An Astronaut 'Bio-Suit' System: Exploration-Class Missions

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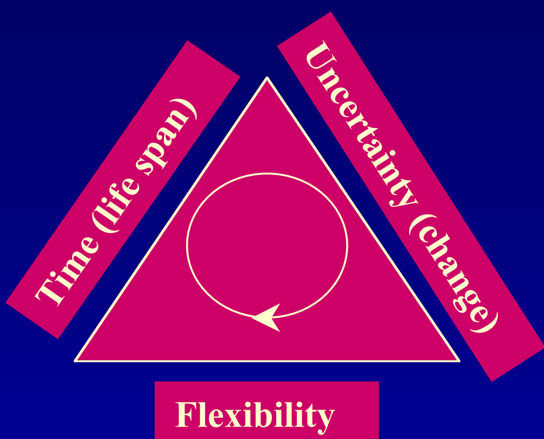
October 30, 2001

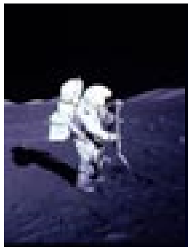
Field exploration, including field geology, will be a major part of future human and robotic exploration of the Martian surface.

Overview

Application of Full-Body Electrospun Bio-Suit
T02



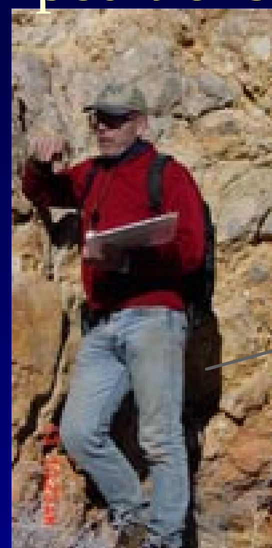
Time (life span)
Uncertainty (change)
Flexibility



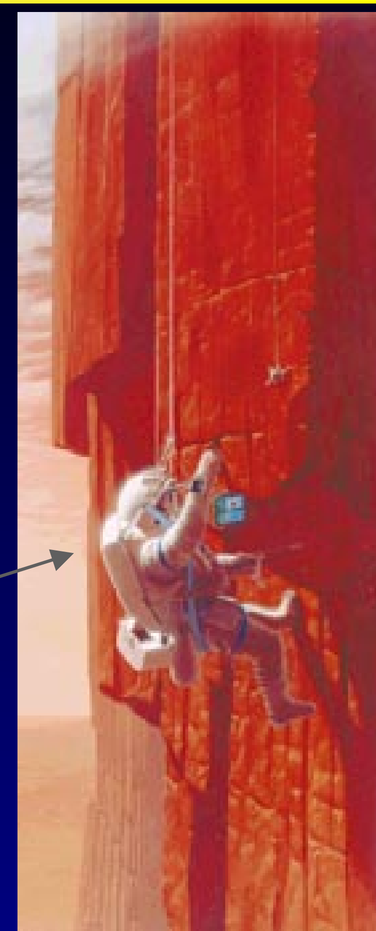
Martian Field Geology: Two Themes

- Look to future and improve (1) Flexibility and enhance (2) Information management
- Understand field geology techniques
- Learn from past expeditions

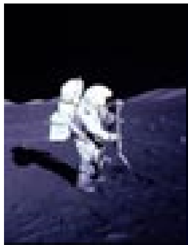
Lewis and Clark



Present Day Field Geology



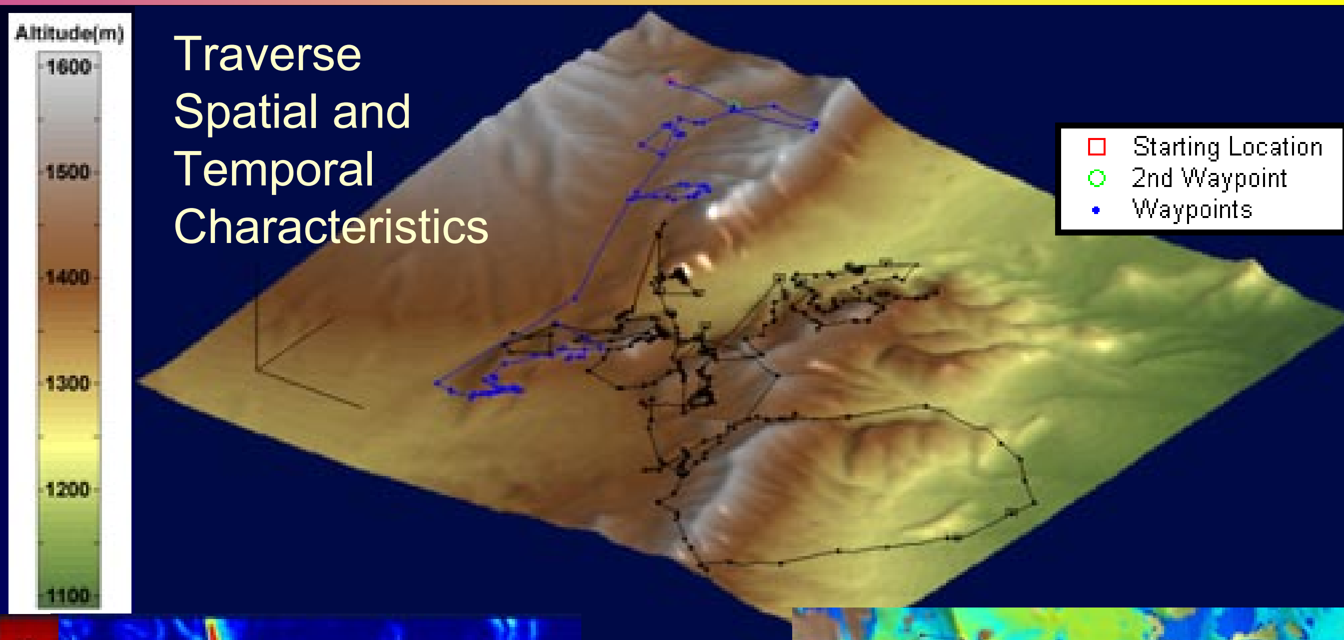
Pat Rawlings (NASA)



