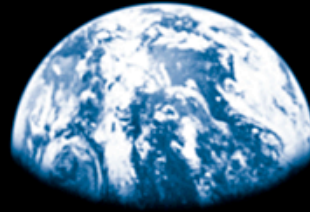


An Astronaut Bio-Suit System for Exploration Missions



Professor Dava J. Newman, Ph.D.

Director, MIT Technology and Policy Program; Engineering Systems Division
Harvard-MIT Division of Health Science and Technology

Professor Jeff Hoffman, Dr. Christopher Carr, Kristen Bethke, Nicole Jordan, Liang Sim, & Nina Wolfrum

MIT Department of Aeronautics and Astronautics

Guillermo Trotti, A.I.A.

Trotti & Associates, Inc.

Dainese, Italy

NIAC Annual Meeting, Tucson, Arizona

18 October 2006





Research Partners & Advisors

Trotti & Associates, Inc. (TAI)

TAI is a design consulting firm helping private and public organizations visualize and develop solutions for new products, and technologies in the areas of Architecture, Industrial Design, and Aerospace Systems.

Award-winning designs for: Space Station, South Pole Station, Underwater Habitats, Ecotourism. (Phase I and II)

Advisory Board

Dr. Chris McKay, expert in astrobiology, NASA ARC.

Dr. John Grunsfeld, NASA astronaut.

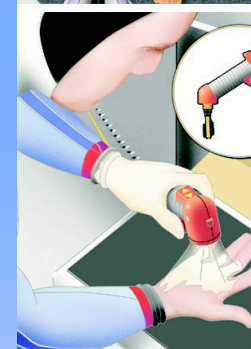
Dr. Cady Coleman, NASA astronaut.

Dr. Buzz Aldrin, Apollo 11 astronaut.

Dr. Michael Gernhardt, Dr. Claude Nicollier, Dr. Daniel Burbank, Dr. Joseph Tanner, Dr. Bruce Webbon, Dr. Bernie Luna, and Dr. Paul Webb.



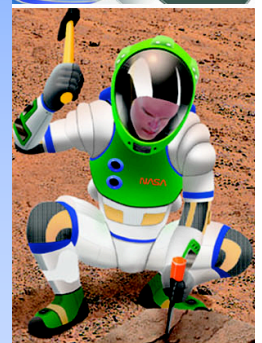
Midé Technology Corporation is a R&D company that develops, produces, and markets High Performance Piezo Actuators, Software, and Smart (Active) Materials Systems; primarily for the aerospace, automotive and manufacturing industries.





Bio-Suit Advanced EVA Research

- **Astronaut EVA Performance**
 - Human/Robotic database
 - Design Requirements & Spacesuit Modeling
 - Energetics and Biomechanics – Design Requirements
 - Mission Planning and Geological Traverse Analysis
 - EVA System Design for Flexibility and Uncertainty
- **Advanced Spacesuit Design: Bio-Suit MCP System**
 - Human Modeling & Requirements Definition
 - Space Suit Simulator – Exoskeleton Research
 - Bio-Suit Mechanical Counter Pressure (MCP)
 - Feasibility and Prototypes
 - International Design Collaboration: MIT, TAI, Dainese
- **Educational Outreach**
 - Bio-Suit & Knowledge Station





Background and Contributions

Space Suit Mobility	Performance & Modeling	Bio-Suit Concepts/ Systems Engineering
<p>Iberall, 1964</p> <p>Empty Suits Dionne, 1991 Abramov, 1994 Menendez, 1994</p> <p>Human Subjects Morgan et al., 1996 <i>Newman et al., 2000</i> <i>Schmidt et al., 2001</i> <i>Carr, 2005</i></p>	<p>Biomechanics & Energetics Streimer et al, 1964; Wortz & Prescott, 1966; Wortz, 1968; Robertson & Wortz, 1968; Johnston, 1975 <i>Newman et al., 1993, 1994, 1996</i> <i>Carr and Newman, 2005, 2006</i></p> <p>Modeling Iberall, 1970 <i>Rahn, 1997; Schmidt, 2000-2001; Carr, 2001, Bethke et al., 2004; Bethke, 2005</i></p> <p>Enhanced Performance <i>Blaya, Newman, Herr, 2003</i></p>	<p>Mechanical Counter Pressure-Related Webb, 1968 Annis and Webb, 1971 Clapp, 1983 Toubier <i>et al.</i>, 2001 Korona, 2002 Waldie <i>et al.</i>, 2002 Tanaka <i>et al.</i>, 2003 <i>Pitts, Newman et al., 2001</i> <i>Newman et al., 2004</i> <i>Sim et al., 2005</i></p> <p>Engineering Systems <i>Saleh, Hastings, Newman, 2002, 2003, 2003, 2004, 2005</i> <i>Jordan, Saleh, Newman, 2005, 2006</i></p>



Human/Robotic Systems

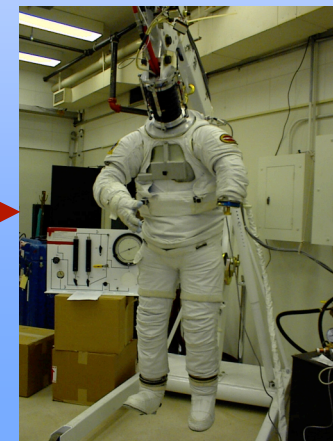
- EMU, 27 kPa (4.3 psi)
- Human, robot, human suited, & robot suited
- 11 simple motions isolating individual joints
- 9 complex motions:
 - Multi-joint reaching
 - Locomotion
 - Step up 15 cm (6 in)

Human



Angles

Robot



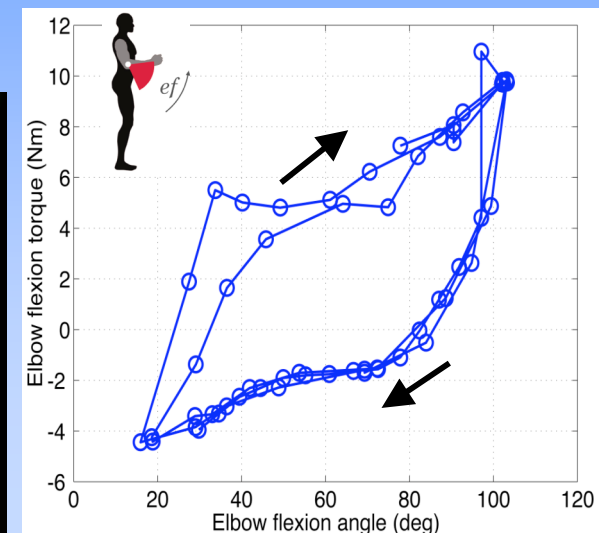
Torques

Angles

M. Tallchief

Robotic Space Suit Tester (RSST)

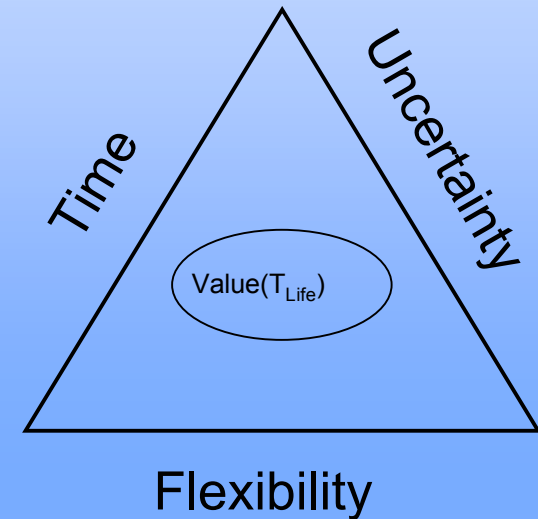
SARCOS Salt Lake City, Utah





Looking Back to Look Forward: Adaptation & Flexibility

- EMU: evolution from a contingency-only spacesuit to one that is capable of performing complex space station tasks
- Future EVA systems must be designed with change in mind otherwise we risk allowing the design to evolve in a suboptimal way.
- Want the design to be able to adapt to change in requirements:
 - within a *single mission* (change accommodation)
 - across *multiple missions* (flexibility)



*Time, Uncertainty, and Flexibility:
the three faces of the same coin*





Extravehicular Mobility Unit and the Russian Orlan

Environment Change - Use Shuttle EMU Aboard ISS

Requirement Change	Design or Procedure Change
Make EMU sizable on-orbit	Adjustable cam sizing in softgoods Sizing rings in arms and legs HUT replaceable on-orbit HUT redesign from pivoted to planar
Increased EMU life	Recertification of EMU components Change in static seal material PLSS noise muffle Flow filter redesign Coolant water bladder material change

Environment Change - Physical Environment of ISS

Requirement Change	Design or Procedure Change
Minimum metabolic rate lowered	LCVG Bypass Designed Heated Gloves Designed Thermal Mittens Designed
PNP must be <0.995 over 10 years	Track Orbital Debris Define Allowable Penetrations
Different radiation exposure	Carefully plan all EVAs
Risk of propellant exposure	1-hr bake-out procedure Lengthen SCU

Environment Change - Technical Environment Advances

Requirement Change	Design or Procedure Change
Advance in suit joint technology	Joint patterning and materials changed Bearing design and materials changed
Need for delicate assembly tasks	Glove design and materials changed
Increased EMU life	Battery redesign CCC upgrade to regenerable canister Carbon Dioxide sensor upgraded
Secondary system in case of crewmember separation	SAFER

Environment Change: Use Shuttle EMU Aboard ISS

Requirement Change	Design Change
Make EMU sizable on-orbit	Adjustable cam sizing in softgoods Sizing rings in arms and legs HUT replaceable on-orbit HUT redesign from pivoted to planar
Increase EMU life	Recertification of EMU components Change in static seal material Flow filter redesign Coolant water bladder material change



Pressurization - pressure, air, and carbon dioxide removal
Thermal Control - heating, cooling, and humidity control
Environmental Protection - radiation, micrometeorite, etc.
Human Performance - mobility, locomotion, hygiene, and nutrition

- COMPLETED EIA
- FUTURE/ISS EIA

VOISINAGE
1991-92
1993

CEMPH
7912-18
SCS

307102
1967-1968
2 DAIAPOLLO
1967-72
26 ENR590
591
592

617

176	5441
177	1591
178	2617

1.40

IDENTITY

PMR
1997-200
150 D.M.

