Science Enabling Engineering Enabling Science Enabling Engineering

*Field Geology from an Engineer’s Perspective*

Ruthan Lewis, Ph.D.
Co-Chair, Optimizing Science and Exploration Working Group
Exploration Systems Mission Directorate
NASA Headquarters

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Why the Moon?
Global Exploration Themes

- Human Civilization
- Scientific Knowledge
- Exploration Preparation
- Global Partnerships
- Economic Expansion
- Public Engagement
Constellation Architecture

Earth Departure Stage

Altair Lunar Lander

Ares I Crew Launch Vehicle

Orion Crew Exploration Vehicle

Ares V Cargo Launch Vehicle

Altair Lunar Lander

Constellation Architecture
Exploration Roadmap

- Exploration and Science Lunar Robotics Missions
- Lunar Outpost Buildup
- Research and Technology Development on ISS
- Commercial Orbital Transportation Services for ISS
- Space Shuttle Operations
- Space Shuttle Program Transition and Retirement
- Ares I and Orion Development
- Orion and Ares I Production and Operation
- Altair Lunar Lander Development
- Ares V and Earth Departure Stage
- Surface Systems Development
Lunar Crewed Mission Profile

Crew of 4 + 500 kg cargo

Altair performs LOI

Orion performs 3 Burn TEI up to 1,492 m/s

Direct or Skip Entry

Orion performs TLI on FD5

ERS Performs TLI on FD5

Ares-1 Ascent Target

90 min. launch separation

Nominal Water Landing
Integrated Lunar Architecture Analysis

Ares V Concepts
- Altair Concept
- Orion, Ares I, EVA Baseline
- Ground Operations

Strategic Analysis
- Cost, Risk Assessments
- Reserves & Margins Methodology
- "Basis Mission" Buyback

Integrated Performance
- "Trade Set" Option & Comparisons
- Element Configuration Concepts - Operational Strategies

Surface System Design/Analysis
- "Trade Set" Cost, Risk, Scenario Analyses
- Altair Capabilities
- "Basis Mission" Buyback

Additional Technical, Cost, Risk Analyses
- Ares V "Contenders"
- Altair Concept

Programmatic and Requirements Impacts
- System and Mission Recommendations

Continued Assessments leading to Surface System LCCR
Functional Relationships
Design Reference Scenarios as a Hub

- Objectives
- Sites
- Exploration Requirements
- Analog Planning & Verification
- Operations Concepts
- Campaign Analysis
- Payload ID and Data
- Req’d/Suggested Technologies

- Robotic Support
- Mobility
- Navigation
- Communication
- Carriers, Packaging
- Logistics

- Sequence, Phasing
- Servicing
- Sample Acquisition
  - Decision Making Criteria
  - Analysis
  - Tools
Design Reference Missions (DRMS): Scenarios

- Scenarios and methodologies based on practical knowledge and experience
- Comparison of scenarios to get a sense of and/or optimize our trade spaces as we build our architecture
- They tell us
  - How we do
  - What we do
  - Why we do
The Systems Engineering and Science Perspectives are Similar

• From a science perspective: conceive/define the problem (hypothesis), identify the variables needed to be studied, plan and carry out the methodology to collect data, analyze, validate by observing similarities in other areas, conditions, etc. put the puzzle pieces together

• Consider the complete problem, define needs and required functionality (early in the development cycle), document requirements, synthesize design, verify and validate system

• In doing so, one expects
  – recognition and minimization or reduction of risks
  – improvement and guarantee of quality: improve understandability and verifiability; consistent, repeatable, reliable results
  – reduction of total cost: applying standardized process obtains uniform, easily retraced results
  – improvement of communication between all stakeholders: standardized and uniform description of all relevant elements and terms is the basis for mutual understanding between all stakeholders
Why is an Engineer Concerned about Field Geology?
Needs and Processes

- Transformation of science requirements
- Getting the results through operations and technology planning
- Remote sensing
- Infrastructure to support science
  - Pre mission
  - During mission
  - Post mission for future missions
- Human observation
  - Human factors
  - Mobility and access
  - Crew training

- Real-time implementation and processes
  - Crew interaction and communication
    - Surface to surface
      - EVA to EVA
      - EVA to IVA
      - IVA to IVA
    - Surface to Orbiter
    - Surface to Earth
  - Crew autonomy
  - Analytical tools and facilities
  - Decision Making

