Development and Validation of a Multidisciplinary Spacesuit Model

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Outline

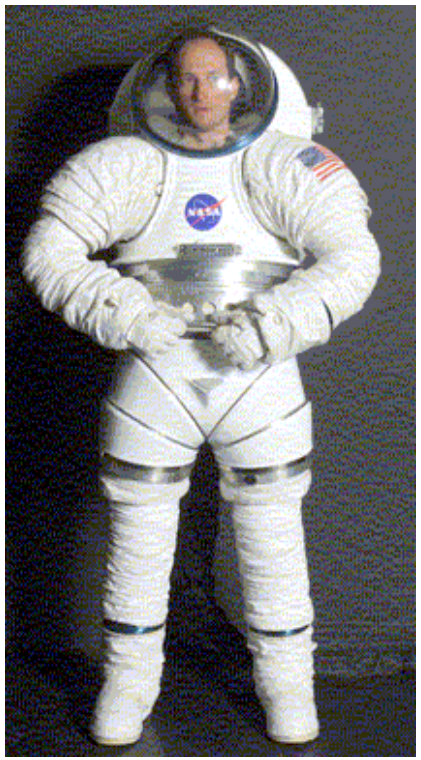
- Why a Spacesuit?
- Model Description
- Subsystem Details
- Model Validation
- Optimization Preview
- Conclusion
- Acknowledgment

Spacesuits 101

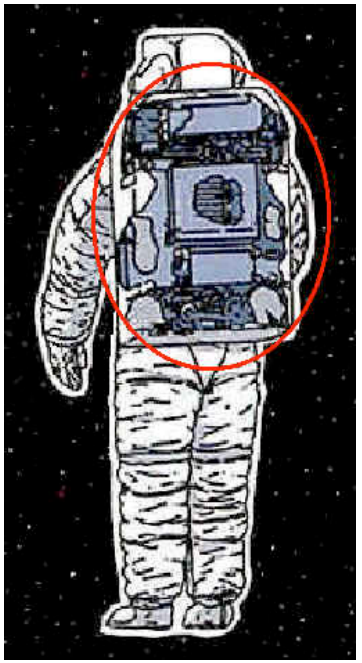
- Why do we need a spacesuit?
  - Regulate temperature
  - Provide oxygen for breathing
  - Pressurized environment
- Important issues to consider
  - Mobility
  - Mass
  - Stowage Volume
  - Pre-breathe time