INTER
2001
2186

RONALD SPENCE
JAMES
JAMES

14

10



514
EVAs to
Date

1028
MARS
EVA's

MERCURY M-20 PRESSURE SUIT

GEMINI GAC EVA SLIT

APOLLON A7L8

OSLAW-1

SHUTTLE / ISS EMU



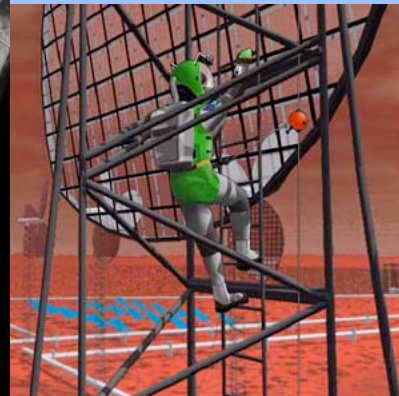
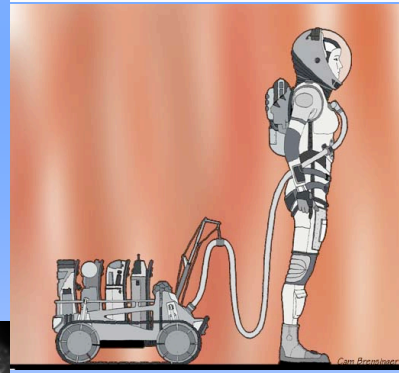
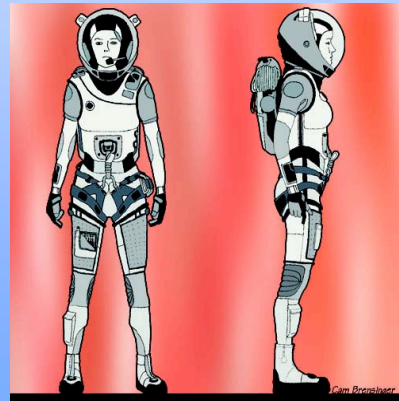
Creativity, Imagination, Innovation

Incredibly Creative & Innovative Designs





Revolutionary Design: *Bio-Suit System*



Bio-Suit multiple components:

- Mechanical Counter Pressure (MCP) Bio-Suit
- A pressurized helmet
- Extremely mobile gloves and boots
- Armadillo-like articulated back structure
- A modular life support backpack

Systems Engineering: req's., design life, model, interchangeable components

Idea: Custom-fit *skin suit* to an individual human/digital model

Space & Earth Applications: Mobility, Performance and Safety

$$\Delta W = \Delta W_p + \Delta W_e$$

ΔW_p - Minimize through MCP design

ΔW_e - Bending (design) and Strain Energy (min. or max E)





Technology Road Map



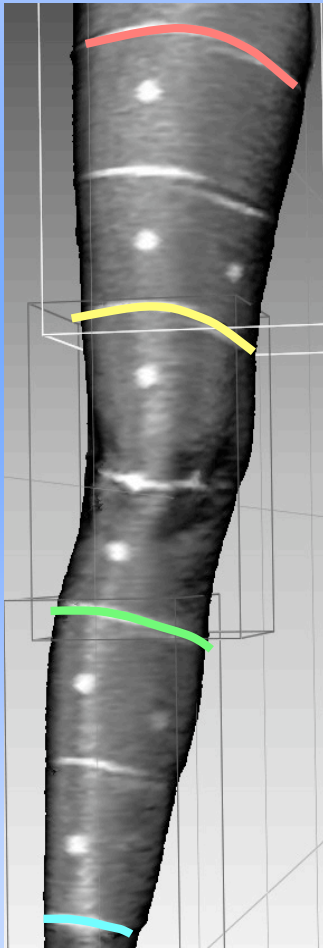
- ***Paint On, or Shrink Wrap, Second Skin***
- ***Electrospinning*** seamless MCP layer.
 - Multi-filament fiber projected via electric charge onto grounded surface
 - Greatly improved tactile feedback
 - Custom, form fit
 - Seamless integration of wearable computing
- ***Electroactive Materials***
 - MIT Field & Robotics Laboratory (Dubowsky)
 - MIT Institute Soldier Nanotechnology (ISN)
- ***Electro-Mechanical assistance***
 - Augments astronaut's capabilities
 - Countermeasure for microgravity deconditioning
 - Assisted locomotion 1G (AAFO) or Enhanced performance (Exoskeleton)
- ***Shape Memory Alloys & Polymers***
 - De-couple donning/doffing
 - Large maximum strains ($> 100\%$)



Results → MCP Requirements

MCP Tension

~2 kN/m



0.8 kN/m

Knee Surface Area

↓ 16%

In knee region, when leg flexes from 0 to 90 degrees

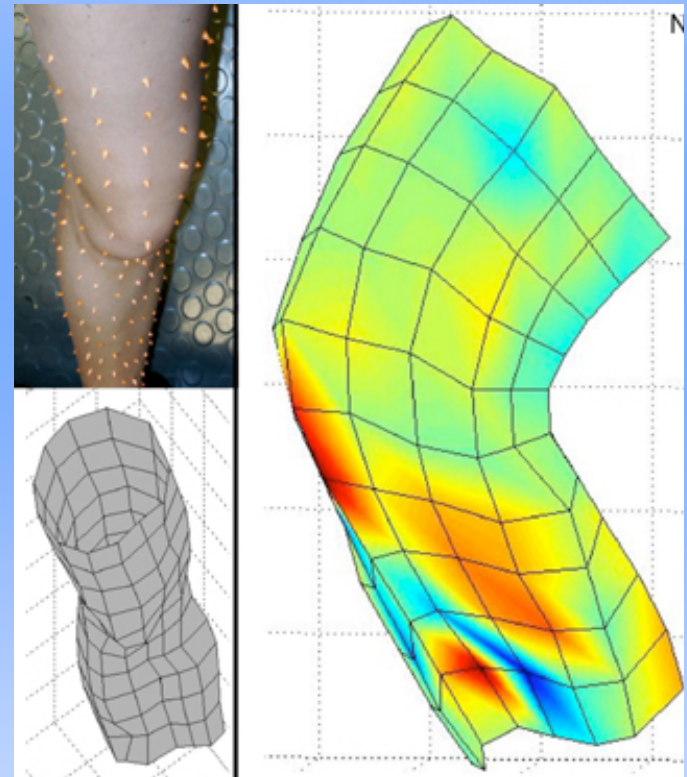
Knee Volume

↓ 18%

In knee region, when leg flexes from 0 to 90 degrees

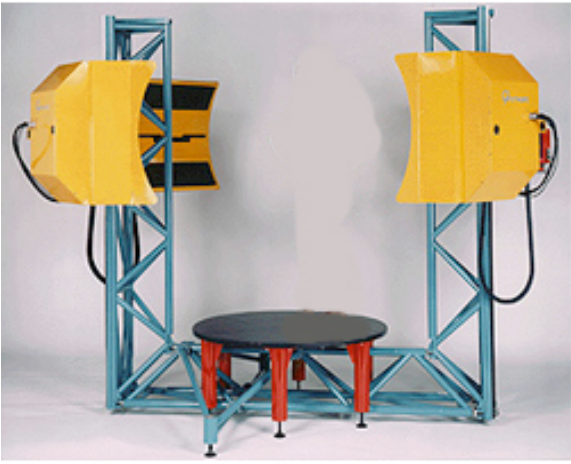
Skin Strain Field Mapping

Circumferential Strain



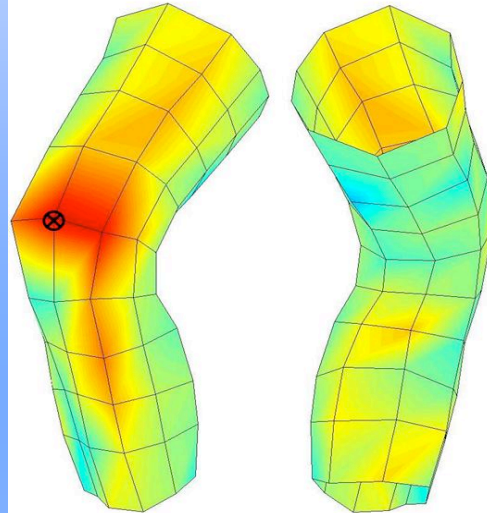


Bio-Suit Skin Strain Model

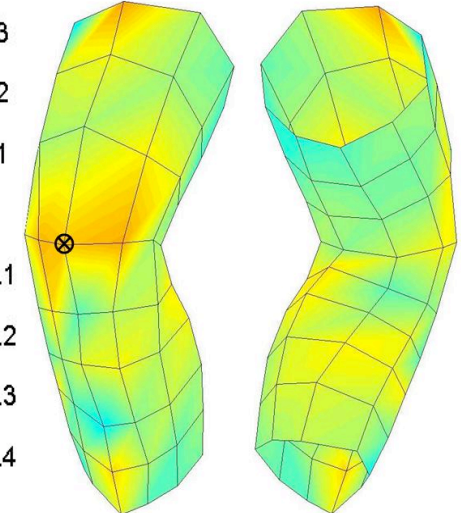


(MOU: Natick National Protection Center)

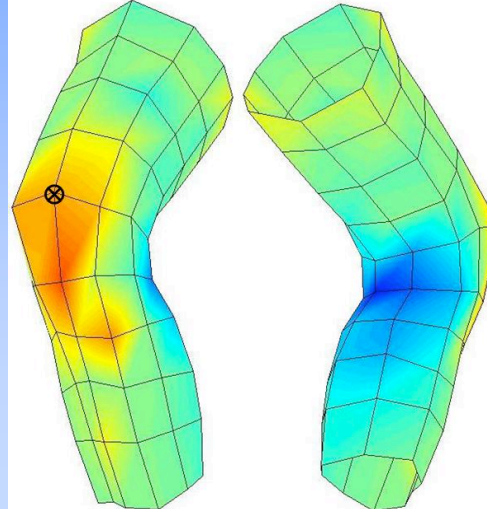
Circumferential Strain (Subject 1)



