A Versatile Lifting Device for Planetary Surface Payload Handling, Excavation and Surface Construction

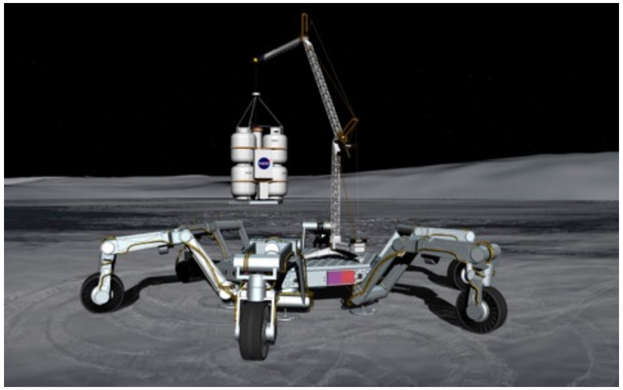
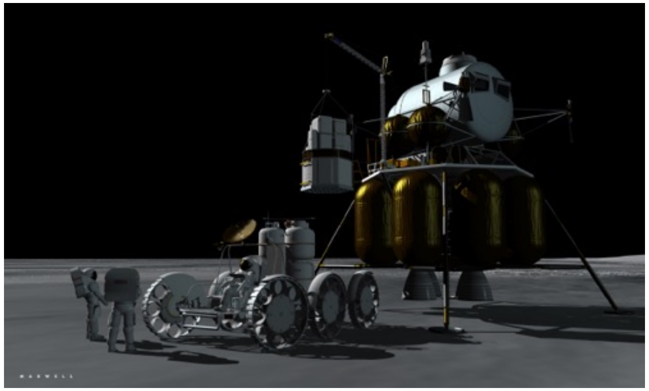
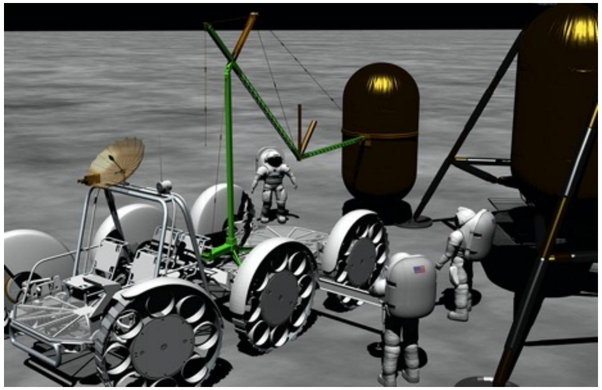
1st Annual NASA Excavation and Construction Technology Program Review
September 1, 2021

John T. Dorsey, Structural Mechanics and Concepts Branch
NASA Langley Research Center
(john.t.dorsey@nasa.gov)

Lightweight Surface Manipulation System (LSMS) Introduction (From 2008 STAIF Paper)

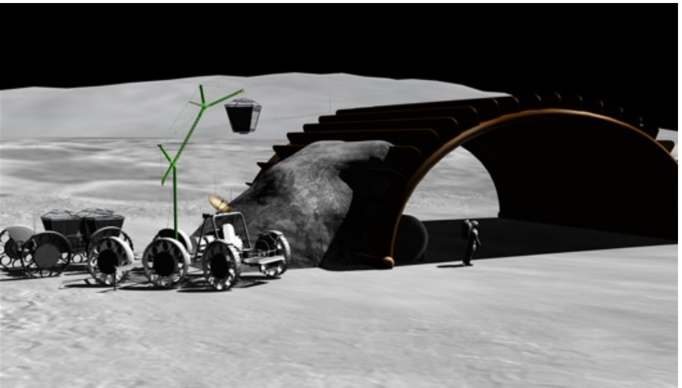
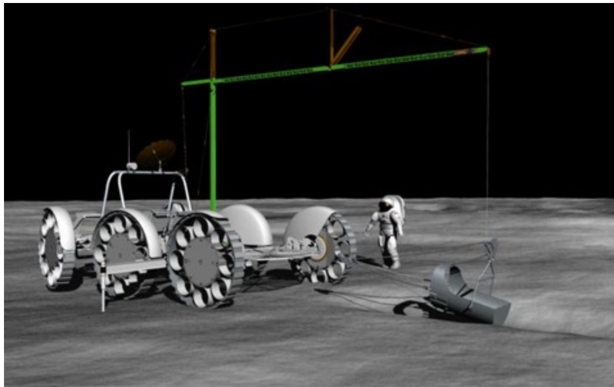
- **Motivation**
  - **Vision for Space Exploration and now ARTEMIS goal: establish a "sustained and affordable human and robotic program to explore the solar system and beyond.**
  - **Recent architectures focusing on initial development of a permanent lunar outpost at the Moon's south pole.**
  - **Permanent outpost increases need for operational capabilities, infrastructure and devices that can support a variety of surface operations.**
  - **Payload handling and manipulation, inspection, repair, site preparation/excavation and surface construction operations will be required.**

Lunar Outpost Construction and Operations Require a Variety of Handling Capabilities

