cSc

Lunar Surface Structural Concepts and Construction Studies

Martin Mikulas

Third Annual Symposium
November 21 & 22, 1991

A NASA Space Engineering Research Center at the University of Colorado

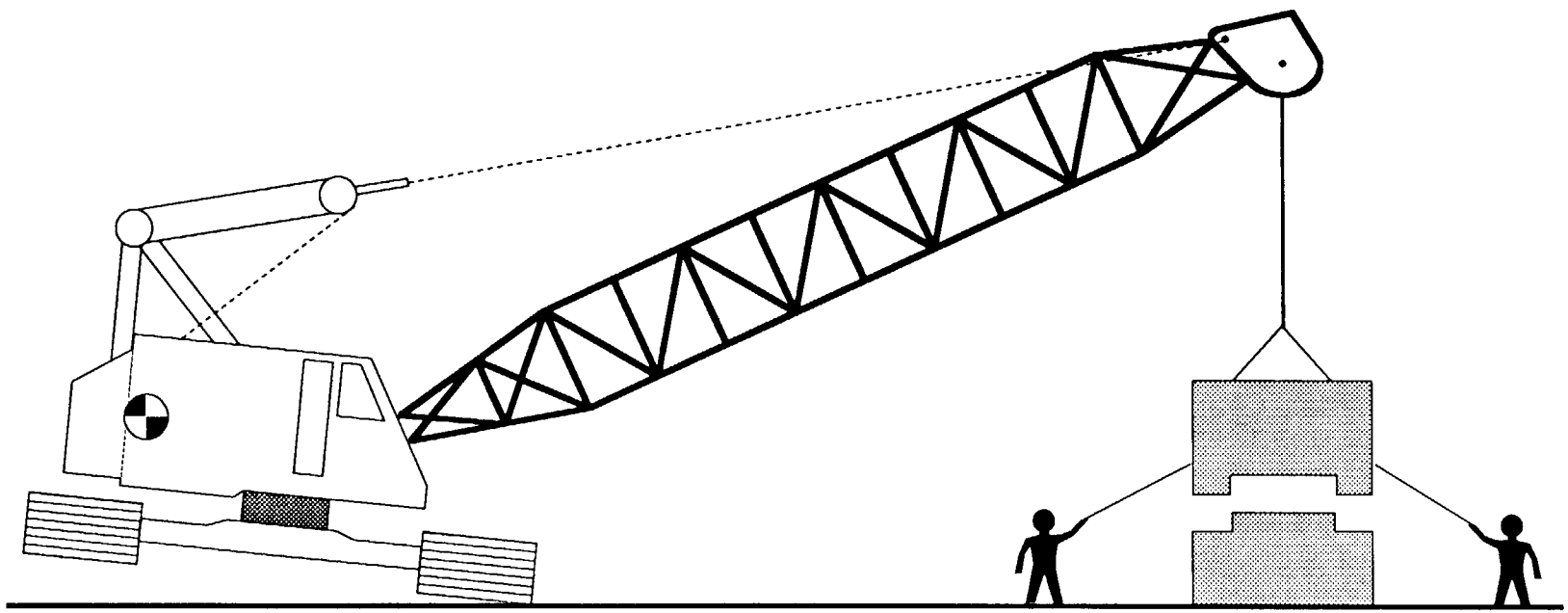
LUNAR SURFACE STRUCTURES CONSTRUCTION RESEARCH AREAS

RESEARCH AREA	OBJECTIVE
- Multiple Cable Crane - Articulating Arm Crane	Remote and/or Precision Positioning Capability For Lunar Construction
- Deployable Tower	Automatically Deployable Towers and Beam Type Structures With Minimal Deployment Equipment
- Lunar Module Unloading Device	Capability For Self Off-Loading of Modules & Equipment
- Deployable Solar Concentrator	Automatically Deployable Reflector With Minimal Deployment Equipment

LUNAR CRANE RELATED DISCIPLINES

- o Remote control and/or autonomous precision construction operations
- o Multibody dynamics analysis and control of large flexible systems
- o Analysis and control of cable structures
- o Quantification of control actuator concepts for large flexible systems
- o Design of large complex flexible sytems
- o System identification of nolinear systems

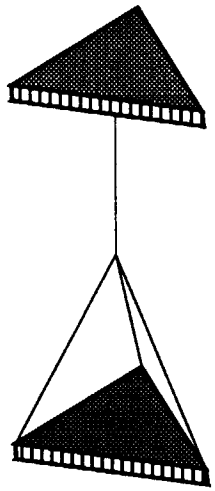
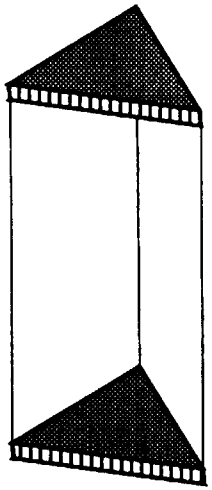
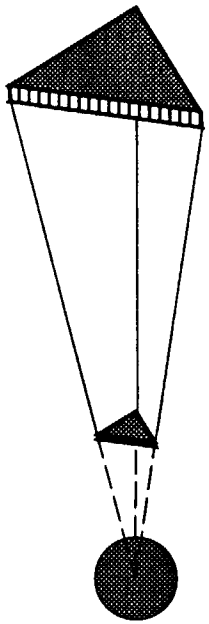
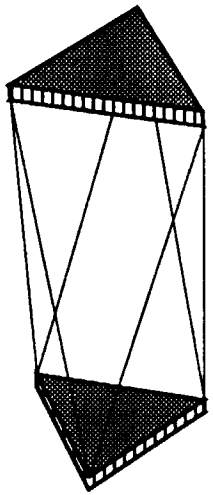
TYPICAL MOBILE CRANE HAS TWO MAJOR SHORTCOMINGS FOR LUNAR BASE APPLICATION



1) Very large mass required to resist tipping

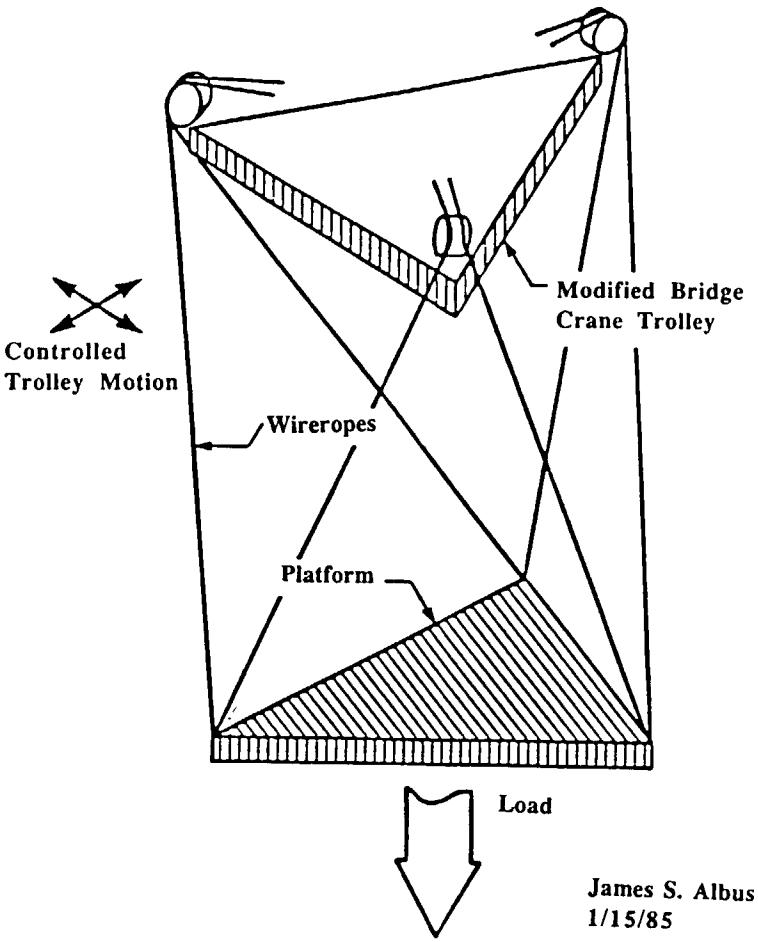
2) Human guidance required for accurate positioning

CANDIDATE CRANE CABLE SUSPENSION SYSTEMS

			
Single Cable	**Three Cables**	**Three Cables**	**Six Cables**
1 DOF **Structurally Stiff**	**3 DOF** **Structurally Stiff**	**3 DOF** **Structurally Stiff** **3 DOF** **Stiffened by** **Triangulated** **Cables**	**6 DOF** **Structurally Stiff**