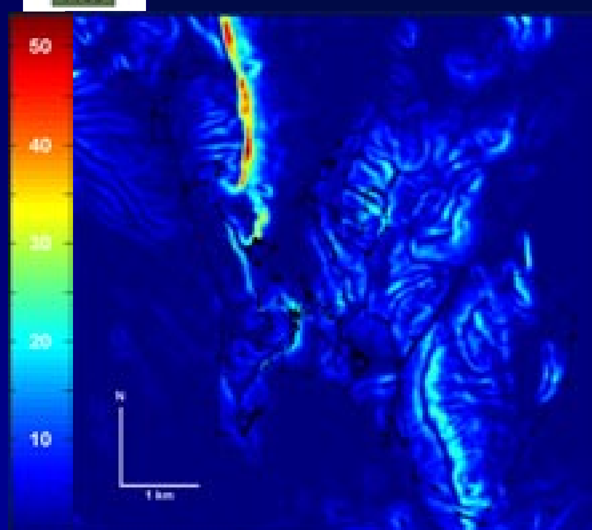
Field Geologic Mapping Experiment

Bird Spring Mountains, Nevada

Traverse Spatial and Temporal Characteristics

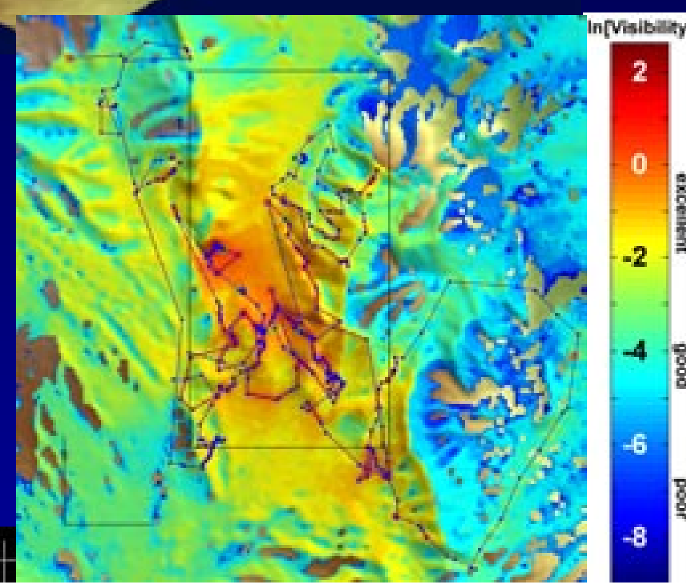


Slope analysis (degrees)

