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Lenticular Communication Satellite

with

Gravity-Gradient Stabilization

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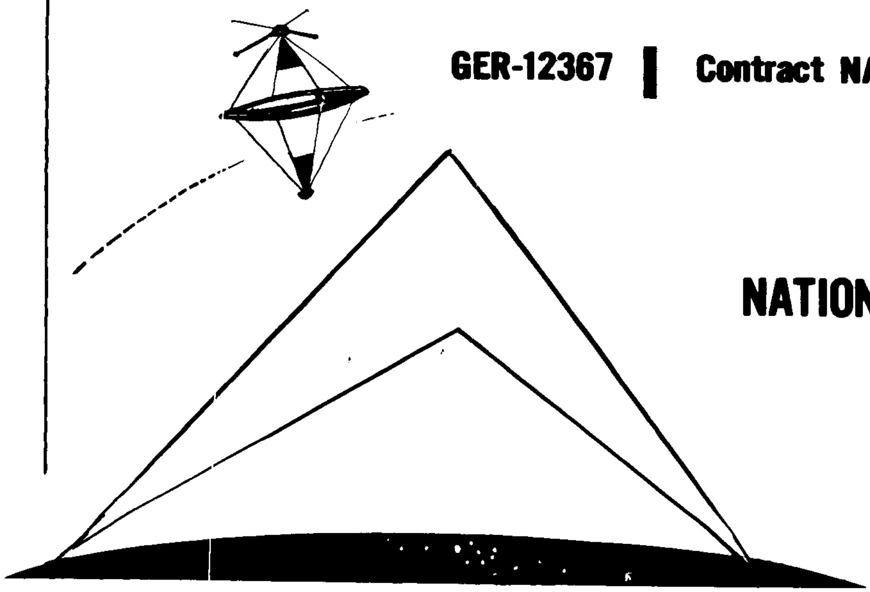

NATIONAL AERONAUTICS and SPACE ADMINISTRATION

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ABSTRACT

GER 12367

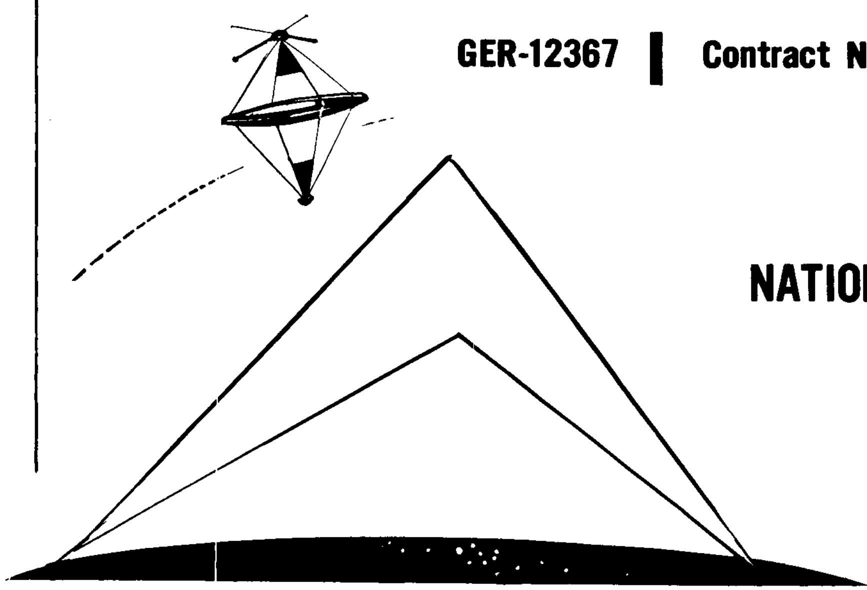
This report consists of a brief description of concepts, program developments, and typical performance estimates of gravity-gradient stabilized, lenticular passive communication satellites. The program was funded through the OSSA, Division of Communications and Navigation, under Contract NAS1-3114. More detailed discussions are contained in the references listed in this report.

NASA CR- 66054

Lenticular Communication Satellite

with

Gravity-Gradient Stabilization



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CONTENTS

INTRODUCTION

This report summarizes development of the lenticular communication satellite. Comparisons of the lenticular communication satellite with other passive systems are made.

More detailed information is obtainable from the references given in the List of References at the end of the report.

The work reported was accomplished by Goodyear Aerospace Corporation for National Aeronautics and Space Administration, Langley Research Center, under Contract NAS 1-3114.

PASSIVE SATELLITE CONCEPT

COMMUNICATION TECHNIQUE

Microwave signals are reflected off satellite surface to provide communications between remote stations.