- Measuring success – were the science objectives addressed?
  - Planning
  - Replanning
Why is an Engineer Concerned about Field Geology?
Informing and Enabling

- Techniques used to determine viability of field sites
  - Geoscience significance – physical and chemical aspects
  - Other metrics and “figures of merit” under discussion
- Instrumentation network, global access is of high priority
- Resources/utilities available to support science operations and activities
  - Lighting
    - Instrumentation placement, viewing
    - EVA implications (sighting)
    - Power (for mobility, instrumentation, etc.)
  - Thermal
    - Instrumentation limitations
    - EVA
    - Mobility
  - Communication and Navigation
  - Operational/Path planning flexibility – nominal and contingency, planned/unplanned (realtime changes, e.g. new discoveries leading to re-planning)
  - In-Situ Resources for sustainability
  - Crew health and protection
  - Mobility
    - Observational and tactile access
    - Robotic assistance
    - Sample acquisition
    - Traveling laboratories and analysis
Instrument/Payload Characteristics

- Payload/Instrument Point of Contact
- Payload/Instrument Concept Name
- Applicable NRC Lunar Science Goals
- Science objectives
- Type of Instrumentation/Sensor (e.g. spectrometer, imaging, magnetometer, etc.)
- Measurements
- Site Requirements
- Operations
- Redeployment
- Modes of use
- Positioning Requirements
- Pointing or Orientation Requirements
- Vibration Requirements/Concerns
- Contamination (dust, particle)
- Astronaut Time Required for Deployment
- Mass and Volume
- Power System
- Power Profile
- Thermal Design
- Commanding
- Data Rate/Volume
- Mission Life/Operational Duration
- Technology
- Serviceability
List of Questions and Preparation for Field Geology Trip

- Where is each team member with respect to the other and the point(s) of interest?
- Are there multiple points of interest being observed at one time?
- Is there a differentiation of macro observation vs. micro observation?
- What is the sequence of events, questions asked, etc.? Is the sequence repeated at each point of interest?
- Is there a checklist for things to ask, or is it in one’s head?
- How does one make sure that one hasn’t forgotten to ask a particular question?
- How does one know when to move from one point to another, i.e. what is the decision criteria for moving from one point to another?

**My preparation**
- Had “primer” Field Geology 101 course in Arizona with practicing field geologists and engineering colleagues
- Met with principal investigator and team to understand the science hypothesis, statement of the problem, objectives of the trip
- Read reference material to better understand the area, geological principles and theories, the relationship of the area to other areas of the islands
Field Geology Trip Observations

• The Field Team
  – Communication
    • PI control and how briefings were conducted
    • How communication was conducted in the field
    • How the group observed in the field
    • Merging and splitting of personnel
  – Personnel expertise
    • Recognition by team members of each other’s responsibilities and expertise
    • Previous team member joint excursions; “tightness” of the group

• Use of instrumentation
• Variation of observational techniques
  – By training background
  – Where trained, and by who
  – Where experienced; previous excursions

Subject matter experts (e.g. flow, texture, channels, inflated flows, etc.)
Field Geology Trip Observations
An Example of General Surface Exploration Philosophy

- Each mission should explore new territory and continue to push back the frontier
- Each mission builds on previous missions
- Each mission extends range and time away from outpost as confidence is gained in surface systems and operational experience
- Every mission should plan time for revisits to prior sites based on discoveries and Earth-based research (e.g., initial reconnaissance can be followed up with detailed investigation)
- Every mission will likely involve local fieldwork (e.g., science station emplacement, regolith studies)
Basic Geological Field Approach

- Determine temporal relationships from spatial relationships
  - uses the superposition principle
  - observe such relationships for exposed strata
    - in impact or volcano-tectonic formations
    - in surface deposits, such as ejecta or pyroclastic deposits
    - by traversing regolith for expression of underlying geochemical boundaries, such as flow fronts

- Surface expression of underlying stratigraphy will be found in discernable stratigraphic contacts and nonconformities
  - vertical (crater, volcano-tectonic ridge, scarp, or rille walls)
  - horizontal (traverse underlying bedding, sample surface outcrops, cross volcanic flow fronts or impact debris fields)