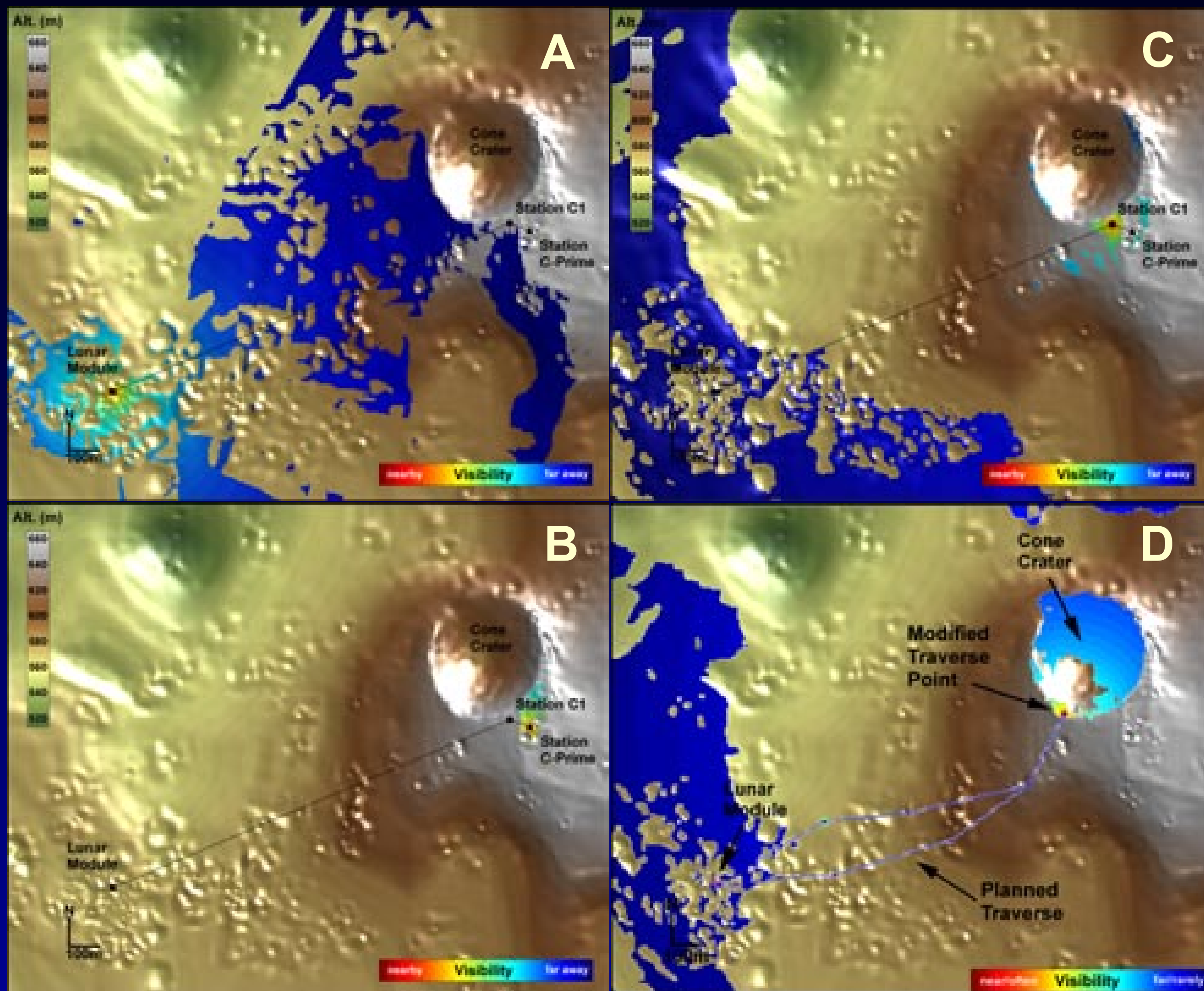


Visibility

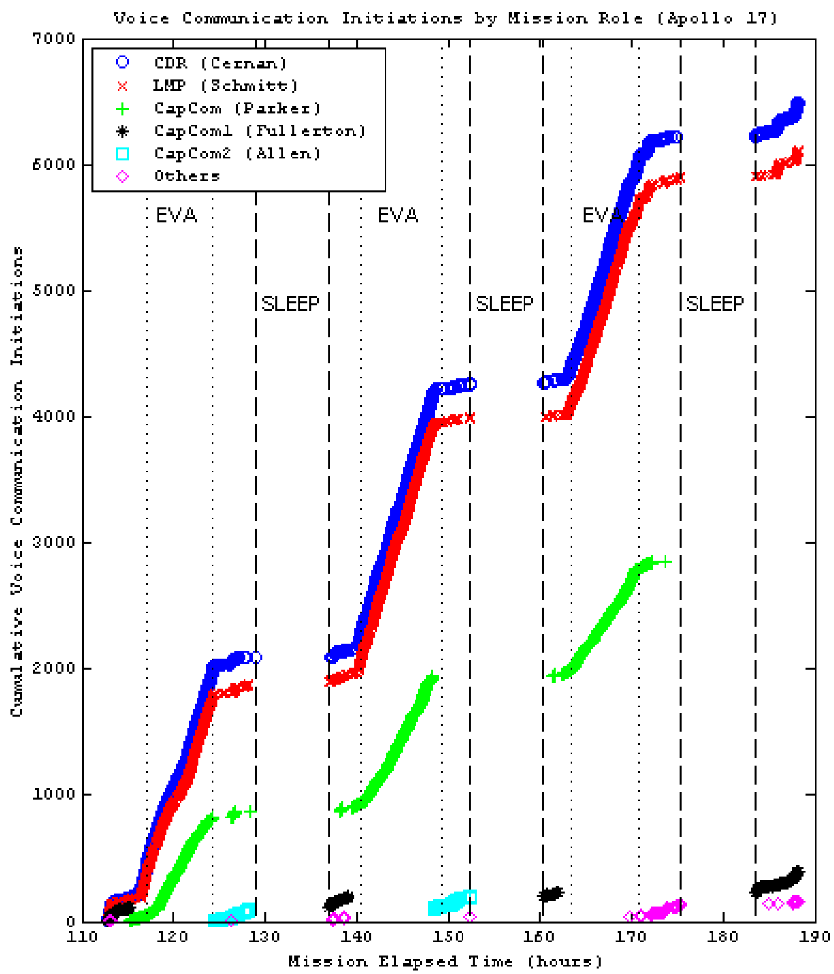
Maps

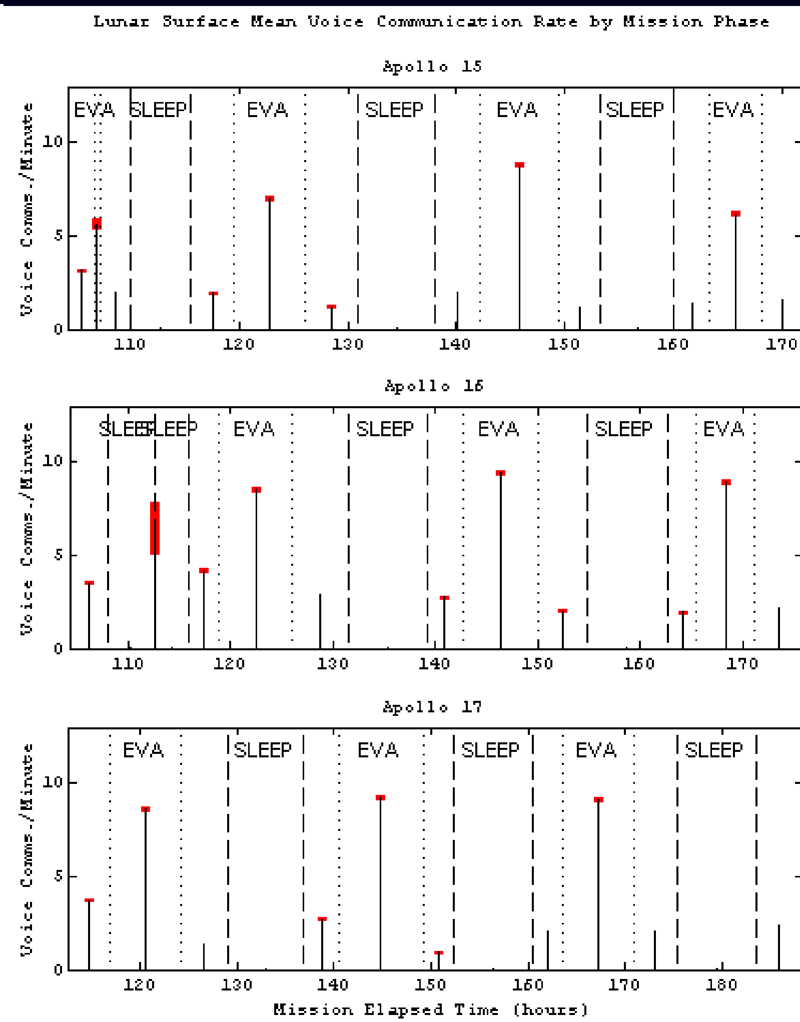


Apollo 14 EVA 2: Finding Cone Crater



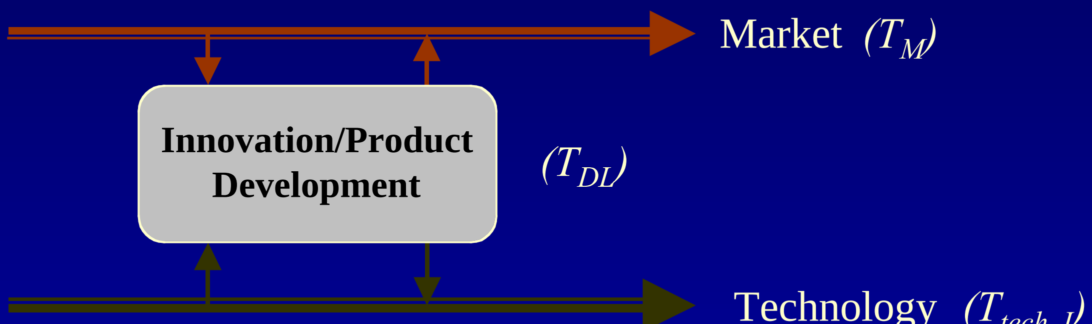
Apollo Voice Communications



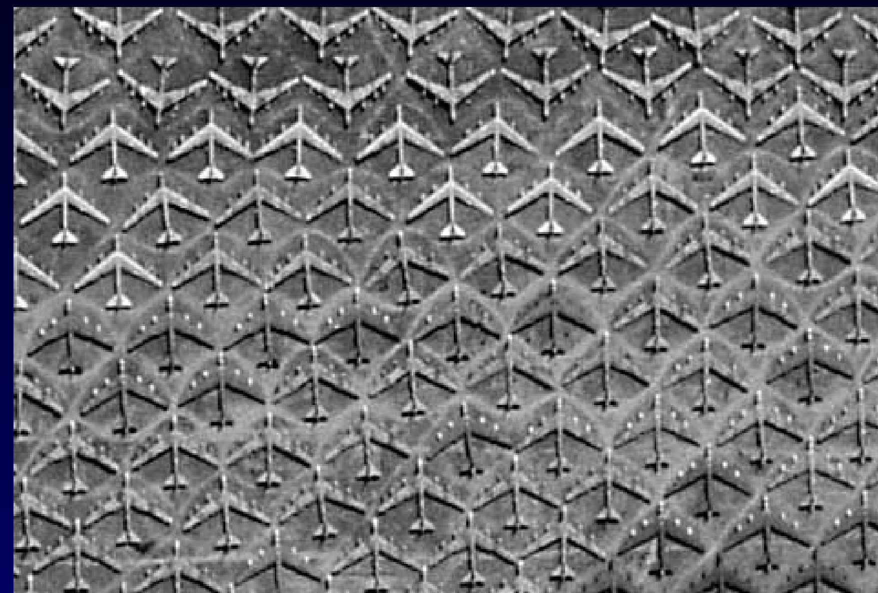


Space Systems: Flexibility in Design

- The ***need*** for flexibility in the design:
  - Large uncertainty in system's environment
  - System's technology base evolves on a time scale considerably shorter than the system's design lifetime
- ***Flexibility***:
  - Reduces design exposure to uncertainty (e.g., mitigates market risk)
  - Mitigates risks of obsolescence



The Aircraft Graveyard