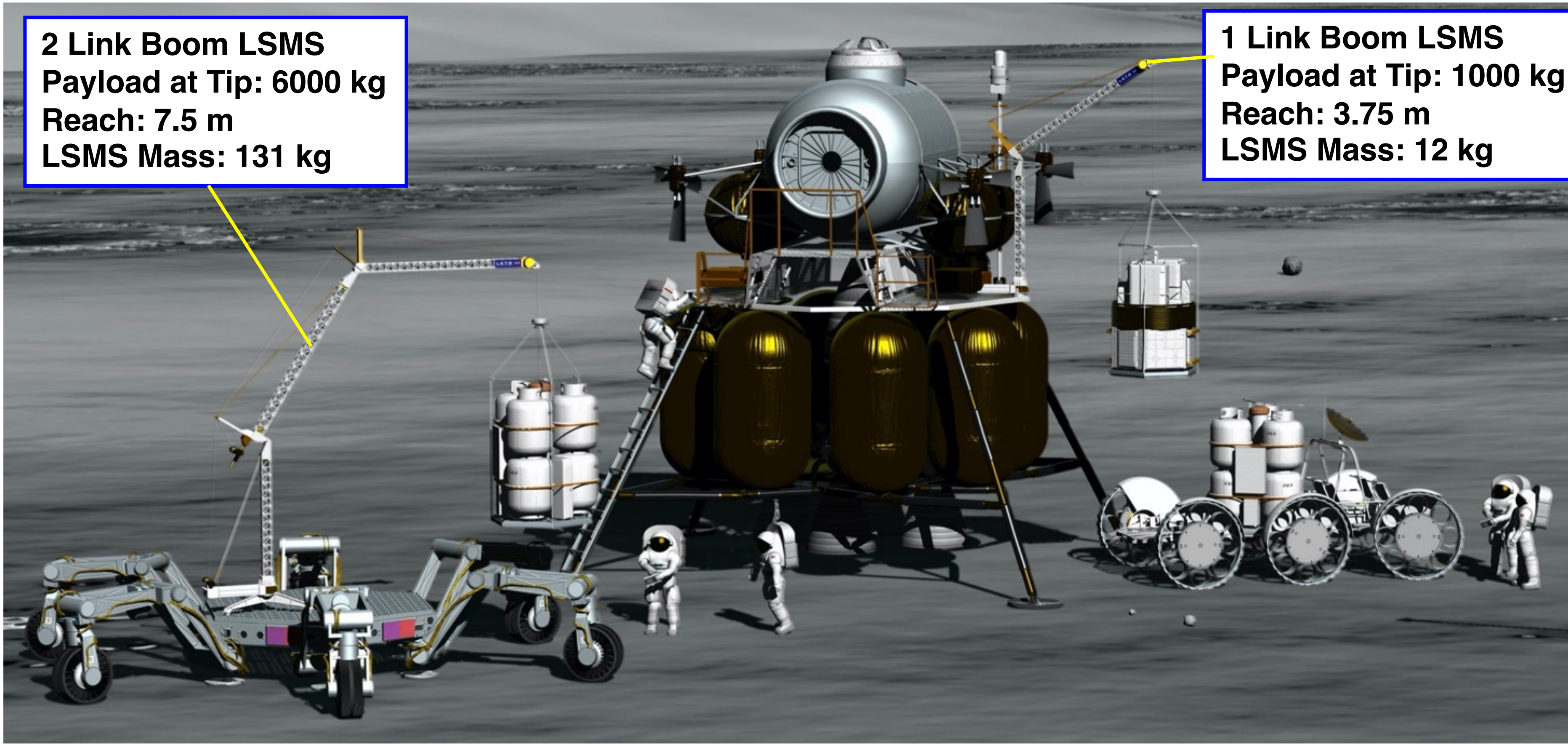




Major Construction Tasks: Lunar Base Construction (Eagle Engineering, 1988)

- Unloading cargo from lunar landers
- Transporting loads
- Lifting and positioning loads
- Preparing lunar surface for a base site, roads, landing pads
- Providing quantities of lunar soil for habitat radiation protection
- Assembling large structures and shelters

LSMS Overview: A New and Novel Device Incorporates Many Desired Features and Solves Many Needs



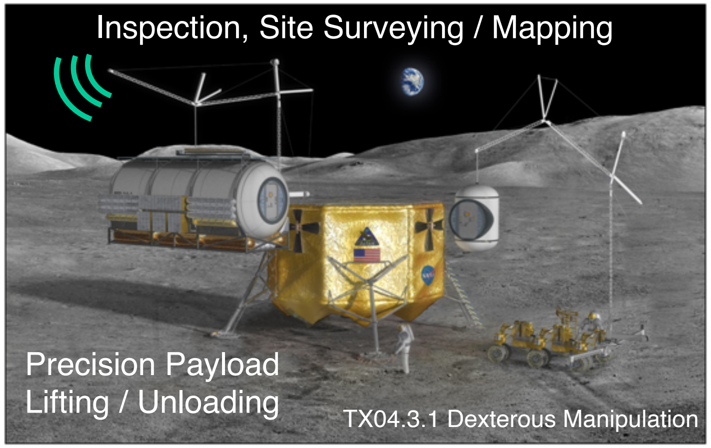
LSMS Features

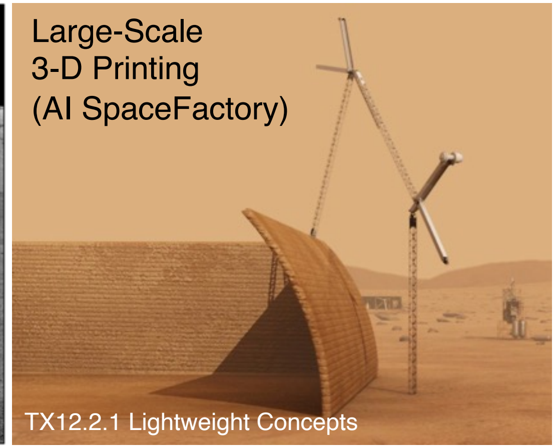
- Lightweight truss design
- Compact packaging for launch
- Modular and reconfigurable in-situ
- Hybrid (features of crane and manipulator)
- Self unloading and base repositioning

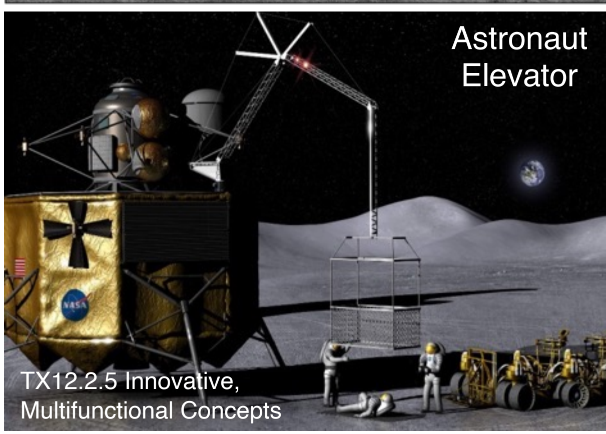
LSMS Operations

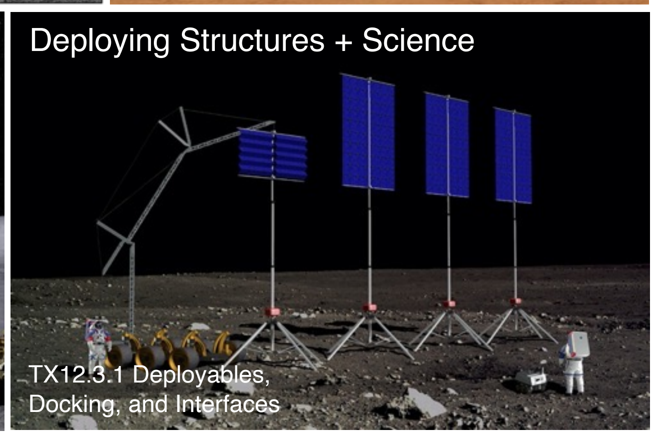
- Payload unloading
- Payload positioning
- Inspection
- Regolith excavation & placement
- Site preparation

