The Lunar Split Mission: Concepts for Robotically Constructed Lunar Bases

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Introduction

- The current exploration architecture calls for human missions to the Moon to precede those to Mars
  - Develop new transportation infrastructure
  - Confirm ability to safely explore extra-terrestrial worlds
  - Demonstrate ability to utilize extra-terrestrial resources

- Regardless of the destination, human exploration of the Moon and Mars entails risks to the crew
  - Transportation
  - Exploration
  - Construction and Mining

- The technology either exists, or can be developed over the next decade, to substantially reduce these risks
  - Combine the Split Mission concept with advanced robotics and automation and autonomy technology
Motivation

- Develop a lunar base mission concept based on the use of robotics and teleoperation for construction
  - Update a lunar base development concept first conceived in the late 1980’s by a multi-disciplinary team of graduate students working at NASA JSC
  - Assume a southern polar site, e.g., the Aitken Basin, since both exploration and science objectives can be met there
    - The concept is not constrained to polar sites, equatorial sites such as Riccioli or Grimaldi are equally legitimate destinations
- Examine what must be done to establish the base
  - Emplace human habitation capabilities
  - Emplace telescopes and other science equipment
  - Emplace in-situ resource utilization equipment
- Identify the technologies available, and those that are likely to be developed, to support such concepts
  - Robotics and Teleoperation
  - Automation and Autonomy
  - Communication, Networking, and Information Technology
Potential Lunar Base Sites

South Pole

Equatorial
Mission Objectives

● Science
  ○ The Moon as an Object of Study
    – Determine the composition and structure of the lunar highland crust at sites other than Apollo to help determine how the Moon formed
    – Determine if there is solar wind-implanted hydrogen or comet-implanted water ice in the permanently shadowed regions of the Moon
  ○ The Moon as a Site for Astronomy
    – Lunar-based telescopes and detectors emplaced on the Moon might provide cost and capability advantages over space-base means
    – This is particularly true for distributed aperture and interferometer missions in which multiple spacecraft flying in precisely controlled formations are required
      ● Examples include Stellar Imager, Constellation-X, Terrestrial Planet Finder, etc.

● Exploration
  ○ Demonstrate the ability to extract and exploit lunar resources to make a long-term lunar presence affordable and sustainable
  ○ Develop robotic construction capabilities that can be used to develop bases at other lunar sites and to develop future Mars bases
  ○ Gain experience and confidence in exploring and working on extra-terrestrial surfaces to reduce the risk of going to Mars
Advantages of Lunar-Based Astronomy

- No atmosphere; all radiation (EM and particulate) reaches the lunar surface directly; unlimited spectral window
- Stable platform upon which ground emplacement of large telescope arrays is feasible
- No orbital debris problem; micrometeorite flux similar to earth orbital environment
- Slow rotation time permits up to 14 days of continuous exposure at equator; polar sites permit exposures of indefinite length for corresponding hemispheres
- Far side site offers complete radio silence at all frequencies (assuming regulation of radio use); ideal for SETI, VLF investigations

Image courtesy of Space Age Publishing Co. and Lunar Enterprise Corp.
The Split Mission Concept

- **First Conceived for Human Missions to Mars**
  - Large Earth-to-Mars spacecraft require large amounts of fuel, even for the minimum Energy Hohmann transfer
  - Minimum energy missions require long surface stays, subjecting crews to extended periods of weightlessness, isolation and radiation exposure
  - Most of the mass destined for Mars is not sensitive to time of flight and can travel on longer duration, lower energy trajectories
  - The crews can travel on shorter duration “sprint” trajectories and rendezvous with the cargo ship

- **Subsequently Adapted for Lunar missions,**
  - Travel time is not the issue, but the health and safety of the crew is still paramount
  - Challenger and Columbia tragedies have shown that the loss of life in the U.S. space program could result in multi-year stand downs, and possibly even cancellation
  - Base construction will require significant amounts of extra-vehicular activity (EVA) if done solely by suited astronauts
  - Potential injury or death due to radiation exposure, life support system failures, construction accidents, etc. must be considered
The Lunar Split Mission

- Studies in the late 1980’s at NASA JSC looked into various base development strategies in the post-Space Station Era
  - Civil Needs Database formed the baseline study
  - “Habitation as Soon as Possible” vs. “Science as Soon as Possible” scenarios were derived from this baseline
- The original Lunar Split Mission (LSM) concept used these studies as inputs for various assumptions on payloads, mass, power, transportation, etc., plus assumptions on future technology
- The goal of the LSM design team was to develop a base design that minimized mass delivered to the lunar surface and minimized astronaut EVA time
  - The use of robots and teleoperation achieved this goal, but it assumed great advances in technology would occur by the year 2000
- The current LSM concept takes into account the present state of technology, plus potential advances in the next 10 years
  - It seeks to drive the development of technology that supports exploration while also creating long-term value for society
Lunar Split Mission Base
Updated Lunar Base Elements