- 21st Century Ruins: reminder that nothing is permanent
- Through physical or functional degradation, or loss of economic usefulness, the hand of time lies heavy on the work of humans

Essential Flexibility

- **Analyst's perspective**

  Products that thrive longer, or have a longer life span, are the ones that are capable of coping with unpredictability and change in their environment.

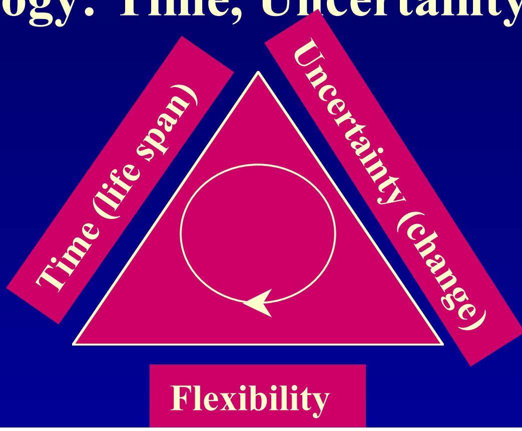
- **Designer's perspective**

  Designing for an extended design lifetime, the ability to cope with unpredictability and change has to be embedded in the system

- **Parallel with another *struggle for life*: Biological organisms**
  - "the process of Natural Selection operates daily and hourly, scrutinizing the slightest variations; rejecting those that are bad, preserving those that are good."

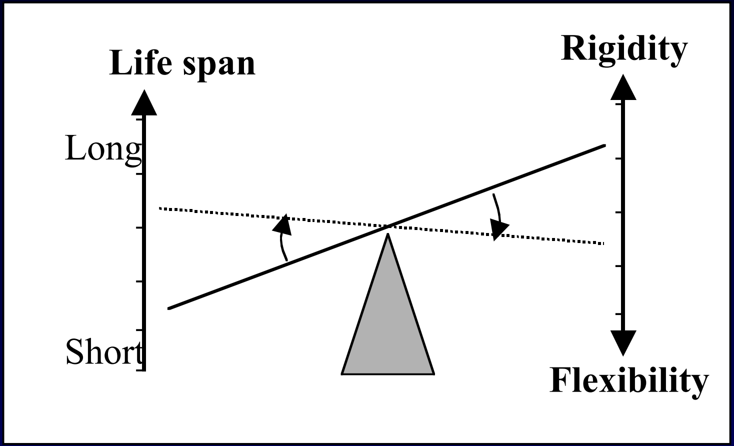
    – Darwin, *Origin of Species*

The Trilogy: Time, Uncertainty, and Flexibility



Investigating Flexibility

- Why? Relationship Design Lifetime → Flexibility



  - Current complex engineering systems designed for increasingly longer design lifetime (e.g., communications satellites, rotorcraft, etc.)
  - Flexibility has become a key concept in many disciplines (urban planning, architecture, finance, manufacturing, software design, etc.)
- Formal attempt to Define, Quantify, Achieve, and Value flexibility

