SPACE WEAR VISION

Development of a Wardrobe for Life in Space Vehicles and Habitats

- Trivia questions
  - Do you know approximately how mammal species are known in the world?
  - A: In 2006, there were 5416 mammal species known in the world
  - Do you know one human physical characteristic that scholars are still pondering on and that distinguishes us from other mammals?
  - A: Human are mostly hairless
  - Do you know approximately when the history of clothing started?
  - At least 100,000 years ago

- Facts:
  - Humans are amazingly adaptive to create the necessary protection to move and settle in a wide variety of environment. How they do it is by creating living space and develop adapted clothing.

THE VISION STATEMENT

Design and Engineer space wear to extend human capability to live in space and explore the universe

WHY A VISION?

- STRETCH our imagination to think of an ideal space wear
- BRIDGE our space clothing history with an ideal that can be reached
- CLARIFY our purpose and direction in researching what can become the future space wear
- GUIDE our research efforts by defining reasonable framework and goals

TO

- CREATE the new space wear from the balance between the ideal and the resources

STRETCH

- Collection of pictures all in public domain
- From Mercury to ISS and beyond
  - Show drawings of Mercury, Gemini, Apollo to Jeannie
  - Find futurist representations of clothing in space (Jeannie's)

BRIDGE

- Mercury, Gemini, Apollo
  - Common element: small space inside a capsule
  - Mercury (1958-1963): short flights
    - Cotton underwear
    - Cotton long-johns modified with Triloc waffle-weave patches for ventilation
    - Pressure garment
  - Gemini (1961-1966): longer flights
    - Same as Mercury
    - Addition of diapers for waste management
    - Long-johns modification with attached bio-instrumentation and communication connectors given the new name of “Constant-Wear Garment”
    - Coveralls over the Constant-Wear Garment
    - Pressure Garment

BRIDGE

- Apollo (1961-1972)
- Apollo-Soyuz (1975)
- Skylab or ”laboratory in the sky” (1973-1979)
  - First spacecraft in which astronauts wear inflight overall garments in a 5 psi, 80% oxygen, 20% nitrogen environment
  - First time crew have clothing kits packaged in what was then called their “Rucksack”

28-Day Clothing Rucksack Content

	Mass (Kg)	Nominal	Option 1	Option 2	Option 3
Jacket Assemblies	0.68	4	3	2	2
Trousers Assemblies	0.91	4	3	4	2
Shirt Assemblies	0.34	4	8	8	12
Underwear Sets	No data	14	14	14	14
Gloves (pair)	0.09	1	1	1	1
Boots (pair)	0.45	1	1	1	1

BRIDGE

- Space Shuttle (1981-2011)
  - Volume to move around and work
  - Stowage compartments
  - Cabin atmosphere mostly ambient air except during airlock conditioning prior spacewalks
  - Ready-to-Wear apparel mostly made of cotton for flammability safety
  - Addition of a few no cotton personal items for exercise
- Shuttle-Mir (1993-1998)
  - Same cabin clothing as in the space shuttle

BRIDGE

International Space Station (1998-present)

- A changing Joint Crew Provisioning Catalog with

1) introduction of new items (i.e. polyester exercise tops, belts per crew preference)

2) disappearance of some items

i.e. X-Static shirts, and custom made shuttle pants per depletion of inventory)

- A beginning of on-orbit clothing studies

Clothing Usage Rates

Name	Mass (kg)	Usage Rate (No. of days)	No. of Items for 1 Year
Crew Preference Shirt (Long Sleeve)	0.55	15	13
Crew Preference Shirt (Short Sleeve)	0.45	15	13
Cargo Shorts	0.35	30	5
Cargo Pants	0.65	30	7
Trousers	0.6	30	3
X-Static T-Shirt	0.3	14	27
Colored T-Shirt	0.25	7	53
Underwear	0.1	2	183
X-Static Crew Socks	0.08	14	27
Crew Socks, White	0.08	7	53
Athletic Shorts	0.15	7	53
Total Mass (kg) - 1 Crew	75		
Total Mass (kg) - 6 Crew	451		

CLARIFY

All human space missions require significant logistical mass and volume that will become an excessive burden for long duration missions beyond low Earth orbit. The goal of the Advanced Exploration Systems (AES) Logistics Reduction (LR) project is to bring new ideas and technologies that will enable human presence in farther regions of space. The LRR project has five tasks:

1) Advanced Clothing System (ACS) to reduce clothing mass and volume,

2) Multipurpose Crew Transfer Bag (MCTB) to repurpose existing cargo bags,

3) Heat Melt Compactor (HMC) to reprocess materials in space,

4) Universal Waste Management System (UWMS) to reduce mass and volume od waste collection systems, and

5) Systems Engineering and Integration (SE&I) to integrate these logistical components.