Model Overview

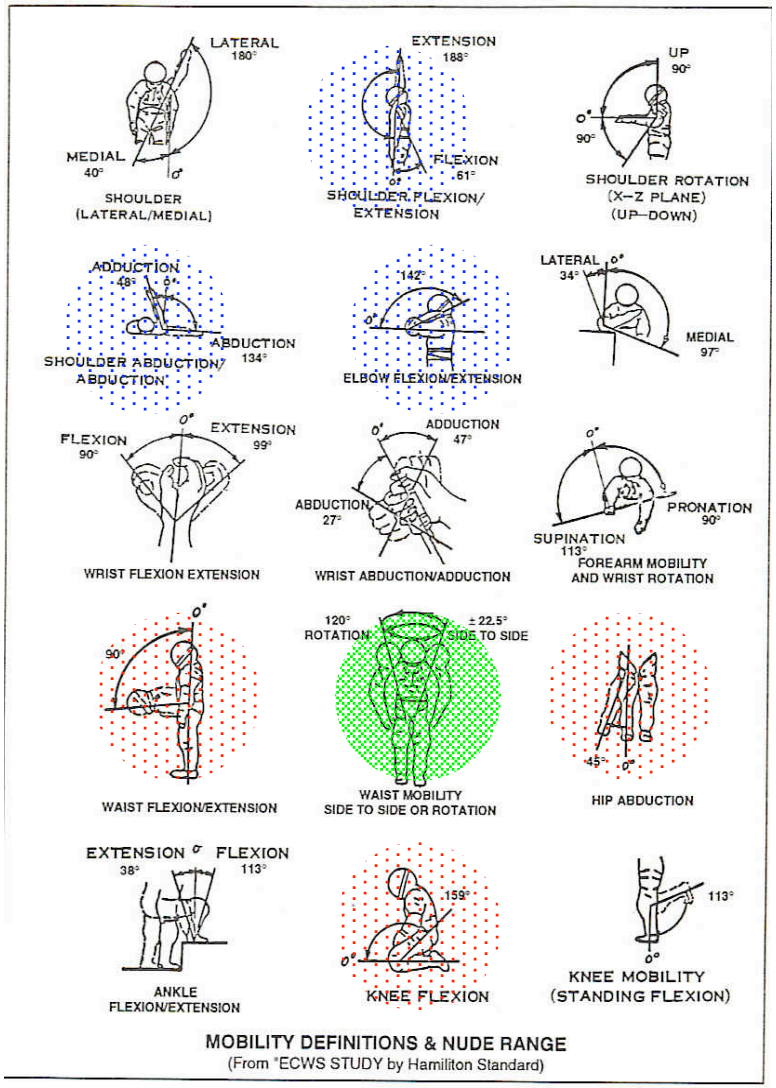
- Spacesuit Garment
  - Mobility



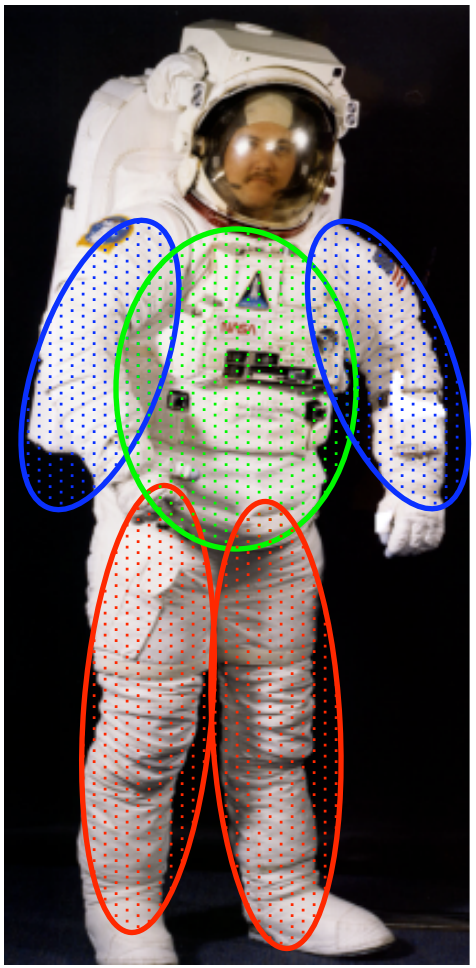
- Primary Life Support System (PLSS)
  - O2 Flow
  - Thermal Regulation
  - Power



Mobility Subsystem



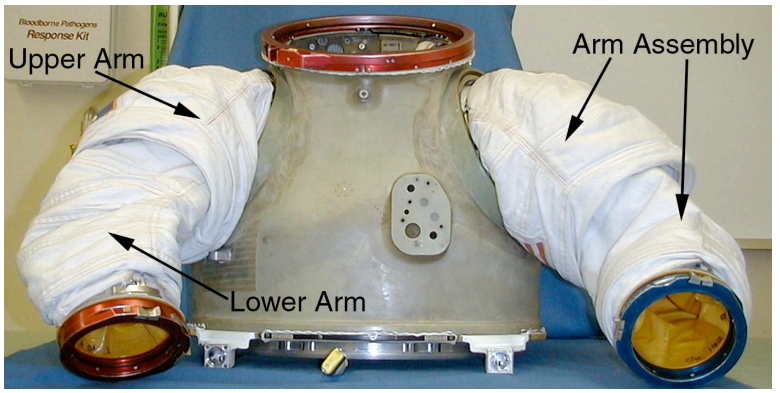
- Arms
  - Elbow flexion
  - Shoulder flex/ex
  - Shoulder ad/abduction
- Legs
  - Hip flexion
  - Hip ad/abduction
  - Knee flexion
- Torso
  - Torso rotation