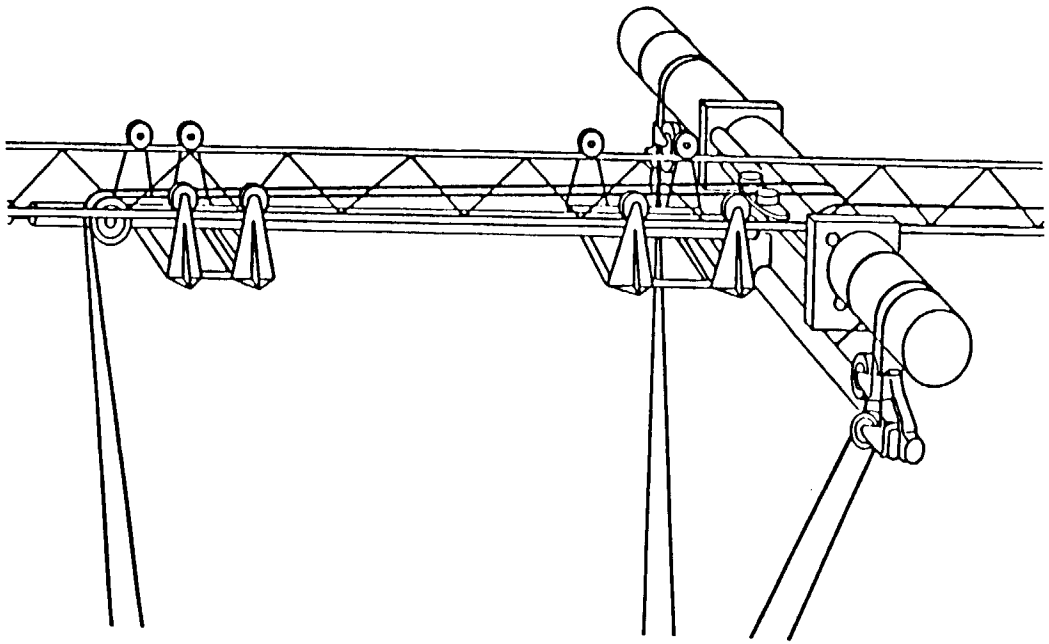
NIST SIX-CABLE SUSPENSION CRANE

Cable Geometry



James S. Albus
1/15/85

Cable Drive System



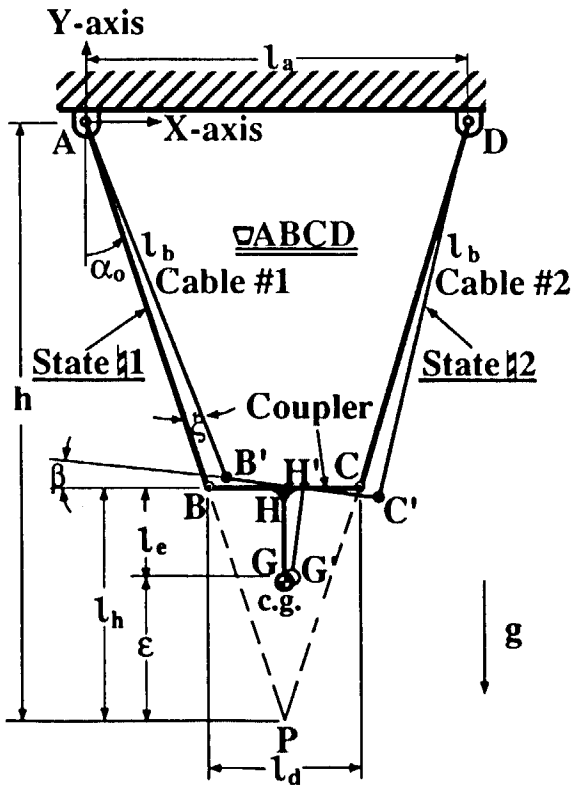
NUMERICAL EXAMPLE OF NATURAL FREQUENCY

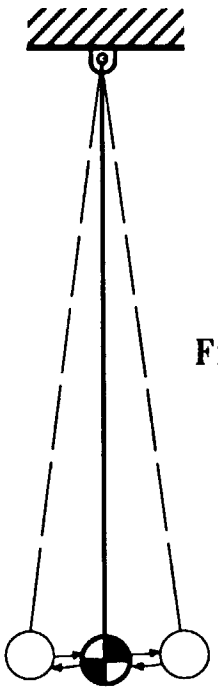
A Symmetric Model

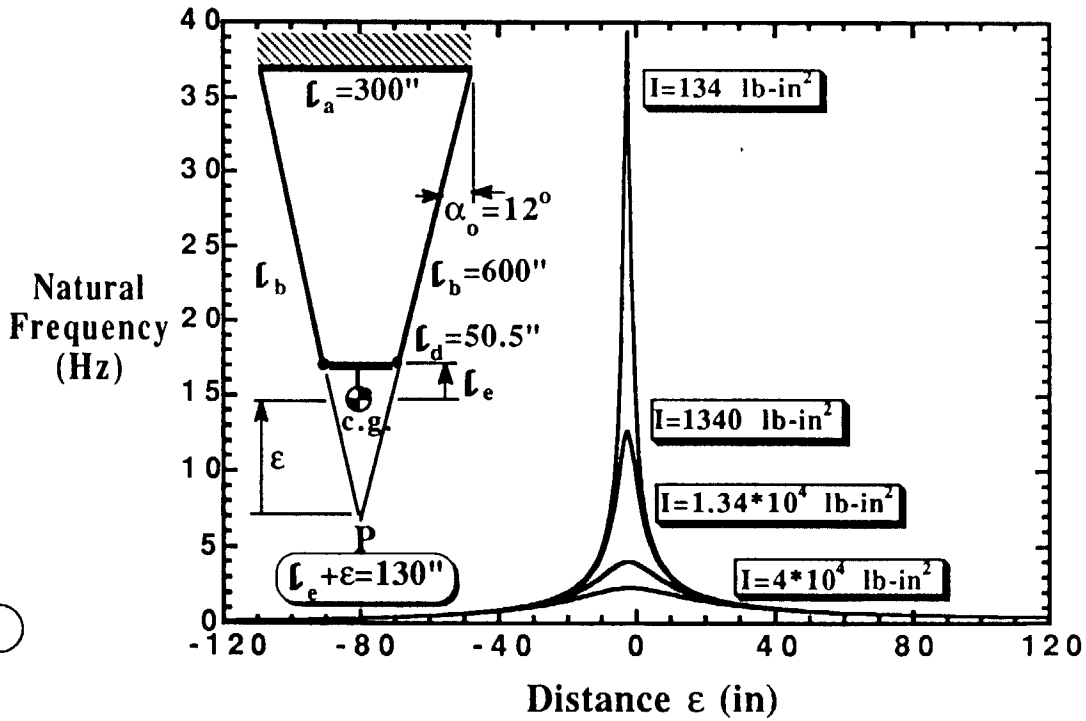
A Swinging Pendulum

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

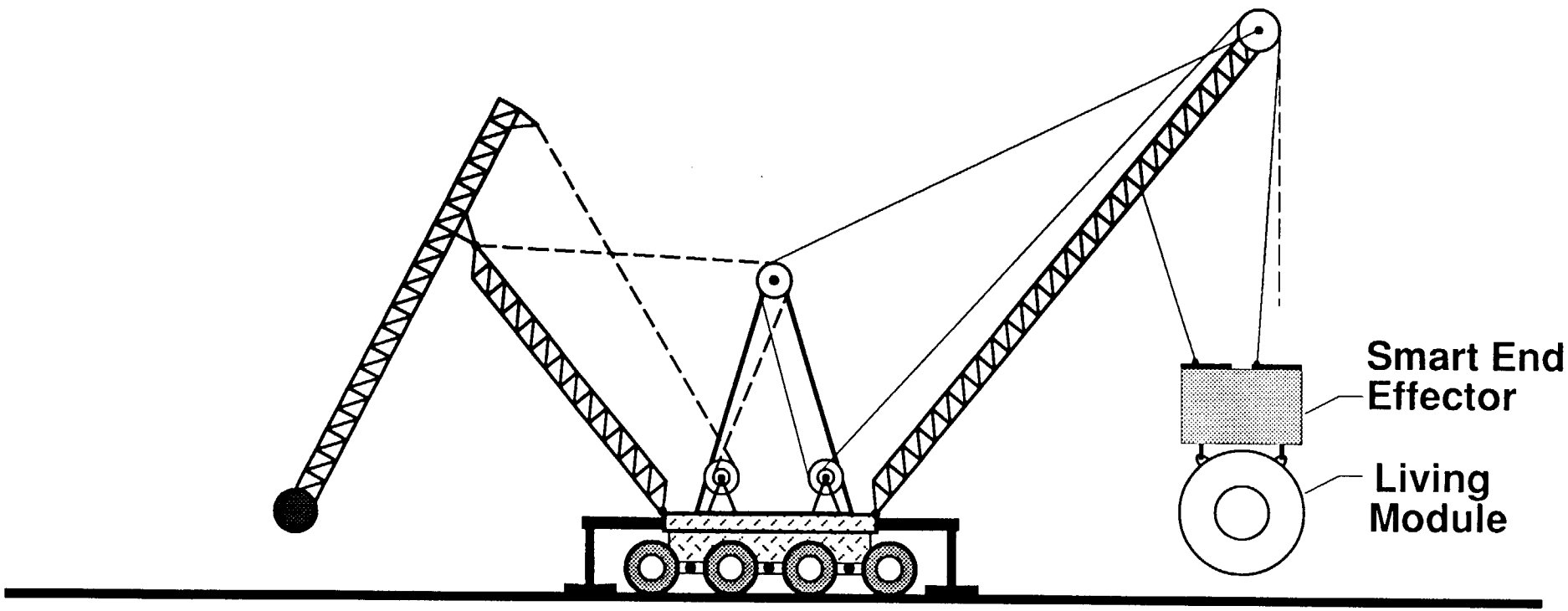
$$\mathcal{F}_{pendulum} = \frac{1}{2\pi}\sqrt{\frac{G}{h}},$$







COUNTER-BALANCED ACTIVELY-CONTROLLED LUNAR CRANE INCORPORATES TWO NEW FEATURES FOR IMPROVED PERFORFORMANCE



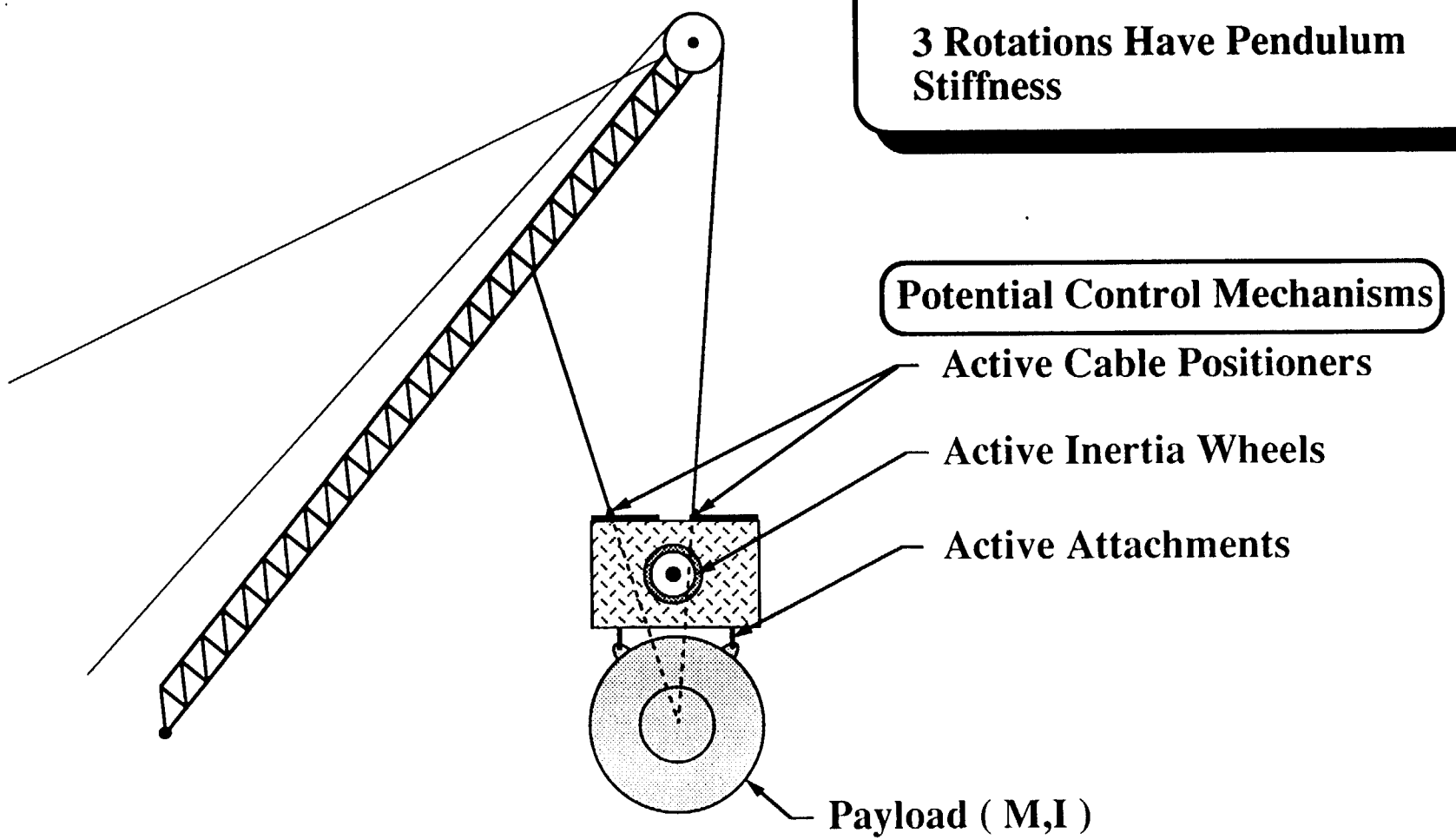
1) Active Counter Weight to Reduce Overturning Moment