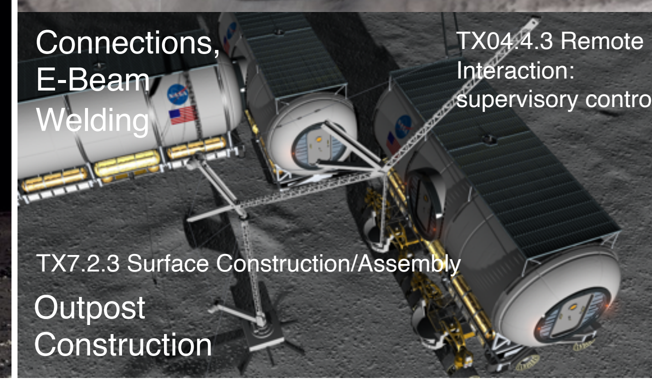
LSMS Supports a Diverse Set of Future Capabilities and Functions Required By NASA 2020 Taxonomy Areas











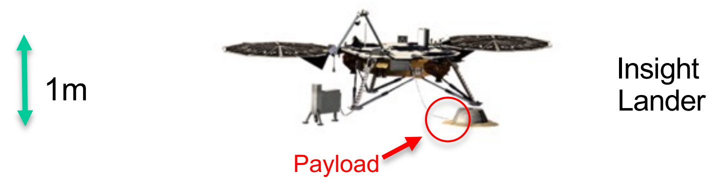
John T. Dorsey, LaRC john.t.Dorsey@nasa.gov

The State of the Art in Long Reach, High Mass Payload Handling for Moon and Mars Surfaces Does Not Exist

- **Current Status:** Mars Insight lander's 1.8 m long arm, offloaded a 29 kg seismometer 1 m to the Martian surface, one time.
  - Payload mass and size, reach required, and height and size of lander, are all significantly greater for Artemis and large Commercial Lunar Payload Services (CLPS) landers.
  - Planetary-surface serial manipulators do not scale to heavy payloads.

- **LSMS Advantages vs. Other Approaches:**
  - Vs. Serial robotic arm:
    - Higher structural efficiency: tension-compression vs. bending.
    - Higher mechanical advantage: greater payload mass at a given reach.
    - Significantly lower system mass.
  - Vs. Davit (simple arm with hoist):
    - Greater operational versatility in a lighter weight system.

- **Past Experience**
  - 1st generation prototype LSMS, over a decade of development and testing with successful field tests at Moses Lake, WA.
  - Recently, LSMS-mini prototype developed to demonstrate scalability to small CLPS missions.

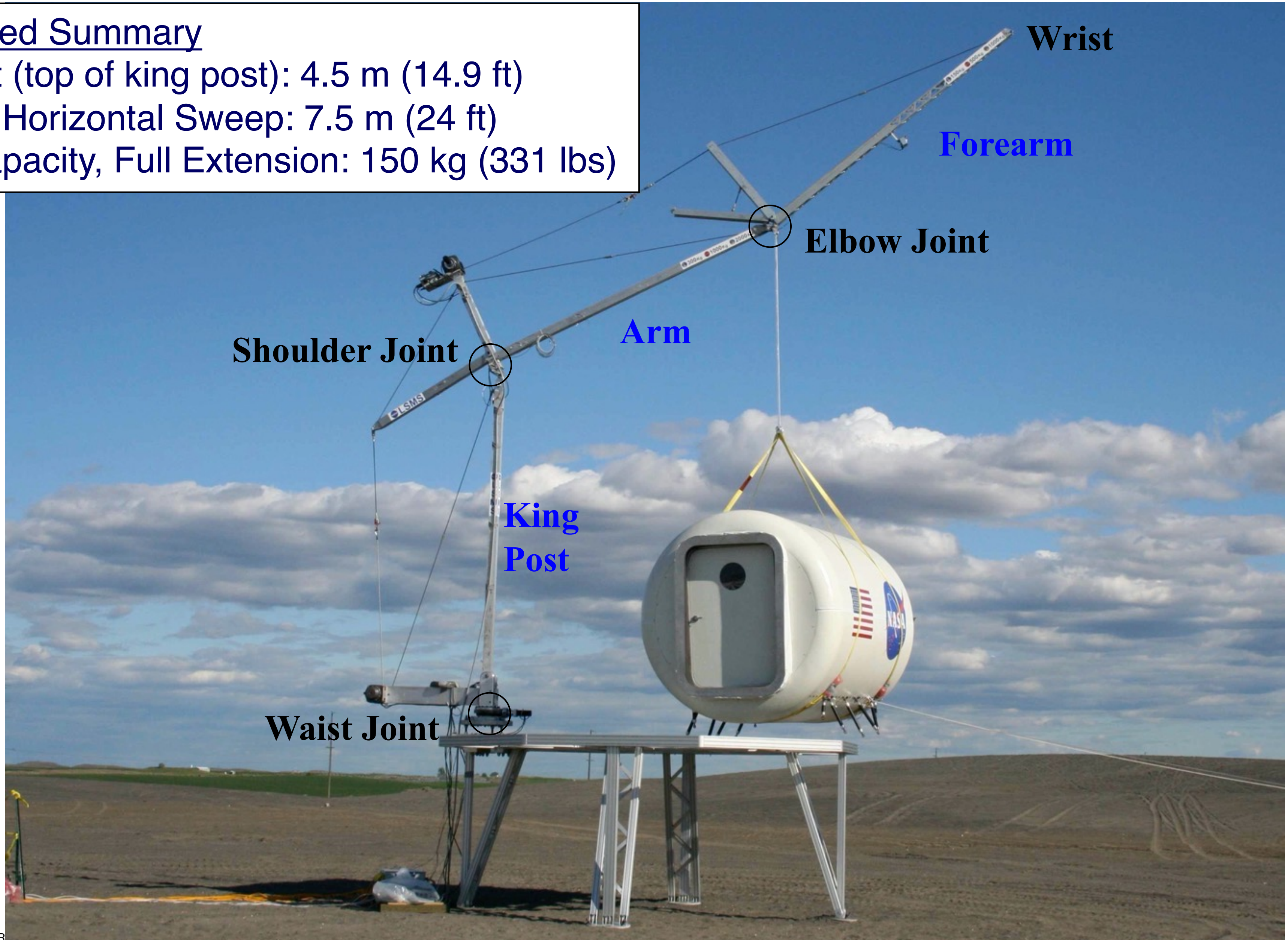


John T. Dorsey, LaRC john.t.Dorsey@nasa.gov

Key Point: The LSMS Designed to Crane Safety Factors

Successful Field Testing at Moses Lake, WA (6/1-13/08) as Member of Human Robotics Systems Team