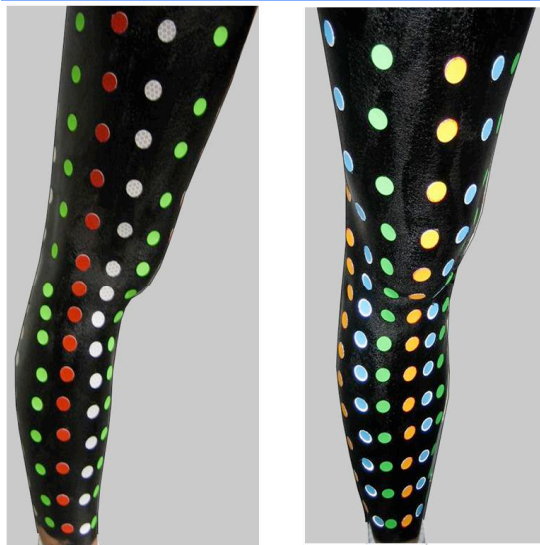
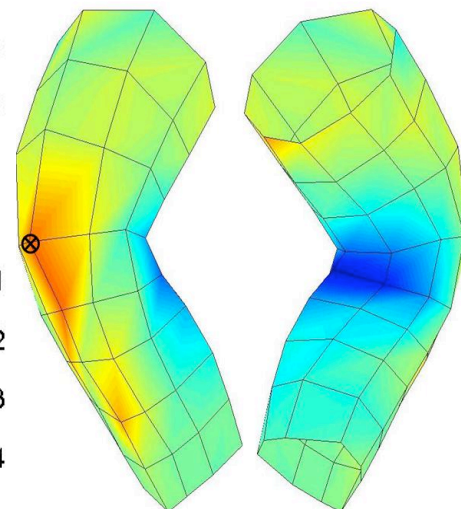
Circumferential Strain (Subject 4)

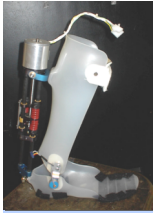


Longitudinal Strain (Subject 1)



Longitudinal Strain (Subject 4)





Augmented 1G Human Performance

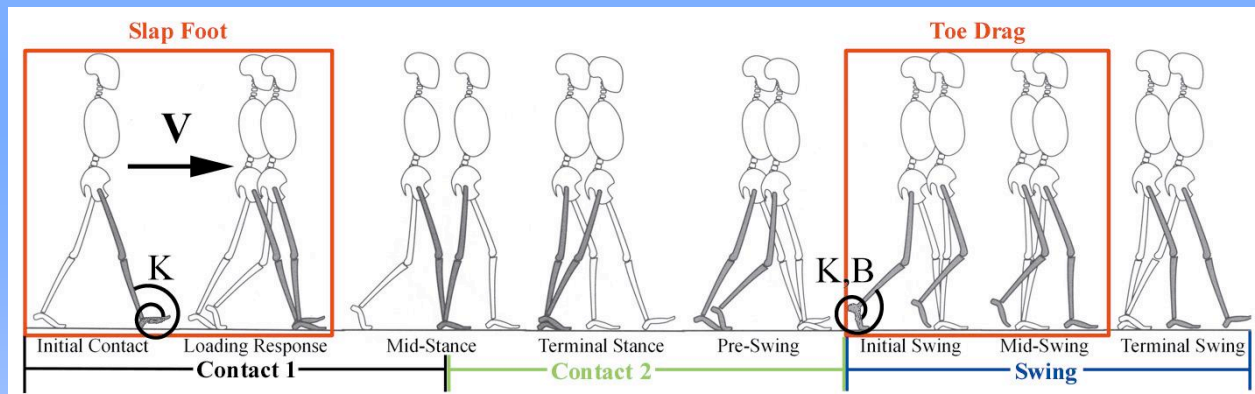
Problem: Drop foot, pathology (Stroke, Cerebral Palsy (CP), Multiple Sclerosis (MS))

Solution: Creative design of an active ankle device

Contact 1: Adaptive biomimetic torsional spring - minimize slap

Contact 2: Minimized impedance

Swing: Adaptive torsional spring-damper to lift (propel) foot



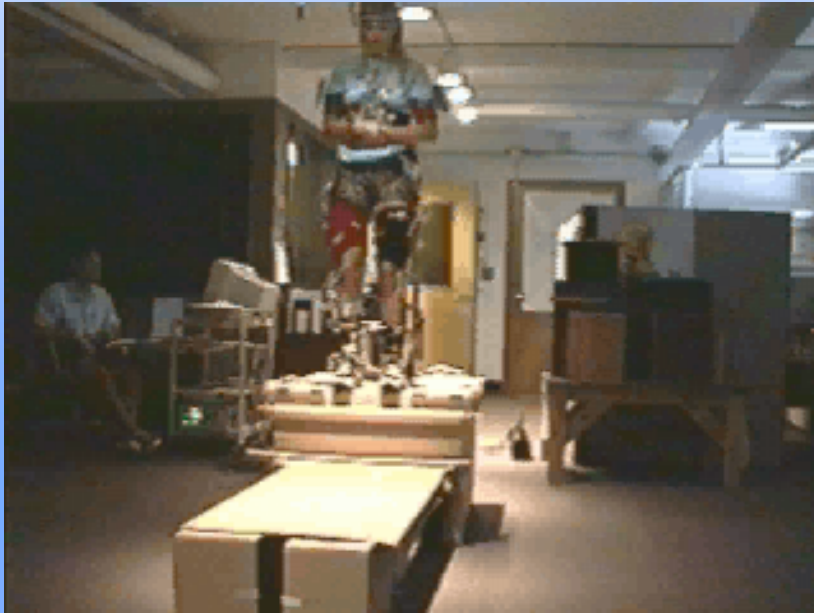
Currently: Exoskeleton

- Harness, hip bearing, fiberglass members, ankle
- Fiberglass spring mechanism provides energy

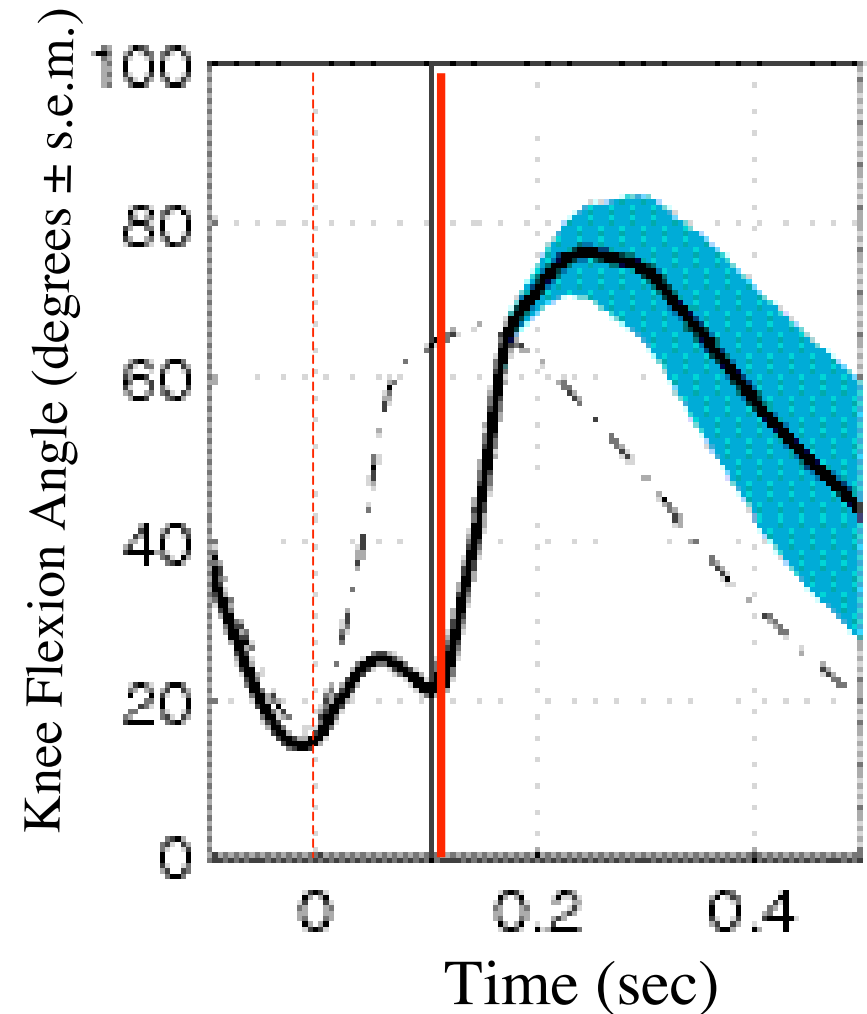
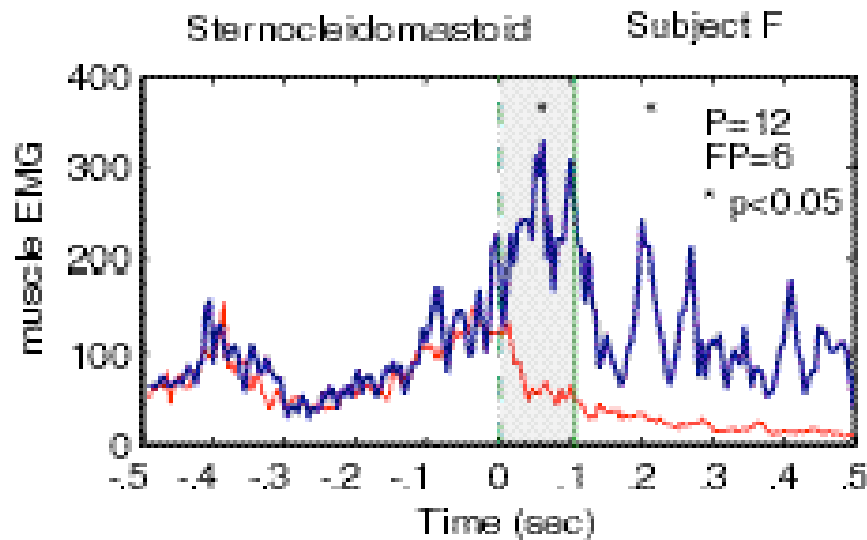
Blaya, J.A., Newman, D.J., Herr, H.M., "Comparison of a variable impedance control to a free and rigid ankle foot orthoses (AFO) in assisting drop foot gait," *Proceedings of the International Society of Biomechanics (ISB) XIXth Congress*, Dunedin, New Zealand, July 10, 2003.