2) Multiple Payload Suspension Cables to Provide Stable Precision Positioning

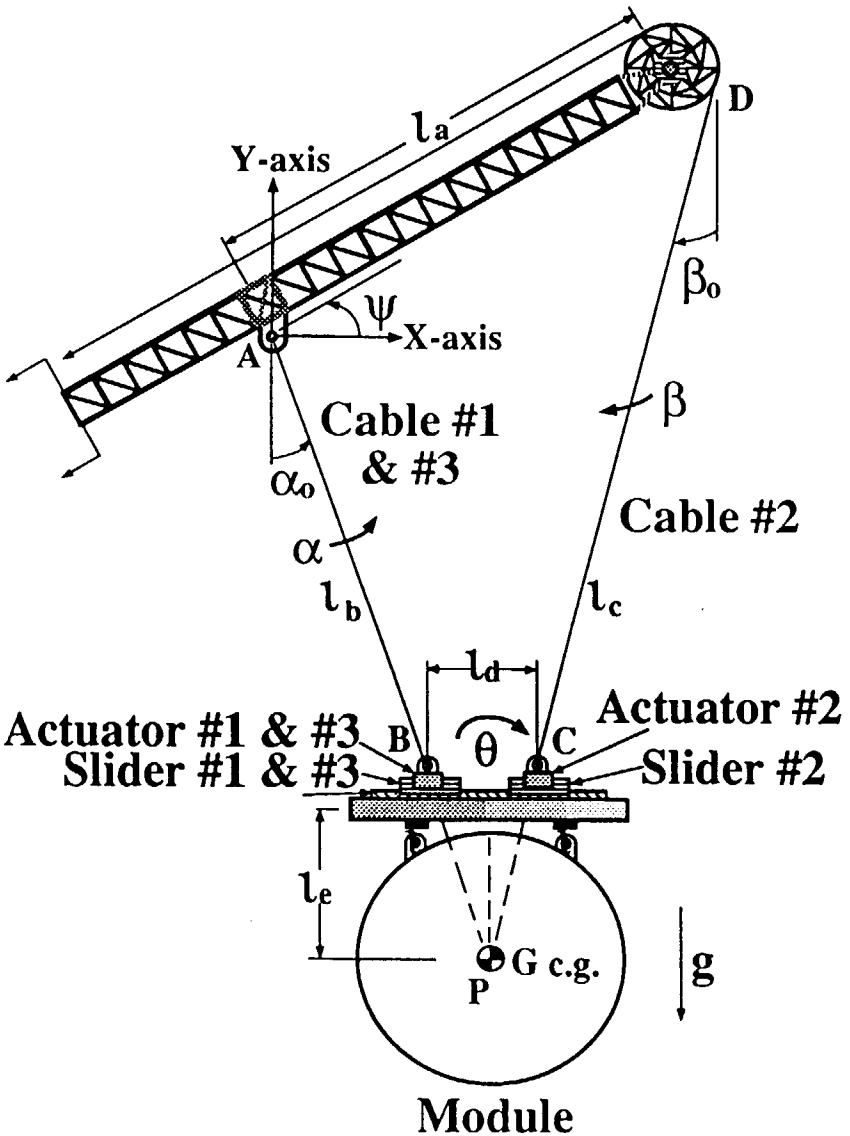
LUNAR CRANE PENDULUM MECHANICS

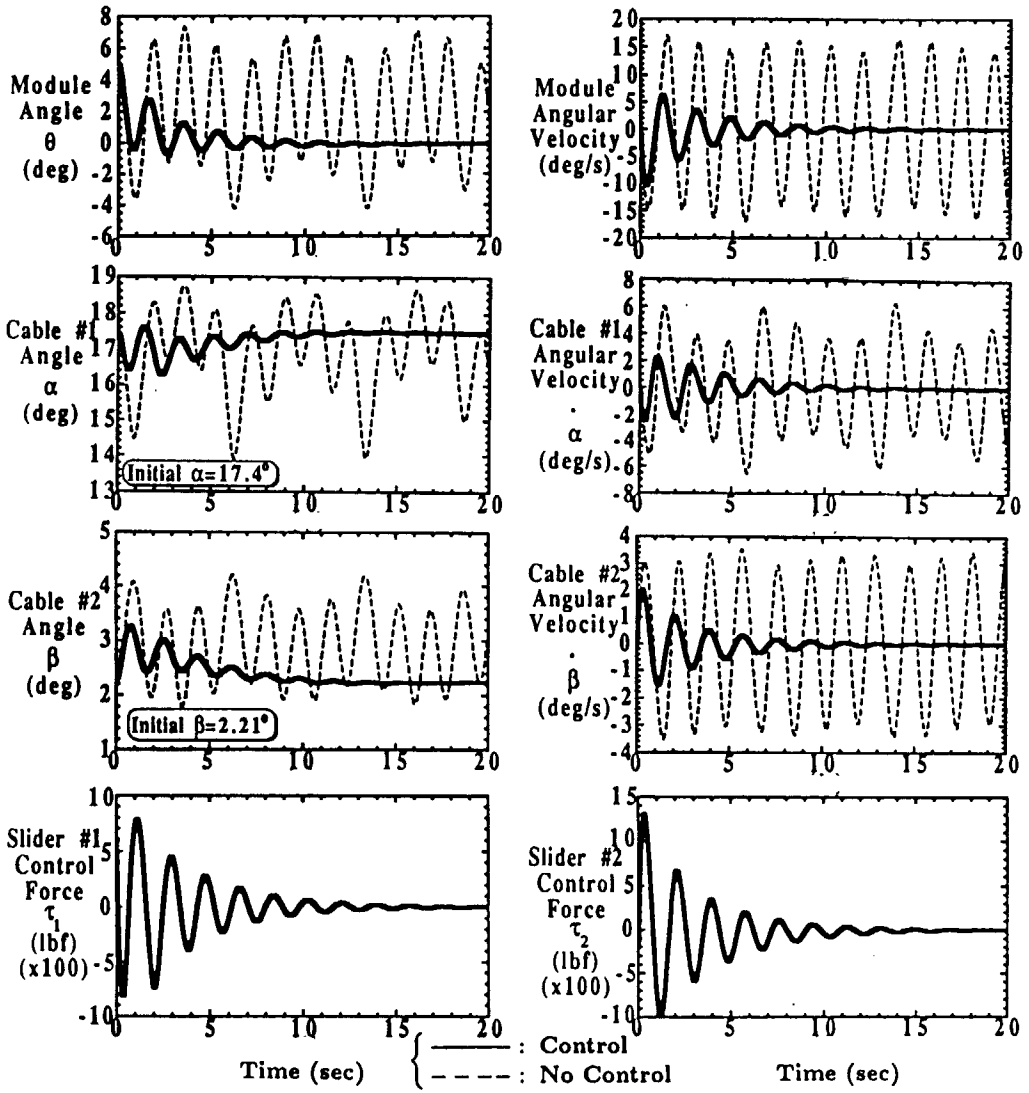
3 Translations Have Structural Stiffness

3 Rotations Have Pendulum Stiffness

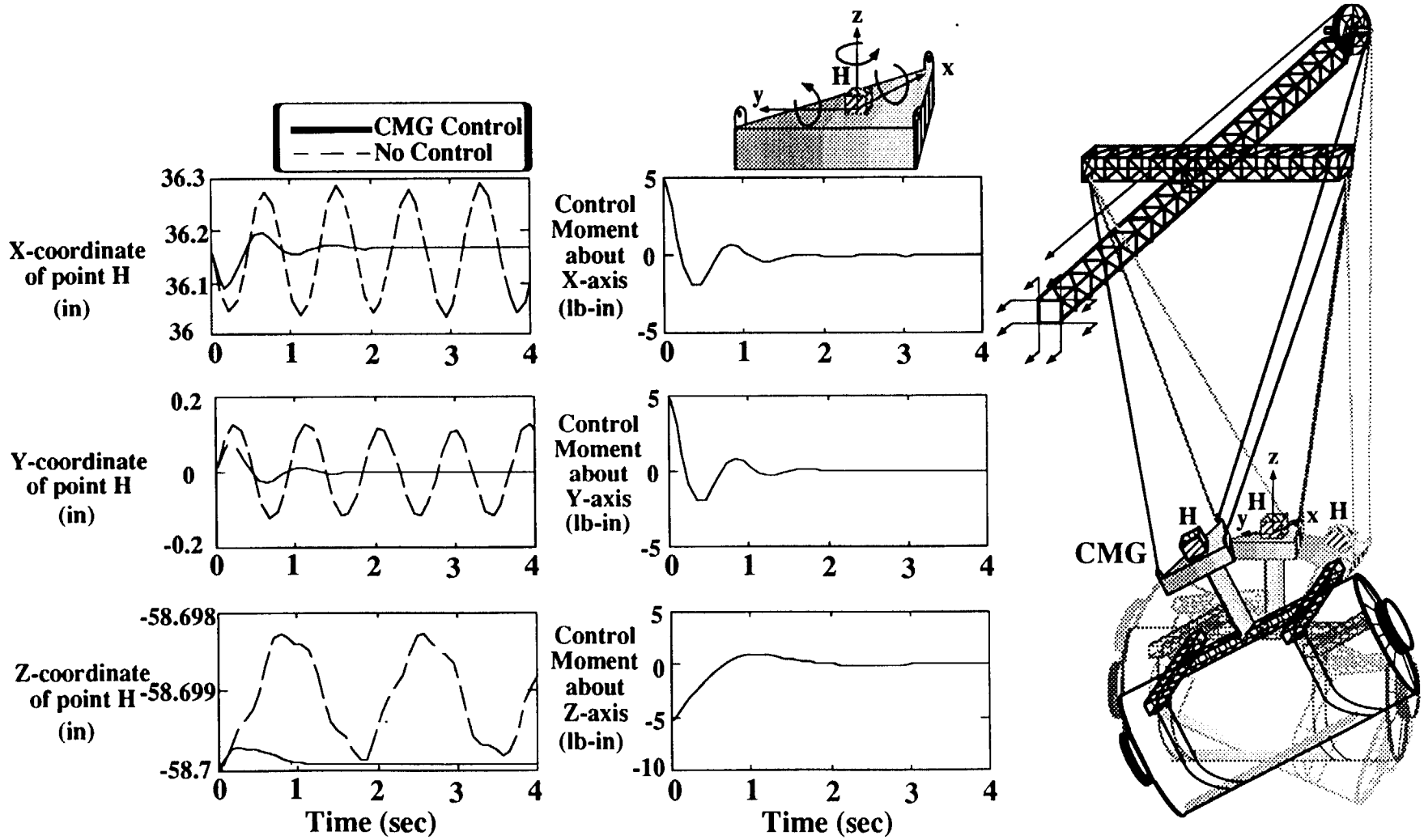


SIMULATION RESULTS (II)

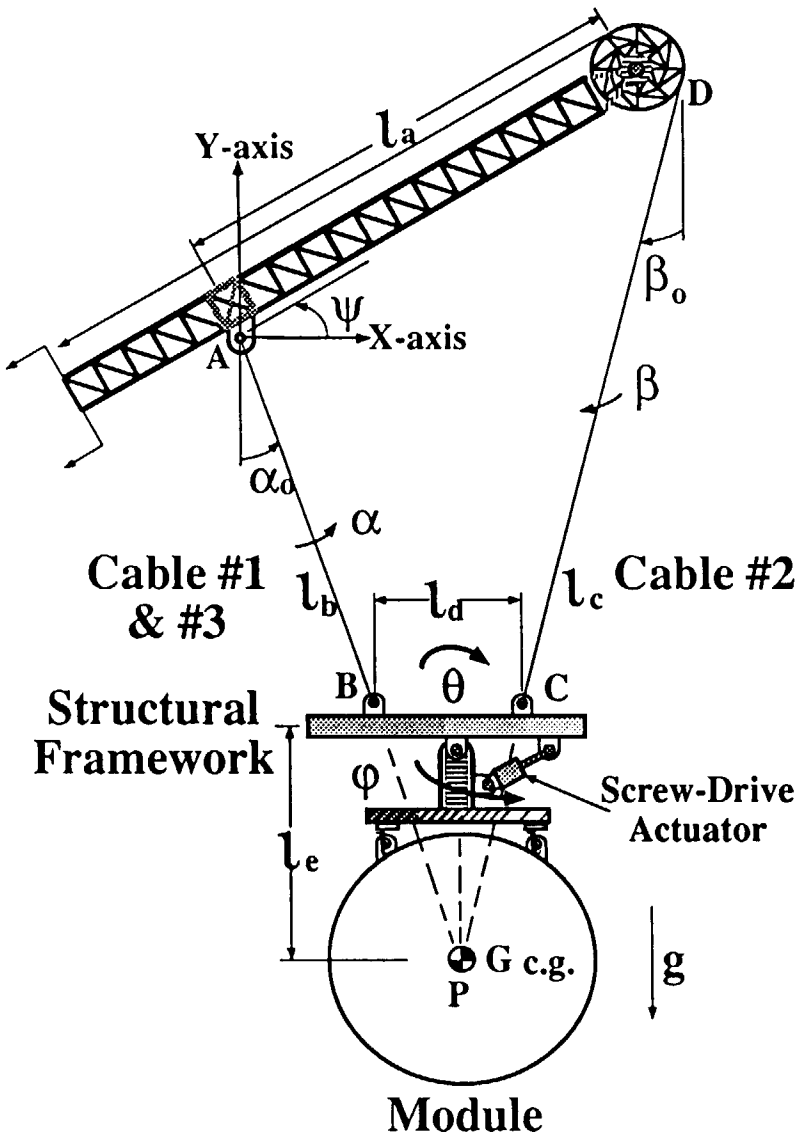


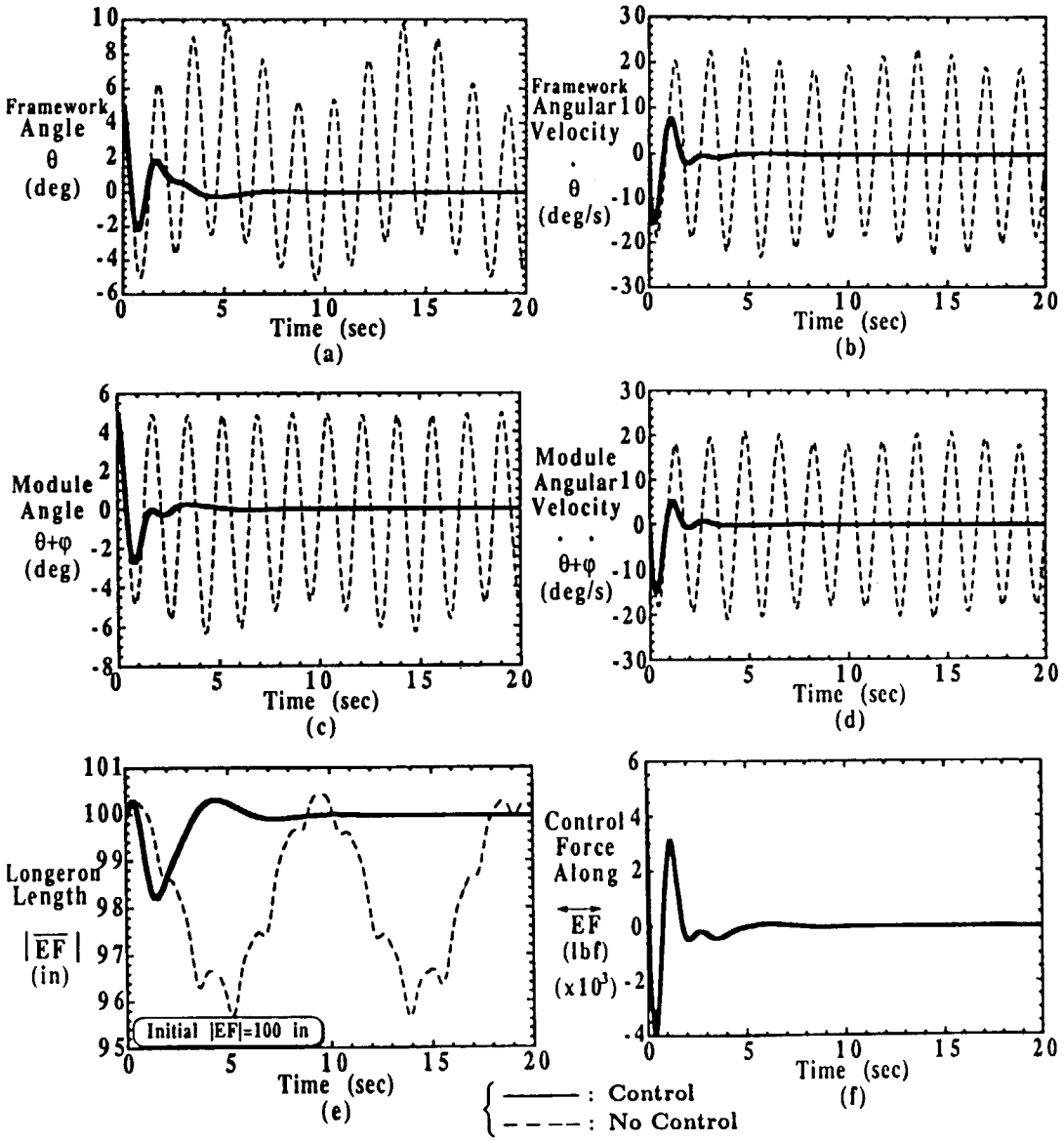


CMG CONTROL SIMULATION RESULTS

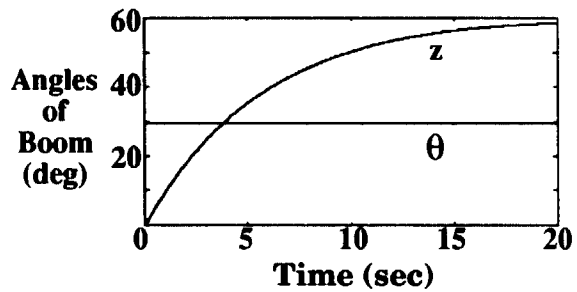


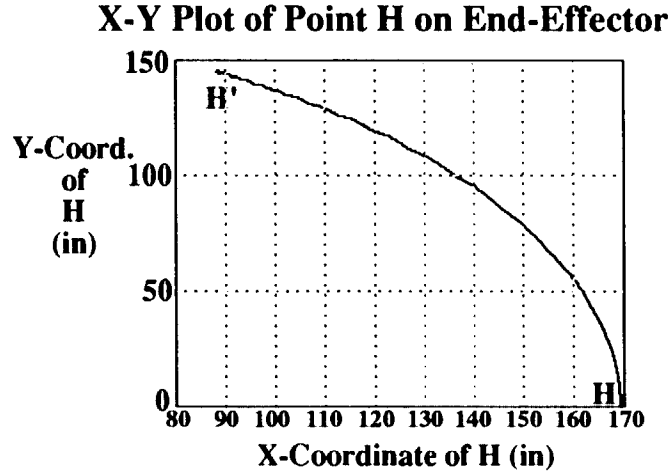
SIMULATION RESULTS (I)

