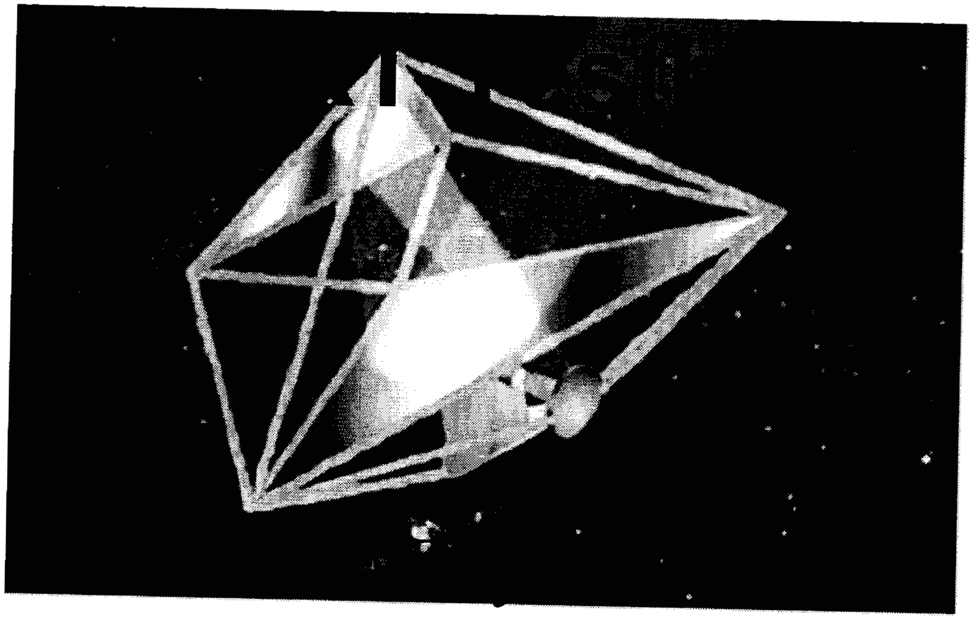


Greg Agnes – Task Manager

Jennifer Dooley – Former Task Manager

September, 2003

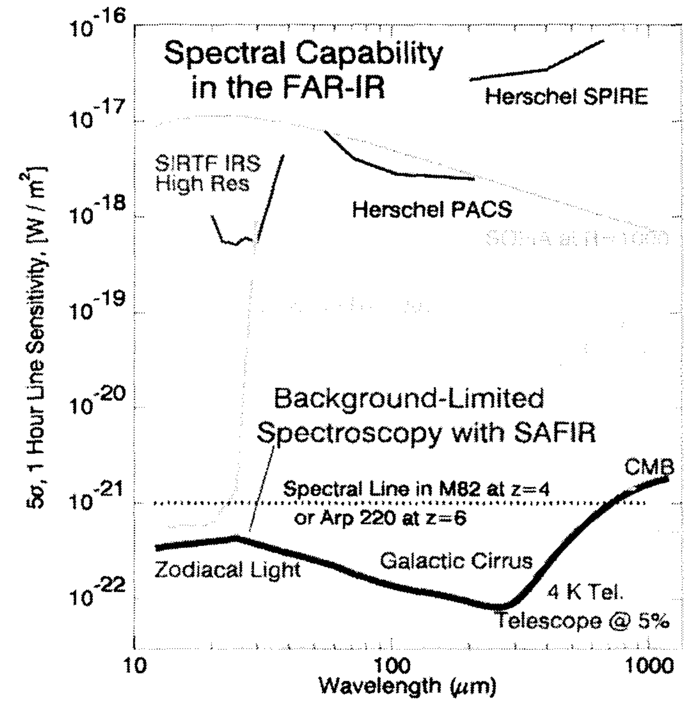
Outline

- Science Ties
- DART Architecture
- Code R Taskplan
- Current Status
  - Modeling
  - Single Membrane Testbed
    - Design
    - Metrology
    - Results
- Future Plan
  - Full Testbed
  - Model-Test Correlation
- Summary