GUIDE

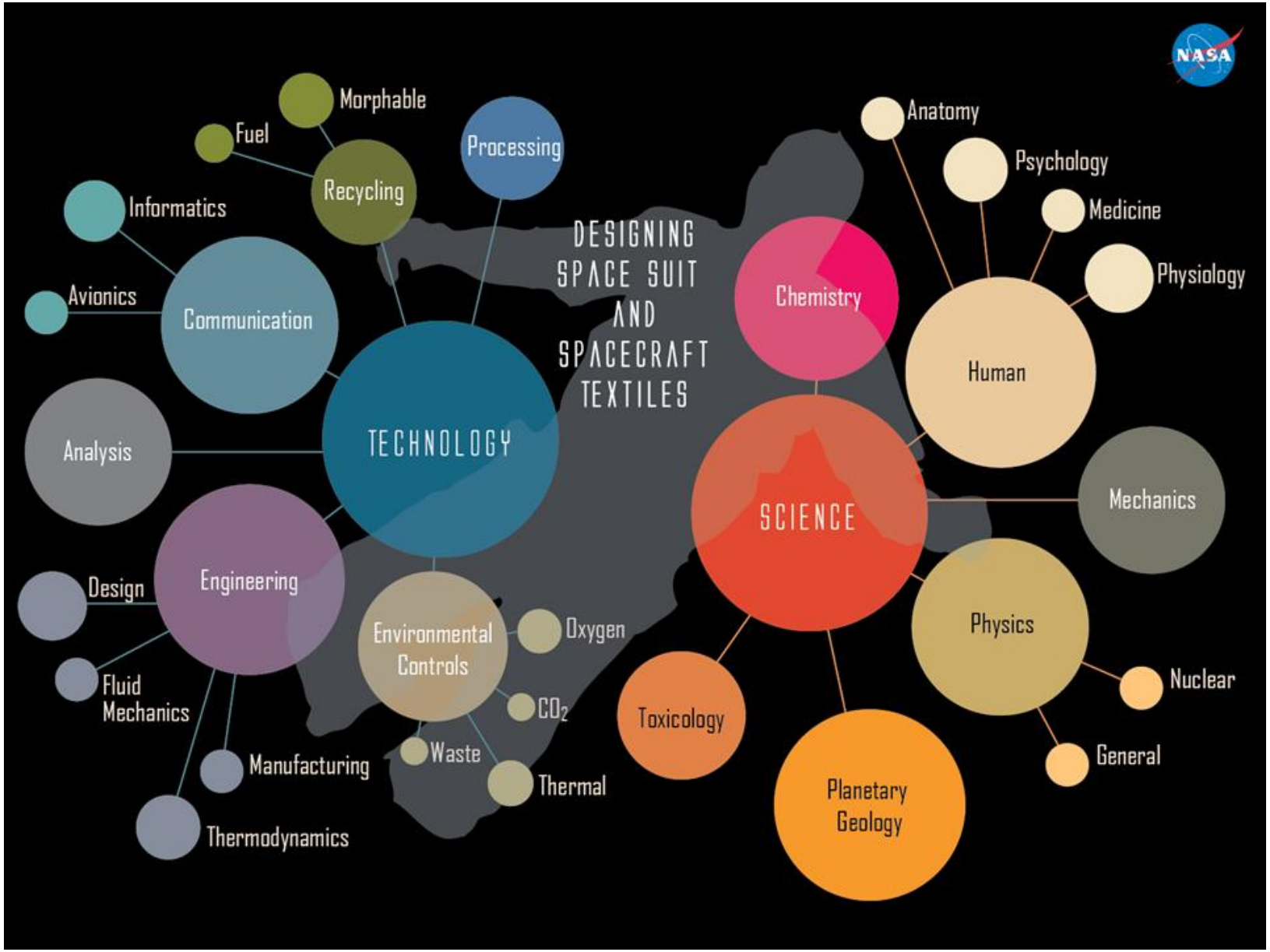
Framework for the development of clothing for future missions

- Cabin environment (gases, pressure, relative humidity, temperature, lighting)
- Cradle-to-grave approach (disposable or reusable or both)
- Footprint of clothing in the space craft (effect on ECLSS, mass and volume at launch if disposable and if reusable with auxiliary devices for maintenance)
- Human factors (social, cultural, individual)
- Technological advances in textiles science and apparel design
- Resources availability