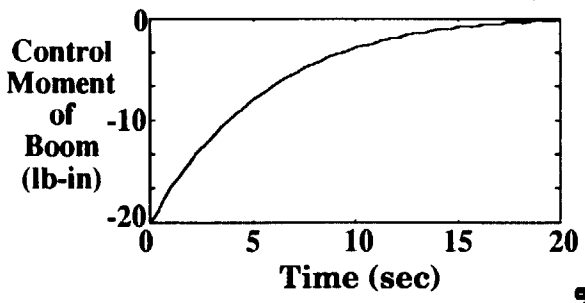


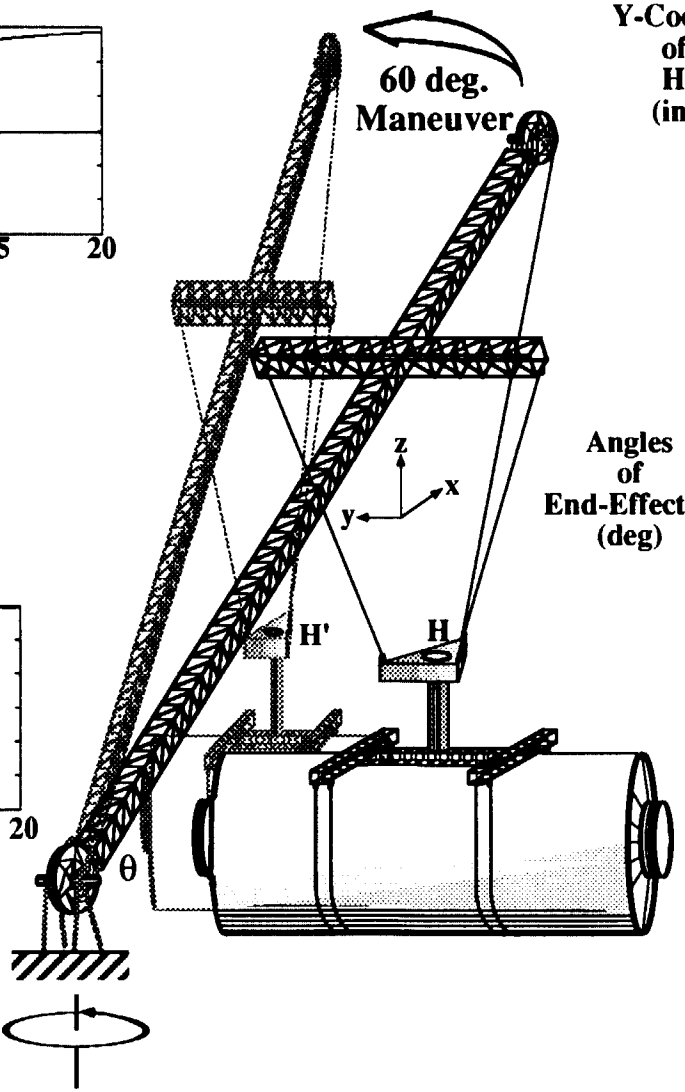


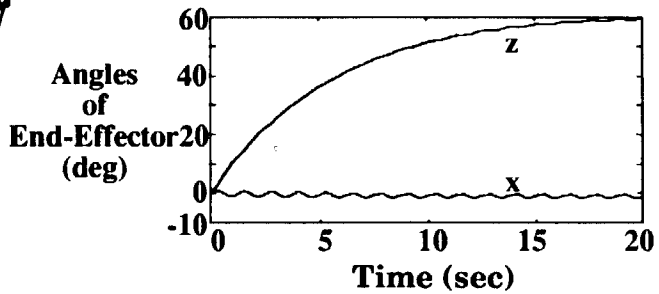
SLEWING SIMULATION RESULTS

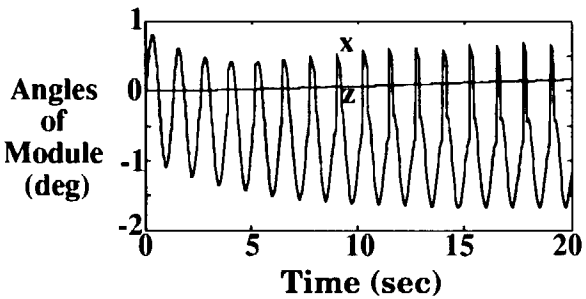




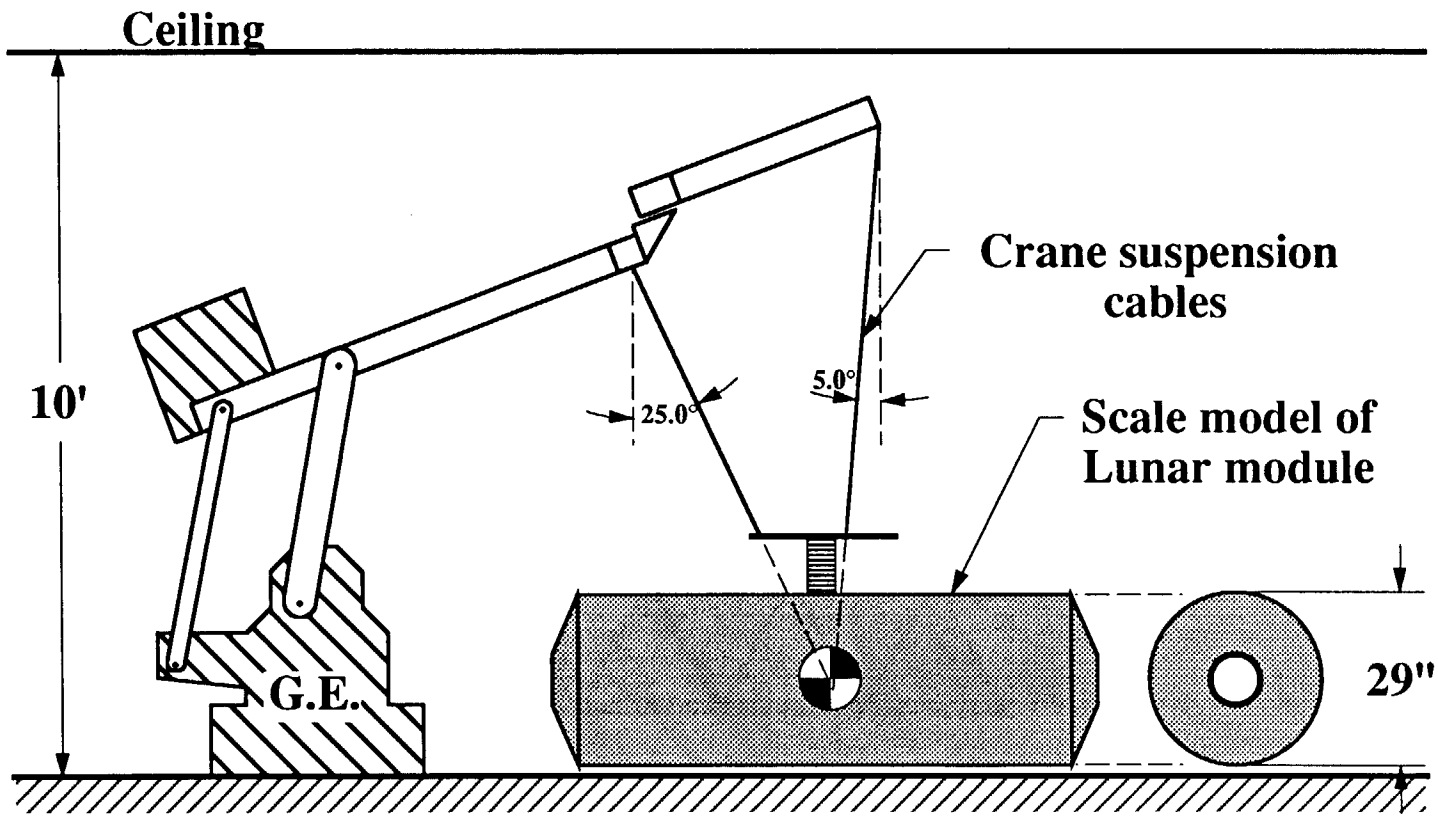




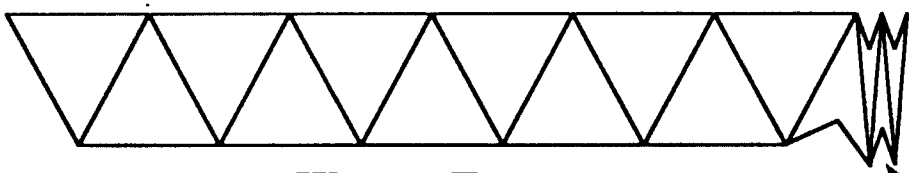




ONE-SIXTH SCALE LUNAR CRANE TEST-BED USING G.E. ROBOT FOR GLOBAL MANIPULATION.

