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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<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></td>
<td>Six Cables</td>
<td>6 DOF Structurally Stiff</td>
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<tr>
<td></td>
<td>Three Cables</td>
<td>3 DOF Structurally Stiff, Stiffened by Triangulated Cables</td>
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<td>Three Cables</td>
<td>3 DOF Structurally Stiff</td>
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<tr>
<td></td>
<td>Single Cable</td>
<td>1 DOF Structurally Stiff</td>
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NIST SIX-CABLE SUSPENSION CRANE

Cable Drive System

Cable Geometry

Modified Bridge Crane Trolley
Wireropes
Platform

Controlled Trolley Motion

Load

James S. Albus
1/15/85
NUMERICAL EXAMPLE OF NATURAL FREQUENCY

\[ f = \sqrt{\frac{L_4}{\pi}} \left[ \frac{L_4}{r} \right] + \frac{L_4}{\pi} \cdot \frac{\rho^2}{\epsilon^2} + \frac{\rho^2}{\epsilon^2} \]

\[ f_{\text{pendulum}} = \frac{1}{2\pi} \sqrt{\frac{L_4}{G}} \]

A Swinging Pendulum

A Symmetric Model

Natural Frequency (Hz)

Distance ε (in)

\[ L_a = 300'' \]

\[ \alpha = 12° \]

\[ L_b = 600'' \]

\[ \epsilon = 50.5'' \]

\[ \epsilon_e = 130° \]

\[ L_e = 134 \text{ lb-in}^2 \]

\[ L_e = 6.4 \times 10^4 \text{ lb-in}^2 \]

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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,I)
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)

Diagram of a simulated system with labeled parts:
- Y-axis
- X-axis
- β₀
- Cable #1 & #3
- Structural Framework
- Screw-Drive Actuator
- Module
- G c.g.
- lₐ
- l₆
- l₇
- l₈
- l₉
- l₁₀
- l₁₁
- β
- Ψ
- α₀
- θ
- η
- θ+φ
- φ
- EF
- g

Graphs showing:
- Time (sec) vs. Framework Angular Displacement (θ)
- Time (sec) vs. Framework Angular Velocity (θ°/seg)
- Time (sec) vs. Module Angular Displacement (θ & φ)
- Time (sec) vs. Module Angular Velocity (θ & φ°/seg)
- Time (sec) vs. Control Force Along EF (lbf)
- Control vs. No Control

Initial EF = 100 in
SLEWING SIMULATION RESULTS

- Angles of Boom (deg)
  - Time (sec): 0 5 10 15 20
  - Angles: 0 deg, 20 deg, 40 deg, 60 deg

- Control Moment of Boom (lb-in)
  - Time (sec): 0 5 10 15 20
  - Moment: 0 lb-in, 10 lb-in, 20 lb-in

- X-Y Plot of Point H on End-Effector
  - X-Coord. of H (in)
  - Time (sec): 80 90 100 110 120 130 140 150 160 170
  - Y-Coord. of H (in)

- Angles of End-Effector (deg)
  - Time (sec): 0 5 10 15 20
  - Angles: 0 deg, 20 deg, 40 deg, 60 deg

- Angles of Module (deg)
  - Time (sec): 0 5 10 15 20
  - Angles: 0 deg, -1 deg, -2 deg
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
BI-PANTOGRAPH ELEVATOR PLATFORM
COMPARISON OF ELEVATOR PLATFORMS

Bi-Pantograph

Pantograph
PERSPECTIVE OF BI-PANTOGRAPH BEAM

Deployed Beam

Stowed Beam
BI-PANTOGRAPH SYNCHRONOUSLY DEPLOYABLE TOWER/BEAM

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

Warren Truss (18 Bays)
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
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
FOCAL POINT AND THICKNESS PACKAGING CONSIDERATIONS

(Cargo Bay Volume

Relector Volume

3 Ring, 20 m D eff.)

Panel Thickness, in
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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