UNIQUE CAPABILITIES

Natural long life

Station keeping by using solar radiation pressure

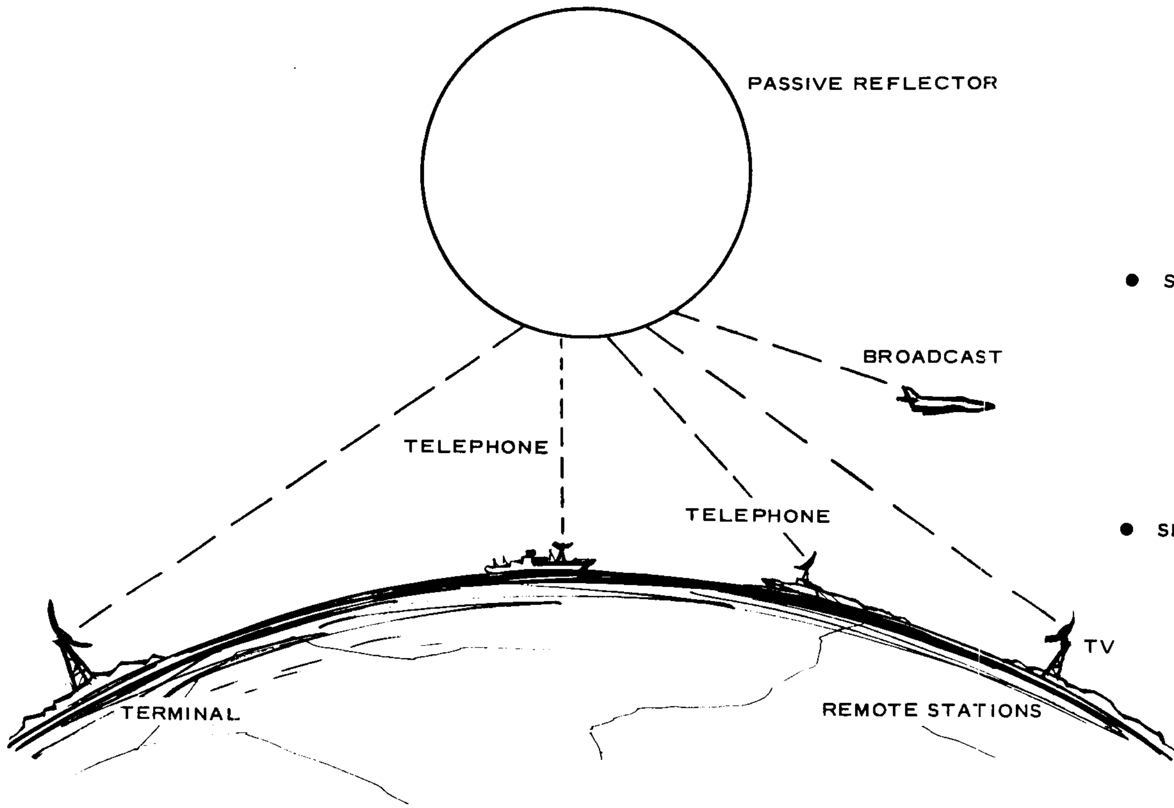
Linear signal response

Wide communications bandwidth

Terminal sharing

Relative immunity to jamming

PASSIVE COMMUNICATION SYSTEM PERFORMANCE



- SERVICE
  - TELETYPE - CW
  - TELEPHONE
  - TELEVISION
  - BROADCAST
- SIMULTANEOUS OPERATIONS

By trading ground-terminal capability into a master terminal duplex, simultaneous communications are possible with a variety of remote stations of lesser capability.

PASSIVE SATELLITE MILESTONES

Echo I - 100-ft-diameter, ultrathin, metalized mylar sphere. Satellite demonstrated:

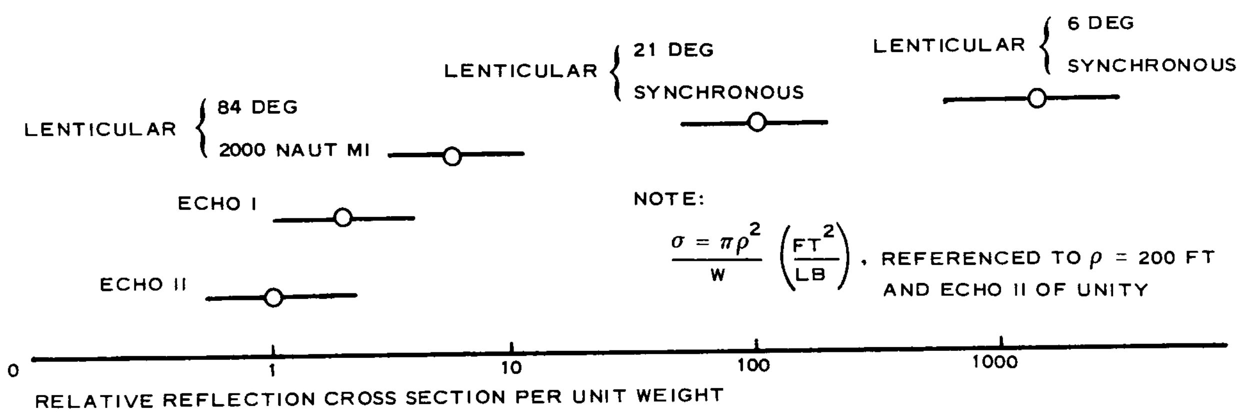
1. Capability of establishing teletype facsimile, two-way voice and television communications

2. Feasibility of deploying large, inflatable satellites in orbit

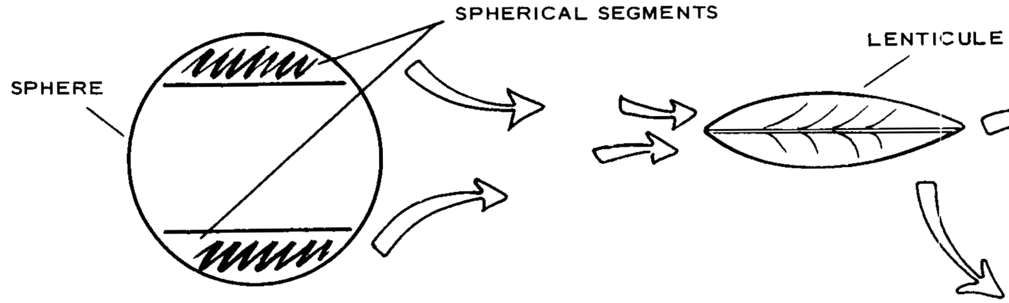
Echo II - 135-ft-diameter sphere made of aluminum/mylar laminate - larger rigidized structure