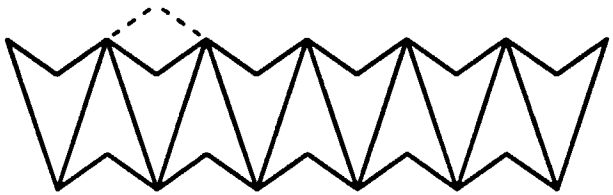


BASIC DEPLOYABLE TRUSS APPROACHES

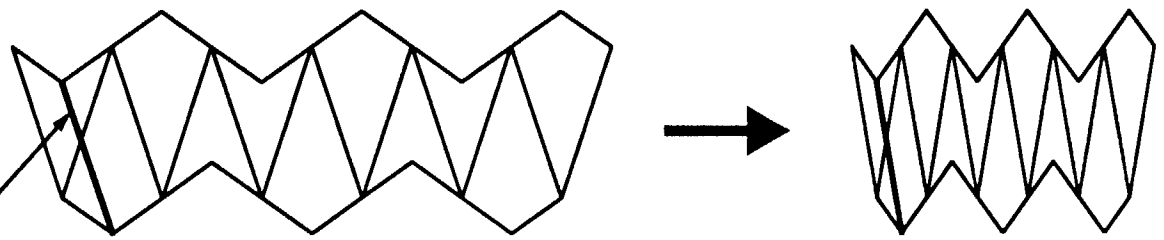


Warren Truss

Standard Sequential Packaging

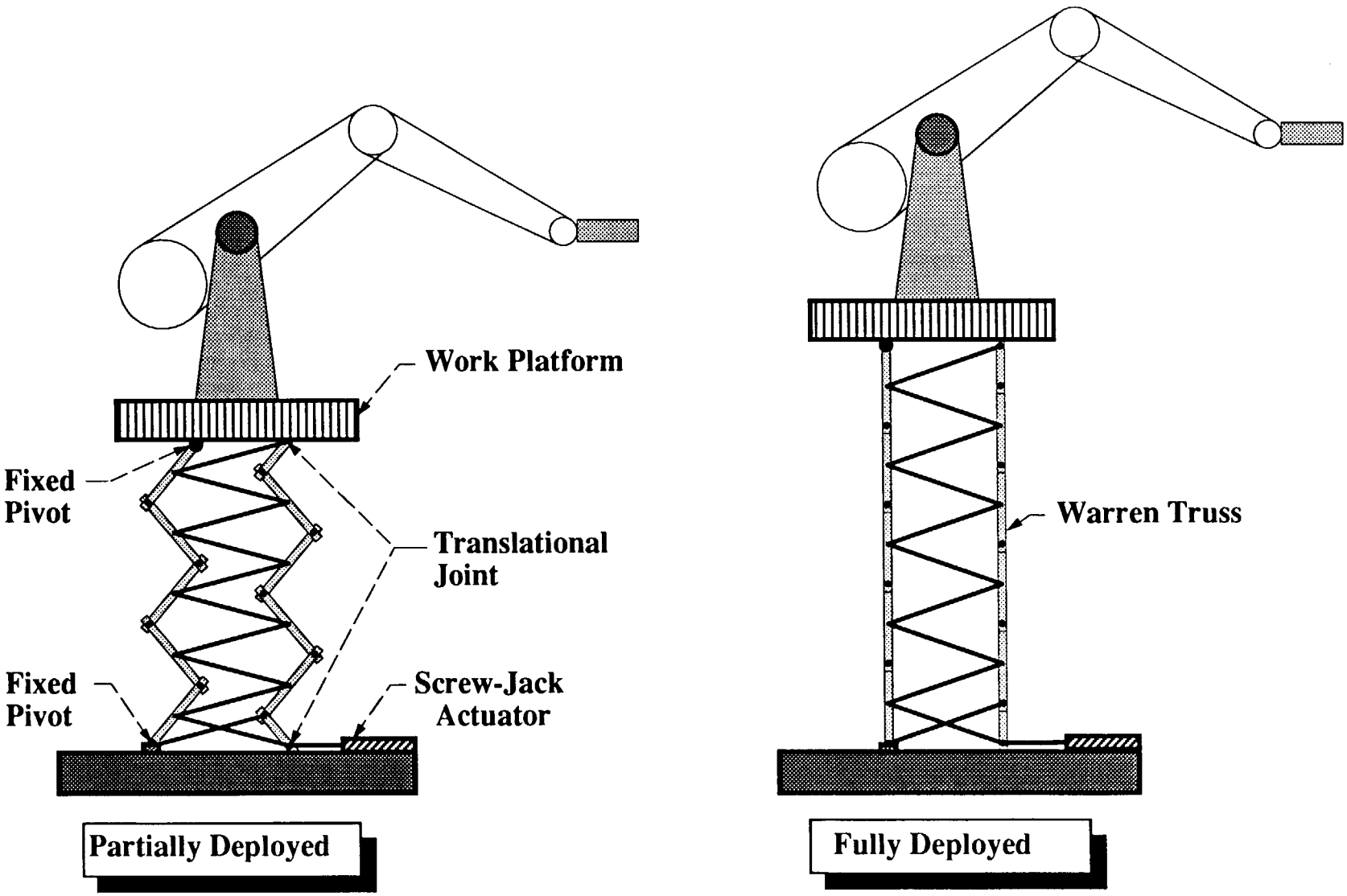


Sequentially Deployable Truss

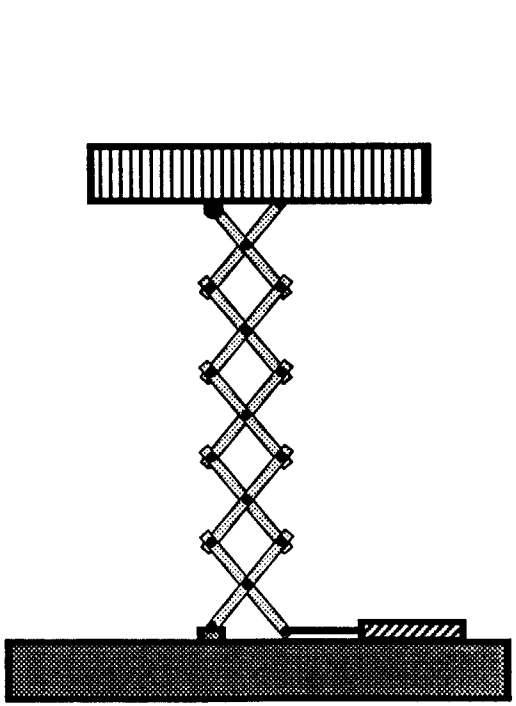


Synchronously Deployable Truss

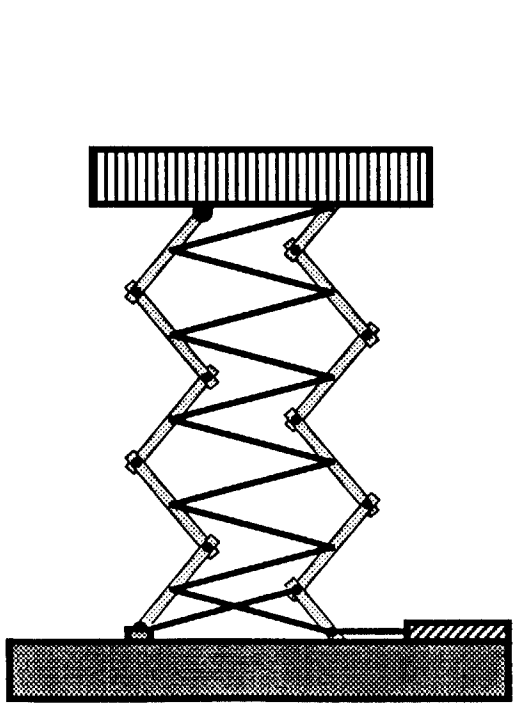
BI-PANTOGRAPH ELEVATOR PLATFORM

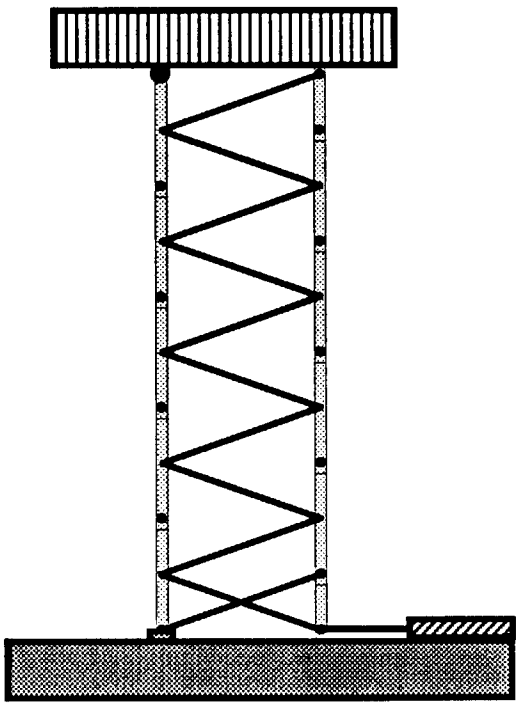


COMPARISON OF ELEVATOR PLATFORMS



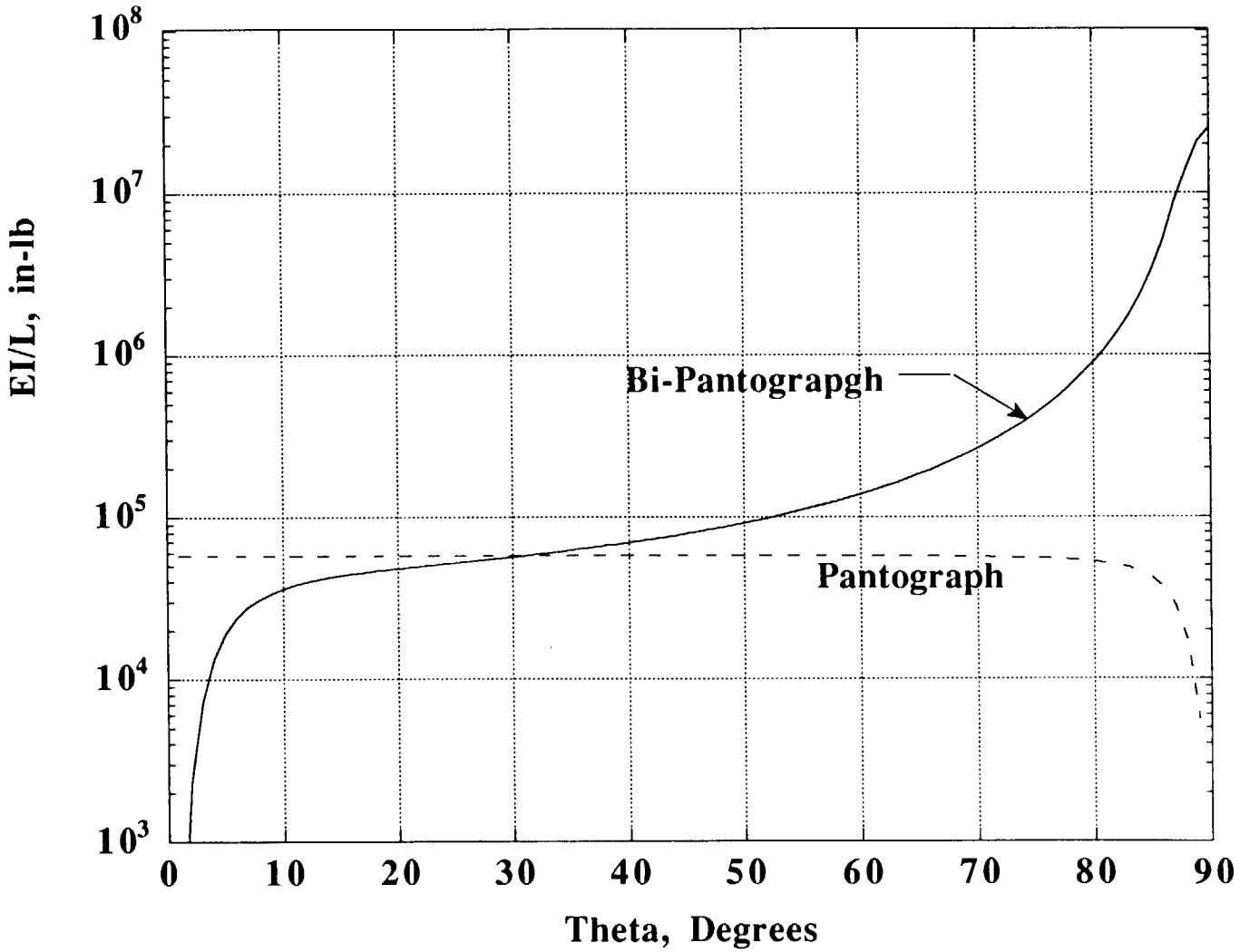
Pantograph



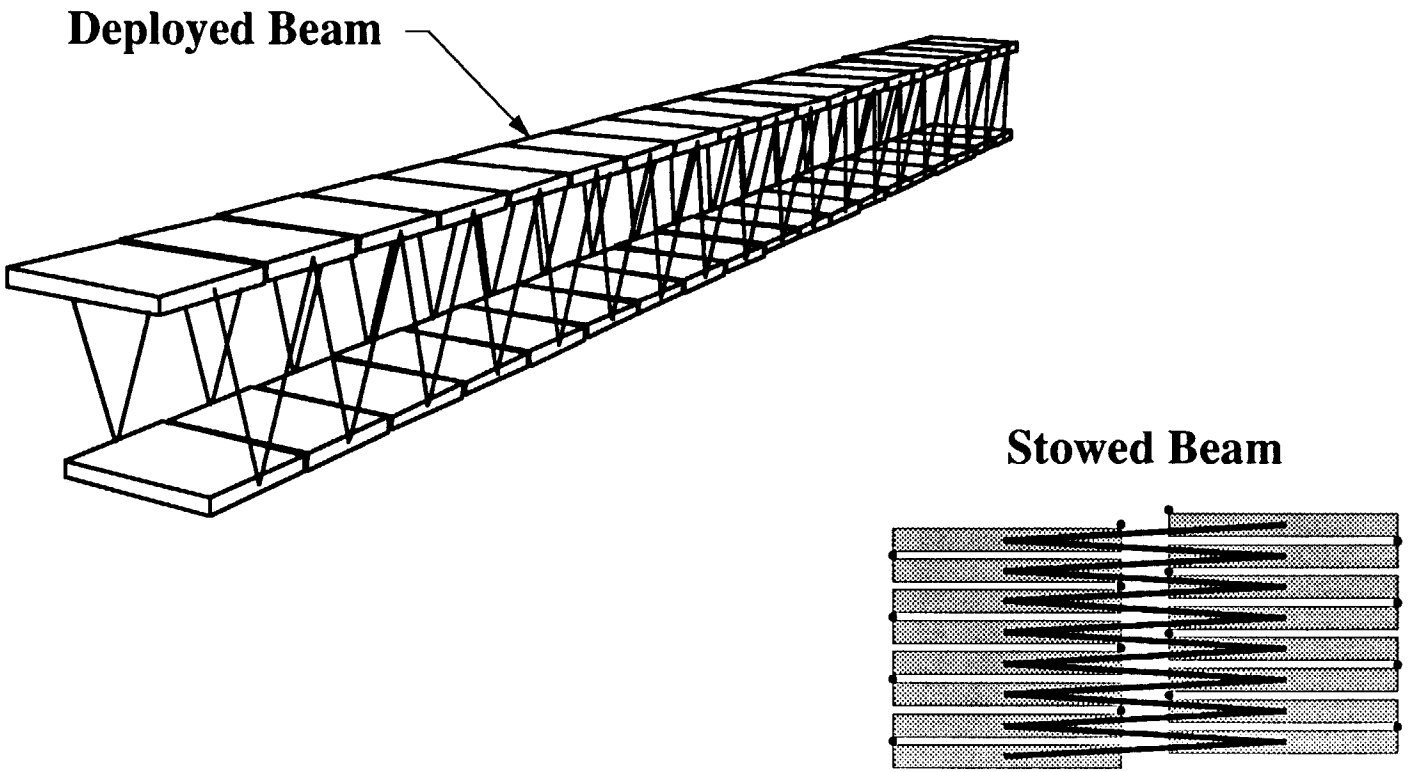