Galileo Spacecraft

- Galileo Mission to Jupiter: Launched in 1989, arrived in 1995
  - Prime Mission Overview
    - Study the planet's atmosphere
    - Conduct long-term observation of its magnetosphere
- Initial science objectives:
  - Investigate circulation and dynamics of the Jovian atmosphere and ionosphere
  - Characterize vector magnetic field and the energy spectra, composition, and distribution of energetic particles and plasma to a distance of $150R_J$
  - Conduct long-term observation of its magnetosphere
  - Characterize the morphology, geology, and physical state of Galilean satellites
- 1997, Galileo completed its original missions objectives.
  New mission, Galileo Europa Mission (GEM)
  - **Europa**: Study and characterize crust, atmosphere, and possible ocean (i.e., exobiology) using imaging, gravity, and space physics data.
  - **Io Plasma Torus**: Explore and map Io plasma Torus as orbit approaches Io
  - **Io**: Intensive study of Io's volcanic processes, atmosphere, and magnetosphere

Flexibility for the Future

- The ***need*** for flexibility in the design:
  - Large uncertainty in system's environment
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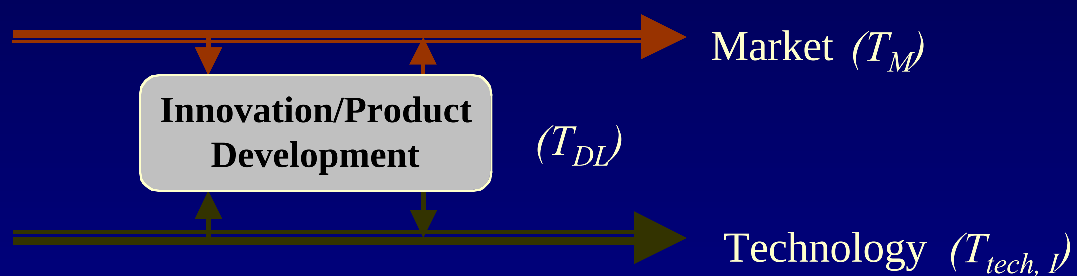

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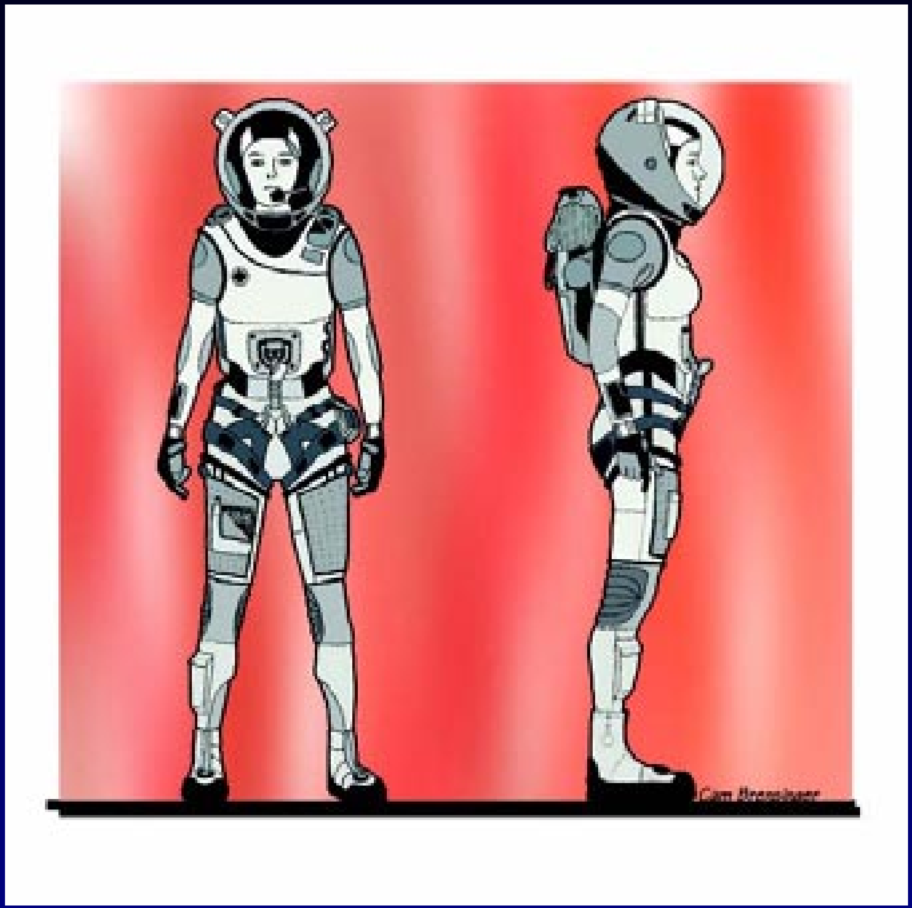
The ‘Bio-Suit’ Concepts