The Single Aperture Far-InfraRed Observatory (SAFIR)

The next step in the far-IR beyond SIRTF and Herschel

SAFIR is a 10-meter, 4 K space telescope optimized for wavelengths between 20 microns and 1 mm. The combination of aperture diameter and telescope temperature will provide a raw sensitivity improvement of more than a factor of 1000 over presently-planned missions. The sensitivity will be comparable to that of the JWST and ALMA, but at the critical far-IR wavelengths where much of the universe's energy has emerged since the origin of stars and galaxies. In consideration of its enormous scientific potential and technological feasibility, the mission was recommended by the National Academy of Sciences Astronomy Decadal Committee as "the next step in exploring this important part of the spectrum."



Above: SAFIR will provide a sensitivity improvement of about 4 orders of magnitude over planned systems between JWST and ALMA. The ultimate sensitivity for spectroscopy is determined by the Zodiacal and Galactic Cirrus backgrounds. The dotted line shows a far-IR spectral line flux for local templates redshifted to the early epoch of galaxy formation.

Mission Overview of SAFIR

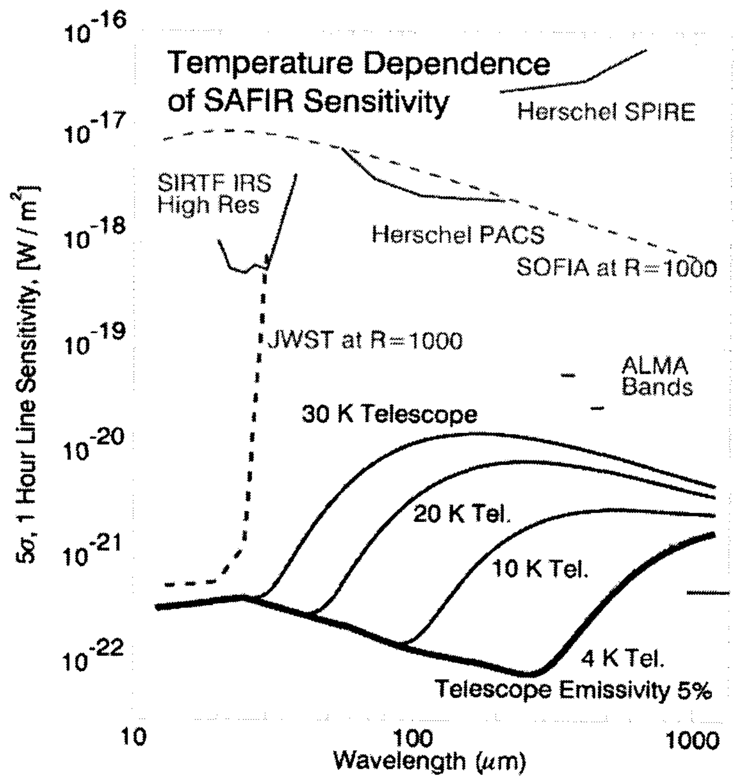
Telescope Diameter	10 meters
Telescope Temperature	5 K or lower
Wavelength Coverage	20 μm to 1 mm
Instruments on Board	• Kilo-pixel imaging arrays for all wavelengths. • Broad-band direct-detection spectrometers with background-limited sensitivity. • Heterodyne spectrometers operating at the quantum noise limit.
Orbit	Sun-Earth L2 Halo Orbit
Mission Lifetime	5 Years
Schedule	Launch between 2015-2020

More information at www.safir.jpl.nasa.gov

JPL

DART is a candidate for the SAFIR Mission

- An arrangement of cylindrical-parabolic reflectors can be made to function as an astronomical telescope
  - Unobscured design
  - Field of view accomodates a large format (50x50) Far-IR array
  - The aberrations are similar to those found at the focal surface of a parabolic reflector.
- The individual reflecting surfaces can be constructed using low areal mass density membrane technology.
- Early analysis shows design is compatible with cryogenic operation.