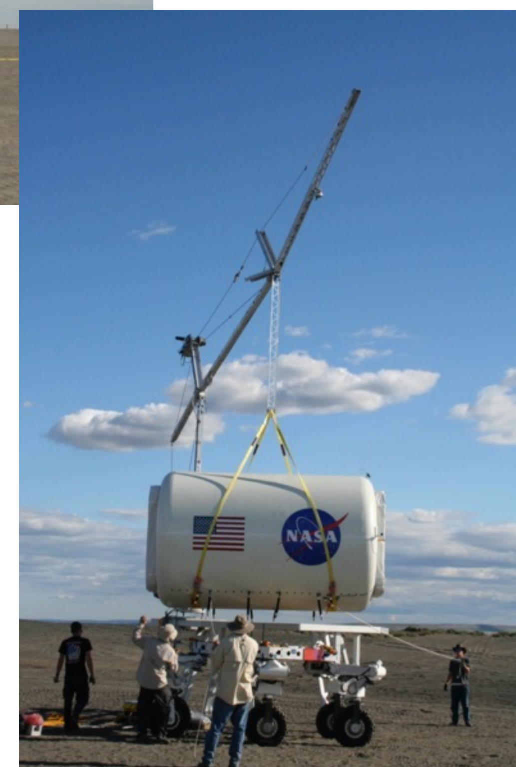
Test Bed Summary
Height (top of king post): 4.5 m (14.9 ft)
Boom Horizontal Sweep: 7.5 m (24 ft)
Lift Capacity, Full Extension: 150 kg (331 lbs)



Successful Field Testing at Moses Lake, WA (6/1 - 13/08) as Member of Human Robotics Systems Team

- **LSMS unloading large/small payloads from: elevated platform, ground base, mobile base (All-Terrain Hex-Limbed Extra-Terrestrial Explorer robotic mobility system [ATHLETE]).**
- **Approximately 4.8 minutes per payload off loading (continuous operations).**

- **LSMS assists JPL ATHLETE team in unplanned lift of habitat module using conventional rigging.**
- **LSMS demonstrates precise positioning of ISRU payload on Chariot (test not preplanned).**

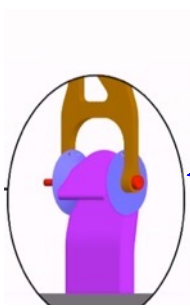


John T. Dorsey, LaRC john.t.Dorsey@nasa.gov

Field Test Details: Versatile Operations, Innovative Strategies

Precision placement of payloads on Chariot mobile base

Versatility for unplanned operations:
here shown field adapted for large payload handling of simulated habitation modules