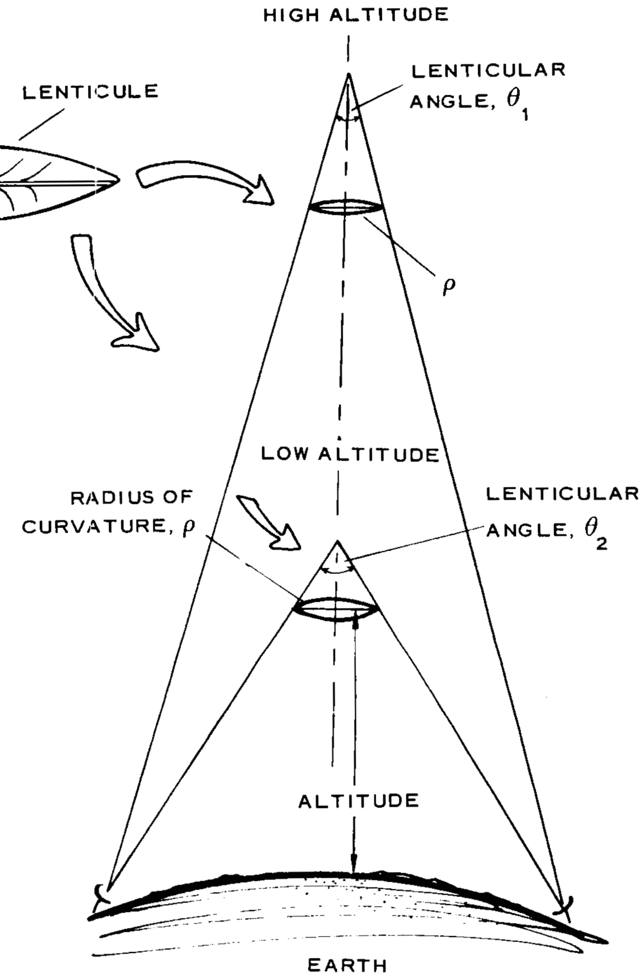
Lenticular satellite feasibility study - (July 1963 to October 1965)

Studies and ground tests indicate that trades between stabilization, altitude, and ground coverage will give order-of-magnitude improvements in reflectivity-to-weight ratio of the lenticular configuration compared with Echo-type spheres.



LENTICULAR CONFIGURATION CONCEPT

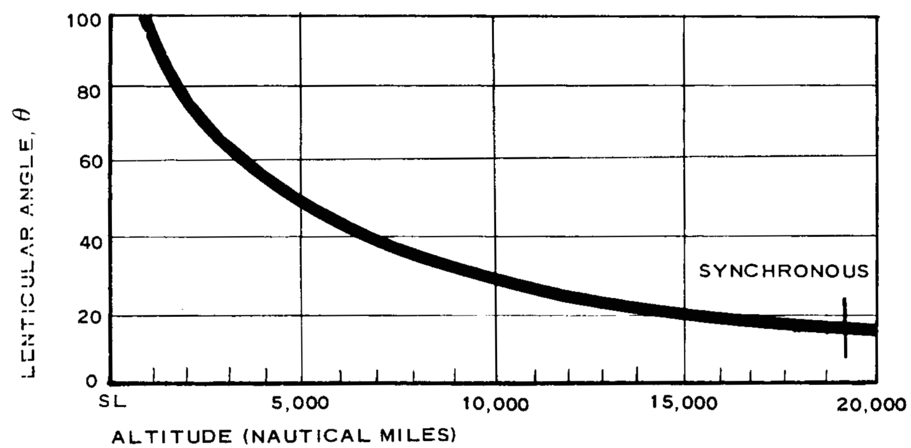




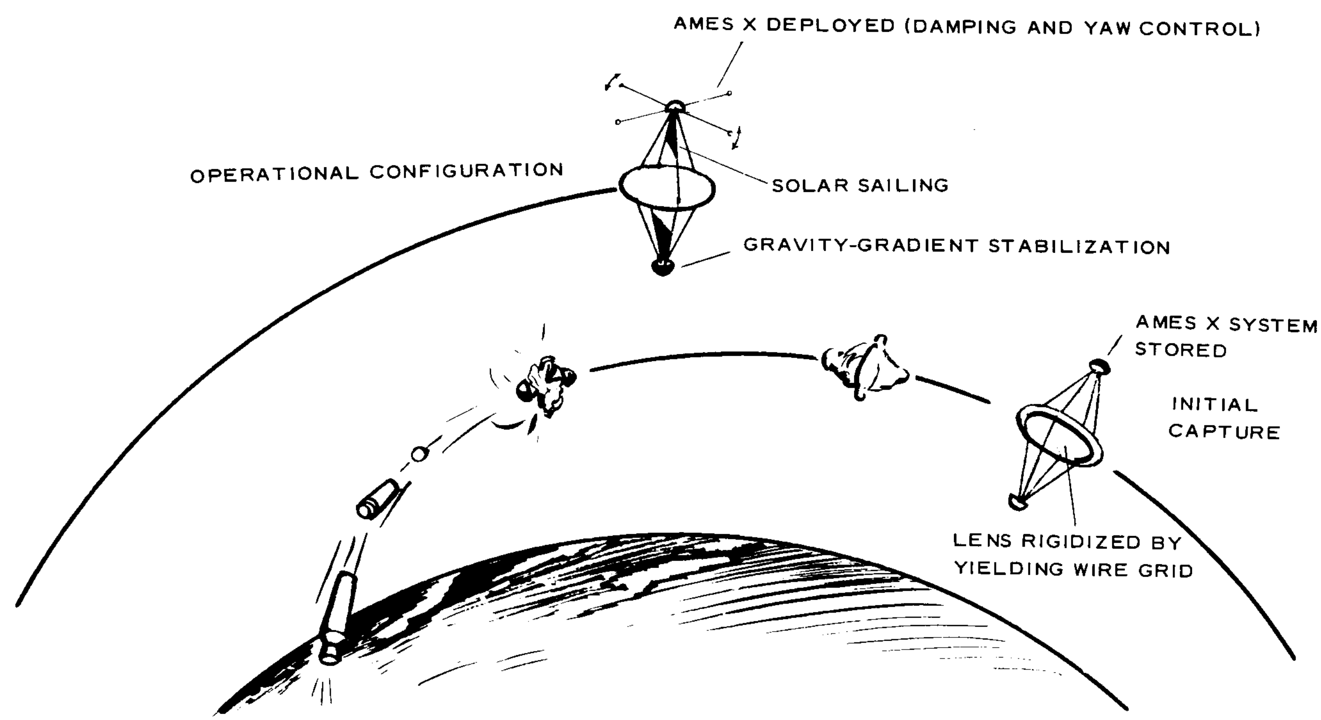
HORIZON-TO-HORIZON COVERAGE

NOTE:

FOR GROUND ANTENNA ELEVATION ANGLE = 5 DEG



LENTICULAR CONFIGURATION PRINCIPLE



LENTICULAR SATELLITE PROGRAM

Objectives - **To determine feasibility of stabilizing the lenticular satellite passively by means of earth's gravity-gradient field**

To determine feasibility of rigidized RF lens, utilizing wire-grid/photolyzable-film materials

LENTICULAR FEASIBILITY STUDY

KEY RESEARCH AREAS

Deployment

Dynamics and solar sailing

Structures

Materials

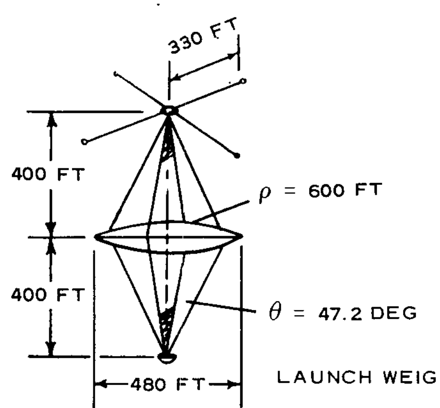
Microwave

PROGRAM SUMMARY (JULY 1963 TO OCTOBER 1965)

1. Feasibility study (Ref 1 and 2)
   - Preliminary design, structural, materials, and dynamics analyses
   - Component, material, and model tests
   - Preliminary design of flight and full-scale units
2. Detailed stabilization, damping, and yaw-control studies (Ref 3, 4, and 5)
   - Gravity-gradient-stabilization definition
   - Initial capture problem analysis
   - Transient response studies
   - Steady-state performance analysis
3. Advanced configuration studies (Ref 4, 5, and 6)
   - Yaw control methods for solar sailing
   - Damping system evaluation
   - Component definition studies
   - Structural studies - tumbling loads, canister separation, weight tradeoff
4. RF analyses and tests (Ref 7 and 8)
   - Theoretical predictions verified by tests
   - Monostatic and bistatic far-field range tests on lenticular configuration
   - Edge-diffraction phenomena noted at zero-degree condition
   - Boom, sail, canister interference investigated
   - RF tests of solid-surface and simulated inflated grid surface
   - RF tests of typical seams and materials
5. Parametric design studies (Ref 9)
   - Determine effect of altitude, lens radius of curvature, and lens included angle on lenticular satellite characteristics and performance
   - Determine component weights and moments of inertia for four lens materials
   - Performance analysis of several typical configurations, low to synchronous orbit