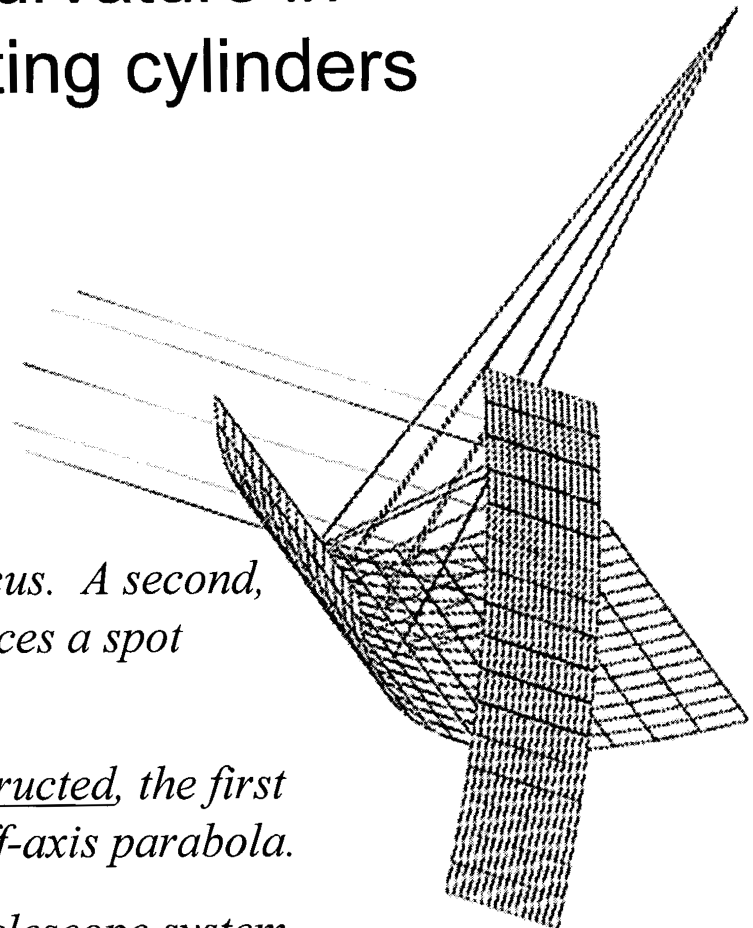


DART Shows promise for a number of NASA and DOD applications including radar, lidar, antennas, optical comm., and visible imaging

DART controls curvature in one direction, creating cylinders

Membranes are difficult to shape in 2 directions of curvature.

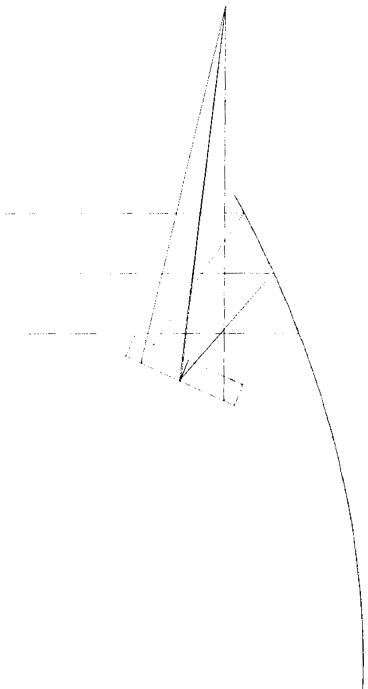
A membrane can be shaped in one direction of curvature using boundary control. This yields a cylindrical reflector.



A cylinder produces a line focus. A second, perpendicular cylinder produces a spot focus.