Neuroengineering: Human/Robotic



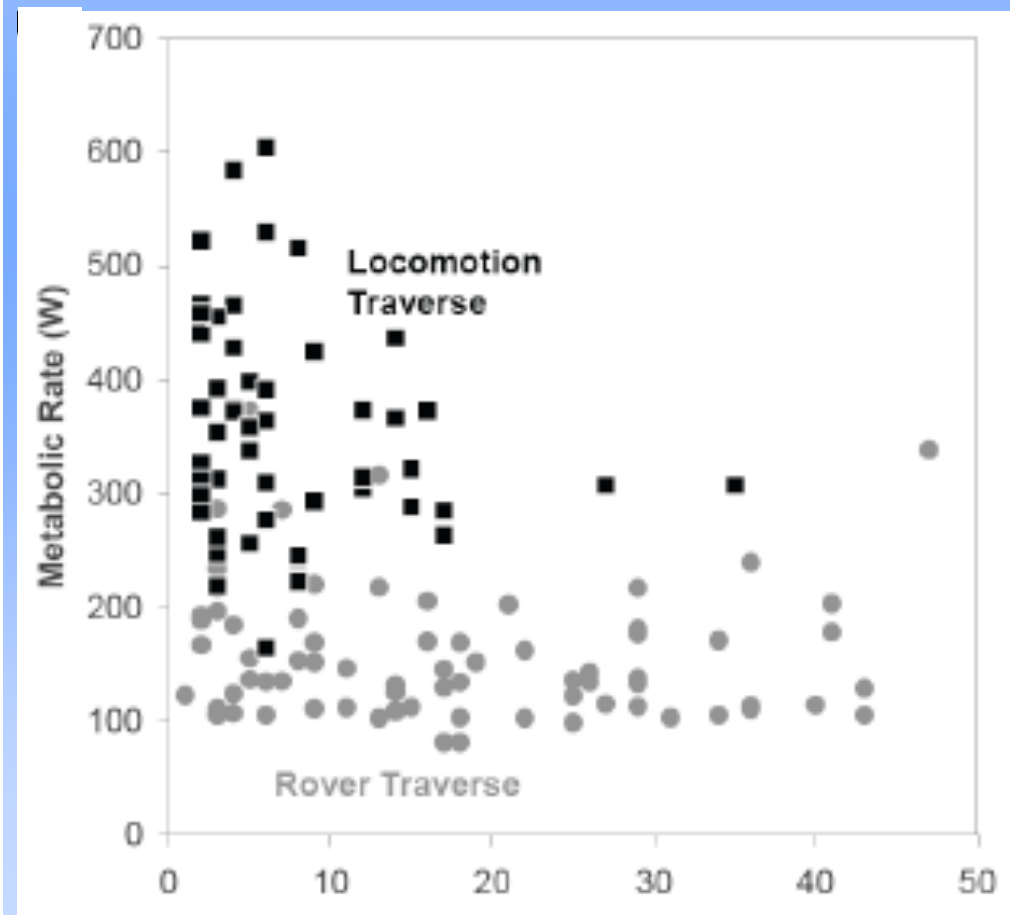
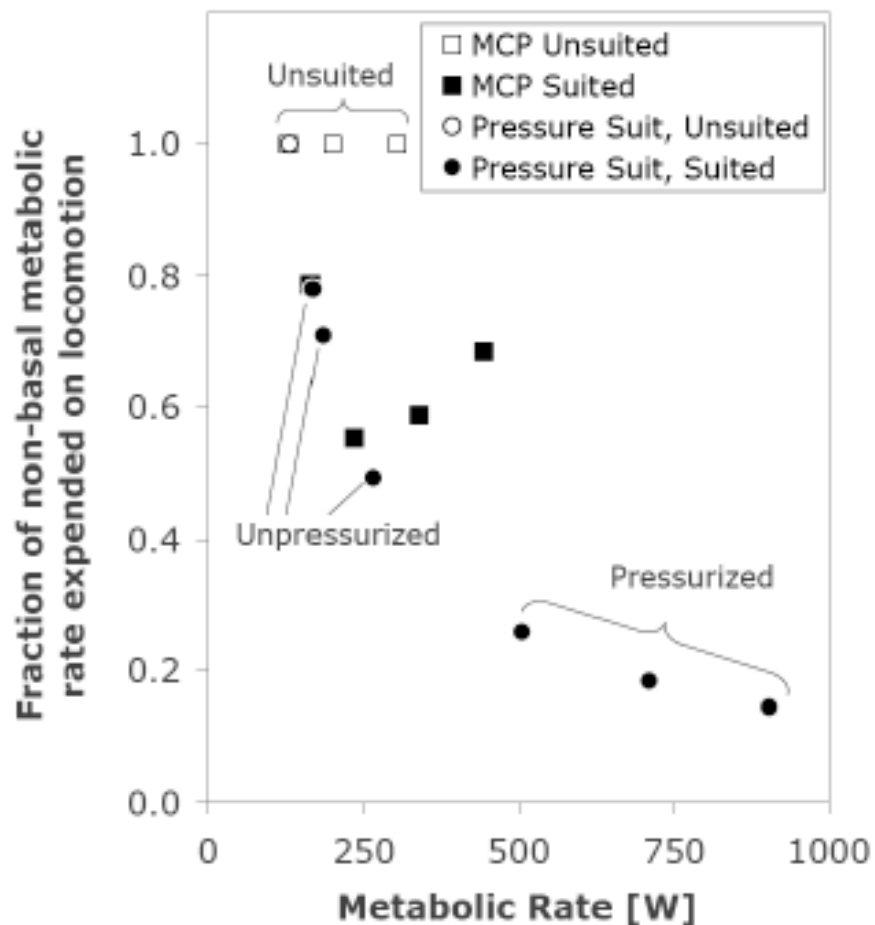
False Platform Response





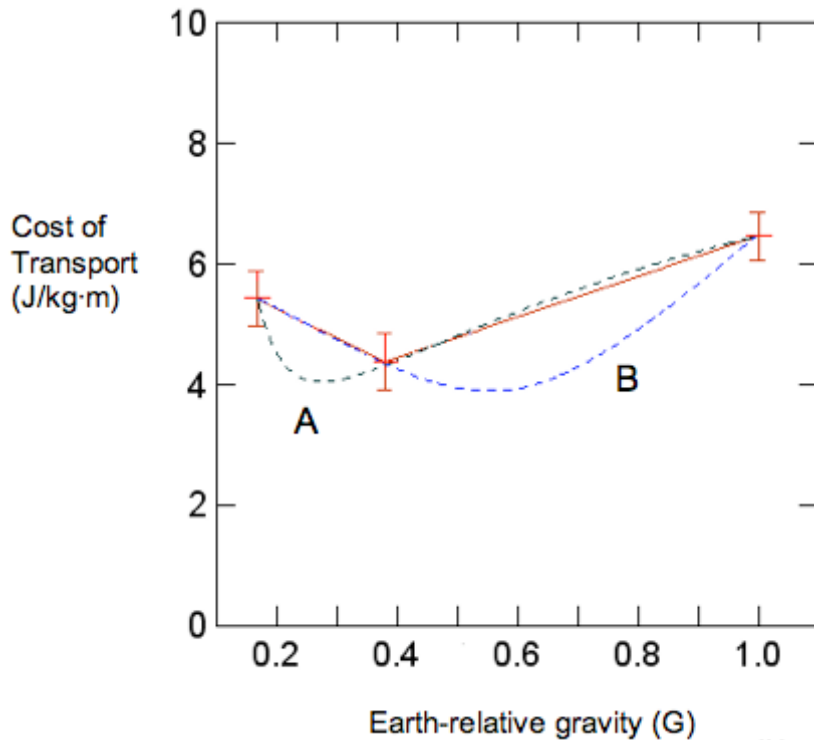
Energetics & Biomechanics

- **Apollo data as a baseline, first MCP suit (Webb)**
 - Improve space suit design: minimize energy, max. mobility

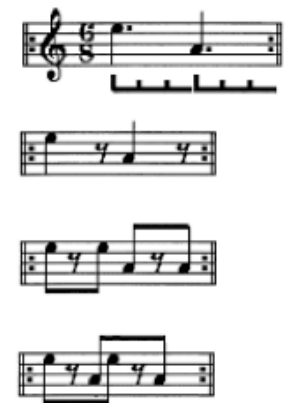
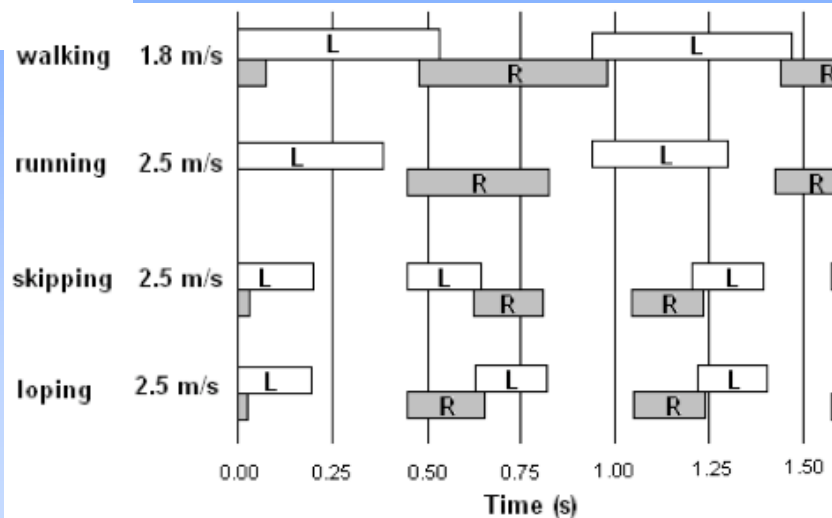