LENTICULAR SATELLITE - THEORETICAL STABILIZATION PERFORMANCE

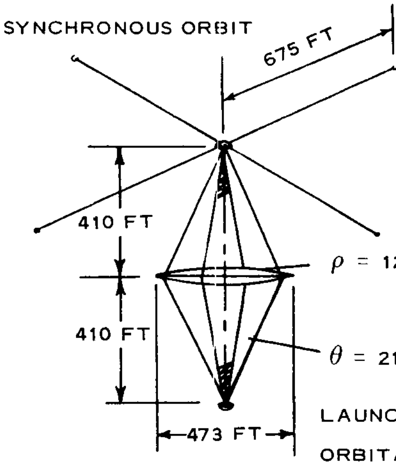
A. 6000-NAUT-MI ALTITUDE



LAUNCH WEIGHT - 2,256.5 LB

ORBITAL WEIGHT - 1,116.5 LB

B. SYNCHRONOUS ORBIT

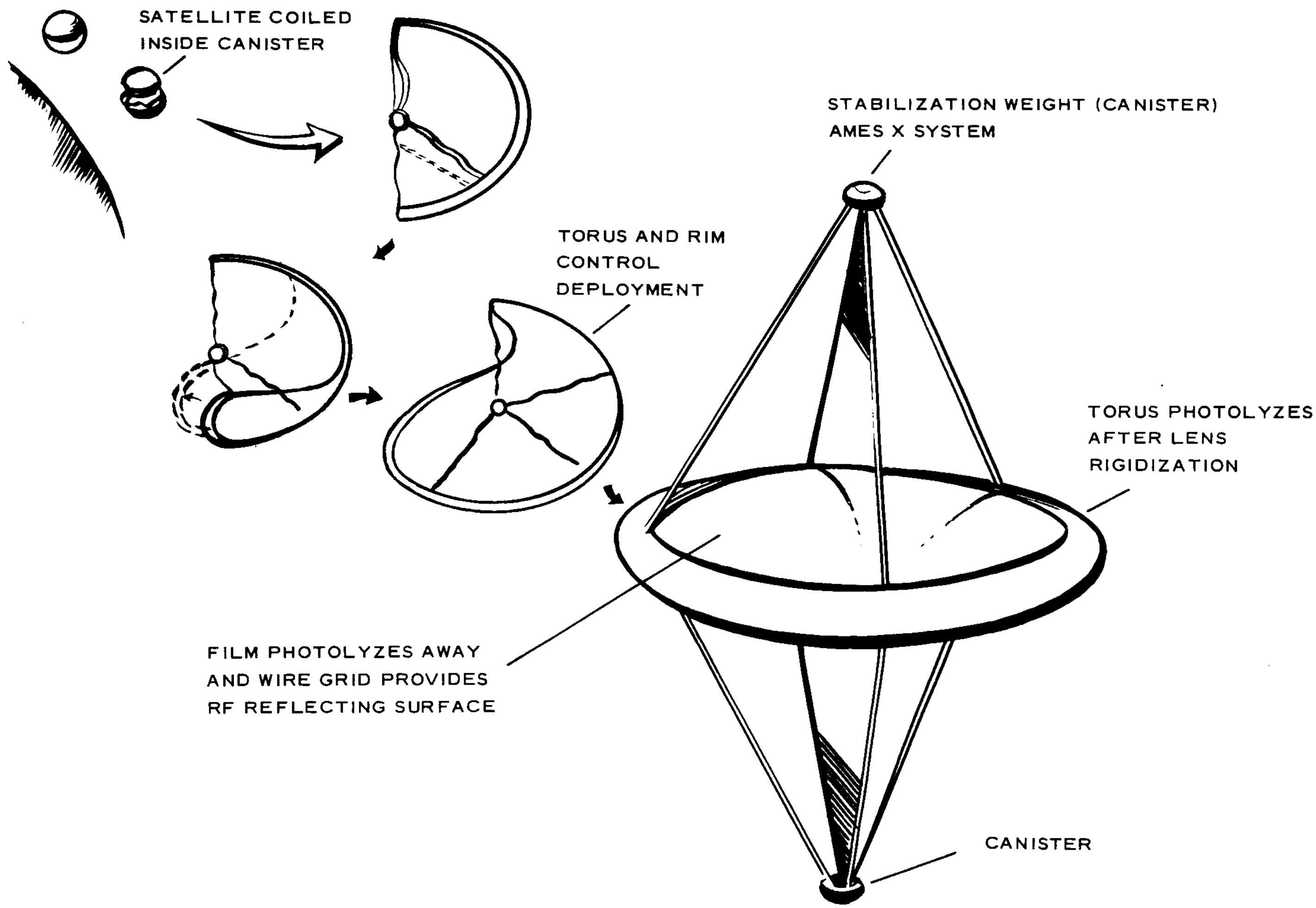


LAUNCH WEIGHT - 3,636.7 LB

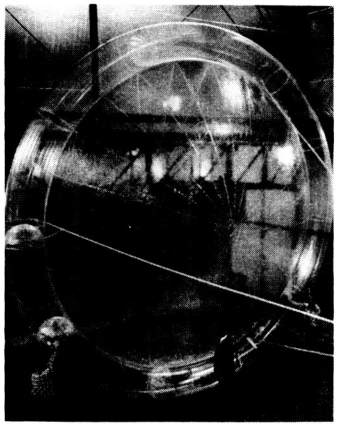
ORBITAL WEIGHT - 2,380.6 LB

	A	B
ROLL AND PITCH AXIS INERTIA, $I_{XX} = I_{YY}$ (SLUG-FT^2)	28.66×10^5	78.2×10^5
YAW AXIS INERTIA, I_{ZZ} (SLUG-FT^2)	4.359×10^6	6.336×10^5
DAMPER BOOM INERTIA, I_F (SLUG-FT^2)	5.73×10^4	7.82×10^5
STABILIZATION SYSTEM WEIGHT (LB)	98.9	269.1
NO. OF ORBITS TO ACHIEVE 95-PERCENT TRANSIENT DECAY (TIME, DAYS)	31 (8.3 DAYS)	4.2 (4.2 DAYS)
STABILIZATION ERROR CAUSED BY 1-PERCENT ORBIT ECCENTRICITY	PITCH - 0.8	PITCH - 1.06
	ROLL - 0.02	ROLL - 0.02
	YAW - 0.2	YAW - 1.4
STABILIZATION ERROR CAUSED BY SOLAR PRESSURE TORQUES	PITCH - 0.2	PITCH - 2
	ROLL - 0.16	ROLL - 1.6
	YAW - 0.1	YAW - 3.1

DEPLOYMENT CONCEPT



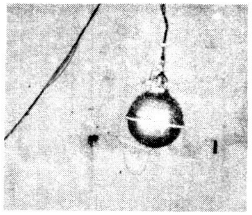
DEPLOYMENT TESTS

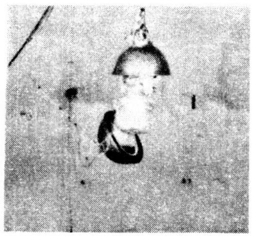


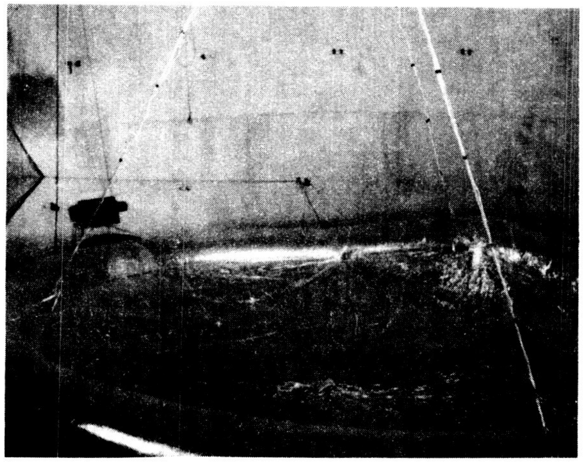
20-FT-DIAMETER MODEL

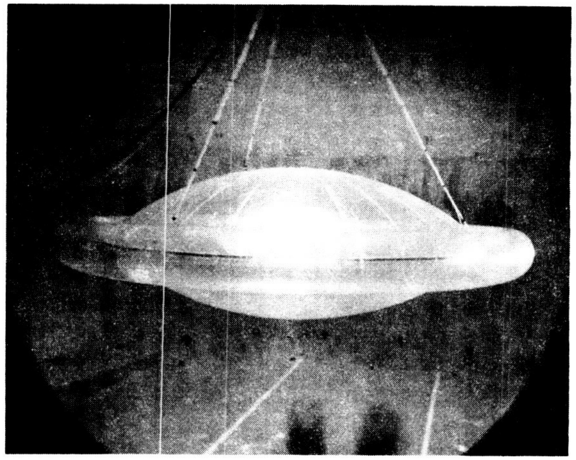
PACKAGED MODEL AND CANISTER

DEPLOYMENT TEST MODEL 20-1









DYNAMICS INVESTIGATION

1. Initial capture

   Problem - deployment from dense package to large, inflated system can result in tumbling of satellite - may cause critical structural loading and preclude upright capture by gravity-gradient field