CREATE

- Implementing the vision
  - Imagine the ideal space wear
    - Initiate research towards the realization of the ideal from future technology
      (i.e. synthetic skin that we treat like our skin for hygiene?)
    - Initiate research using current technology
      ACS studies
      Present studies
      Future studies
  - Develop novel apparel for life in space
    - For Orion
    - For Martian Habitat

CREATE


DESIGNING SPACE SUIT AND SPACECRAFT TEXTILES
TECHNOLOGY
SCIENCE
Communication
Informatics
Avionics
Analysis
Engineering
Design
Fluid Mechanics
Manufacturing
Thermodynamics
Environmental Controls
Oxygen
CO_2
Waste
Thermal
Recycling
Morphable
Fuel
Processing
Chemistry
Toxicology
Planetary Geology
Human
Anatomy
Psychology
Medicine
Physiology
Physics
Nuclear
General
Mechanics

ACS Studies

The current International Space Station (ISS) crew wardrobe has already evolved not only to reduce some of the logistical burden but also to address crew preference. The ACS task is to find ways to further reduce this logistical burden while examining human response to different types of clothes. The ACS task has been broken into a series of studies on length of wear of various garments:

1. three small studies conducted through other NASA projects (MMSEV, DSH, HI-SEAS) focusing on length of wear of garments treated with an antimicrobial finish;
2. a ground study addressing both length of wear and subject perception of various types of garments worn during aerobic exercise; and
3. an ISS study replicating the ground study, and including every day clothing to collect information on perception in reduced gravity in which humans experience physiological changes.

The first three years

2012

- Perform Market Survey of state-of-the-art Commercial Off the Shelf (COTS) exercise clothing
- Select lightweight clothing and anti-microbial treatment
- Develop ground study protocol
- Integrate with Deep Space Habitat (DSH) and Multi-Mission Space Exploration Vehicle (MMSEV) testing as a proof-of-concept for ground study

2013

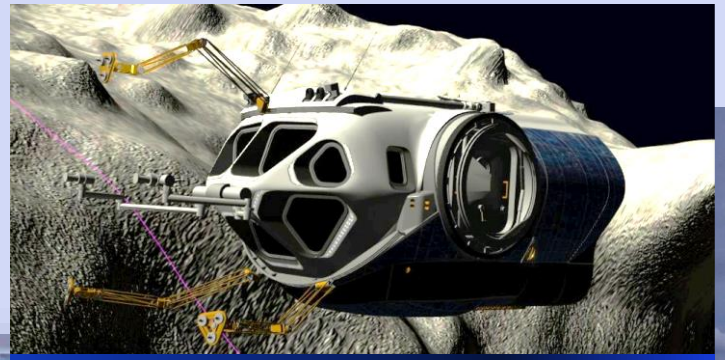
- Analog Ground Study to evaluate the extended wear of clothing
- HI-SEAS mission 1

2014

- HI-SEAS mission 2
- ISS Demonstration Test

MMSEV & DSH

Analog environments to test multiple concepts for operations and technologies simultaneously