- Ground Truth is currently limited
  - to a small number of nearside, mostly near equatorial sites
  - extended by remote sensing and imaging with relatively low spatial resolution (by terrestrial standards)

- Processes as observed and sampled in these landings sites will utilize
  - previous limited lunar field work
  - major contribution from terrestrial analogue studies
Example: South Pole Lunar Outpost Exploration
(Crew Mission #1, FY2019, 4 crew, 7 days)

- **General Surface Capability**
  - Living out of Lander
  - Unpressurized rover
- **Science Activities**
  - Emplace lunar environment monitoring station
    - Lunar atmosphere composition
    - Radiation level
    - Volatile transport to the poles
    - Suitability of the Moon for observatories
  - Conduct geological reconnaissance of Shackleton rim; circumferential and radial traverses
    - Age of Shackleton impact (e.g., Imbrian)
    - Composition of target massif
    - Age of target massif (e.g., SPA inner ring)
    - Impact process
  - Collect life science/crew biology data (note: continues on every crew mission)
    - Biological samples
    - Function monitoring

(from Margot et al, 1999 and Bussey)
Example: South Pole Lunar Outpost Exploration
(Crew Mission #2, FY2020, 4 crew, 14 days)

• **General Surface Capability**
  – Living out of small pressurized rovers (SPR)
  – Robotic assistant

• **Science Activities**
  – Emplace lunar geophysical station
    • seismicity, heat flow, magnetic fields, rotational dynamics
    • Lunar interior
  – Conduct traverse geophysics (note: continues on every crew mission)
    • mega-regolith stratigraphy
    • gravity
  – Conduct geological reconnaissance of Shackleton massif
    • Composition of target massif
    • Age of target massif (e.g. SPA inner ring)
  – Revisit sites of interest based on prior discoveries and research on returned samples (note: continues on every crew mission)

(from Margot et al, 1999 and Bussey)
Example: South Pole Lunar Outpost Exploration Composite
## Scenario 4.2.0 South Pole Lunar Outpost

### Manifest-Driven Case

<table>
<thead>
<tr>
<th>Crew Mission</th>
<th>Mission Duration</th>
<th>Approximate max. radius of exploration</th>
<th>Approximate area available for exploration based on max. radius</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>7 days</td>
<td>10 km</td>
<td>310 km²</td>
</tr>
<tr>
<td>2</td>
<td>14 days</td>
<td>20 km</td>
<td>1260 km²</td>
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<tr>
<td>3</td>
<td>21 days</td>
<td>30 km</td>
<td>2830 km²</td>
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<td>4</td>
<td>21 days</td>
<td>40 km</td>
<td>5030 km²</td>
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<tr>
<td>5</td>
<td>30 days</td>
<td>50 km</td>
<td>7850 km²</td>
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<tr>
<td>6</td>
<td>45 days</td>
<td>80 km</td>
<td>20,110 km²</td>
</tr>
<tr>
<td>7</td>
<td>50 days</td>
<td>90 km</td>
<td>25,450 km²</td>
</tr>
<tr>
<td>8</td>
<td>75 days</td>
<td>100 km</td>
<td>31,420 km²</td>
</tr>
</tbody>
</table>

### Graphs

#### Scenario 4.2.0 South Pole Lunar Outpost

**Manifest-Driven Case**

- **Mission Duration**
- **Approximate Maximum Radius of Exploration (km)**

#### Mission Duration

- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
- 90
- 100

#### Approximate Area Available for Exploration Based on Maximum Radius (km²)

- 0
- 5000
- 10000
- 15000
- 20000
- 25000
- 30000
- 35000
Modeling
Path Planning, What If’s
Modeling
Path Planning, What If’s

- Data gaps influence simulated path
- Variation between “planned/desired” path and possible path
- More like “Orienteering”
Appreciating that

Science Enables Engineering Enables Science…

• Provides an understanding of the complexities and subtleties of field study and the accompanying implementation techniques
• The process is not all that different from an systems engineering approach
• Challenges our definition of “success” and the “metrics” by which we make trades for architecture evolution while considering that science is the evolution of discovery
• Take advantage of the opportunity to strike a balance and facilitate one of the primary reasons for going to the Moon – Scientific Knowledge
Inspiration, Innovation and Discovery
Who Knows What We’ll Discover

We probably shouldn’t mess with it.