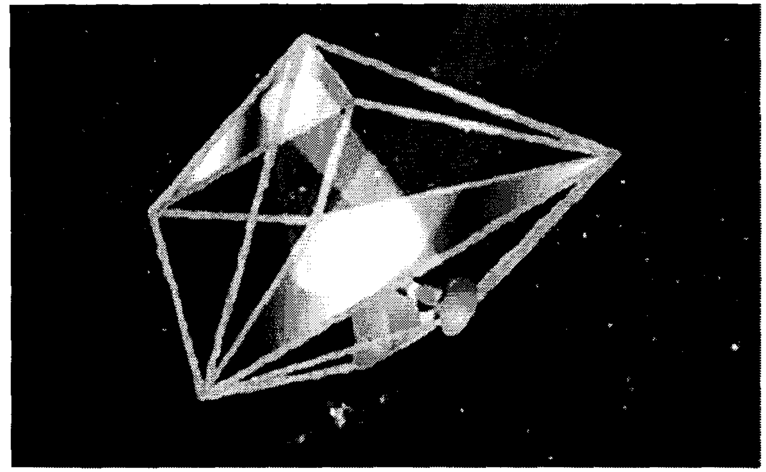
To make the telescope unobstructed, the first cylinder is a segment of an off-axis parabola.

The 'primary mirror' of the telescope system is comprised of two cylindrical reflectors.



DART TASK- Overview
JPL Task Plan No. 71-7856

Objectives
- Demonstrate a functioning 50 cm, DART-architecture telescope using metallic membranes
- Formulate and experimentally validate mechanics models for singly-curved membrane reflectors
- Examine the scaling of these results to future NASA missions



Major Milestones

♦ Nonlinear Mechanics Modeling, April 03

♦ First Light Single On-Axis Reflector, May 03

◊ First Light Single Off-Axis Reflector, May 04

◊ First Light, Full Testbed, Sept 04

◊ Validated Membrane Reflector Models, Sept 04

◊ Full Testbed Characterized and Aligned, Sept 05

◊ System Scaling and Risk Assessment, Jan 06

Funding

FY03	FY04	FY05	FY06*
1000	1000	466	134

*Carryover from FY05

Deliverables

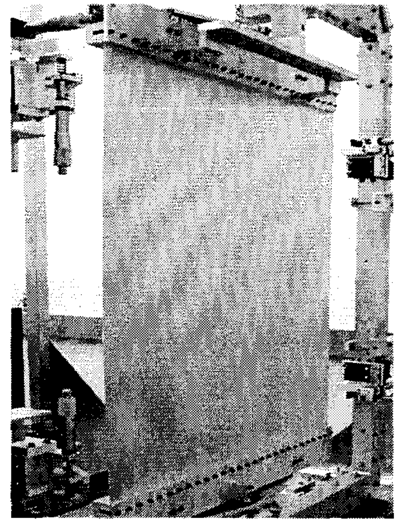
•Mid-Term Report, March 2004

•Final Report, March 2006

DART TASK- Current Status
JPL Task Plan No. 71-7856

FY03 Accomplishments

- Modeling--Nonlinear Mechanics analysis of a perfect membrane with precision rails
- On-Axis Testbed
  - Testbed designed and built
  - Metrology complete
  - Alignment procedure determined
- LMSSC Contract Awarded, Kickoff 10 Sept



