Extreme Expeditionary Architecture (EXP–Arch)

Guillermo Trotti, A.I.A.
President

Santiago Alfaro, Hubert Davis, Mitchell Joaquim
Shaun Modi, Einar Thornstein
Trotti and Associates, Inc.

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Expeditionary Architecture Introduction

Introduction
Mission Architecture
Rover Concepts
  Mother Ship Rovers
  Mini Rovers
Expandable Environments
  Inflatable Structures
  Foldable Structures
Educational Outreach
Conclusions
Next steps
Extreme Expeditionary Architecture: Paradigm Shift – Suite of systems, quickly deployable, transformable, autonomous & human collaboration, explore many diverse sites

Mobile “convoy” of rovers:
- 2 large pressurized rovers,
- 4 small un-pressurized rovers

Pressurized rovers:
- 1 habitation; 1 laboratory/exploration
- Inflatable Structures (> 2x volume)
- Crew of 4-8 all supplies and equipment

Un-pressurized rovers:
- Transport crew and cargo
- Agile exploration
- Regolith moving

Mission: weeks–months; 10–12 yr design life
EXP-Arch Mission Architecture Purpose

Go Beyond NASA’s Lunar Mission of a Single Outpost, Extensive Infrastructure at the South Pole – EXP-Arch enables us to become a “spacefaring species”

- **Human & Robotic Experience**: Surface operations, Planetary Exploration, Mars Mission Training, Self-Sufficiency
- **Technology Testbeds**: Mining, Construction, Science, Experience, Rapid Excavation and Regolith Movement (for radiation protection), Systems Testing, Mars Mission Testbed
- **Hands-On Lunar Surface Exploration**: Investigate caves/lava tubes, Search for water (ice)
- **Scientific Research**: Selenology, Physics, Astronomy, Geology, Chemistry, & Life Sciences
- **Public Interest/Outreach**: Engage public participation: “The People’s Moon”
Historically, breakthrough exploration has been accomplished by highly mobile systems.

Deep Sea Exploration

Field Geology

Sailing Expeditions

Antarctic missions
EXP–Arch mission architecture fully realized on two Ares V class launch vehicles. Operational capability after first launch.

- Payload Configurations:
  - 1 pressurized rovers (8 mT) and 2 mini-rovers (2 mT)
  - 2 pressurized rovers
  - 4 mini-rovers
- Single launch: 1 pressurized rover and 2 mini–rovers.
- Alternative launch configurations: 2 pressurized rovers or 4 mini-rovers
- Ares V capacity: 65000 kg to the moon and >20 mT payload to the lunar surface.
Rovers and Vehicle Design Background

Advanced automotive, materials, and other industries can be leveraged in planetary exploration concepts. We have researched the new technologies and have applied them to our design.

There is a paradigm shift on the way we think about planetary rover design and construction.

- Past rover designs
  - Apollo rover
  - NASA past research
- Vehicle design innovations
  - Composites
  - Electrical Motors Propulsion
  - Fuel Cells
  - Hydrogen Storage
  - Power storage
  - Wheel design
  - Joystick control
  - Multidirectional
  - Bio-mimetic systems
Mother Ship Rover (MSR) Design Criteria

Highly mobile, smart, autonomous computational system…Trigger!

Pressurized vehicle and transportable habitat
- All terrain omni-directional vehicle
- Novel 8 wheel traction
- Reduce mass (use of composites /40% less mass)
- Self healing structures
- Passive and active radiation protection
- Crew of 4
- Stereoscopic vision
- Teleoperation and autonomous thinking
- Wireless controls
- Multidirectional telemetry control
- Navigational warning systems
- Docking capabilities
- Re-supply
  - Fuel: Hydrogen - Oxygen
  - Food
  - Tools and equipment
- Maximum mass 10 mT