Mobility Subsystem

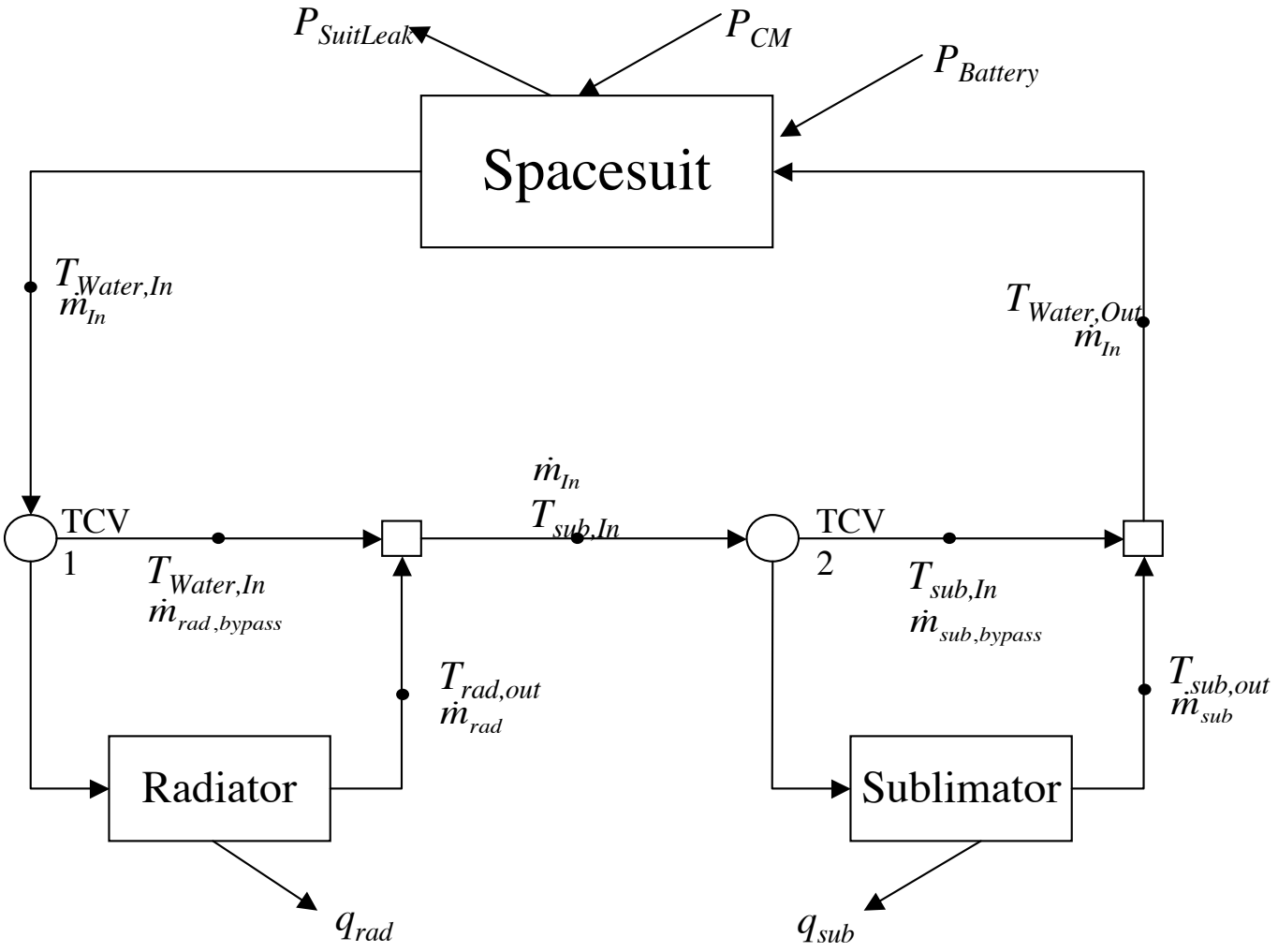
- Mobility = f(Range of Motion, Torque)
- Empirical and Physical Model

0	**All Soft Suit**
0.3	**HUT, Soft Legs, Soft Arms (EMU)**
0.5	**HUT, Soft Legs, Hard Arms**
0.8	**HUT, Hard Legs, Soft Arms**
1	**All Hard Suit (AX-5)**



$$mobility = w_{arms}(-\sum ROM_{arms} + \sum Torque_{arms}) + w_{legs}(-\sum ROM_{legs} + \sum Torque_{legs}) + w_{torso}(-\sum ROM_{torso} + \sum Torque_{torso})$$

Thermal Subsystem



Power Subsystem

- Given battery energy density, battery volumetric density, and power needs of suit, model calculates mass and volume of power subsystem
- Technology options modeled: NiCd Batteries, NiH_2 Batteries, Regenerative Fuel Cells, NiMH Batteries, Lithium-Ion Batteries, AgZn Batteries, Li-Solid Polymer, Electrolyte, Li-Solid Polymer, Inorganic Electrolyte
- Mass calculation includes supporting hardware:

$$m_{PMAD} = 0.02 * P_{demand} + 0.025 * P_{demand}$$

Oxygen Subsystem

- Models oxygen ventilation loop
- Primary determinant of backpack geometry
- CO_2 technologies modeled:
  - LiOH (single use)
  - Metox (multi-EVA use)

Model Validation

- Validated at the system and subsystem level
- Integrated model validated against the Extravehicular Mobility Unit (EMU) currently used on the ISS

Output	EMU	Model	% Error
Overall Mass (kg)	53.69	53.72	0.06%
Pre-Breathe Time (hr)	4	4.67	16.75%
02 Tank Volume	0.0079	0.0073	7.59%
Sublimator Water (kg)	3	2.9	3.33%
Battery Mass (kg)	6.81	6.67	2.06%

Model Interactions

S/O	Mass	Volume	PBT	Mobility
Oxygen	+	+	++	++
Thermal	+	+	-	-
Structures	++	++	++	++
Power	+	+	-	-