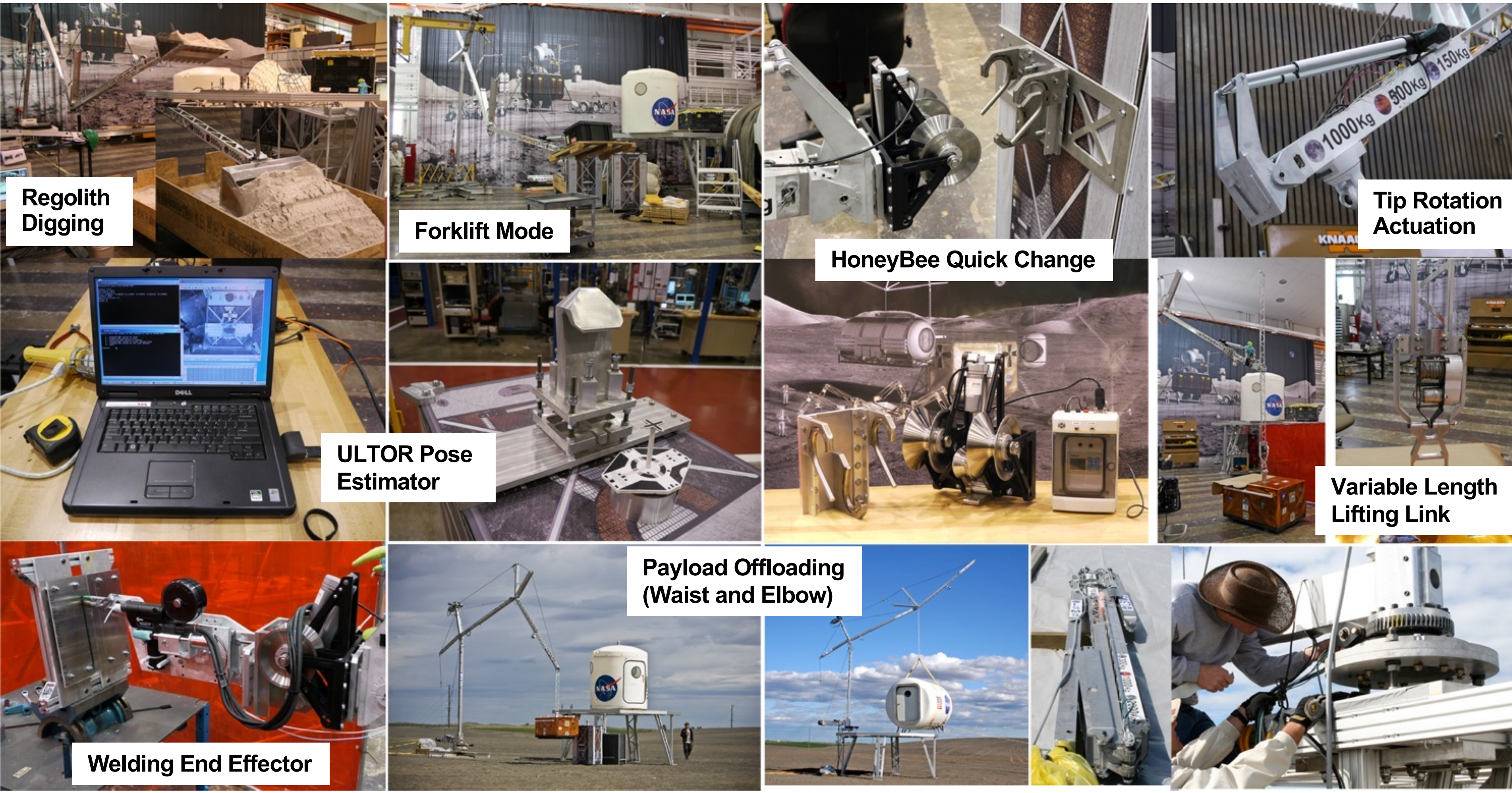


Simple hook provides robust connection to payload with large capture envelope (+/- 10 degrees)

Lifting links used to provide structurally stiff connection to payload

LSMS-L1000 (Kg) Prototype

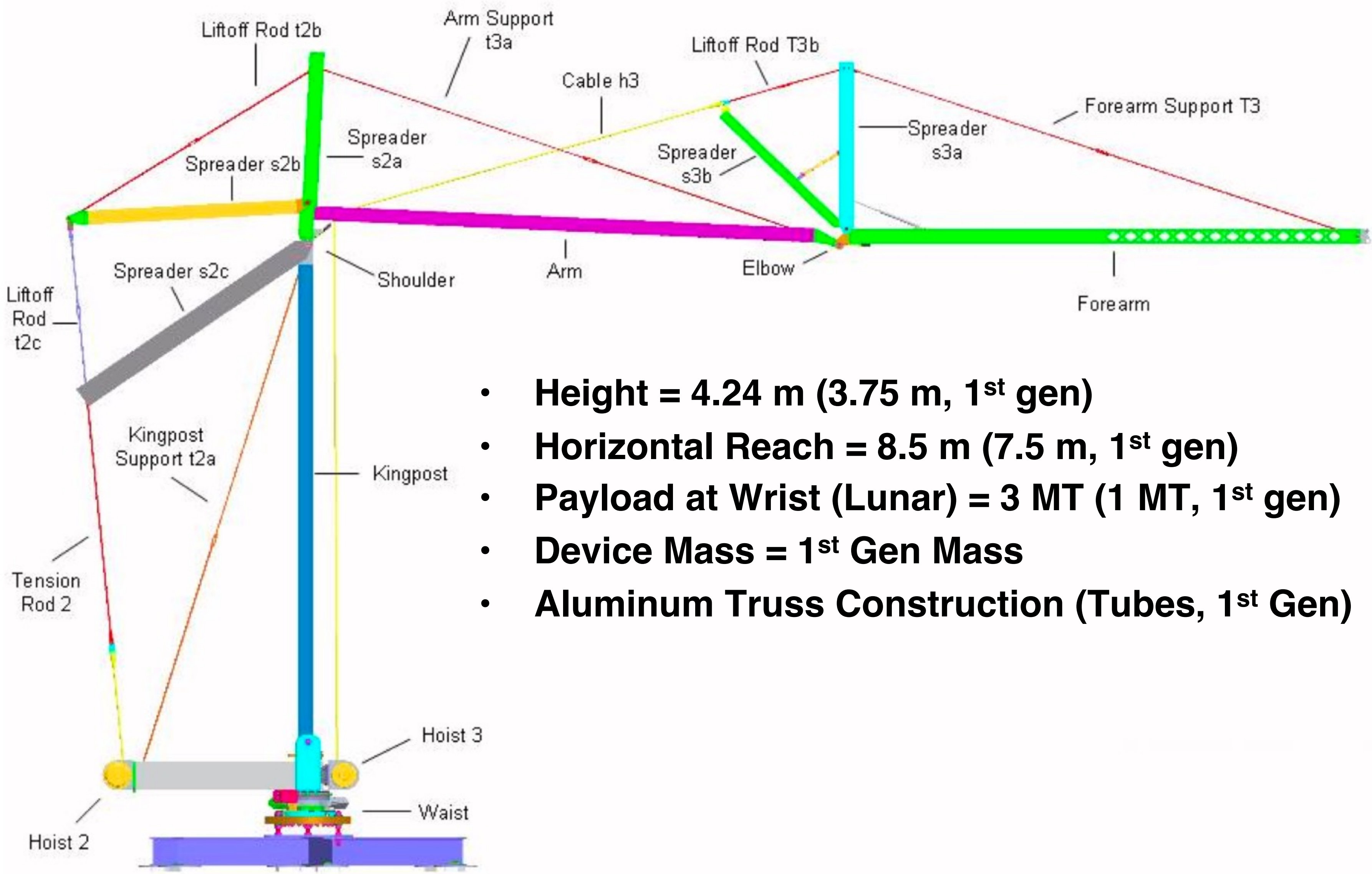
Versatile Set of Tools and Capabilities Developed and Demonstrated for Moon and Mars Surface Applications