   Approach - strength of tetrapod booms can be increased for minimum weight. "Repeated flip system" using a pair of beacons and jets at tetrapod apex is recommended

2. Gravity-gradient stabilization

   Concept - deployment of canister weights away from lens to control moment-of-inertia ratio

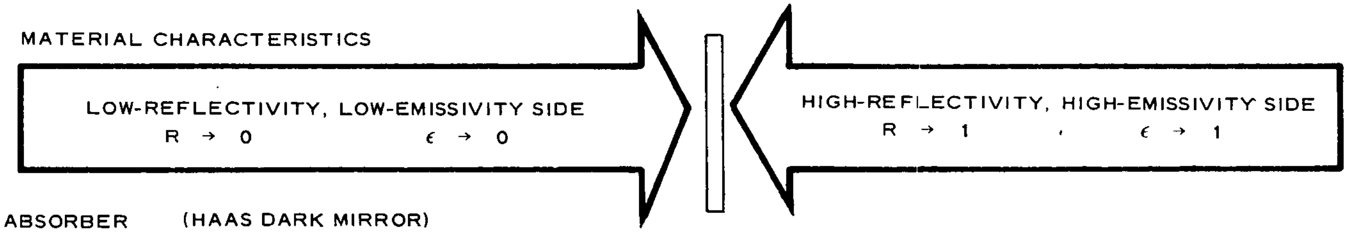
   Approach - satellite roll-yaw moment-of-inertia ratio is kept close to 5.75. Ames X concept at Tetrapod Apex is satisfactory damper and yaw control system

3. Computer studies - satellite transient response was improved through damper optimization. Altitude effect on steady-state error due to orbital eccentricity and solar pressure was determined.

ORBIT POSITION CONTROL - SOLAR SAILING

CONCEPT - USE OF SOLAR REFLECTOR/ABSORBER SURFACE AND SATELLITE YAW CONTROL FOR STATION KEEPING

MATERIAL CHARACTERISTICS



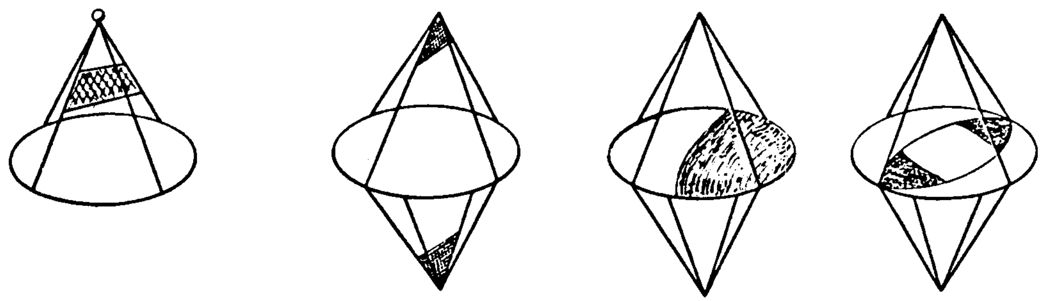
SOLAR ABSORBER (HAAS DARK MIRROR)

- 1000 A THICK SiO
- 100-200 A THICK AL
- 1000 A THICK SIO
- 2000 A THICK AL
- 1/4-MIL MYLAR SUBSTRATE

SOLAR REFLECTOR

- 2000 A THICK SiO
- 2000 A THICK AL
- 1/4-MIL MYLAR SUBSTRATE

CONFIGURATIONS STUDIED



A - SAIL (ASYMMETRIC) B - SAIL (SYMMETRIC) C - OPAQUE LENS D - SAIL IN LENS

PERFORMANCE - SATELLITE YAW STIFFNESS THROUGH $I_{PITCH} = 1.07\ I_{ROLL}$

MOBILITY - 100 DEG/MONTH

MODES - BUILDUP/DECAY/STANDBY

UPSETTING TORQUES - KEPT AT MINIMUM OR BALANCED

STRUCTURES - ANALYSES

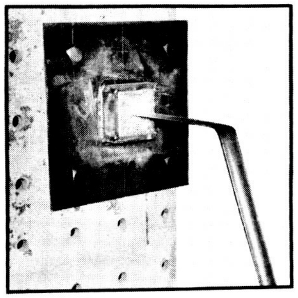
COMPONENTS

- Basic materials -
  - Fabrication techniques
  - Strength
  - Weight
  - Seams
- Lens characteristics -
  - Rigidization
  - Tolerances
  - Deployment
  - Temperature distribution
  - Structural stability
- Rim -
  - Materials
  - Fabrication
  - Deflection
- Booms -
  - Materials
  - Deployment
  - Rigidization
  - Torsional rigidity at apex

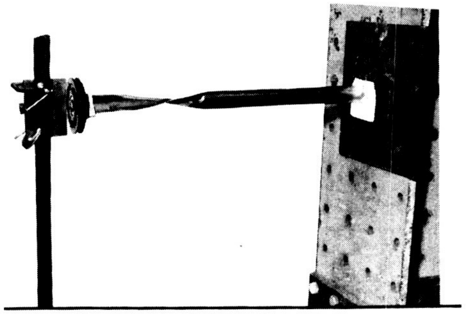
SYSTEM CONSIDERATIONS

- Deployment -
  - Lens inflation/deflation
  - Moment of inertia buildup vs time
- Stabilization review -
  - Satellite tumbling
  - Initial capture
  - Gravity-gradient loadings
  - Solar sailing effects
  - Yaw control effects
- Miscellaneous -
  - Symmetrical vs asymmetrical configurations
  - Canister separation and stopping
  - System weight tradeoff