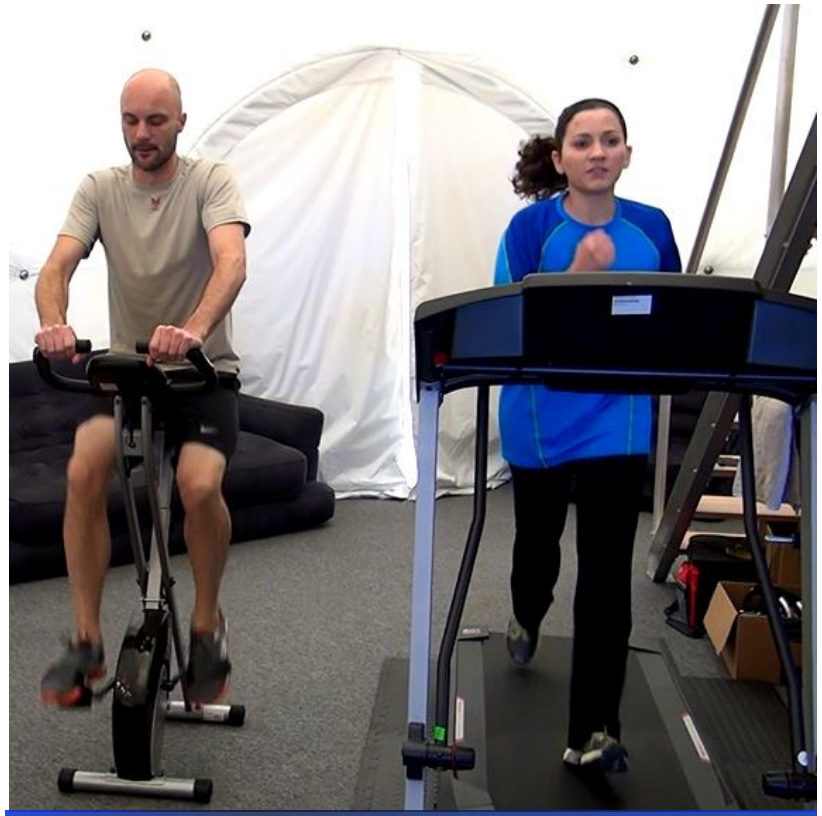
Multi-Mission Space Exploration Vehicle

ACS Shirt in MMSEV Test

Habitat Demonstration Unit–Deep Space Habitat, or HDU-DSH.

HI-SEAS

Hawaii Space Exploration Analog and Simulation is a human spaceflight analog for Mars