Bi-Pantograph

BI-PANTOGRAPH VS PANTOGRAPH STIFFNESS

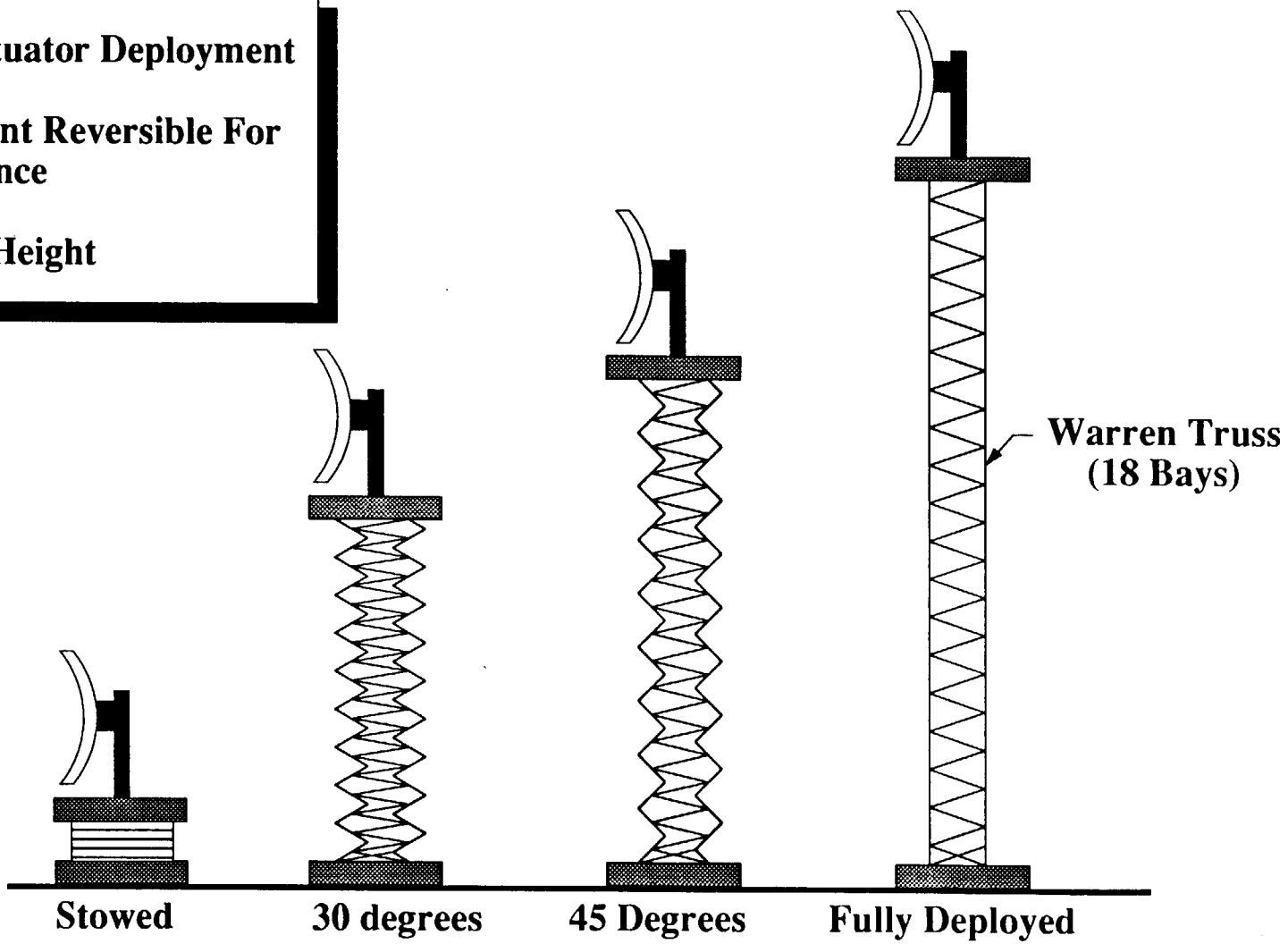


PERSPECTIVE OF BI-PANTOGRAPH BEAM

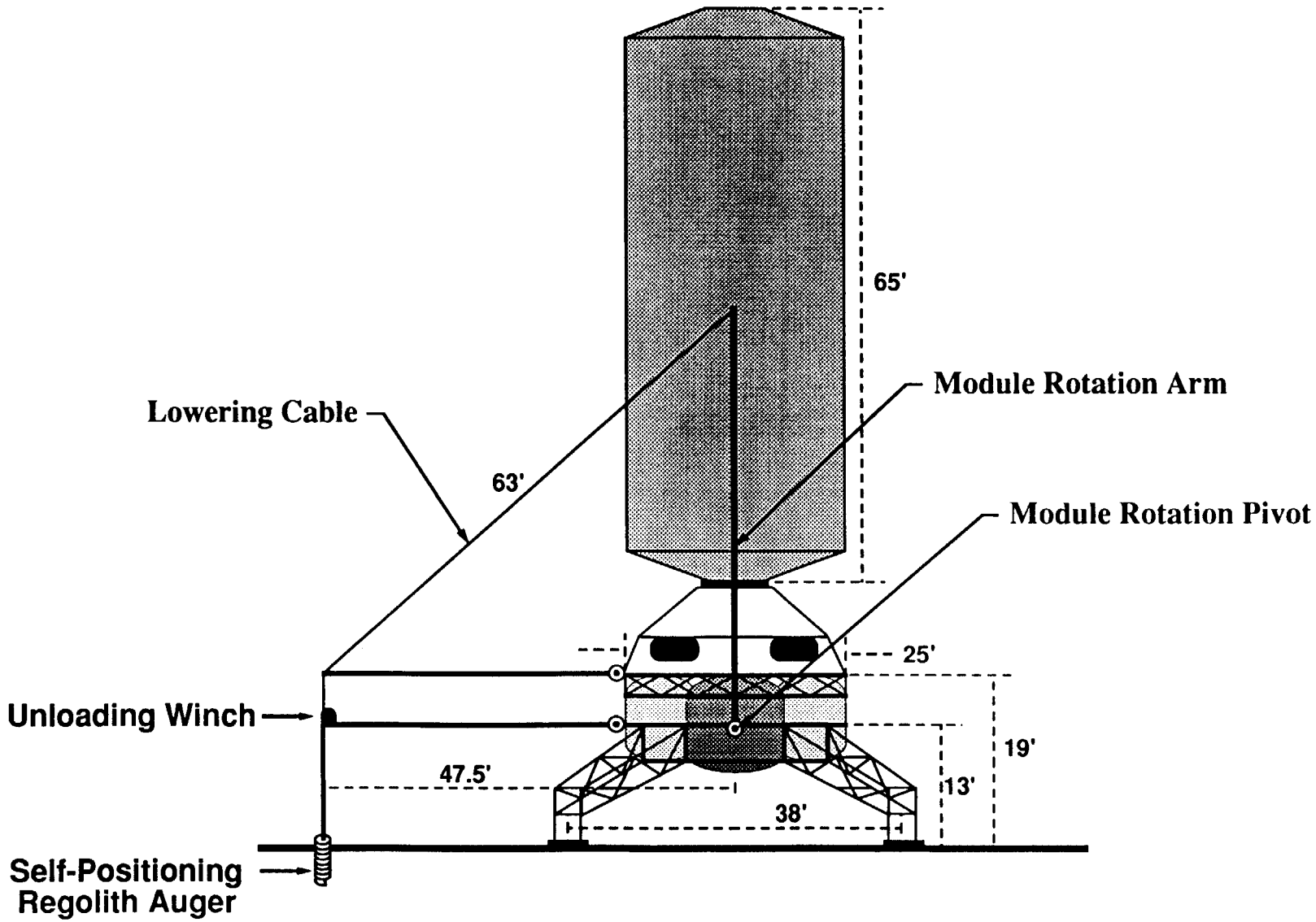


BI-PANTOGRAPH SYNCHRONOUSLY DEPLOYABLE TOWER/BEAM

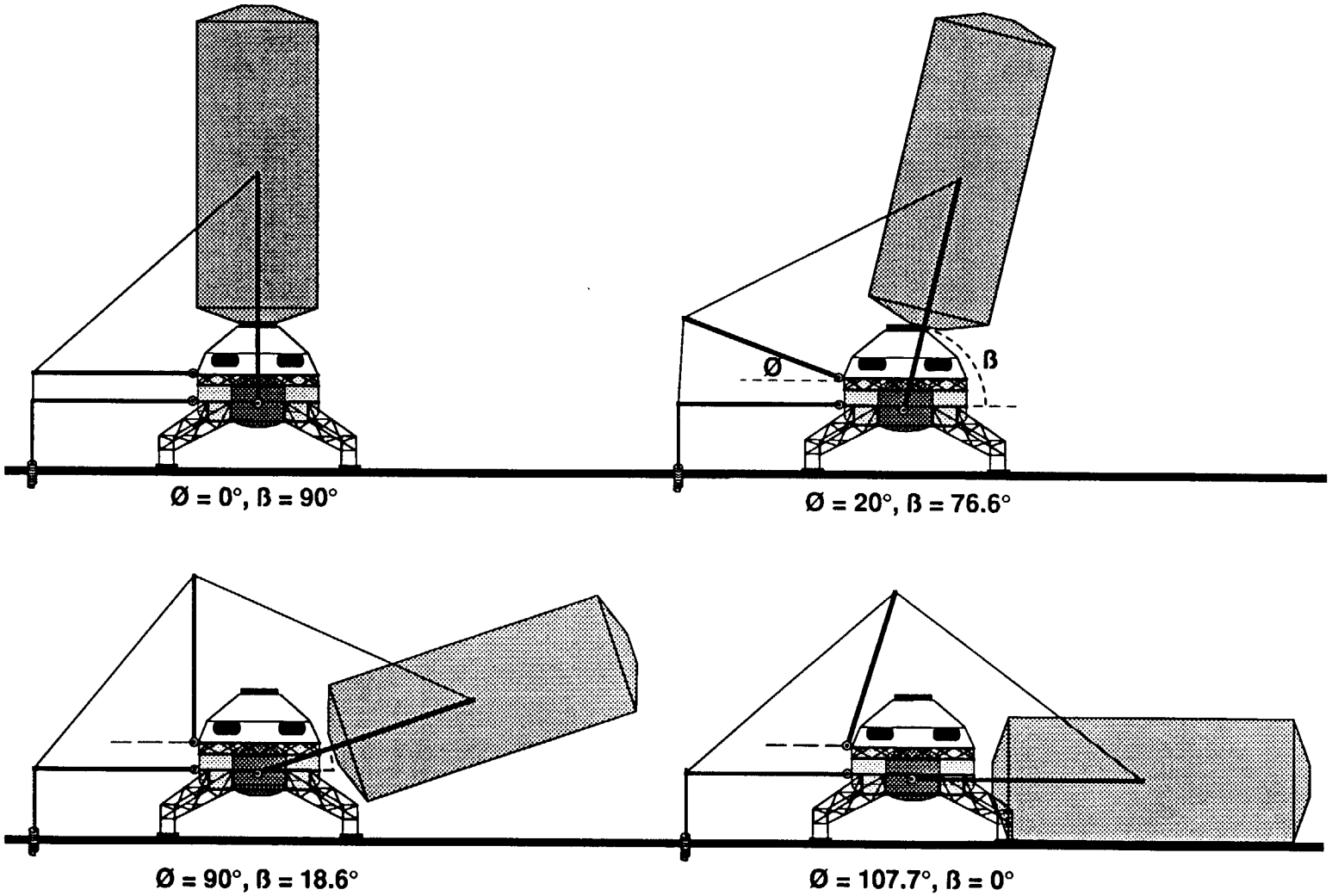
- Single Actuator Deployment
- Deployment Reversible For Maintenance
- Variable Height



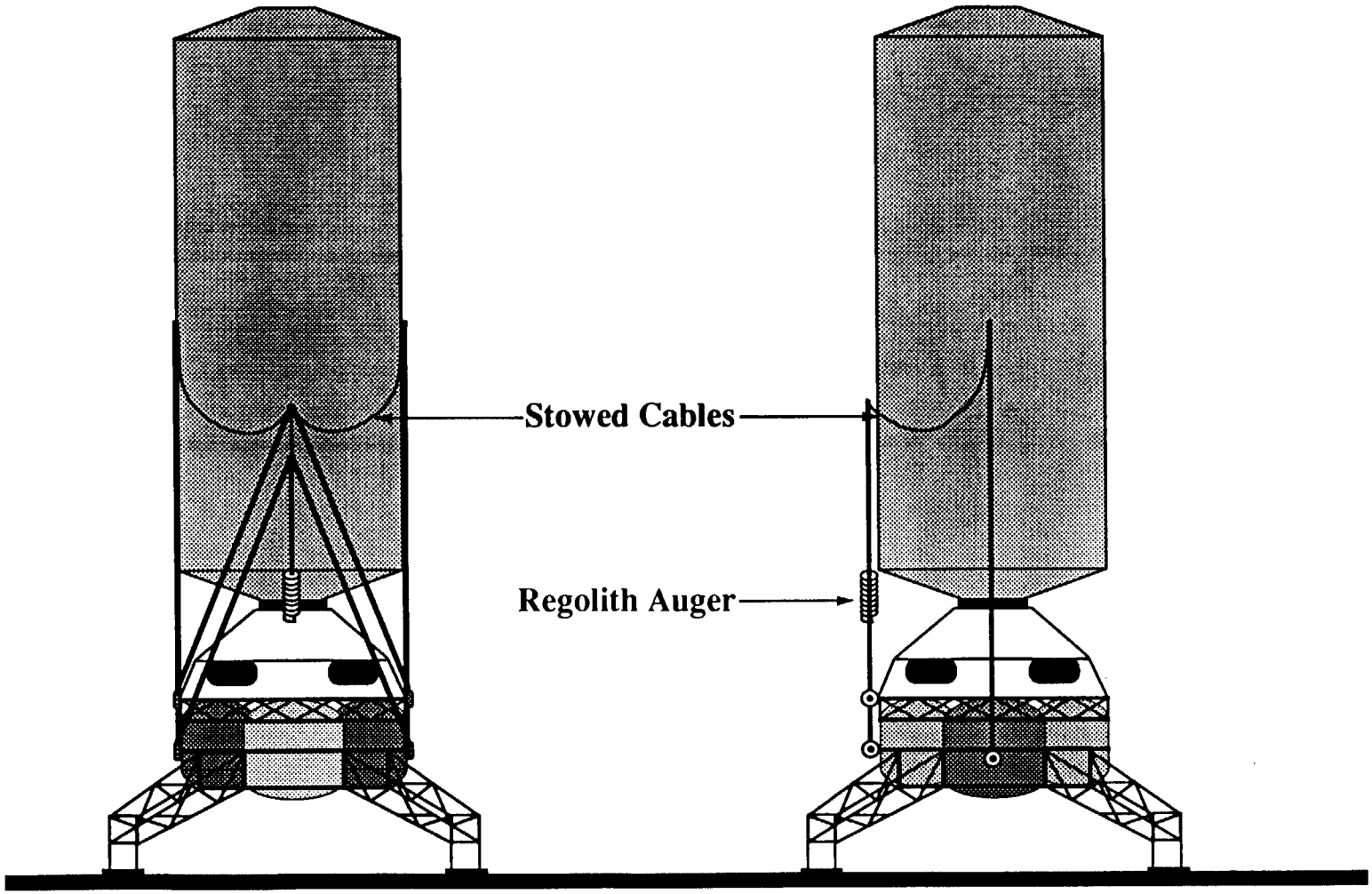
LUNAR MODULE OFF-LOADING CONCEPT



LUNAR MODULE OFF-LOADER CONCEPT DURING VARIOUS PHASES OF OPERATION



MODULE OFF-LOADER CONCEPT PACKAGED
(REAR & SIDE VIEWS)