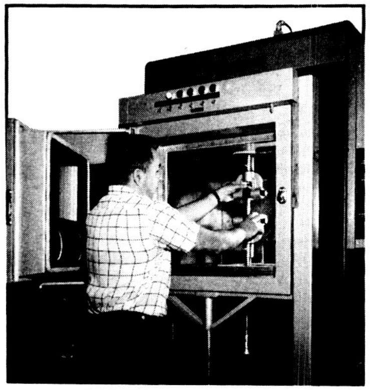
STRUCTURES - TESTS



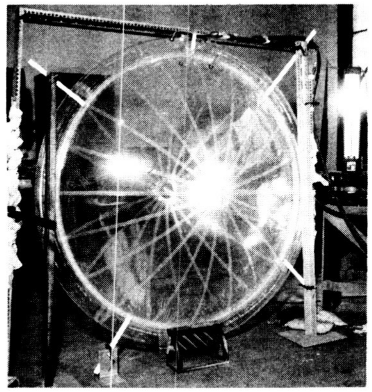
RIM BENDING TEST



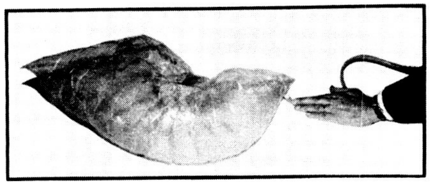
RIM TORSION TEST



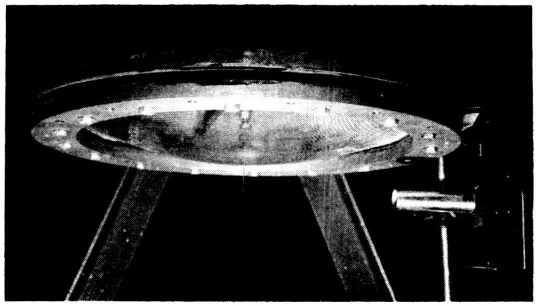
TENSILE TESTS - INSTRON



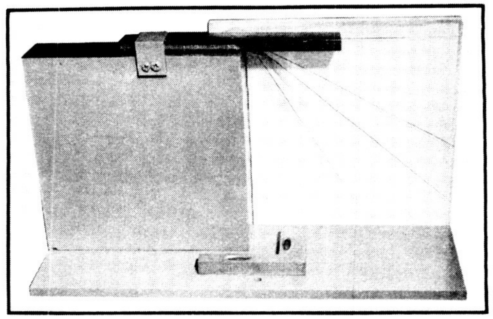
STABILITY TESTS



RAPID INFLATION TESTS



DIAPHRAGM TESTS



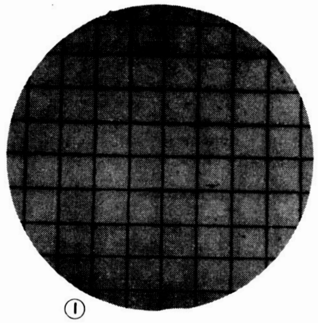
FLEXURAL STIFFNESS
MEASUREMENT (EI)

MATERIALS - PHOTOLYZABLE FILM DEVELOPMENT

Concept - through the action of solar ultraviolet energy, polymeric films are photodegraded to a molecular weight form, which is volatile and evaporates readily.

Application - torus and lens made with photolyzable film. Lens incorporates wire mesh with film to aid rigidization. After satellite becomes operational, film is eliminated to minimize destabilizing effect due to solar radiation pressure.

PHOTOLYZABLE FILM TEST DATA



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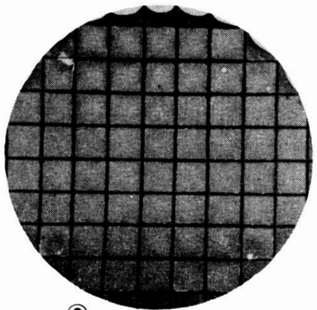

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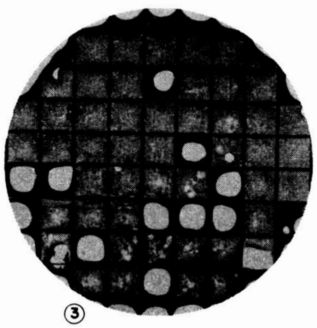

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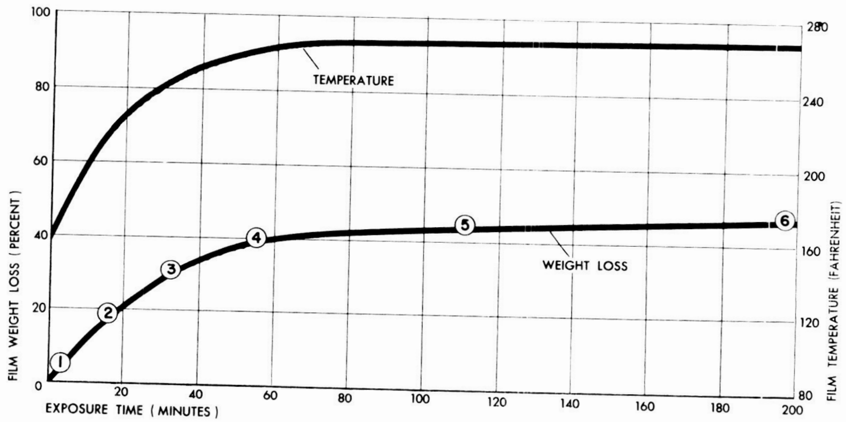

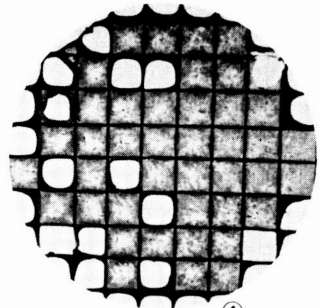

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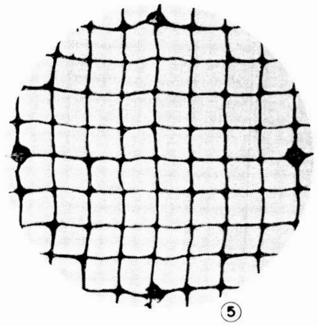

