

Crewmembers
Inc. 40, 41, 42

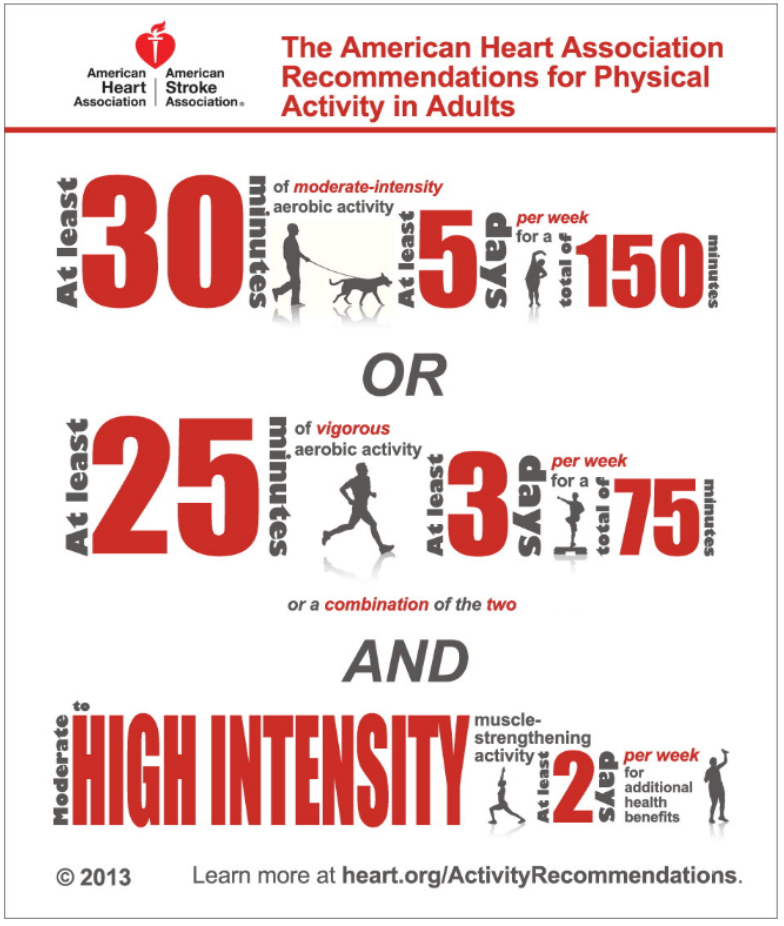
# BACKUP CHARTS

# ARED EXERICSES

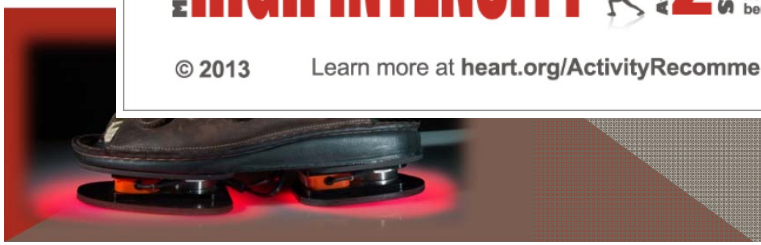
| Traditional Bar Exercises: | Traditional Cable Exercises: |
|---|---|
| Heel Raises | Biceps curls |
| Front Squat | Bent over row |
| Single leg squat | Triceps extension |
| Squat | Upright row |
| Sumo squat | Single arm row |
| Bench press | Side bend |
| Shoulder press | Crunches/Situps |
| Shrugs | Cable deadlift |
| Deadlift | Cable RDL |
| Romanian deadlift | Cable sumo deadlift |
| Sumo deadlift | Cable tripceps extension |
| Biceps curl | Hip adduction |
| Bent over row | Hip abduction |
| Tricep extension | Hip extension |
| Upright row | Hip flexion |
| | Lateral shoulder raise |
| | Rear shoulder raise |
| | Triceps kickback |
| | Wrist curl |



# RECOMMENDATIONS ON PHYSICAL ACTIVITY LEVELS FROM THE AHA AND ACSM

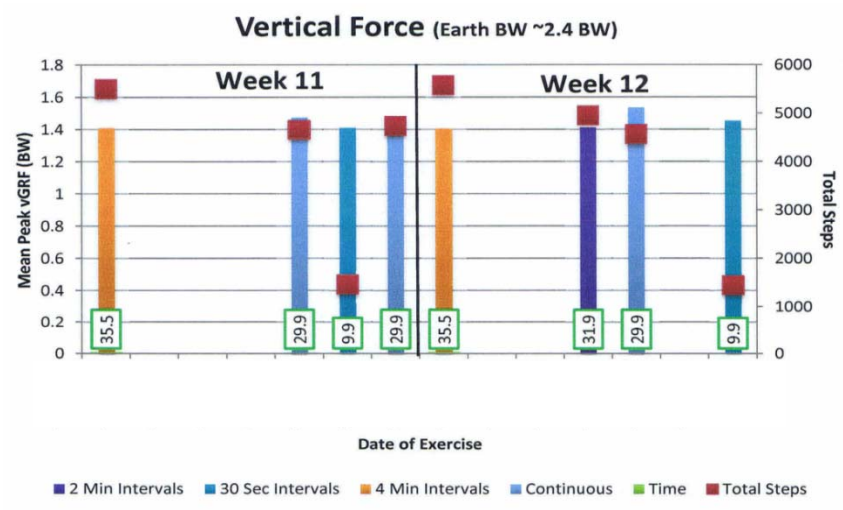






# HOW DO ACSM/AHA RECOMMENDATIONS COMPARE TO ISS EXERCISE?

| | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
|---|---|---|---|---|---|---|---|
| ARED | 35-60 min | 35-60 min | 35-60 min | 35-60 min | 35-60 min | 35-60 min | |
| T2 | 30 min | 30 min | | 30 min | 30 min | | |
| CEVIS | | | 30 min | | | 30 min | |




- Recommended:
  - 2 days of strength training
  - 150 min of moderate aerobic exercise per week
  - ~10,000 steps per day

- Actual:
  - 6 days muscle strengthening
  - ~180 minutes aerobic activity
  - 5-6K steps per day, 4 days a week are acquired
- Intensity is absolutely key to success in order to reduce exercise time