Field Trials 2008 – Moses Lake, WA

John T. Dorsey, LaRC john.t.Dorsey@nasa.gov

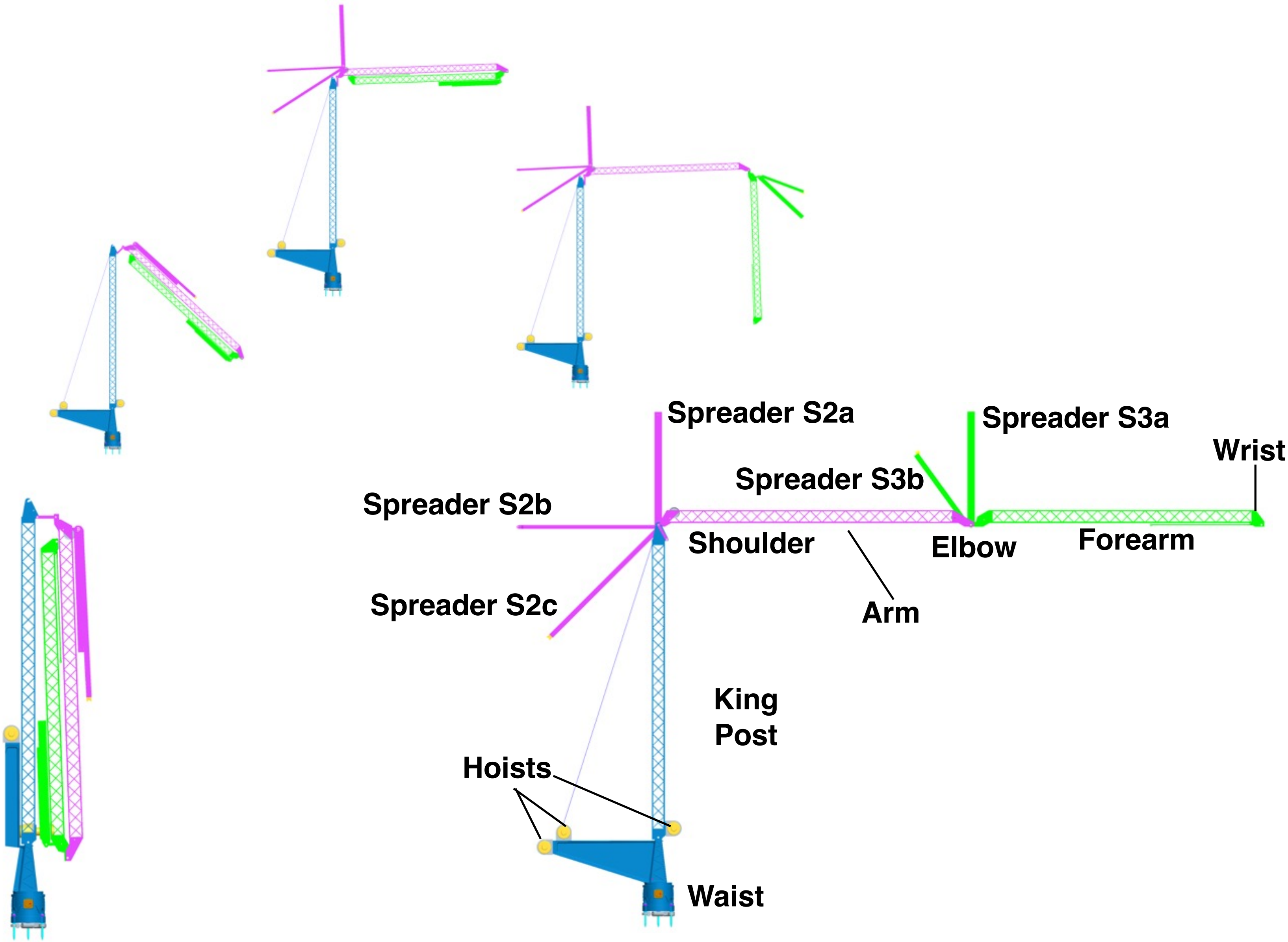
Second Generation Design: Major Modifications



- Height = 4.24 m (3.75 m, 1st gen)
- Horizontal Reach = 8.5 m (7.5 m, 1st gen)
- Payload at Wrist (Lunar) = 3 MT (1 MT, 1st gen)
- Device Mass = 1st Gen Mass
- Aluminum Truss Construction (Tubes, 1st Gen)

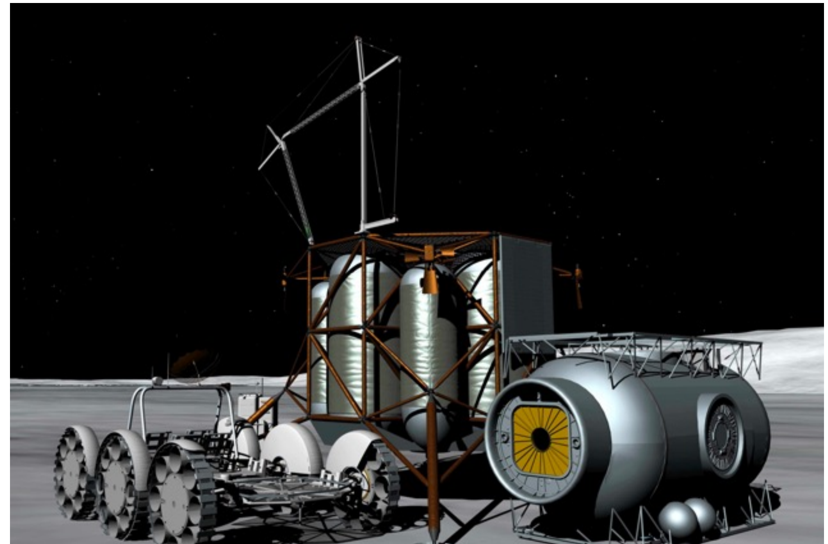
John T. Dorsey, LaRC john.t.Dorsey@nasa.gov

2nd Generation LSMS Deployment Sequence

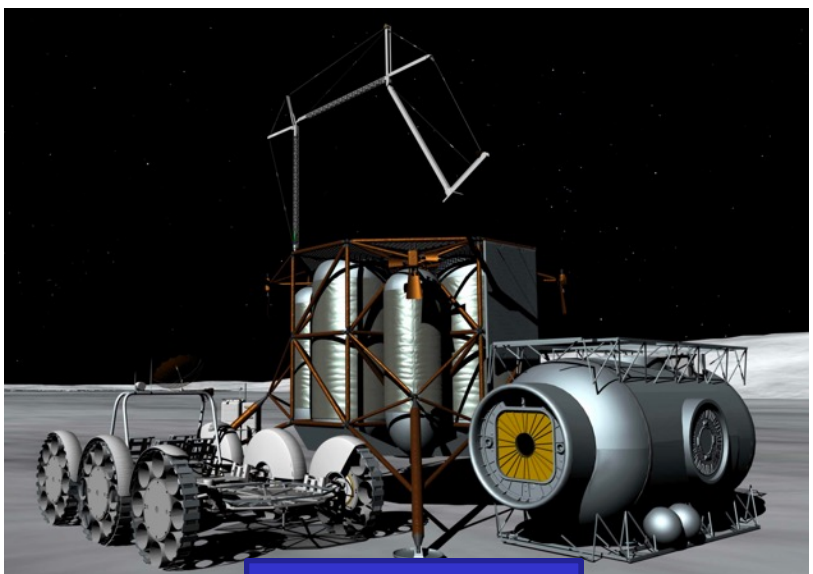


Second Generation Design: Self Offload Capability

- Operational viability depends on LSMS being repositionable and mobile.
- Need to remove LSMS from lander.
- Need to relocate LSMS around outpost.
- Need to mount LSMS on mobility chassis.



