Lunar Surface Structural Concepts
and Construction Studies

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**LUNAR SURFACE STRUCTURES CONSTRUCTION RESEARCH AREAS**

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<th>RESEARCH AREA</th>
<th>OBJECTIVE</th>
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<tr>
<td>- Multiple Cable Crane</td>
<td>Remote and/or Precision Positioning Capability For Lunar Construction</td>
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<td>- Articulating Arm Crane</td>
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<tr>
<td>- Deployable Tower</td>
<td>Automatically Deployable Towers and Beam Type Structures With Minimal Deployment Equipment</td>
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<tr>
<td>- Lunar Module Unloading Device</td>
<td>Capability For Self Off-Loading of Modules &amp; Equipment</td>
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<td>- Deployable Solar Concentrator</td>
<td>Automatically Deployable Reflector With Minimal Deployment Equipment</td>
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LUNAR CRANE RELATED DISCIPLINES

- Remote control and/or autonomous precision construction operations
- Multibody dynamics analysis and control of large flexible systems
- Analysis and control of cable structures
- Quantification of control actuator concepts for large flexible systems
- Design of large complex flexible systems
- System identification of nonlinear systems
TYPICAL MOBILE CRANE HAS TWO MAJOR SHORTCOMINGS FOR LUNAR BASE APPLICATION

1) Very large mass required to resist tipping

2) Human guidance required for accurate positioning
<table>
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<th>Candidate Crane Cable Suspension Systems</th>
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<tr>
<td><strong>Six Cables</strong></td>
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<tr>
<td>6 DOF</td>
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<tr>
<td>Structurally Stiff</td>
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<tr>
<td><strong>Three Cables</strong></td>
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<tr>
<td>3 DOF</td>
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<tr>
<td>Structurally Stiff</td>
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<tr>
<td>3 DOF Stiffened by Triangulated Cables</td>
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<tr>
<td><strong>Single Cable</strong></td>
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<tr>
<td>1 DOF</td>
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<tr>
<td>Structurally Stiff</td>
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Cable Drive System

NIST SIX-CABLE SUSPENSION CRANE

Cable Geometry

Modified Bridge Crane Trolley
Wirerope
Platform
Load

Controlled Trolley Motion
NUMERICAL EXAMPLE OF NATURAL FREQUENCY

A Symmetric Model

A Swinging Pendulum

\[ \mathcal{F} = \sqrt{\frac{(\frac{\ell_h}{\varepsilon}) \left[ \ell_h h + \frac{\ell_a^2}{4} \right] + \ell_c h}{\varepsilon^2 + \rho^2}} \mathcal{F}_{\text{pendulum}} \]

\[ \mathcal{F}_{\text{pendulum}} = \frac{1}{2\pi} \sqrt{\frac{g}{h}} \]
COUNTER-BALANCED ACTIVELY-CONTROLLED LUNAR CRANE INCORPORATES TWO NEW FEATURES FOR IMPROVED PERFORMANCE

1) Active Counter Weight to Reduce Overturning Moment

2) Multiple Payload Suspension Cables to Provide Stable Precision Positioning
LUNAR CRANE PENDULUM MECHANICS

3 Translations Have Structural Stiffness
3 Rotations Have Pendulum Stiffness

Potential Control Mechanisms
Active Cable Positioners
Active Inertia Wheels
Active Attachments

Payload (M, L)
SIMULATION RESULTS (II)

[Diagram showing mechanical components and waveforms]

- Y-axis
- X-axis
- Cable #1 & #3
- Cable #2
- Actuator #1 & #3
- Slider #1 & #3
- Actuator #2
- Slider #2
- Module
- G c.g.
- l_c
- l_d
- l_e
- A
- B
- C
- D
- l_a
- ψ
- β
- α
- β₀
- θ
- Module Angle
- Module Angular Velocity
- Cable #1 Angle
- Cable #1 Angular Velocity
- Cable #2 Angle
- Cable #2 Angular Velocity
- Slider Control Force
- Slider Control Force
- Time (sec)