HI-SEAS Crew in ACS Provided Shirts

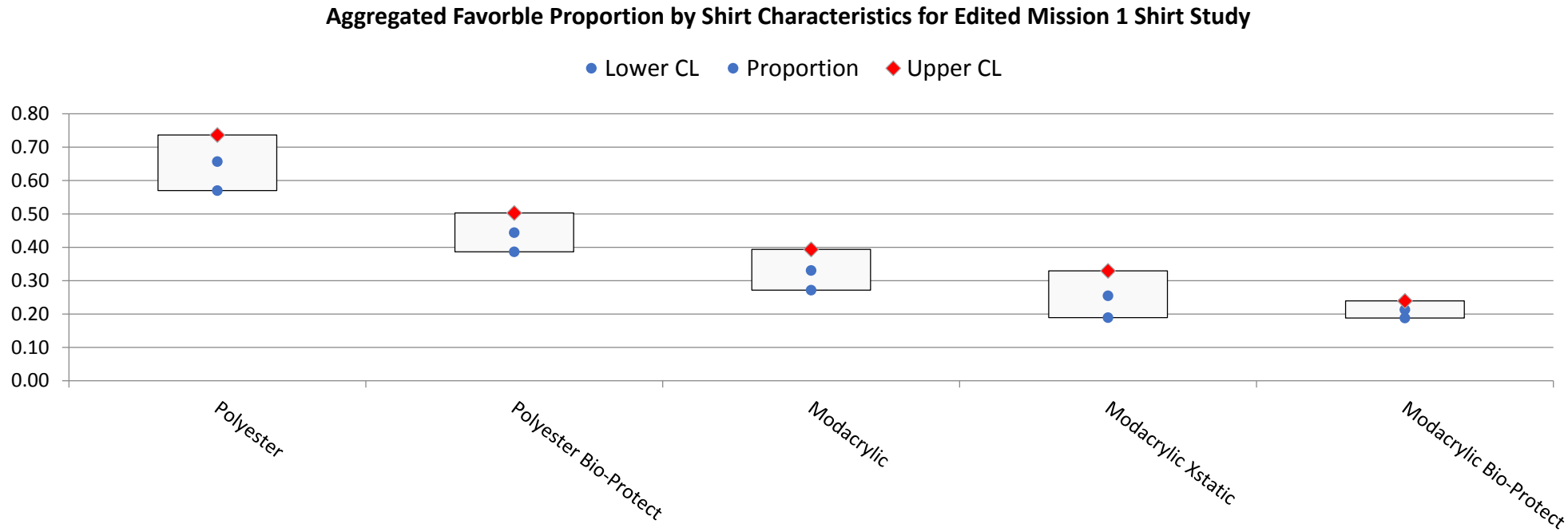
HI-SEAS
HI-SEAS.ORG

HI-SEAS Mission 1

48 shirts supplied to 6 participants

Exercise Hours by Shirt Fabric

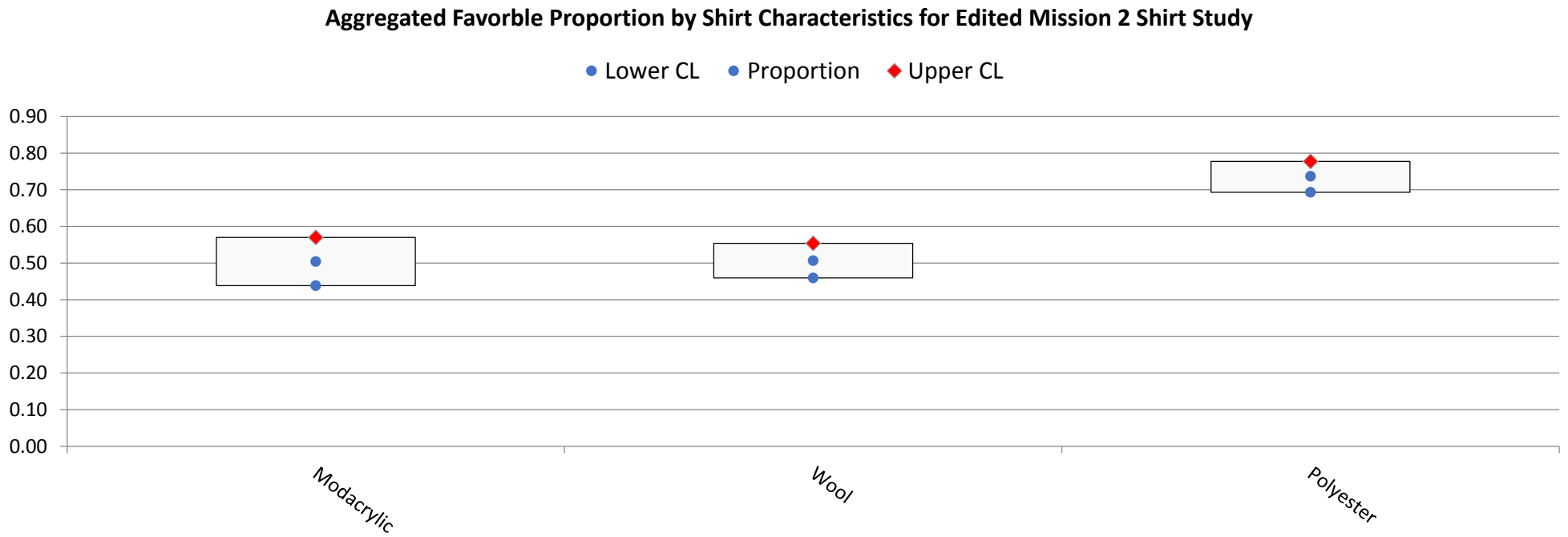
Shirt Fabric	Total Hours	Standard Deviation (hours)	Wearers	Average Hours per Wearer	Total Periods	Average Hours per Period	Total Shirts	Average Hours per Shirt	Survival Times
Modacrylic	21.5	2.23	4	5.38	27	0.80	5	4.30	228.1
Modacrylic Bio-Protect	103.9	11.22	5	20.78	113	0.92	7	14.84	641.6
Modacrylic Xstatic	14.3	2.01	4	3.58	18	0.79	6	2.38	156.7