Cost of Transport and Gravity



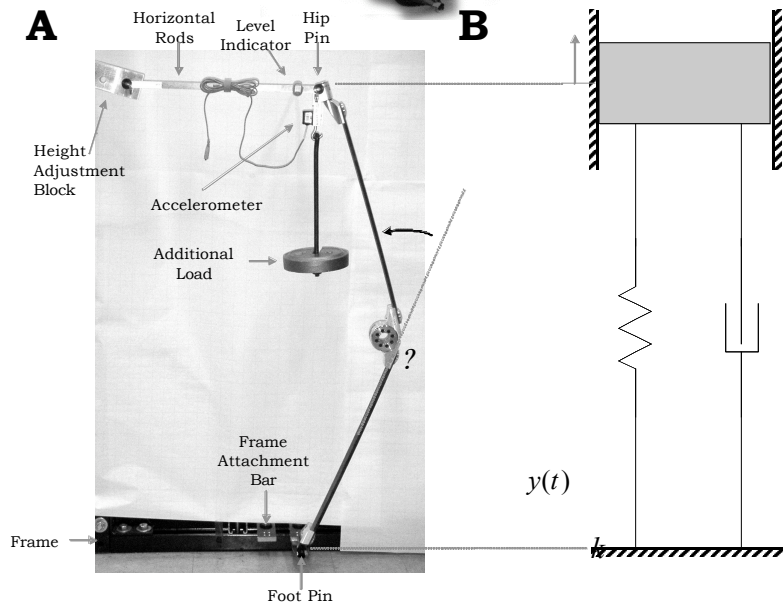
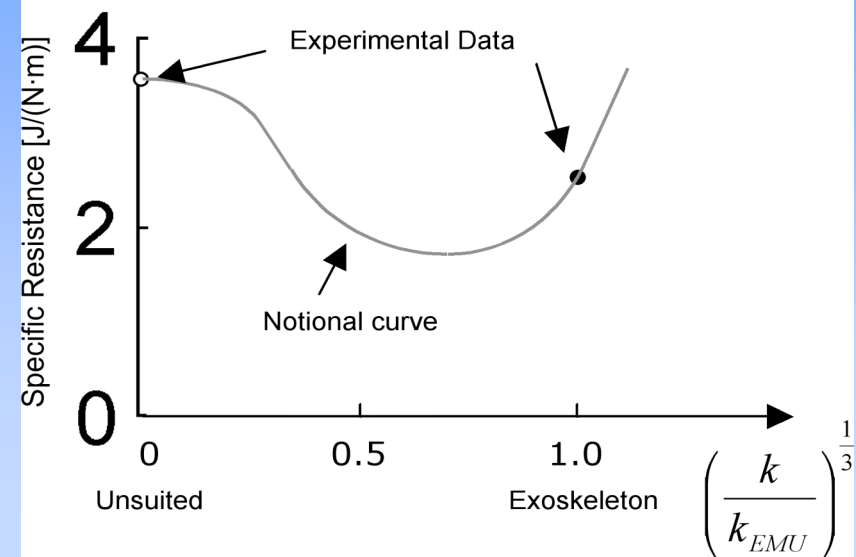
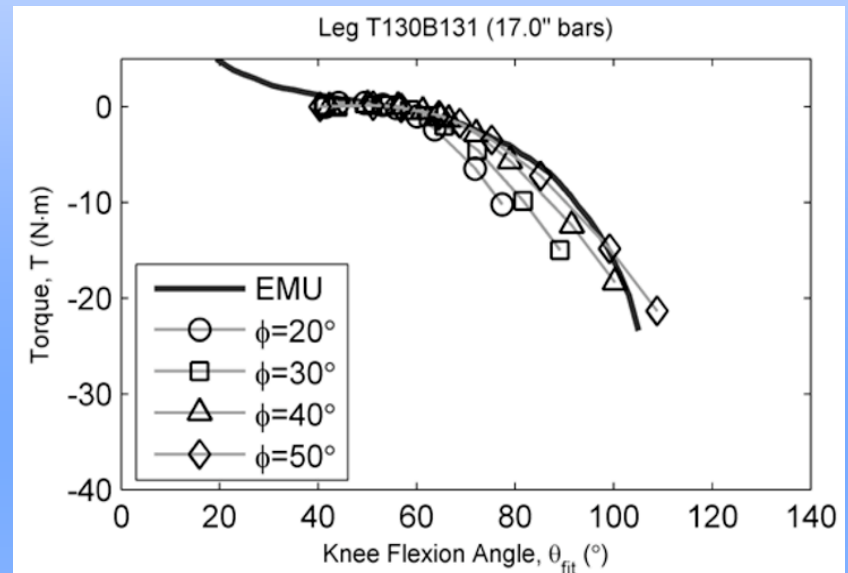
- Energetics of locomotion (walking and loping)?
- Moon: Stability, control
- If on Mars: Run (lope) don't walk!





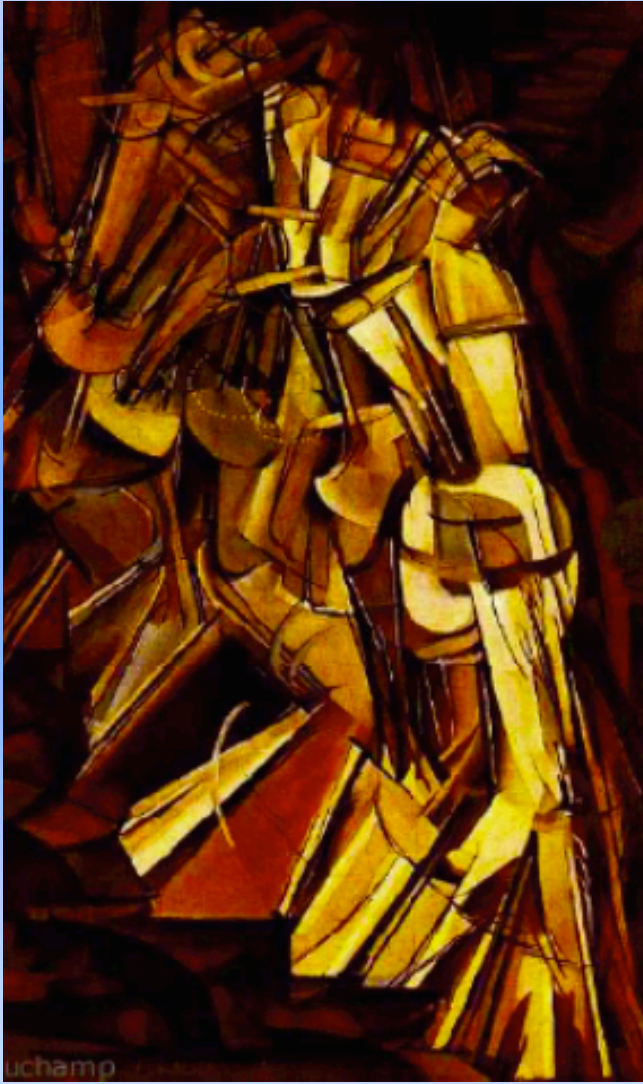
Space Suit Simulator – Exoskeleton

- Exoskeleton joint torques match EMU knee torques
- “Tuned space suit”



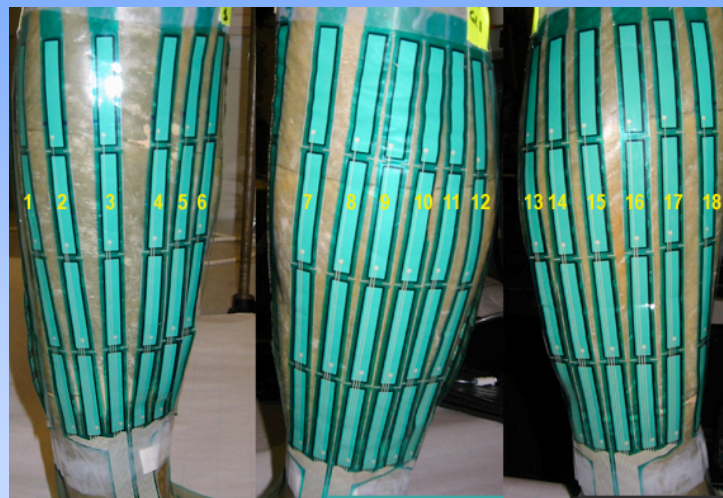
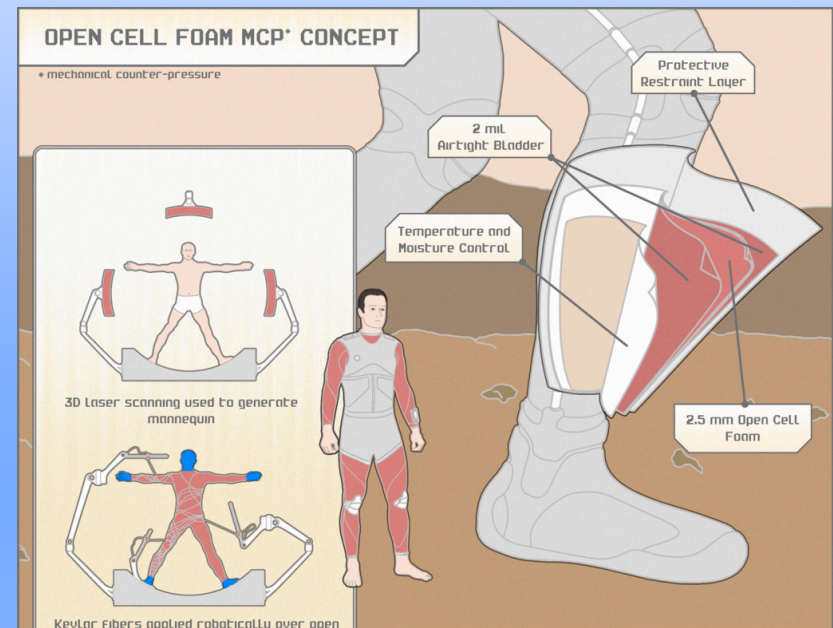
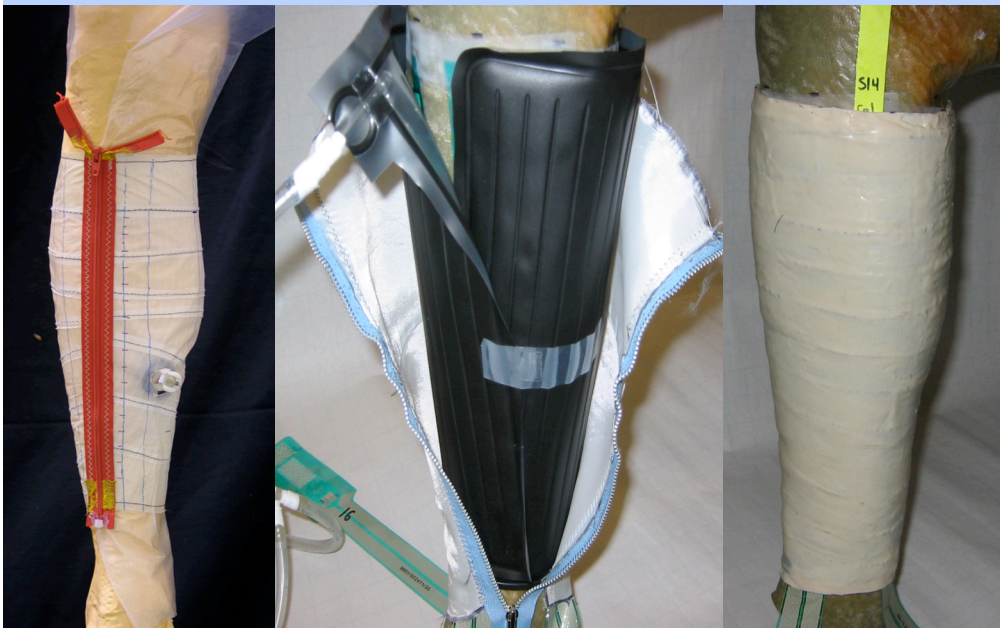