- **Habitation**
  - A habitation module with 2 airlocks and 2 connecting nodes
    - Possibly derived from International Space Station heritage hardware

- **Science and In-Situ Resource Utilization**
  - Drilling and Logging Equipment
  - Geophysical Instruments
  - Astronomical Instruments

- **Robotic Construction Equipment**
  - Lunar Construction Utility Vehicle
    - A generic vehicle platform to which a variety of interchangeable construction modules can be attached, e.g., crane, backhoe, mechanical arm, etc.
  - Lunar Telerobotic Servicer
    - A module of the LCUV that, with human assistance, can perform tasks associated with a suited astronaut
Lunar Split Mission Robots

LCUV with Attachments  
LCUV Construction Ops

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Base Development Scenario

- **Mission #1** – 1st LTS and LCUV are delivered to provide detailed maps of the local surface topography and to emplace the navigation and communication equipment.

- **Mission #2** – 2nd LTS and LCUV are delivered to begin grading, clearing, and preparing the site and the path to where the base will be emplaced.

- **Mission #3** – Habitation components are delivered, and subsequently unloaded, moved, connected, etc. by the LCUV and its various implements. Fine dexterity tasks are performed by the LTS.

- **Mission #4** – Surface rovers and equipment for science and ISRU operations are delivered, and subsequently unloaded, moved, emplace, etc. by the LCUV and LTS.

- **Mission #5** – The first crew and their supplies are delivered to the base. They finish any remaining tasks, effect repairs, and begin occupying the base. ISRU and science operations begin immediately.
Design Considerations

- **Modularity**
  - Design all hardware and software as isolatable, reusable components for easy repair, maintenance, upgrade, etc.

- **Fault Detection, Isolation and Recovery**
  - Design systems for proactive fault prediction, detection, diagnosing, and recovery

- **Robustness and Reliability**
  - Design systems that can withstand the harsh lunar environment

- **Deployability**
  - Design base components and equipment for minimum amount of surface construction

- **Reconfigurability**
  - Design components so that they can be used for more than one purpose via new hardware attachments or software uploads
Technology Considerations
Telerobotics

- **In-Space**
  - The ISS remote manipulator system can deploy, grasp, maneuver, etc. payloads as assumed by the LCUV
  - Telerobots such as Robonaut are being developed to perform suited astronaut operations as assumed by the LTS

- **On-Surface**
  - Spirit and Opportunity are teleoperated rovers that can traverse, avoid obstacles, and deploy small instruments
  - While their tasks seemed simple as compared to in-space assembly, they often took hours or days to complete

- **Issues**
  - Communications delay
  - Automation and autonomy

Images courtesy of NASA
A Mix of Automation and Autonomy is Required

- Automation
  - Robots automatic execute repetitive tasks
  - This is done by industrial robots quite well

- Autonomy
  - Robots employ environment sensing, reasoning, decision-making capabilities
  - More research and development needed here

- Supervised autonomy
  - Human control for many or most tasks, combined with robot’s ability to take limited actions based on local environment

Examples of some of the needed functionality

- Computer-based vision
- Real-time planning and scheduling
- Model-based reasoning
- Cooperative teaming
- Fault prediction, detection, isolation and recovery
- Autonomous navigation
Technology Considerations
Navigation & Communication

● Communication
  ○ Earth-Moon
    - High-bandwidth links for multiple real-time video feeds
      ● Dedicated ground stations, X- and K-band links, Compression, etc.
  ○ Lunar Base
    - Broadband wireless links between all surface elements
      ● Ultrawideband, Wi-Fi, WiMAX, Cellular, etc.

● Navigation
  ○ Earth-Moon
    - Precision navigation/hazard avoidance for autonomous landing
      ● Earth-based tracking, celestial navigation, lunar-based beacons, etc.
  ○ Lunar Base
    - Local navigation and asset tracking
      ● Wi-Fi, RFID, stellar-aided inertial navigation systems, etc.
Conclusions

- The Lunar Split Mission concept is even more viable now than it was almost 20 years ago and should be seriously considered as a means to reduce the risk in developing lunar bases.
- The technologies needed to make the LSM possible have advanced considerably – with proper investment, they can be brought to fruition.
- Developments in advanced robotics, automation and autonomy, wireless communications, autonomous navigation, etc. will contribute to exploration, but to Earth-based economies as well.
- These technology areas offer opportunities for our international partners to contribute to the effort.