Polyester	94.3	2.23	5	18.86	103	0.92	5	18.86	158.2
Polyester Bio-Protect	127.5	34.08	4	31.88	128	1.00	7	18.21	194.7



HI-SEAS Mission 2 Shirts

30 shirts supplied for 5 participants.

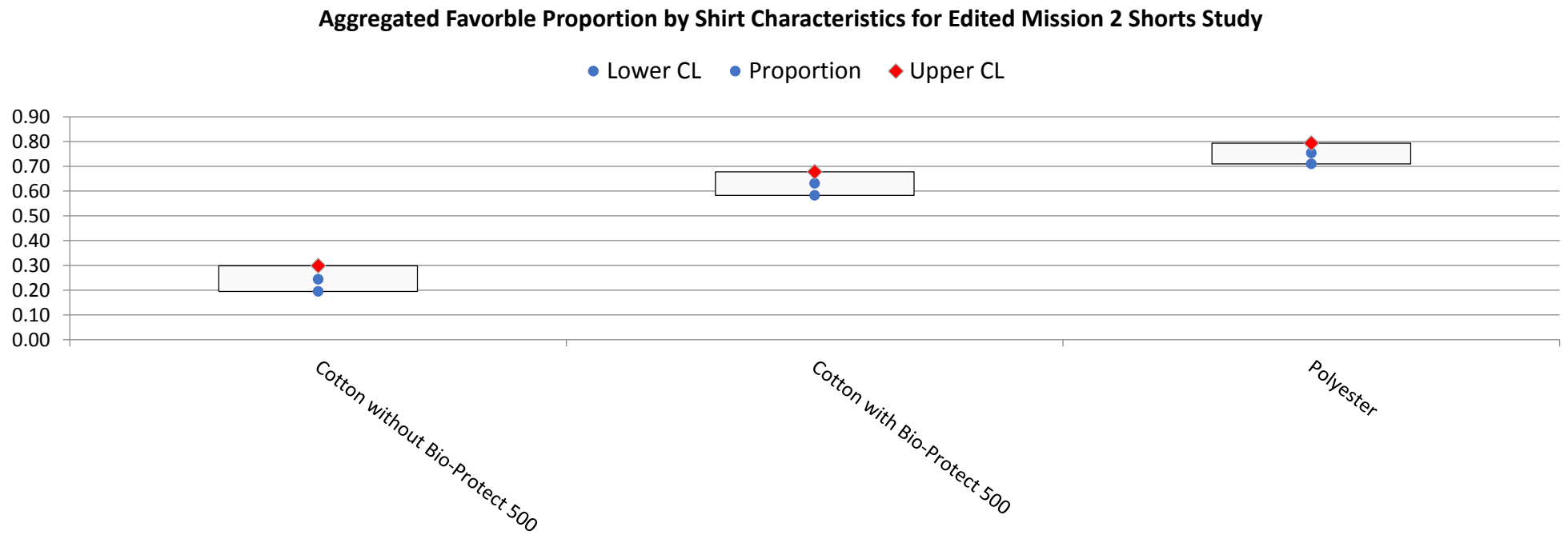
Shirt Fabric	Total Hours	Standard Deviation (hours)	Wearers	Average Hours per Wearer	Total Periods	Average Hours per Period	Total Shirts	Average Hours per Shirt	Survival Times
Modacrylic	32.30	4.52	4	8.08	26	1.24	5	6.46	220.9
Polyester	58.05	5.39	5	11.61	49	1.18	7	8.29	352.2
Wool	50.83	9.09	5	10.17	50	1.02	6	8.47	314.9