- indicates no correlation

+ indicates slight correlation

++ indicates strong correlation

Multi-Objective Optimization

- Four-Objective Optimization using an *N*-Branch Tournament Genetic Algorithm (GA)
- 4 Design Variables
  - [x_1, x_2, x_3, x_4] = [Pressure, Hardness, Power Technology,CO_2 Removal Technology]
- 4 Objectives
  - Minimize(Mass)
  - Minimize(Stowage Volume)
  - Minimize(Pre-breathe Time)
  - Maximize(Mobility) → Minimize(Mobility Metric)
- Hyper-Space Diagonal Counting (HSDC) Visualization Method

Conclusions

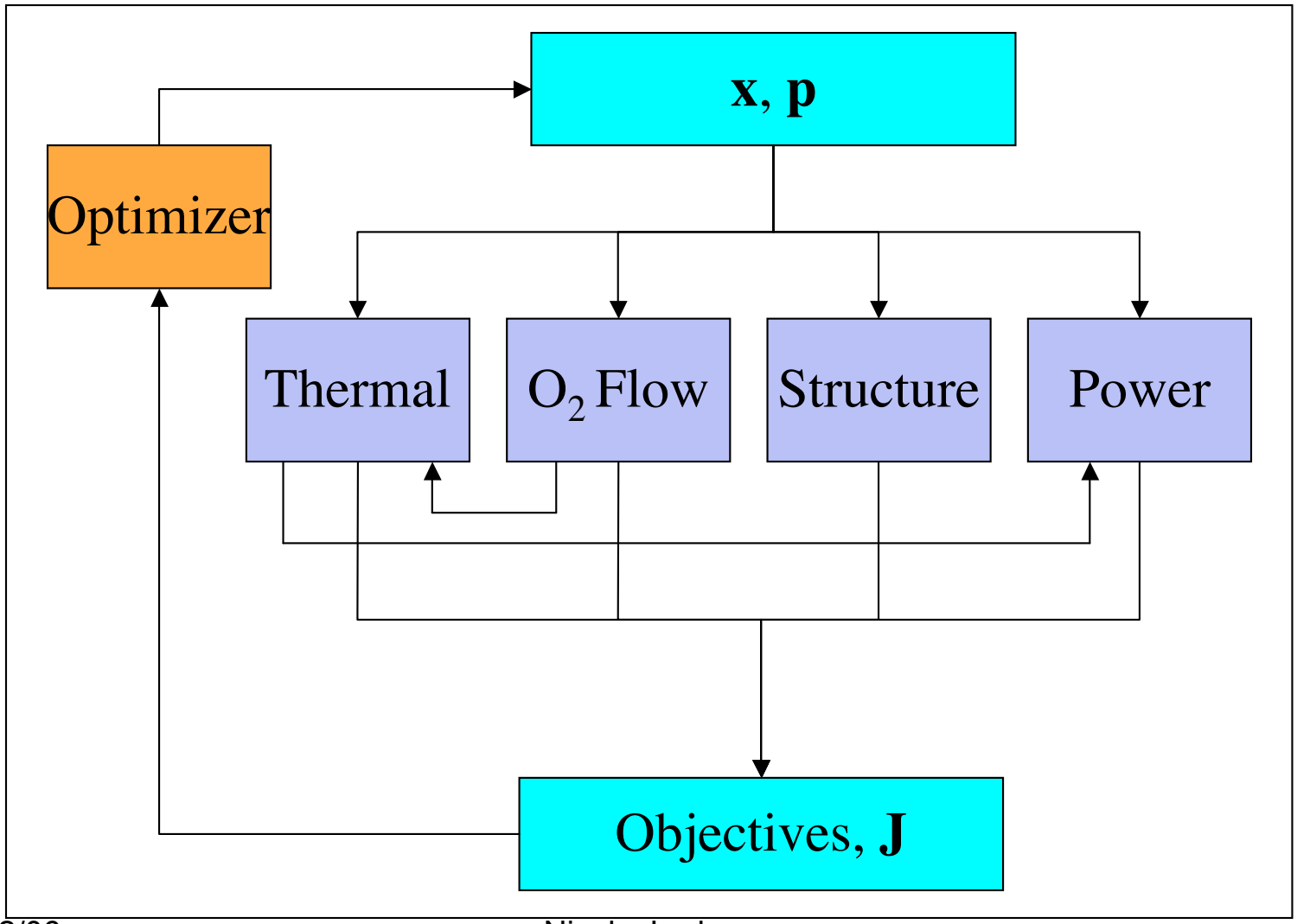
- First attempt at a multidisciplinary spacesuit model
- Has potential to be a very valuable tool in the design of future spacesuits
- Need to increase the fidelity of model
- In the future, we will use the model to investigate commonalities between Mars, Moon, and micro-gravity spacesuits

Acknowledgment

The Soffen Fund Travel Grant provided partial financial support for travel to this conference.

Back-up Slides

Model Description



Model Description