Wrist end effector grapples fixture on lander



Base is released

Base is lowered to mobility chassis

LSMS Architecture Scalability Demonstrated

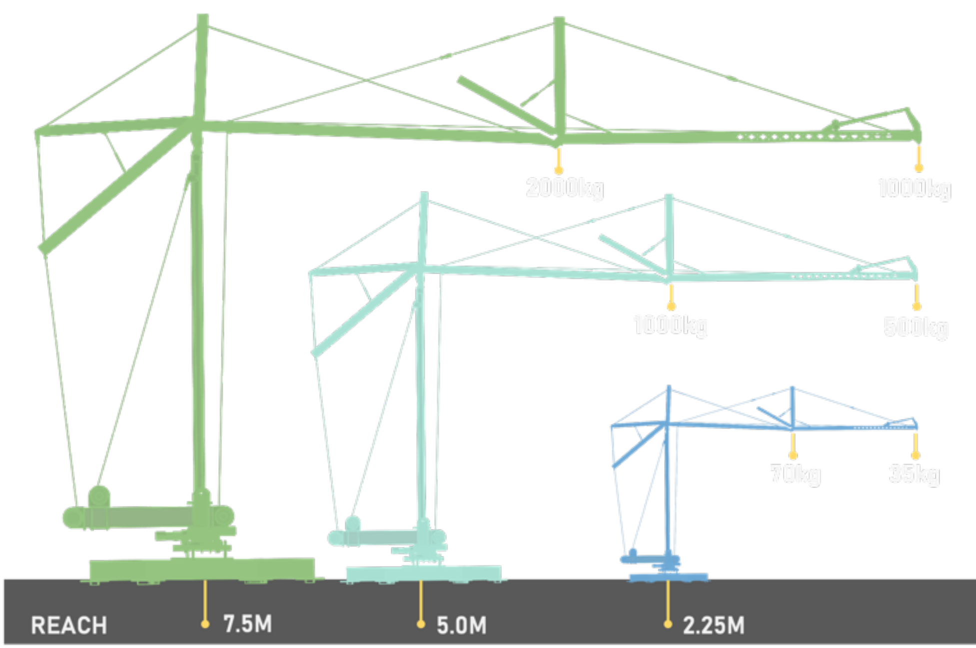
- **LSMS-L35 (35 kg payload on Lunar Surface) prototype developed to support the Commercial Lunar Payload Services (CLPS) Program.**
- **Customized version developed for the Astrobotic Peregrine CLPS Lander.**
- **Recognized need for payload offloading capability in future missions.**

LSMS Commercial Viability Recognized

LSMS-L1000 (1000 kg payload on Lunar Surface) prototype delivered to Blue Origin Facility in Huntsville, AL (December 2020) to support cargo lander offloading studies.

NASA Internal Multi-Center Payload Offloading Study Recently Completed

Identifies LSMS as Preferred Payload Offloading Option Across All Payload Mass Classes



Generic Lander for Different Payload Mass Classes Trade Study Heat Map (October 2020)

Recommended Workable NOT Recommended

Handling Technique	Lunar Terrain Vehicle (~0.5 MT)	Habitable Mobility Platform (~ 5 MT)	Foundation Habitat (~ 10 MT)
LSMS			
Block and Tackle			N/A
Single Boom Davit			
Ramp with Gear Drive			
Double Boom Davit			
ATHLETE Single Limb			N/A
ATHLETE			
Metallic Ramp/Winch			N/A
Inflatable Ramp			N/A
Lift System			
Winch and Pole			N/A
Propulsive Pallet			

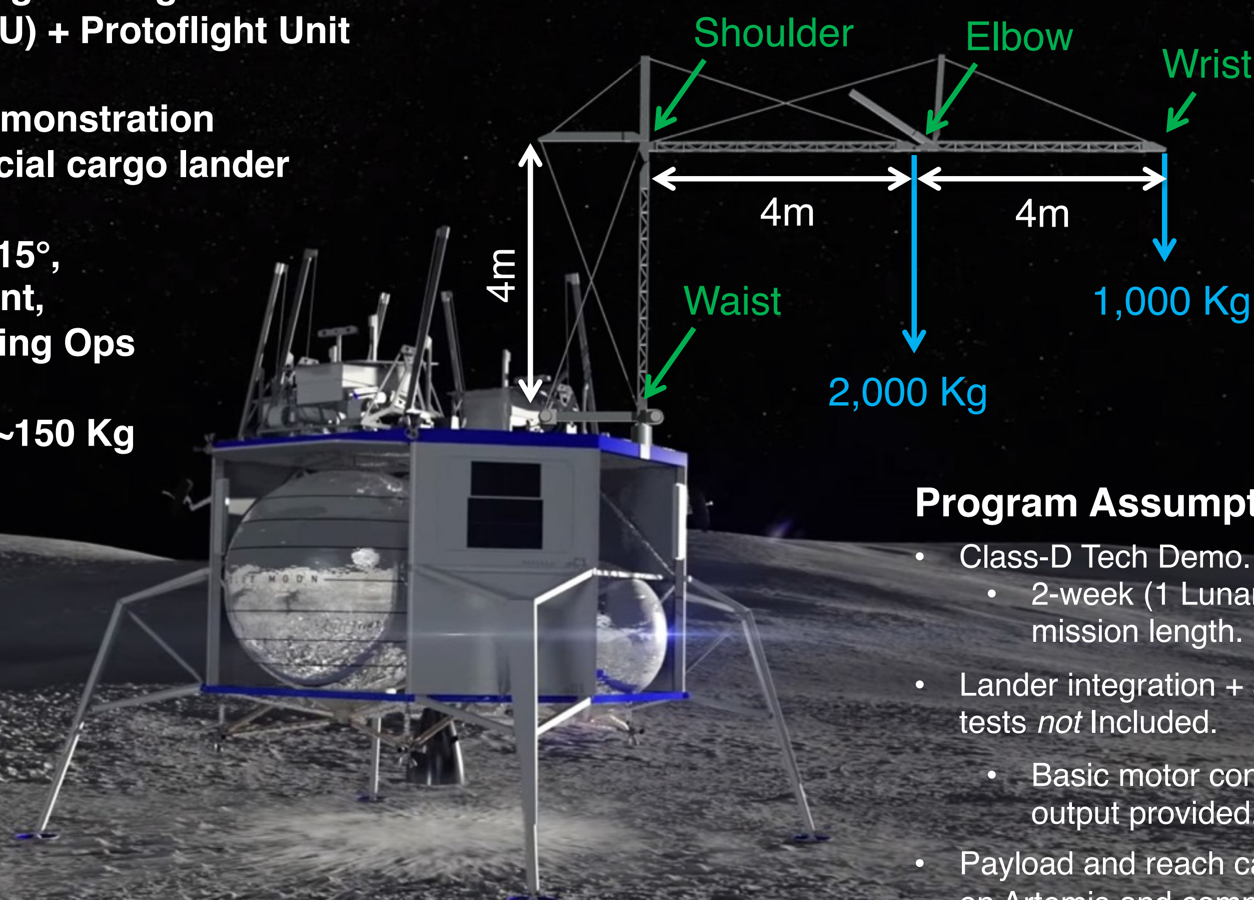
GCD LSMS Program: Protoflight LSMS Development