Hi-SEAS Mission 2 Shorts

Exercise Hours By Shorts Fabric

Shorts Fabric	Total Hours	Standard Deviation (hours)	Wearers	Average Hours per Wearer	Total Periods	Average Hours per Period	Total Shirts	Average Hours per Shirt	Survival Times
Cotton with Bio-Protect 500	52.08	9.85	5	10.42	46	1.13	7	7.44	388.9
Cotton without Bio-Protect 500	39.52	6.80	4	9.88	31	1.27	5	7.90	337.4
Polyester	49.58	7.42	5	9.92	48	1.03	7	7.08	370.6



Ground Exercise Clothing Study

- Minimum of 15 daily aerobic exercise sessions of

45 to 60 minutes in an air-conditioned gym to

simulate the ISS exercise environment

- Factorial experimental designs were used

with each subject assigned a single type

of shirt or shorts

- Three separate studies with 80 participants
  - Cotton-Polyester-Wool Shirt Study (CPM)
  - Polyester-Modacrylic-Cocona Shirt Study – tight knit (PMC)
  - Cotton-Polyester Shorts Study
- Data collected on garment length of wear data and preferences

Ground Exercise Study- CPW and PMC Length of Wear

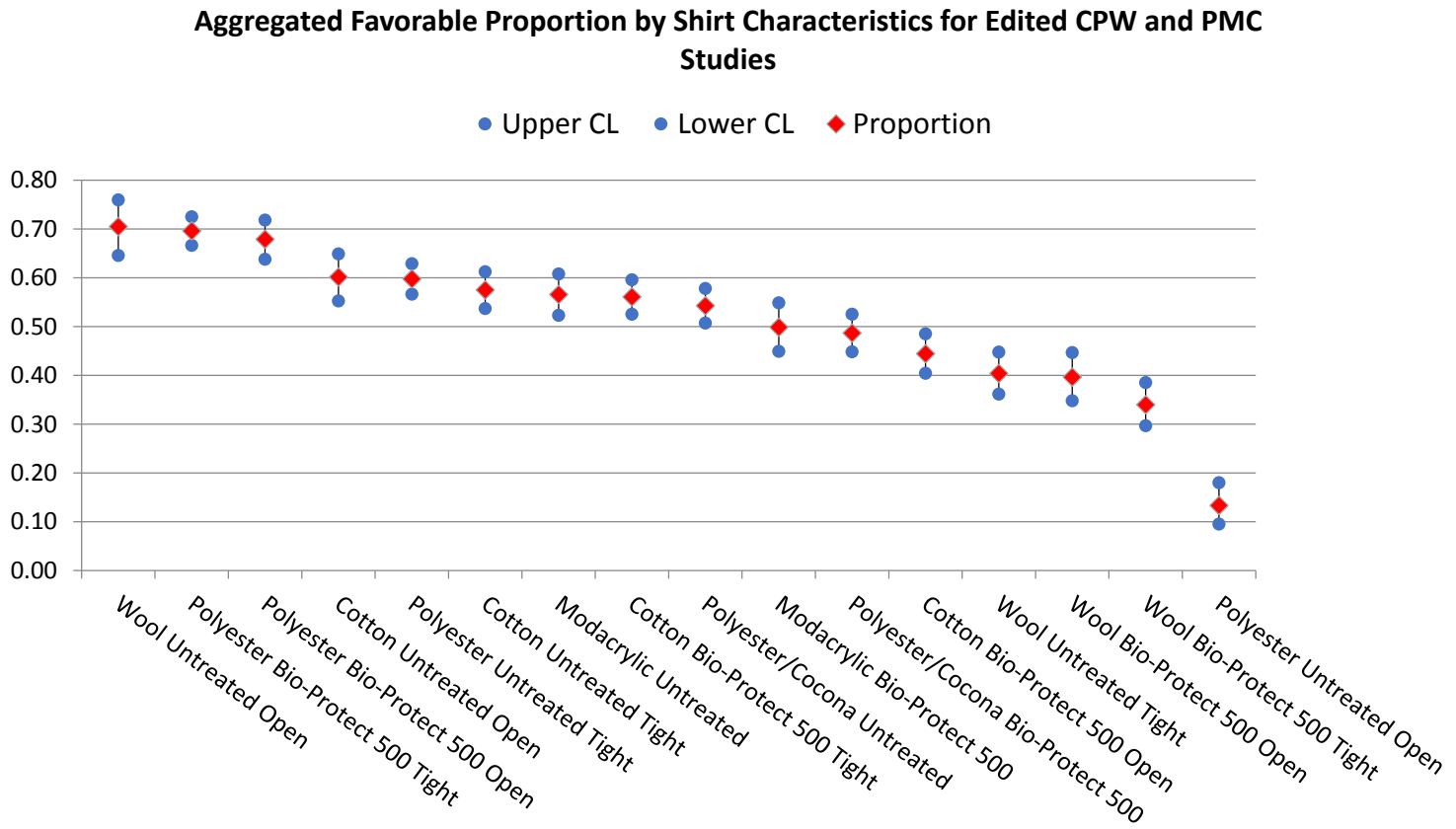
CPW Shirt Study Exercise Hours by Shirt Fabric							
Shirt Fabric	Total Hours	Standard Deviation (hours)	Average Hours per Participant	Total Periods	Average Hours per Period	Total Shirts	Average Hours per Shirt
Cotton	269.33	5.11	12.24	311	0.87	42	6.41
Polyester	249.40	2.27	13.13	303	0.82	36	6.93
Wool	268.78	6.72	13.44	324	0.83	25	10.75

PMC Shirt Study Exercise Hours by Shirt Fabric							
Shirt Fabric	Total Hours	Standard Deviation (hours)	Average Hours per Participant	Total Periods	Average Hours per Period	Total Shirts	Average Hours per Shirt
Modacrylic	162.75	5.11	13.56	190	0.86	20	8.14
Polyester	175.35	4.06	11.69	218	0.80	34	5.16
Polyester/Cocona	188.28	5.02	14.48	209	0.90	28	6.72