Space Suits

- Current Extravehicular Mobility Unit (EMU)
  - Designed for weightlessness
  - Pressurized suit (29 kPa, 4.3 psi)
  - Life support system (O_2, CO_2, etc.)
  - 2 pieces: pants, arms & hard upper torso
  - Donning and doffing are highly involved
  - Adequate mobility for ISS
  - Inadequate mobility for locomotion/exploration

Advanced Space Suit: Bio-Suit

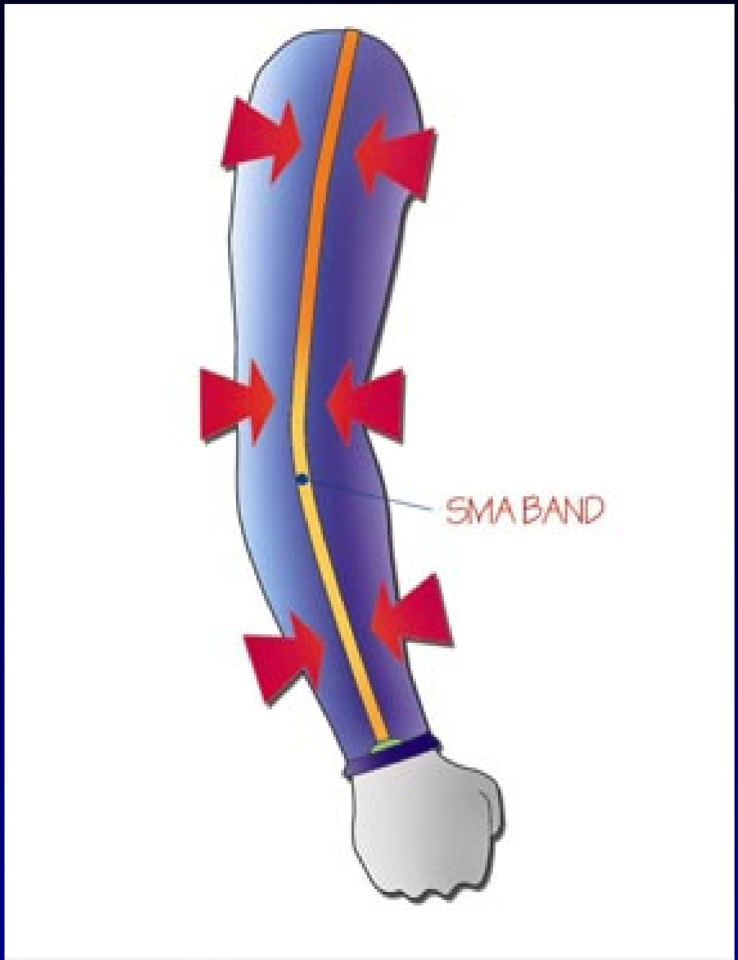


- Mechanical Counter Pressure (MCP)
  - Skin suit cf. pressure vessel
  - Greater flexibility, dexterity
  - Lightweight
  - Easy donning and doffing: {clothing vs. strapping on spacecraft (ISS suits)}
- Mechanical assistance
  - Augments astronaut's capabilities
  - Decreases the effects of microgravity deconditioning
  - Assisted locomotion 1G (ankle orthotic for patients)

Suit Components

- Bio-Suit multiple components:
  1. The MCP bio-suit layer
  2. A pressurized helmet
  3. Gloves and boots
  4. A hard torso shell
  5. A life support backpack
- Components are simple, interchangeable, and easy to maintain and repair.
- Idea: Custom-fit skin suit to an individual human/digital model

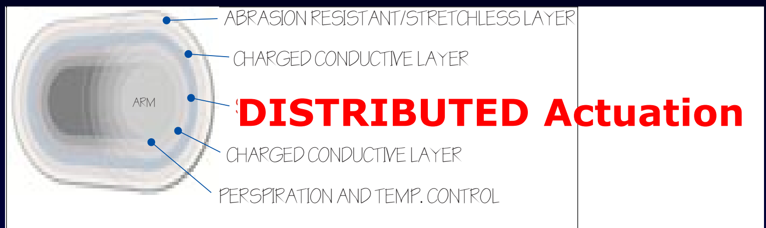
Producing MCP



SMA Band Contracts Fabric

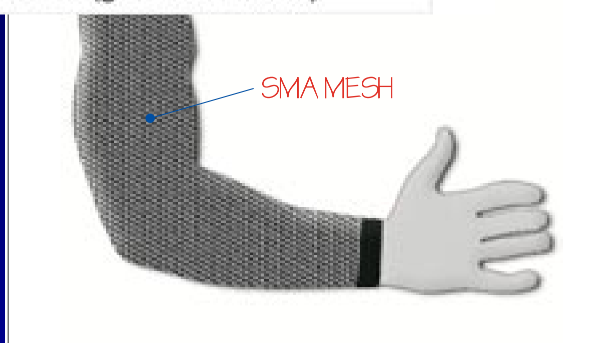
- Donning and doffing
  - Bio-suit shrinks around the body
- Active materials
- Technologies investigated:
  - Piezoelectrics
  - "Smart" polymer gels
    - Expand with heat, voltage, or pH
  - Shape Memory Alloys (SMA)
    - Voltage toggles shape between two states: expanded and contracted
    - TiNi (titanium nickel)

Fully Distributed Technologies



EGS Layers (not proportional).