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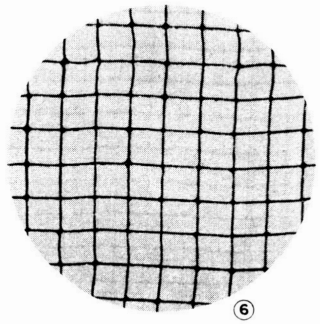


(6)

MATERIALS - PROTOTYPE TESTS

Seam Development -

- Butt and overlap types
- Welded, soldered, and cemented joints
- Tape and strike-through adhesive approach

RECOMMENDED

Fabrication procedures -

- Photolyzable film can be cast on woven-wire grid
- Wire can be filament wound on photolyzable film substrate
- Optical characteristics can be varied
- Space environment has negligible effect on strength and optical properties

Recommended lens material

- Filament-wound wire and photolyzable film composite
- Aluminum wire, square grid - 96-percent reflective
- 1/2-mil photolyzable film
- Typical properties for frequency of 8000 mc

Wire diameter, mils	2	3
Wire spacing, in.	0.06	0.07
Material weight, psf	0.004	0.005
Material strength, psi	0.7	1.4

RELATED MATERIALS

These materials have been considered by Goodyear Aerospace for similar applications:

Wire types and sizes - aluminum (1- to 20-mil range)
copper (1- to 10-mil range)
phosphor bronze (1.6 mil)
stainless steel (3 mil)

Film - photolyzable ($\geqq$ 1/2 mil)
Mylar ($\geqq$ 1/4 mil)
Nylon
Aclar

Grid sizes - (1 by 1) to (40 by 40)

Adhesive - Vitel

MICROWAVE CONSIDERATIONS

ANALYSES

Lens surface acceptable for 2- to 10-gc frequency range

Wire cloth lens offers RF performance equivalent to solid surface

Reflecting tetrapod booms give RF interference at zero-degree operation and when normal to booms

Edge diffraction interference experienced at zero-degree operation only

Canister interference negligible

Overlap seams, conductive or nonconductive, required to minimize scintillation

RF scaling between model and full-sized satellite is difficult

TESTS

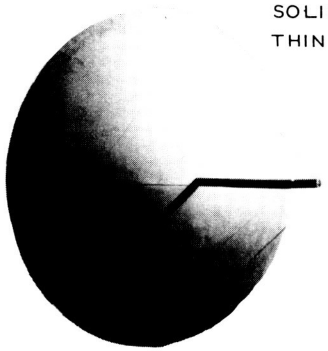
Far-field range tests made on 20-in. and 5-ft-diameter models at X-band

Monostatic and bistatic angle conditions investigated

Tests made of lens with and without tetrapod booms

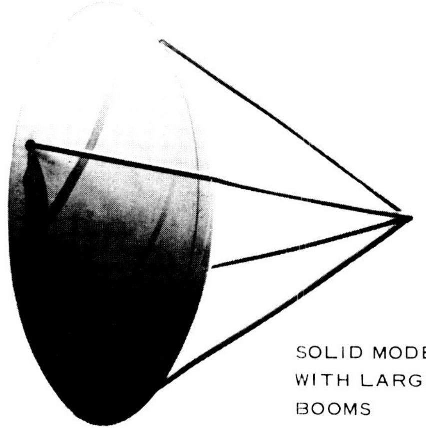
RF tests of typical seams and lens materials evaluated

MICROWAVE MODELS AND TEST SETUPS

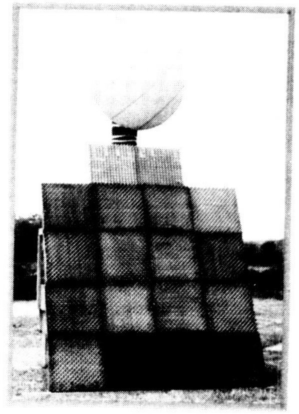


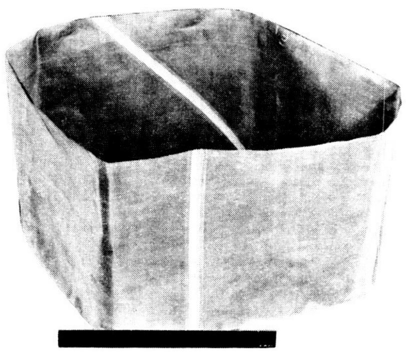
SOLID MODEL WITH THIN BOOMS

FIBERGLASS MODEL



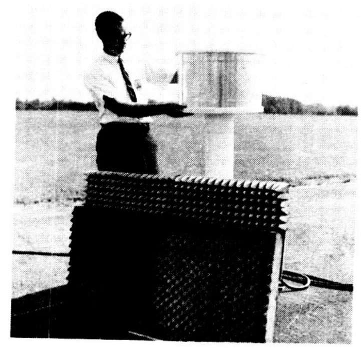
SOLID MODEL WITH LARGE BOOMS





TYPICAL MODEL - VERTICAL AND 45-DEG SEAM

RF TEST SETUP



CONCLUSIONS

Gravity-gradient-stabilized lenticular satellite is feasible

Solar sailing of lenticular satellite is feasible with available materials and techniques

Symmetrical boom system minimizes disturbing moments during satellite deployment

Sails give less steady-state error and disturbing torques than opaque lens

Materials, fabrication methods, and analysis techniques for lenticular satellite concept are within the state of the art

Radar-reflectivity-to-weight ratio of lenticular configuration is significant improvement over passive-sphere satellites for higher orbits

System growth potential - satellite structural damping may be sufficient to eliminate need for Ames X

RECOMMENDATIONS

Study should be conducted to relate satellite requirements with ground equipment to define the most promising passive communication satellite system

Flight test program should be initiated to gain experience for development of prototype communication system

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