Timeline / Budget: 4 Years / $25M
Deliverables: LSMS Engineering Development Unit (EDU) + Protoflight Unit

Target: Technology demonstration on a commercial cargo lander

Tasks: Self-Leveling ±15°, Self-Deployment, Payload Handling Ops

LSMS Mass Goal: 100~150 Kg



Lightweight
Surface
Manipulation
System
(LSMS)

Program Assumptions:

- Class-D Tech Demo.
  - 2-week (1 Lunar day) nominal mission length.
- Lander integration + system level tests *not* Included.
  - Basic motor control, and sensor output provided.
- Payload and reach capability based on Artemis and commercial needs.

John T. Dorsey, LaRC john.t.Dorsey@nasa.gov

Concluding Remarks

- **Past and current architecture studies have repeatedly identified a critical need for payload handling, manipulation, site preparation and construction at planetary outposts and bases.**
- **A Lunar Surface Manipulation System (LSMS) has been invented that is operationally versatile, mass efficient, mechanically simple, modular and packages efficiently for launch.**
- **A first generation LSMS Test-Bed has been constructed and was updated to Version 1.5. Static test data for the test-bed correlates well with analytical predictions.**
- **The first generation device successfully completed field tests at Moses Lake, WA as a member of the Human Robotics Surface Systems Team demonstrating versatility at unloading payloads ranging from 110 lbs to 480 lbs in 1g while operating from an Elevated Platform, a Mobile Base and a Ground Mount.**
- **The LSMS incorporates a versatile and scalable architecture that is now being considered by commercial CLPS and Lunar Cargo Lander providers.**
- **A Protoflight LSMS is currently being developed in the Game Changing Development Program to support the ARTEMIS Program.**

Backup

References

- Doggett, William R.*; Dorsey, John T.*; Collins, Timothy J.; King, Bruce; and Mikulas, Martin M.: **A Versatile Lifting Device for Lunar Surface Payload Handling, Inspection and Regolith Transport Operations.** Presented at the Space Technology and applications International Forum – STAIF 2008, Albuquerque NM, 10 – 14 February 2008. AIP Conference Proceedings Volume 969, Editor Mohamed S. El-Genk, 2008 American Institute of Physics.
- Doggett, William R.; King, Bruce D.; Jones, Thomas C.; Dorsey, John T.; and Mikulas, Martin M.: **Design and Field Test of a Mass Efficient Crane For Lunar Payload Handling and Inspection – The Lunar Surface Manipulation System**. Presented at the AIAA Space 2008 Conference and Exposition, 9 – 11 September 2008, San Diego, California. Available as AIAA-2008-7635.
- Dorsey, John T.; Mikulas, Martin M.; and Doggett, William R.: **Preliminary Structural Design Considerations and Mass Efficiencies for Lunar Surface Manipulator Concepts.** Presented at the AIAA Space 2008 Conference and Exposition, 9 – 11 September 2008, San Diego, California. Available as AIAA-2008-7916.
- Dorsey, John T.*; Jones, Thomas C.; Doggett, William R.; Roithmayer, Carlos M.; King, Bruce D.; and Mikulas, Martin M.: **Developments to Increase the Performance, Operational Versatility and Automation of a Lunar Surface Manipulations System.** Presented at the AIAA Space 2009 Conference and Exposition, 14 – 17 September 2009, Pasadena CA. Available as AIAA-2009-6795.

References

- Doggett, William R.*; Roithmayer, Carlos M.; Dorsey, John T.; Jones, Thomas C.; Shen, Haijun; Seywald, Hans; King, Bruce D.; and Mikulas, Martin M.: **Automation of a Versatile Crane (the LSMS) for Lunar Outpost Construction, Maintenance and Inspection.** Presented at the AIAA Space 2009 Conference and Exposition, 14 – 17 September 2009, Pasadena CA. Available as AIAA-2009-6546.
- Jefferies, Sharon A.; Doggett, William R.; Chrone, Jonathan; Angster, Scott; Dorsey, John T.; Jones, Thomas C.; Haddad, Michael E.; Helton, David A.; Cladwell, Darrell L.: **Lunar Lander Offloading Operations Using a Heavy-Lift Lunar Surface Manipulator System.** Presented at the AIAA Space 2010 Conference and Exposition, 30 August – 2 September 2010, Anaheim CA. Available as AIAA-2010-8804.
- Dorsey, John T.; Jones, Thomas C.; Doggett, William R.; Brady, Jeffrey S.; Berry, Felicia C.; Ganoe, George G.; Anderson, Eric J.; King, Bruce D.; and Mercer, C. David**: Recent Developments in the Design, Capabilities and Autonomous Operations of a Lightweight Surface Manipulation System and Test Bed.** Presented at the AIAA Space 2011 Conference and Exposition, September 27 – 29, 2011, Long Beach CA. Available as AIAA-2011-7266.

- Doggett, William R.; King, Bruce D.; Collins, Timothy J., and; Dorsey, John T.: Robotic-Movement Payload Lifter and Manipulator. United States Patent, **Patent No.: US 7,878,348 B2; February 1, 2011.**