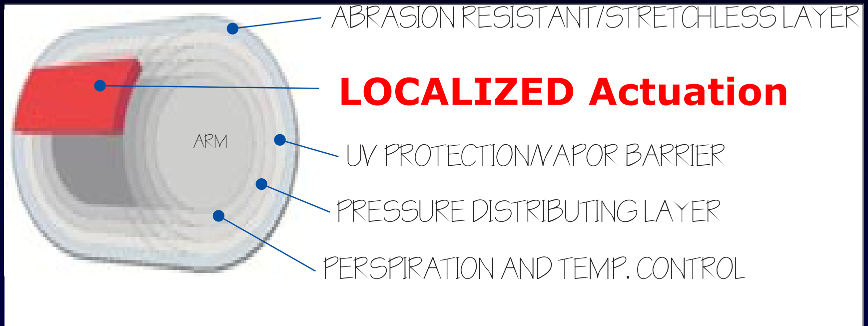
Quilted Smart Gel (glove not shown).



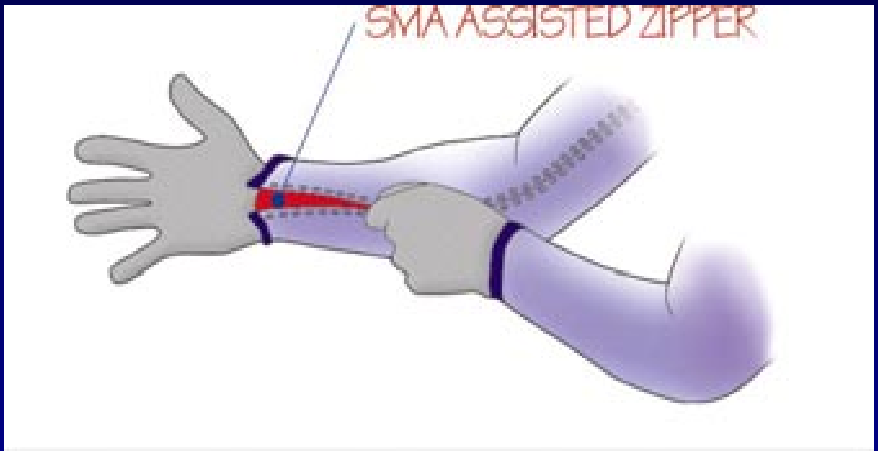
EAMS Concept (glove not shown).

- Active materials throughout
- Piezo-electrics/ceramics
  - Small-scale actuators
  - Not applicable to bio-suit
- Gel Polymers
  - Expand with body heat or electric activation
  - Thermal layer promise
- Shape Memory Alloy (SMA)
  - Human force levels
  - Not entire suit (mesh), promise for hybrid concepts

Hybrid Technologies



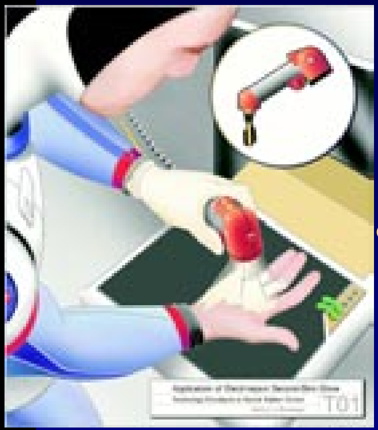
SABS Layers (not proportional).



EAZS Concept (glove not shown).

- Electric Alloy Zipper Suit (EAZS) advantages:
  - Localized use of active materials
  - Materials are activated in donning/doffing
  - Redundant, mechanical system to maintain MCP
  - Aerogel provides insulation between SMA and skin

Advanced Technologies



- *Electrospinlacing* provides seamless MCP layer.
  - Multi-filament fiber projected via electric charge onto grounded surface
  - Greatly improved tactile feedback
  - Custom, form fit
  - "Disposable" glove, easily replaceable
  - Seamless integration of wearable computing
- Alternate Tech.: *Melt Blowing*
  - Blowing liquefied polymer onto surfaces

    (Industry, Academia, Natick National Protection Center)

Explorers on Mars

- Bio-Suit Concept Provides:
  - Novel conceptualization/design
  - Flexibility required to perform useful geology in a partial gravity environment
  - Protection from hazardous material, atmosphere, and radiation
  - Augmented locomotion and movement capabilities
  - IT interfaces and biosensors for real-time data feedback
  - Wearable computing for enhanced communications & sample analyses
  - Individualize skin suit to astronaut/digital model

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