The Art of Engineering and Design





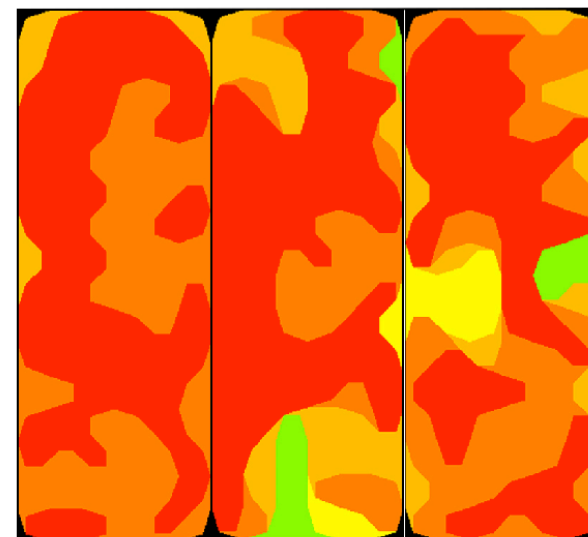
Results: MCP Initial Prototypes



Tibia

Medial-Posterior

Lateral



Tibia

Posterior Medial

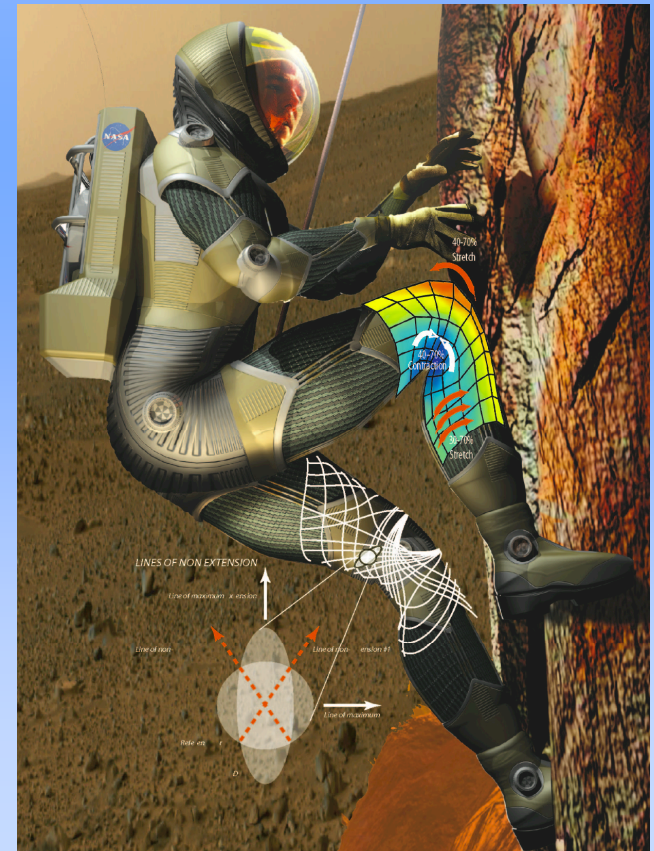
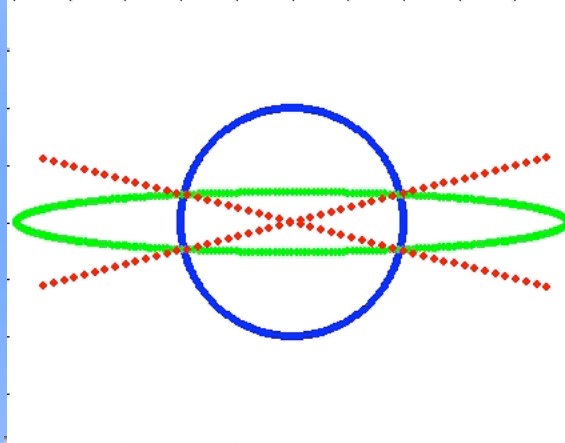
Lateral





Results: Minimum Energy Bio-Suit

- Maximizing mobility
- Minimizing energy
 - (Strain energy, stress and modulus)





Results: MCP Elastic Bindings

- Maximum mobility
- Active materials (de-couple donning/doffing)
- Shape memory polymers (large max. strain)



- Varying circumferential tension gives constant pressure as leg radius changes.
- Donning time ~5 minutes



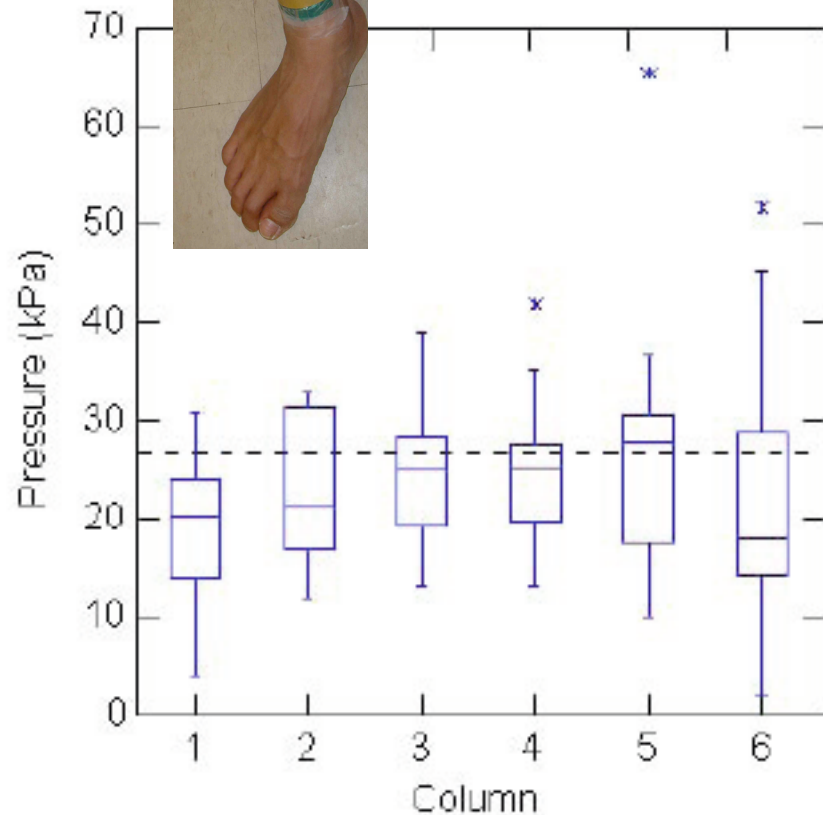
- Knee flexion angle $\sim 140^\circ$



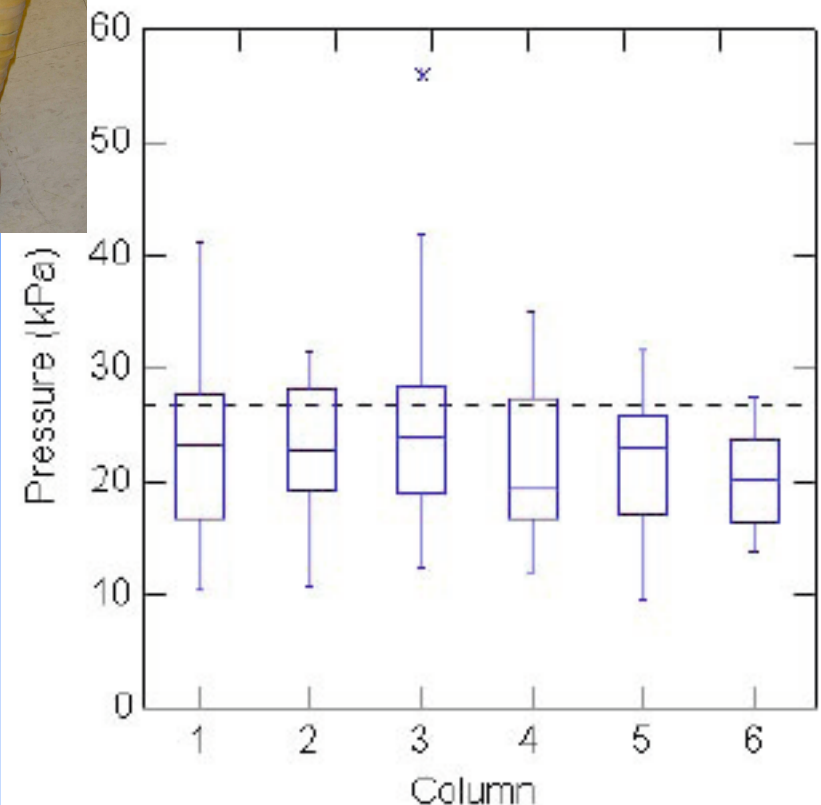
Pressure Distribution Generated by the Elastic Bindings (Design Pressure ~27 kPa)