[Waveforms with annotations: Initial α=17°]

Legend:
- - - : Control
- - - - : No Control

Note: The diagram and waveforms illustrate the simulation results of a mechanical system with various components and their corresponding angles, velocities, and forces over time.
CMG CONTROL SIMULATION RESULTS

- X-coordinate of point H (in)
- Y-coordinate of point H (in)
- Z-coordinate of point H (in)
- Control Moment about X-axis (lb-in)
- Control Moment about Y-axis (lb-in)
- Control Moment about Z-axis (lb-in)

Time (sec)
SIMULATION RESULTS (I)
SLEWING SIMULATION RESULTS

60 deg. Maneuver

X-Y Plot of Point H on End-Effector

Y-Coord. of H (in)

X-Coordinate of H (in)

Control Moment of Boom (lbf-in)

Time (sec)

Angles of Boom (deg)

Time (sec)

Angles of End-Effector (deg)

Time (sec)

Angles of Module (deg)

Time (sec)
ONE-SIXTH SCALE LUNAR CRANE TEST-BED USING G.E. ROBOT FOR GLOBAL MANIPULATION.
BASIC DEPLOYABLE TRUSS APPROACHES

Warren Truss

Standard Sequential Packaging

Sequentially Deployable Truss

Synchronizing Bar

Synchronously Deployable Truss
COMPARISON OF ELEVATOR PLATFORMS

Bi-Pantograph

Pantograph
BI-PANTOGRAPH VS PANTOGRAPH STIFFNESS

![Graph showing comparison between Bi-Pantograph and Pantograph stiffness.](image)
BI-PANTOGRAPH SYNCHRONOUSLY DEPLOYABLE TOWER/BEAM

- Single Actuator Deployment
- Deployment Reversible For Maintenance
- Variable Height

Warren Truss (18 Bays)

Stowed 30 degrees 45 Degrees Fully Deployed
LUNAR MODULE OFF-LOADER CONCEPT
DURING VARIOUS PHASES OF OPERATION
MODULE OFF-LOADER CONCEPT PACKAGED
(REAR & SIDE VIEWS)

Stowed Cables

Regolith Auger
STARBURST DEPLOYABLE PRECISION REFLECTOR

**Features**
- Maximum packaging efficiency for reflector panels
- Simple one-degree-of-freedom deployment of reflector arms
- Permits integrated reflector system

**Applications**
- LDR-type telescopes
- Microwave radiometers
- Solar concentrators
“STAR BURST” CONCEPT HAS POTENTIAL FOR DEPLOYING 20 METER DIAMETER PRECISION DEFLECTOR

Packaged reflector

Deployment Mechanism

Semi-deployed

Deployed Reflector
STARBURST DEPLOYABLE PRECISION REFLECTOR
3 RING REFLECTOR DEPLOYMENT SCHEME

- 37 Panels Total
- 6 Deployment Arms
- 6 Panels Per Deployment Arm

Panel Hinge

Deployment Arm
CROSS-SECTION OF PACKAGED STARBURST REFLECTOR

Shuttle Dynamic Envelope

Deployment Arm

0.384 m

1.15 m

3.616 m

4.240 m
FOCAL POINT AND THICKNESS PACKAGING CONSIDERATIONS

Cargo Bay Volume

Panel Thickness, in

Reflect Volume

3.6 m

21.9 m

4.2 m

(3 Ring, 20 m D eff.)
STARBURST COMMENTS

Low level of effort to date (Primarily a concept feasibility study)

Has potential for deploying 20 meter class reflectors from Shuttle-size cargo bay

Two basic deployment concepts
  o Synchronized mechanism
  o Distributed actuators

Further work needed
  o Detailed packaging study for both concepts
  o Deployment simulation for both concepts
  o Build demonstration model
  o Deployable support structure concept study
  o Dynamic & accuracy active control operation simulation studies
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