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Mother Ship Rover Design

Side View

Solar Arrays
Cockpit
Manipulator Arm
Inflatable Airlock

Front View

Radiators
Inflatable Environment
Skids
Winch

11.2 m
3.4 m
5.8 m

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NIAC Rheo-Adapt: An Innovative Solution for Space Exploration
Mother Ship Rover (MSR) Design

Equipment layout on the rover’s roof enhances radiation protection

Top View

Bottom View
Foldable and Inflatable Structures Studies

The inflatable structures are built of multi-layer para-aramid materials with layers of mylar for thermal and UV radiation protection. NASA and industry have developed and built full scale prototypes (i.e, Spacehab, Honeywell-FTL AIA airlock, Bigelow Enterprises).

We conducted several studies and constructed several models of re-deployable structures using origami principles and fabric folding techniques.
Selected Concept: 20 Sections with 21 section rings, rings are ~2.44 m (~8 ft in dia.) Inflatable Habitat Total Fabric Mass: 857 kg (1890 lb).

Volume=64.7m³ (2285 ft³)

9.15 m = 20 x 0.4575 m  (30 ft = 20 x 1.5 ft)

Re-deployable Inflatable Habitat
Inflatable Details and Airlock Design

Ring/fabric intersecting geometry

Fabric thickness: 8 mm
Fabric Layers:
• Pressure bladder
• Thermal blanket
• Abrasion resistant

Airlock Total Fabric Mass: 245 kg (540 lb)

High Pressure Tubes

Hatch and Docking Ring Mass: 680 kg (1500 lb) each
Interior Design Features

MSR Floor Plan

- EVA Suit Parts
- Inflatable Airlock
- EVA Suit Storage
- Storage Racks
- Hygiene
- Food Storage Racks
- Galley
- Storm Shelter Hatch
- Wardroom
- Work Station
- Cockpit
- Inflatable Environment
- Sample Airlock

Volume = 65 m$^3$ (2265 ft$^3$)

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NIAC - NASA Institute for Advanced Concepts
We have made a first analysis of the interior volumes created by the deployed habitat and conclude that it would be sufficient for a crew of 8 to have a productive working and living experience.
The two Mother Ships can dock together to make a significant base camp. Two different configurations are possible.
Power will be generated by solar arrays during the daytime and by Hydrogen/Oxygen fuel cells during the night.

- Solar Array (50 kW each)
- Size: Two Arrays, each 3.75m x 10m long with tracking capability.
- Area: 75 m² @ 1345 W/m² insolation
- 50% Efficiency
- Gross Power Out: 50.4 kW
- Angularity Factor: 71% for an average of 45° off-axis
- Conductor Losses: 90%
- Power Conditioner: 75%
- Net Power output during daylight hours: 24 kW to batteries or for instant use.

Efficiency and reliability of Solar Cells are improving.
Power Generation and Heat Rejection

Fuel Cell technology is maturing rapidly and should be readily available by the time we return to the moon.

- 25 kW Hydrogen Fuel Cells based upon electrolyzer / compressor efficiency and vehicle power needs other than locomotion.
- An estimated 9.6 kW available while in motion during daylight.
- Batteries Li-ion, NiCd, NiMH
- Carbon-Carbon (K1100) Radiators (50% lighter than aluminum, 3 times more conductive than copper)
Several high efficiency electrical drive motors are available on the market today which could be adapted for use under the extreme conditions of the Lunar environment.

Preliminary requirements:
- <10 mT total mass with 8 wheels
- 17 Km/hr top speed, cruising speed 10 km/hr.
- Ratio on Mass: 14.3 HP = 11 kW power output or
- 1.4 kW output each motor at 75% drive train efficiency.
- Power input per motor: 1.8 kWe or 14.5 kW total drive train.
Wheel Train Design

The rovers will be equipped with ‘proprioceptive’ sensors to determine the position of each joint, the amount of current drawn by each motor, the tilt in 3 dimensions (yaw, pitch, roll) and the load on each wheel.