Prototype MCP generated on calf using Elastic Bindings

Front/Anterior



Back/Posterior



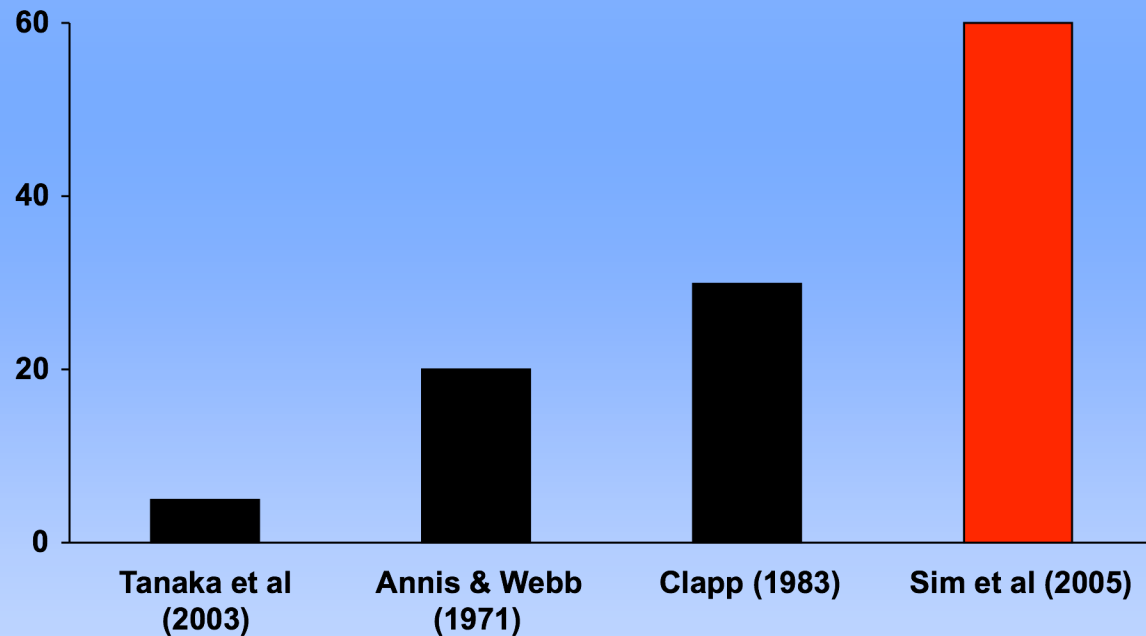


Successfully protected a human leg from the effects of external underpressure

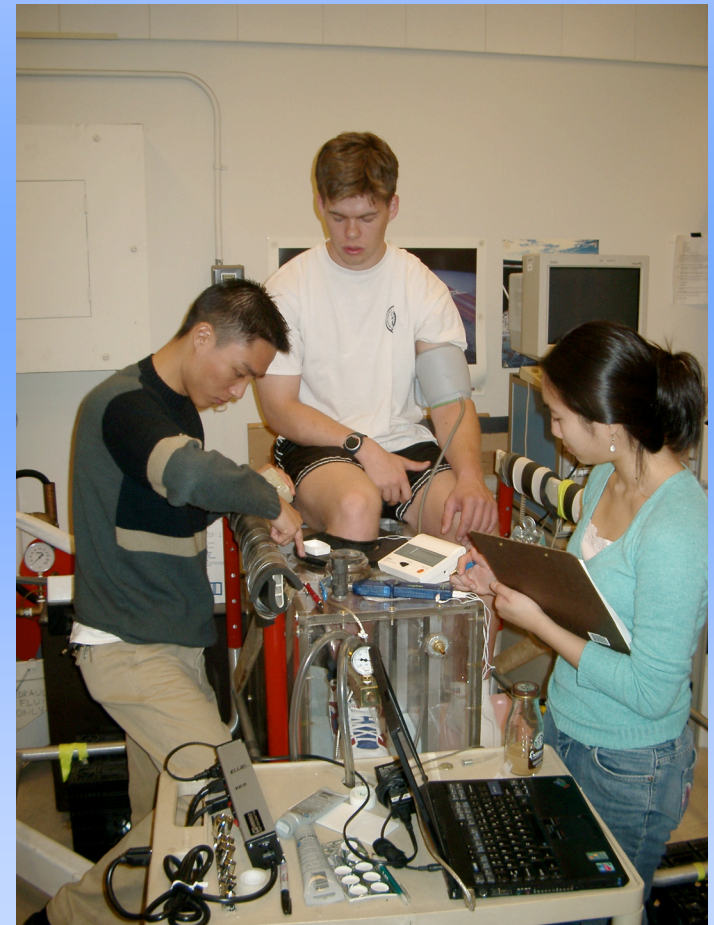
ELASTIC BAND PROTOTYPES

Human MCP Garment Trials in Low-Pressure Chambers

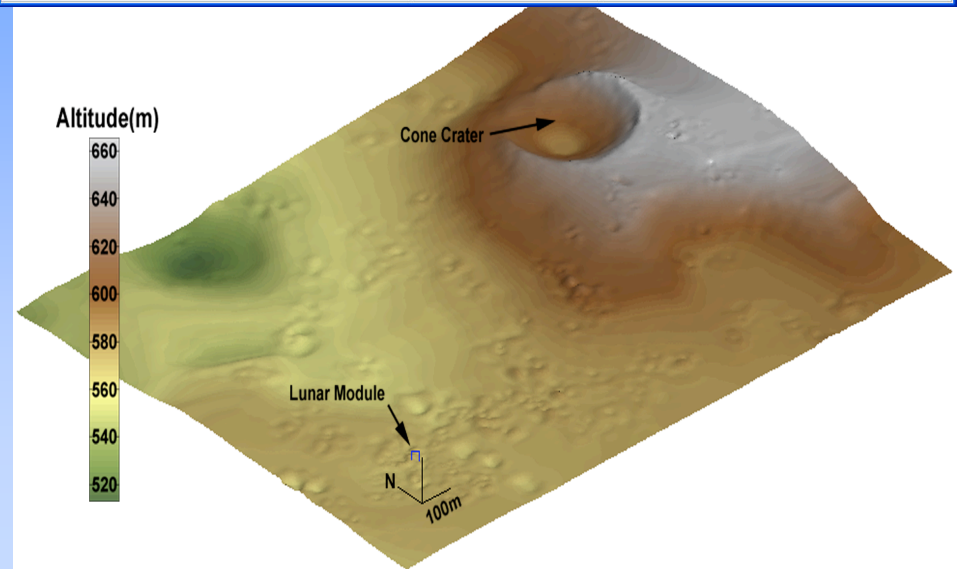
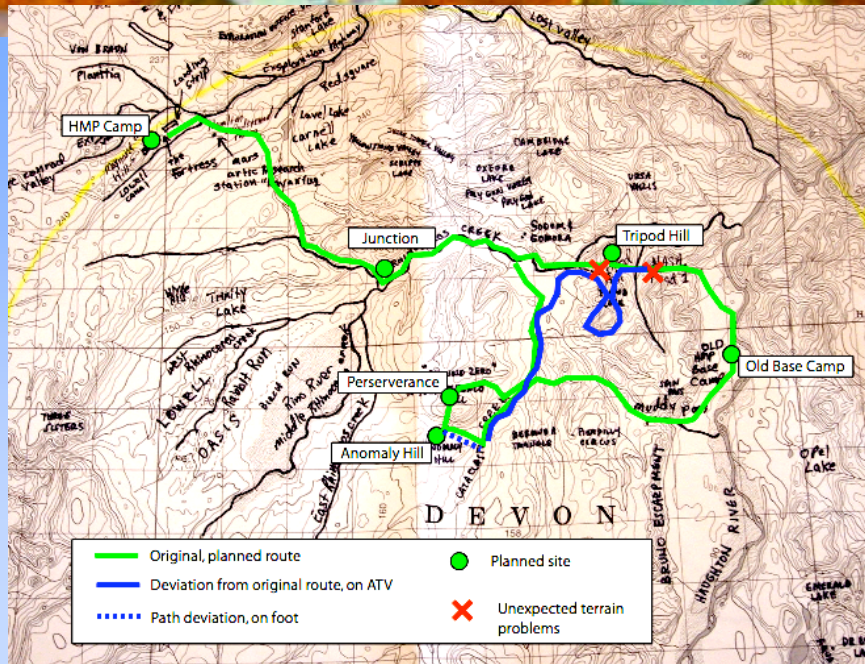
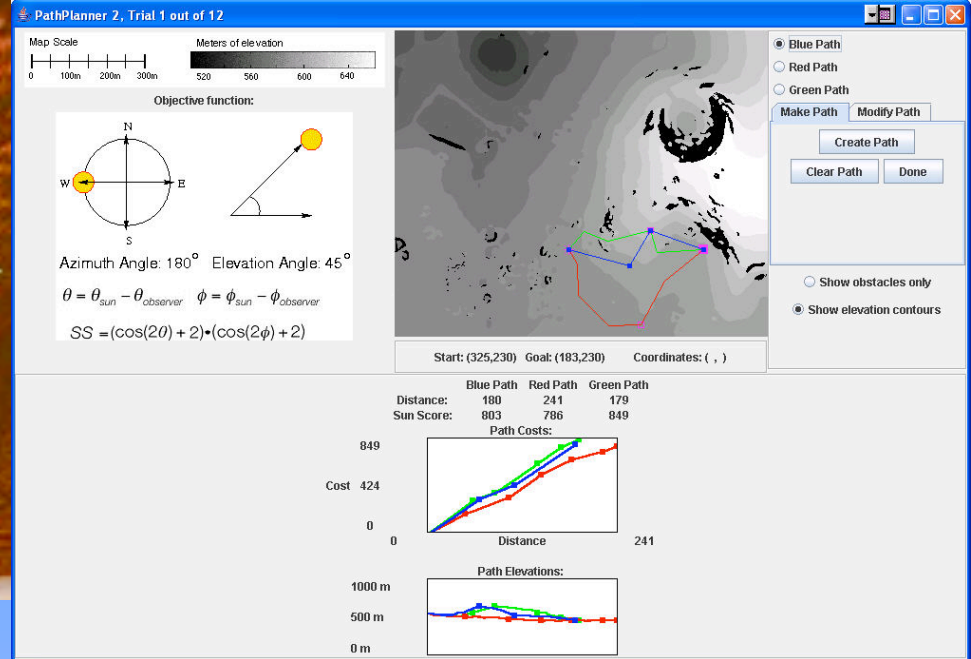
Test
duration*
(minutes)