STARBURST DEPLOYABLE PRECISION REFLECTOR

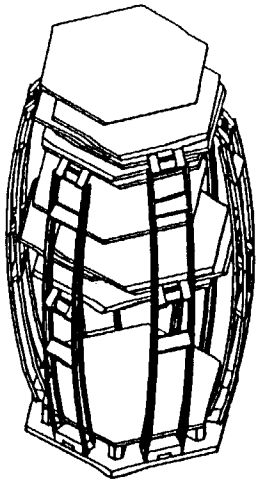
Features

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

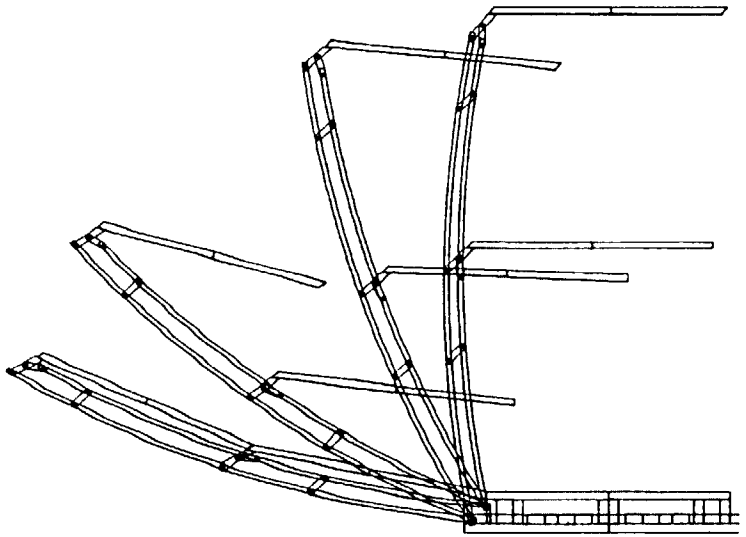
Applications

- LDR-type telescopes
- Microwave radiometers
- Solar concentrators

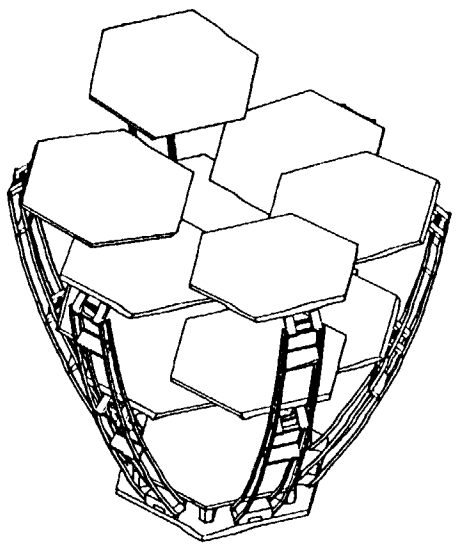
"STAR BURST" CONCEPT HAS POTENTIAL FOR DEPLOYING 20 METER DIAMETER PRECISION DEFLECTOR



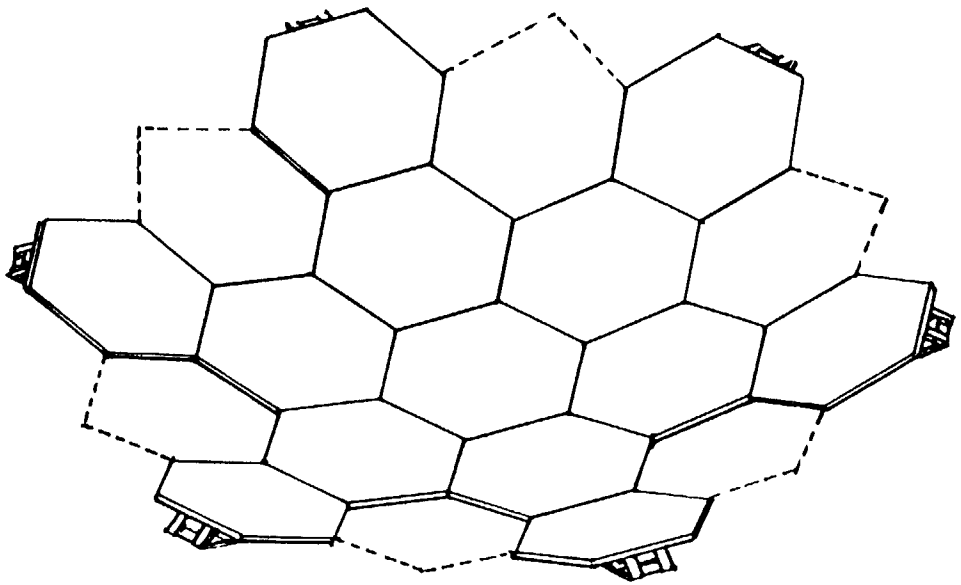
Packaged reflector



Deployment Mechanism

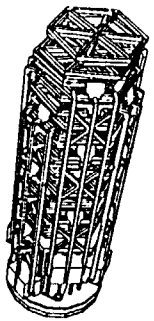


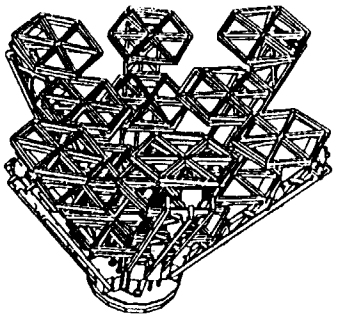
Semi-deployed

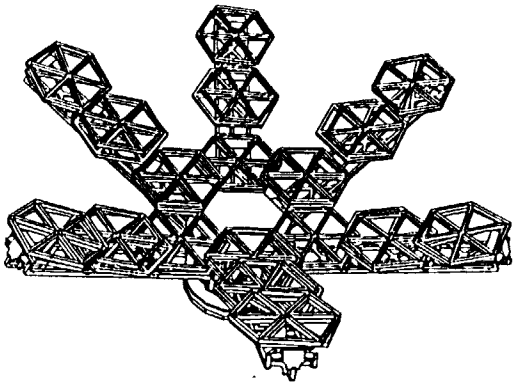


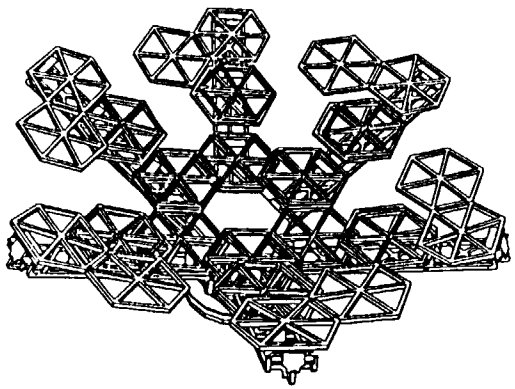
Deployed Reflector

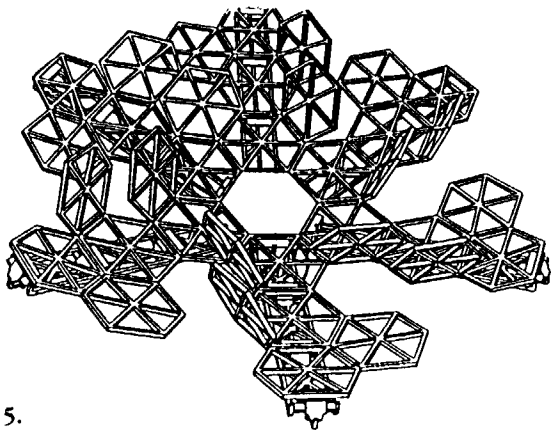
STARBURST DEPLOYABLE PRECISION REFLECTOR

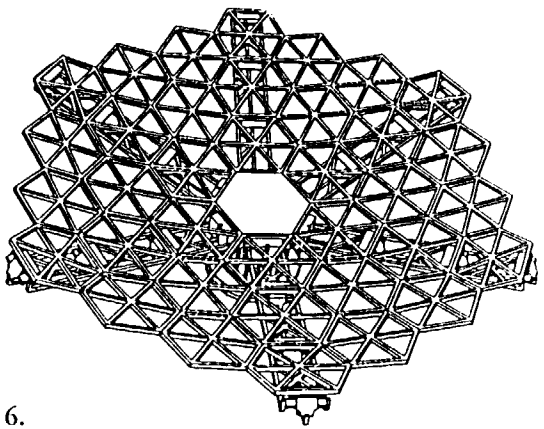
1. 

2. 

3. 

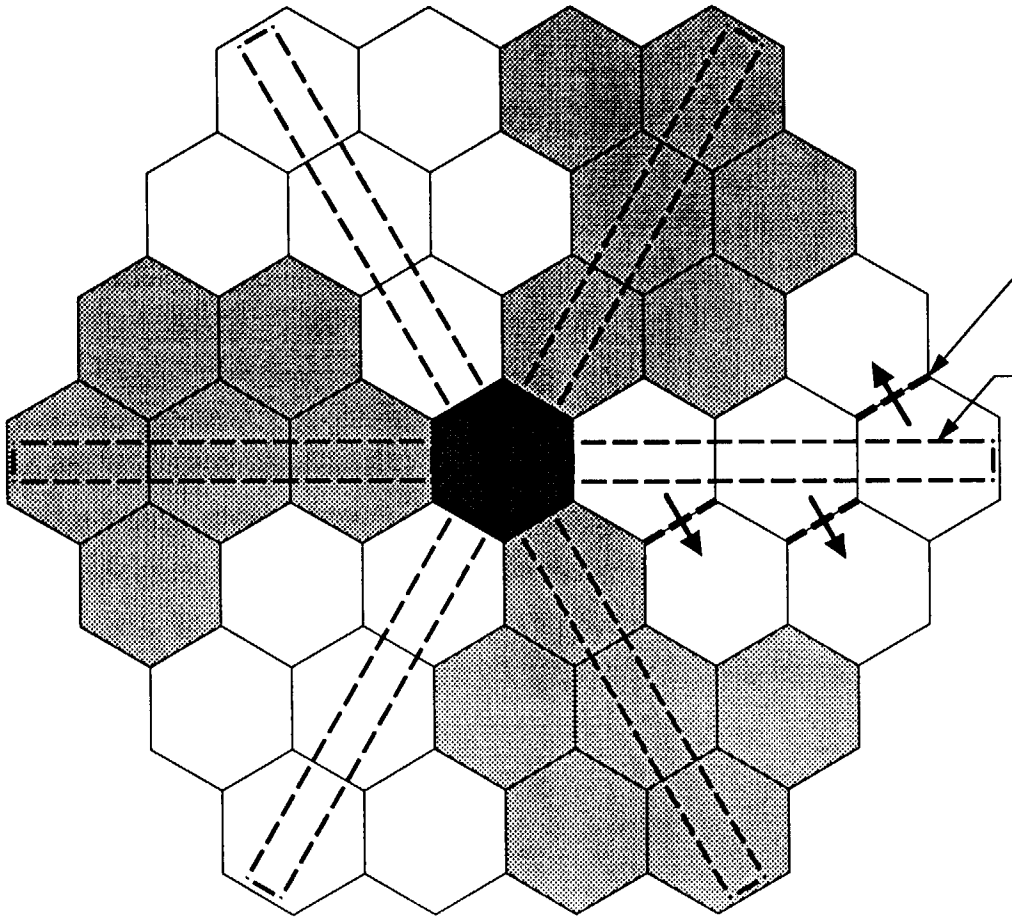
4. 

5. 