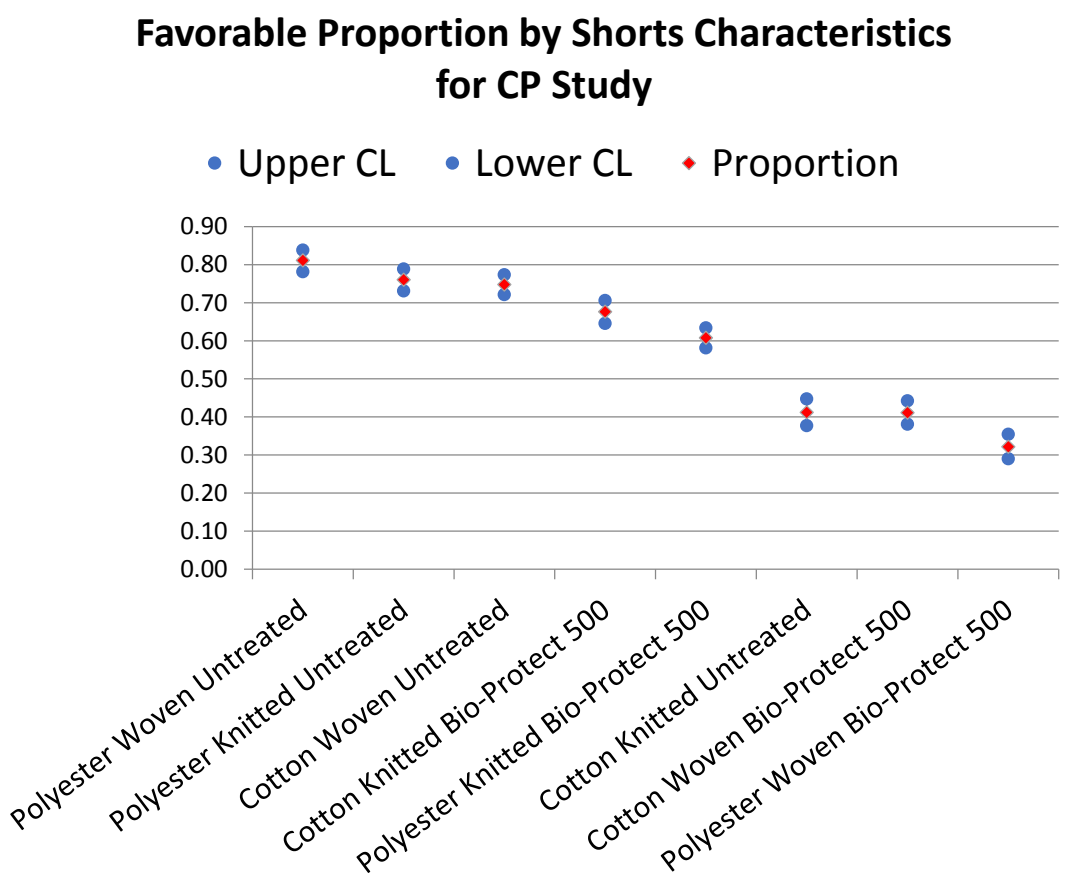
Table 67. Combined CPW and PMC Shirt Fabric by Shirt Treatment Least Squares Means

Shirt Fabric	Shirt Treatment	Estimated Minutes	Lower 95% C. L. (minutes)	Upper 95% C. L. (minutes)
Cotton	Bio-Protect 500	526	396	699
Cotton	Untreated	327	258	414
Modacrylic	Bio-Protect 500	327	218	489
Modacrylic	Untreated	515	344	771
Polyester	Bio-Protect 500	394	311	498
Polyester	Untreated	360	279	465
Polyester/Cocona	Bio-Protect 500	405	287	572
Polyester/Cocona	Untreated	369	274	498
Wool	Bio-Protect 500	465	324	666
Wool	Untreated	600	411	877

Ground Exercise clothing Study- CPW and PMC Perception



Ground Exercise Clothing Study- Shorts



CP Shorts Fabric by Shorts Construction by Shorts Treatment Least Squares Means					
Shorts Fabric	Shorts Construction	Shorts Treatment	Estimated Minutes	Lower 95% C. L. (minutes)	Upper 95% C. L. (minutes)
Cotton	Knitted	Bio-Protect 500	356	278	457
Cotton	Knitted	Untreated	389	296	511
Cotton	Woven	Bio-Protect 500	517	353	759
Cotton	Woven	Untreated	411	295	572
Polyester	Knitted	Bio-Protect 500	511	355	736
Polyester	Knitted	Untreated	466	346	628
Polyester	Woven	Bio-Protect 500	496	378	651
Polyester	Woven	Untreated	465	333	648

ISS On-Orbit Clothing Study

- Small sample size for discovery opportunity rather than statiscally significant study
- 15 wear sessions per crew members, 6 participants on ISS, 8 participants on the ground (Baseline Data Collection)
- Exercise and routine wear
- Experiment completed; Crew debrief information collected for all ISS participants
- Data exchange and consolidation in progress
- Analysis and joint report to come by end of fiscal year

Current Studies

- Men In Black (MIB)

  Single blind Study with a panel of 12 male participants to assess the perception of Merino wool underwear

- Microbes Behavior on Textiles (M_BOT)

  4 fabrics – polyester, wool, polypropylene, modacrylic
  4 treatments – none, metal oxide/salt/ion, superhydrophobic, combination
  2 microbes – Staphylococcus epidermidis, Pseudomonas aeruginosa
  4 time points – 10 minutes, 1 hour, 24 hours, 72 hours
  8 replicates

- Lint of fabrics study
  - Particulates from textiles on ISS collect on air filters affecting ECLSS logistics

Future Work and Needs

- Laundry and textiles sanitation studies to extent useful life of clothing
- For Orion with new flammability concerns because on enriched oxygen environment, fabrics used in Skylab may have to be resurrected or new fabrics engineered
- RFID clothing on ISS with reader in area where crew passes everyday would allow to collect more data on length of wear of the different types of garments used on-orbit
- Long duration ground studies with large samples of participants to avoid data right-censure