Note: * Excludes pressure ramp-down and ramp-up times

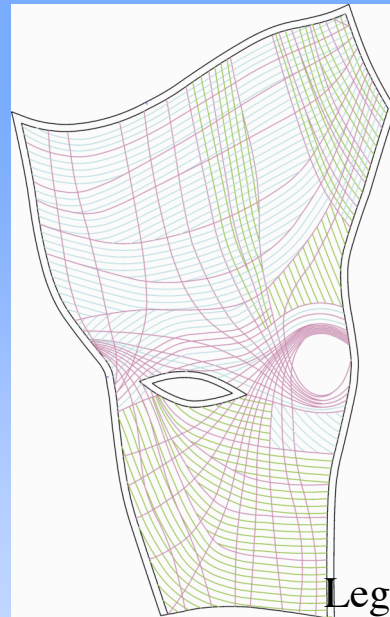
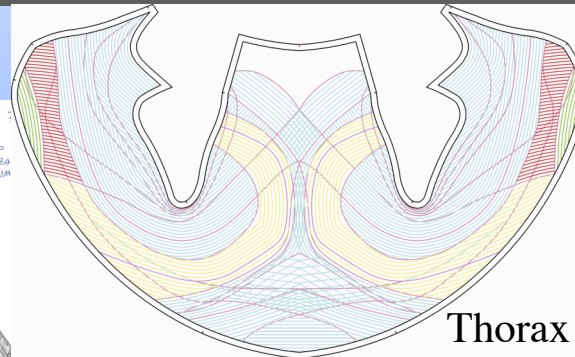
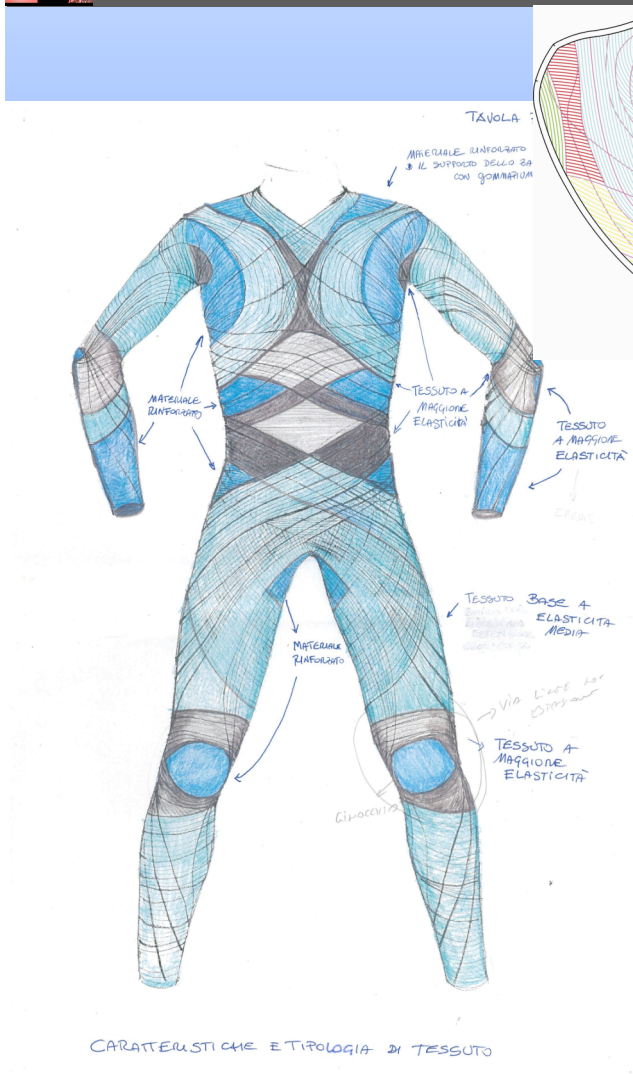


Exploration Path Planning





Digitally Designed: Bio-Suit Mockup



- From the human form – computer – fabrication.
- CAD models – human 3D scans and LoNE
- Automatic seams to positioning LoNE, primary and secondary
- 340 m
- 140,000 points (stitches)
- A novel closure system
- Custom spacesuit



Massachusetts Institute of Technology

TAI





2006 Bio-Suit Mockup





WIRED: NextFest 2006 NYC

Knowledge Station Outreach

Explore Space!

The Knowledge Station is an educational portal where you can Explore, Interact, and Learn.



Explore the International Space Station (ISS), Mars, and Europa.

Interact through the gestural interface to exercise on the ISS, explore Mars with Max in an advanced spacesuit, or teleoperate M. Tallchief (a robot) on Jupiter's moon of Europa.

Learn about the world of NASA and NSBRI's science and technology breakthroughs.

Virtually Travel in the Knowledge Station – an educational environment with freestanding mobility designed for museums and public outreach. Our outreach vehicle is designed for 1-2 users and shares a global vision for peaceful space exploration and hopes to inspire the imaginations of future astronauts.



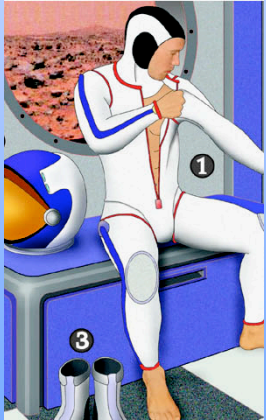


References

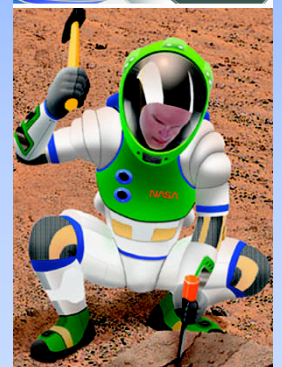
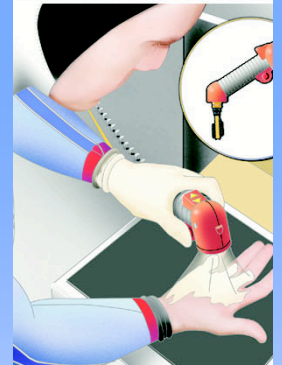
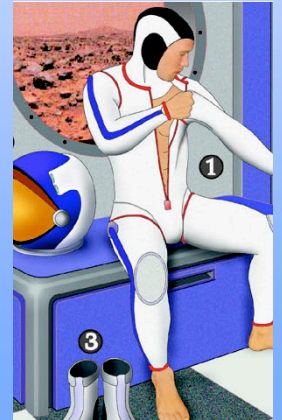
1. Frazer, A.L., Pitts, B.M., Schmidt, P.B., Hoffman, J.A., and D.J. Newman, "**Astronaut Performance Implications for Future Spacesuit Design**," 53rd International Astronautical Congress, Houston, TX, October 2002.
2. Saleh, J.H., Hastings, D.E., Newman, D.J. "**Flexibility in system design and implication for aerospace systems**," *Acta Astronautica* 53 (2003) 927-944.
3. Newman, D.J., Bethke, K., Carr, C.E., Hoffman, J., Trotti, G., "**Astronaut Bio-Suit System to Enable Planetary Exploration**," International Astronautical Conference, Vancouver, B.C., Canada, 4-8 Oct 2004.
4. Bethke, K., Carr, C.E., Pitts, B.M., Newman, D.J. "**Bio-Suit Development: Viable Options for Mechanical Counter Pressure?**" 34th ICES, Colorado Springs, Colorado, July, 2004.
5. Saleh, J.H., Hastings, D.E., Newman, D.J. "**Weaving time into system architecture: satellite cost per operational day and optimal design lifetime**," *Acta Astronautica* 54 (2004) 413-431.
6. Sim, L., Bethke, K., Jordan, N., Dube, C., Hoffman J., Brensinger, C., Trotti, G., Newman, D.J. **Implementation and Testing of a Mechanical Counterpressure Bio-Suit System.** #2005-01-2968, AIAA and SAE International Conference on Environmental Systems (ICES 2005), Rome, Italy, July 2005.
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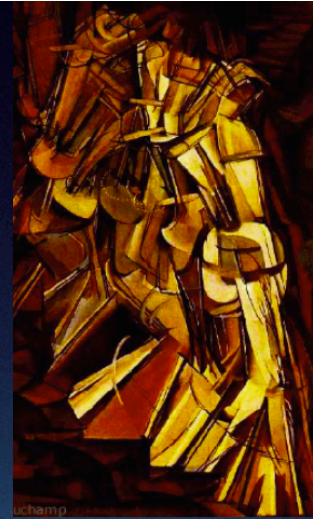


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