Wheel train features:
• Maximum contact patch
• High traction
• Debris reduction
• Passive suspension
• Nano tubes structure
• Easily replaced

Peugeot Spherical mesh
Lunar Rover mesh
Michelline Twheels

EXP-Arch Nanotube structure design
Mini Rover (MR) Design Criteria

The Mini Rovers are the agile assistants to the MSR. They move faster and are able to handle a variety of tasks manned or unmanned

- All Terrain Vehicle
- 4 Wheel drive
- High traction
- Operational during day and night cycles
- Crew Transport (4 Astronauts)
- Cargo Transport
- Regolith mover
- MSR Assistant
- Tele-operation / Joystick control
- Stereoscopic vision
- Wireless controls
- Adaptable to mission requirements
- Mass - 2mT
General Features

- Skateboard containing batteries, fuel cell, and control systems.
- General Dimensions: 12' long x 6' wide x 7' high (unfolded)
- Launch Configuration: Roof and wheels are foldable to minimize volume during launch.
- Energy: Solar cells, fuel cells, batteries
- Propulsion: 4 independent electric motors.
- Mobility: Four wheels 90 degrees rotation.
- Materials: Composites and aluminum.
- Tools: Winch, plow, drills, manipulator arm, trench digger, auger gun.
- Micrometeorite shielding: The Mini’s will have an aluminum canopy to provide some shielding and mounting of the solar cells.
The Mini Rovers play a critical roll on assisting the MSR during a Solar event.
Radiation Protection Strategies

The Storm Shelter concept provides a minimum of 3.5 m of regolith shielding not including the mass provided by the vehicle.

- Rover design/mass allocation
- Storm shelter (maximum depth = 6.2 m)
- Passive shielding - 20 gm/cm²
- Pharmacological measures
- Alert/warning communications infrastructure
- Passive dosimeters on Craft and Astronauts
- Maximum wheel span = 11 m
Education Outreach: Rhode Island School of Design

Michael Lye – Design for Extreme Environment Instructor

Origami / Foldable Structures Studies

Student: Elizabeth Thelen

Although only the work of a few of the students is featured here, this project would not have been possible without the efforts of all of the students that were involved with it: Keith Archer, Hyung Yun Choi, Amy Chuang, Rachael Gordon, Myung Hwan Kim, Kris Lee, Juan Martinez, Irene Noh, Eugene Suh, Elizabeth Thelen.
Education Outreach: Rhode Island School of Design (continued)

Student: Myung Hwan Kim

Student: Eugene Suh

Board of Advisors participated in the final design review
Conclusions

Extreme Expeditionary Mission Architecture is a complex System of Systems – re-deployable, transformable, autonomous & human collaboration, explore many diverse sites

Creative Design: mobile rover “convoy”:
Pressurized rovers, Un-pressurized mini rovers, Foldable structures, Transformable, Lunar camping

Human & Robotic Experience: Surface operations, Planetary Exploration, Mars Mission Training, Self-Sufficiency, Enable “spacefaring species”

Technology Testbeds: Mining, Construction, Science, Experience, Rapid Excavation and Regolith Movement (for radiation protection), Systems Testing, Mars Mission Testbed

Lunar Surface Exploration and Science: Investigate caves/lava tubes, Search for water (ice), Selenology, Physics, Astronomy, Geology, Chemistry, & Life Sciences

Technology assessment: Design, Composites, Controls, Robotics, Re-deployable pneumatic structures, Propulsion, Power

Public Interest/Outreach: Engage public participation: “The People’s Moon”, How about a pole to pole race?
Future Research

Phase II Emphasis

Mission Architecture Feasibility
Expandable Environments Prototyping
  Re-deployable Inflatable Structures
  Foldable Structures
Composite materials research
Radiation Protection Development
  Strategies
  Tools
Large Robotic Systems Operations
Understand Human Performance
Technology Roadmap Development
Extensive Educational Outreach
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Thank You!