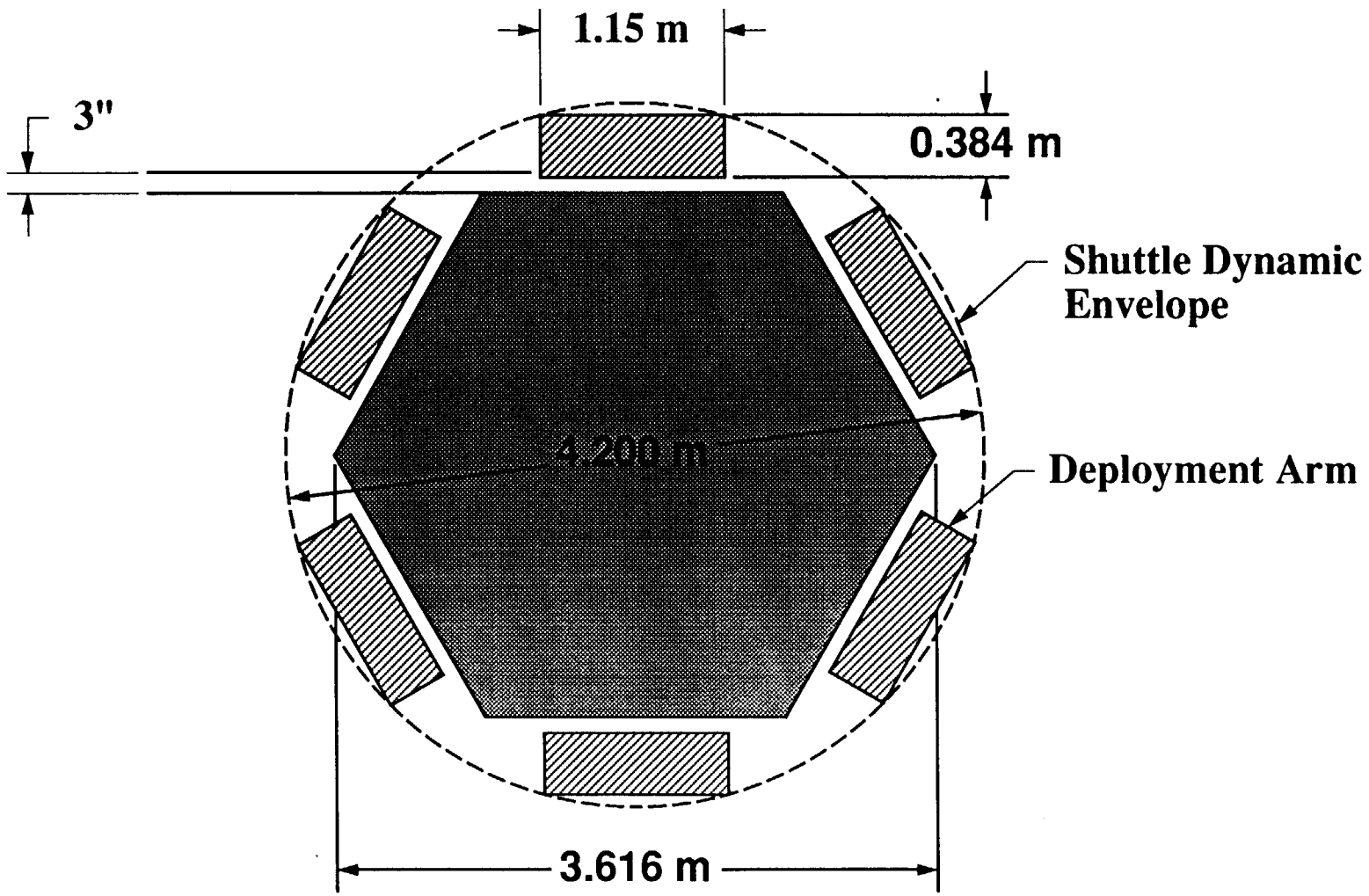
6. 

3 RING REFLECTOR DEPLOYMENT SCHEME

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

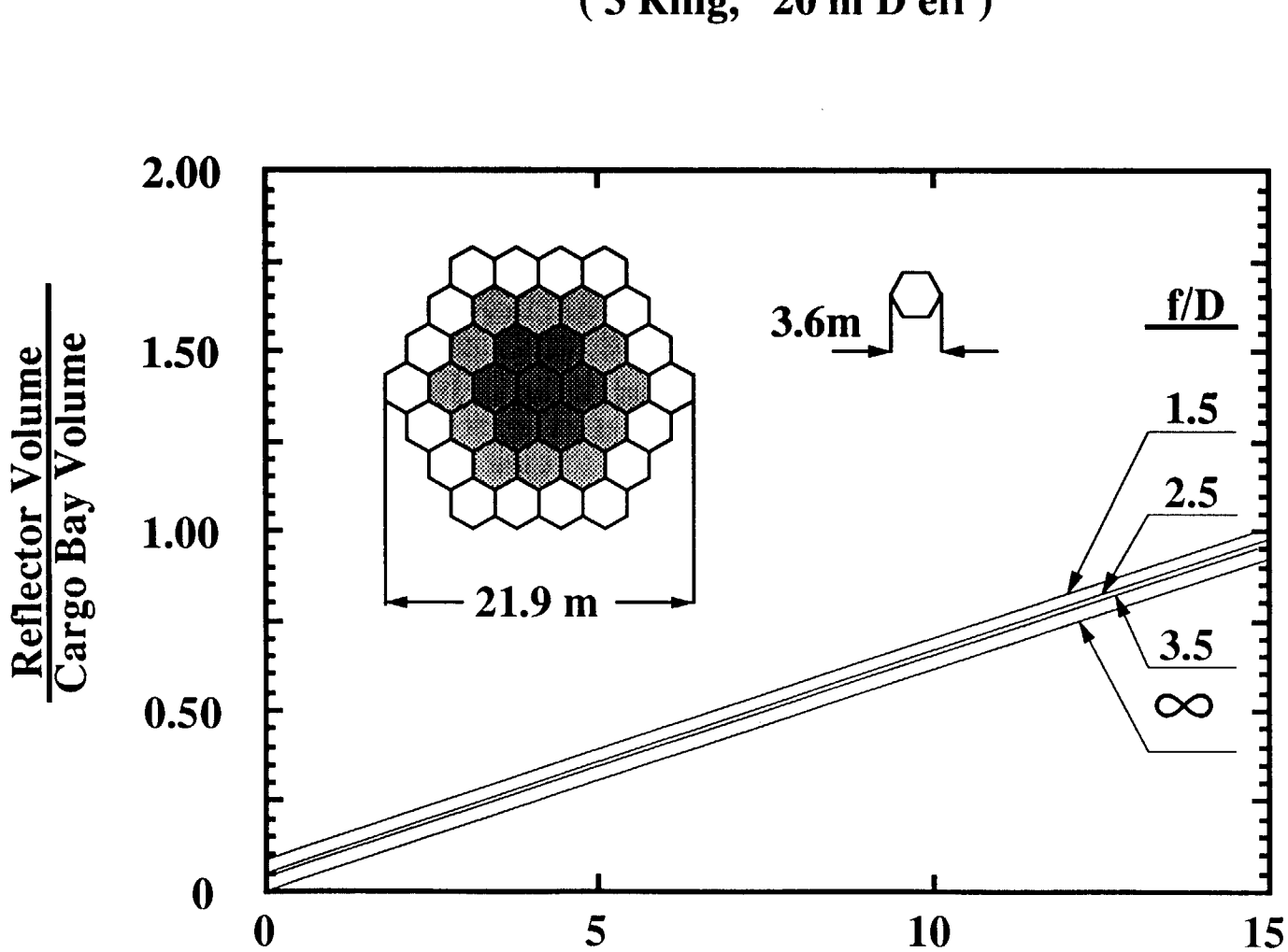


CROSS-SECTION OF PACKAGED STARBURST REFLECTOR

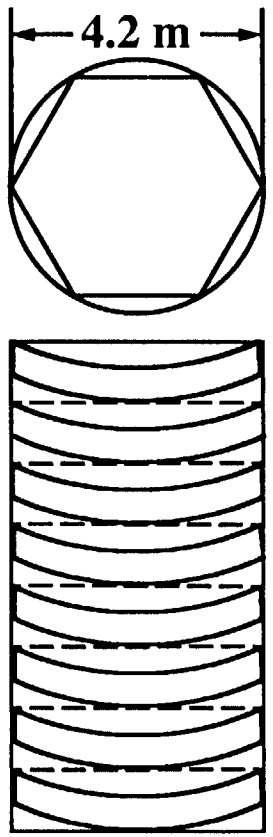


FOCAL POINT AND THICKNESS PACKAGING CONSIDERTIONS

(3 Ring, 20 m D eff)



Cargo Bay Representation



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**

Center for Space Construction
Third Annual Symposium
November 21, 22, 1991

List of External Attendees

Robert Bell
Ball Aerospace
Mail Stop RA-3
P.O. Box 1062
Boulder, CO 80306
(303) 939-6669

Reginald Berka
NASA - Johnson Space Center
Mail Code ER-4
Houston, TX 77058
(713) 483-0144

Jeri W. Brown
NASA - Johnson Space Center
Mail Code SP
NASA Road 1
Houston, TX 77058
(713) 483-6036

Harold G. Bush
NASA - Langley Research Center
MS 199
Hampton, VA 23665-5225
(804) 864-3102

Dr. George E. Cannon Jr.
United Engineers and Constructors
P.O. Box 5888
Denver, CO 80217
(303) 843-2727

John Ciciora
Johnson Engineering
3055 Center Green Drive
Boulder, CO 80301-5406
(303) 449-8152

Hugh Davis
Ball Aerospace
P.O. Box 1062
Boulder, CO 80306
(303) 939-4022

Ted Doederlein
Edwards AFB
OLAC PL/STSS
Edwards AFB, CA 93523-5000
(805) 275-5483

Al Doherty
Explosive Fabricators
1301 Courtesy Road
Louisville, CO 80027
(303) 666-2250

Ralph Eberhardt
Martin Marietta Space Systems
7323 S. Tamarac St.
Englewood, CO 80112
(303) 977-4183

Andy Franklin
Bechtel Group, Inc.
Mail Stop 50/17/D20
P.O. Box 193965
San Francisco, CA 94119
(415) 768-8778

Captain Mark S. Gibson
United States Air Force
Headquarters BMO/MVEG
NAFB, CA 92409-6468
(714) 382-5695

Robert J. Hayduk
NASA Headquarters
Code RM
Washington, DC 20546
(202) 453-2962

Dr. Murray Hirschbein
NASA Headquarters
Code RM
Washington, DC 20546
(202) 453-2859

Adrian J. Hooke
Jet Propulsion Lab
Mail Code 301-235
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-3063

Dr. Steve Howe
Los Alamos National Labs
Mail Stop E-552
P.O. Box 1663
Los Alamos, NM 87545
(505) 667-6787

Clyde (Chip) Jones
NASA - Marshall Space Flight Center
Code EH 42
Huntsville, AL 35812
(205) 544-2701

Major Kenneth J. Knox
USAF Academy
DFCE
Colorado Springs, CO 80840
(719) 472-3618

Al Kullas
Albert J. Kullas, Inc.
5088 W. Maplewood Ave.
Littleton, CO 80123
(303) 794-2013

Eric Madaras
NASA - Langley Research Center
Mail Stop 231
Hampton, VA 23665
(804) 864-4993

Merle McKenzie
Jet Propulsion Lab
Mail Code 180-900
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2577

Alfred Meintel
NASA - Langley Research Center
Mail Stop 152-D
Hampton, VA 23665-5225
(804) 864-1596

James Mohl
Ball Space Systems Division
CO-10B
P.O. Box 1062
Boulder, CO 80306
(303) 939-5064

Tom Nelson
Martin Marietta Astronautics Group
Mail Stop B4480
P.O. Box 179
Denver, CO 80201
(303) 971-8601

Paul S. Nowak
Colorado State University
Fort Collins, CO 80523
(303) 491-7899

Steven G. Oxner
Rockwell International
Mail Code AC-59
12214 Lakewood Blvd.
Downey, CA 90241-7009
(213) 922-5440

Dr. Levent Ozdemir
Colorado School of Mines
Golden, CO 80401
(303) 273-3419

Dale E. Phinney
Lockheed Engineering & Sciences Co.
Mail Code C-19
2400 NASA Road 1
Houston, TX 77258
(713) 333-6217

Dr. Roland Pitts
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 231-1929

D. Michael Pogue
Johnson Engineering
3055 Center Green Drive
Boulder, CO 80301-5406
(303) 449-8152

R. Stephen Price
Martin Marietta Astronautics Group
Mail Stop DC8082
P.O. Box 179
Denver, CO 80201
(303) 977-5143

Ed Repic
Rockwell International
Mail Code AD-21
12214 Lakewood Blvd.
Downey, CA 90241-7009
(213) 922-3487

Vern Rogowski
Ball Aerospace
P.O. Box 1062
Boulder, CO 80306
(303) 939-4657

Dr. Eric Schmitz
Martin Marietta Astronautics Group
Mail Stop 4372
P.O. Box 179
Denver, CO 80201
(303) 971-7144

Curtis L. Schroeder
Ball Aerospace
P.O. Box 1062
Boulder, CO 80306
(303) 939-6504

William R. Sharp
Colorado School of Mines
1500 Illinois Street
Golden, CO 80401
(303) 273-3762

Frank Thomas
NASA - Marshall Space Flight Center
Mail Code ED 52
Huntsville, AL 35812
(205) 544-4936

Robert Wolf
USAF Academy
USAF Academy/DFAS
Colorado Springs, CO 80840
(719) 472-4110