Interactions with Customers

•SAFIR-DART is a candidate architecture

•ST-9 – Support Large Space Telescopes Core Team

•Vision Missions – Proposing SAFIR study with DART Architecture

•DOD – technical interchange with various agencies

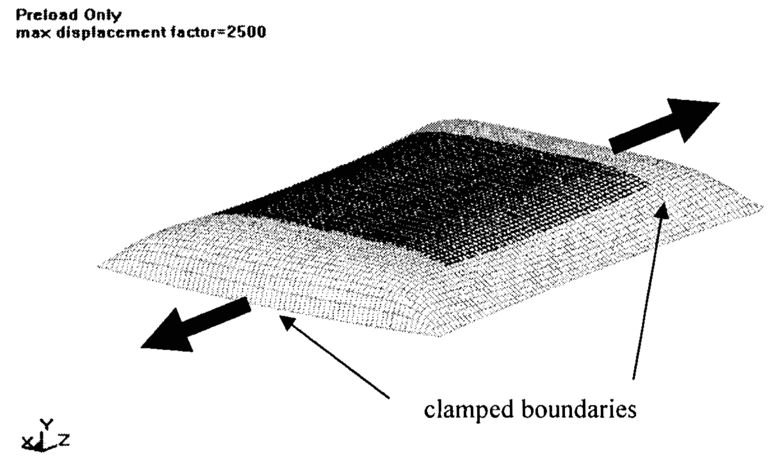
Publications

• *"Shaping of Parabolic Cylindrical Membrane Reflectors for the DART Precision Testbed," 43rd Annual AIAA/ASME/ASCE/ASC Structures, Dynamics, and Materials Conference, Gossamer Forum, Langeley, VA. April 2003.*
•Chang, Prata and Dragovan J.O.S.A. submitted 2003
•Dragovan, US Patent 6,502,944 (issued Jan 2003)

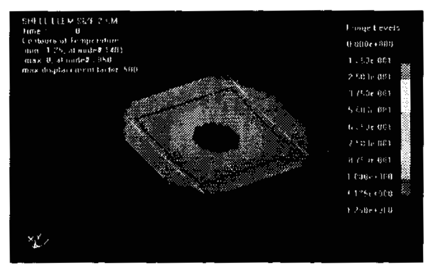
Related Publications
•SPIE Kona-2002, vol 4849 Dragovan et al p1-7
•SPIE Kona-2002, vol 4849 Tolomao et al p8-15.
•SPIE San Diego-2003, Tolomao et al.

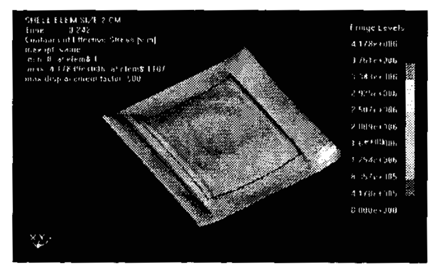
Modeling

- Two structural analysis models are being used:
    1. Nonlinear analytical model of single rail
    2. Fully nonlinear finite element membrane model with rail contact
- Single rail model demonstrates that parabolic shape is possible with ideal conditions. But only simple 'imperfections' (initial curvature, varying E,I) could be included easily. FE model could include more if needed.
- Membrane FE models have examined:
    1. Membrane shape without rail influence
    2. Membrane shape with 'arbitrary' rail positioning
    3. Quick look at environmental effects ~ gravity & temperature



Preload(N)	Y-displ. (μm)	RMS Error (μm)
0	0	1.51
20	5.5	1.33
60	16.5	1.47
100	27.7	1.57

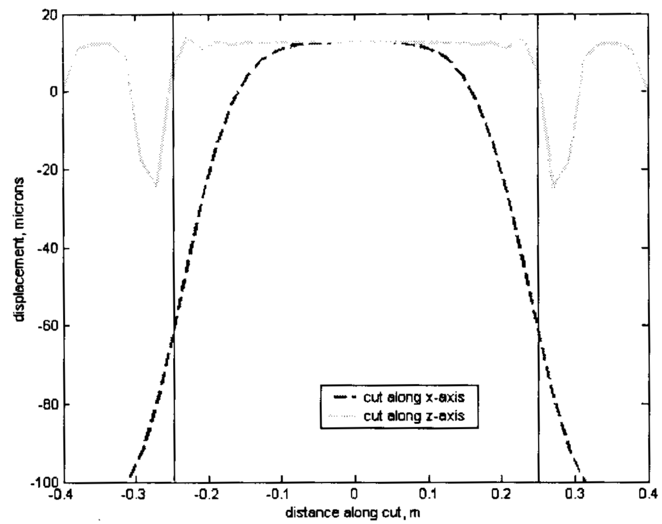




Precision Rail Shaping

- Recent efforts are aimed at computing specific rail shape so that membrane shape is optimal.
  - Objective function is minimum RMS of membrane shape to parabolic surface of any radius.
  - Objective optimized 'automatically' using ls-dyna
  - Requires high degree of integration of ls-dyna, ls-opt, MATLAB, and ls-prepost software.
  - Integration completed successfully in June, 2003.
  - Currently studying the true influence of rails on both 'perfect' and 'realistic' membrane systems.

- Correlation to testbed measurements anticipated early next fiscal year

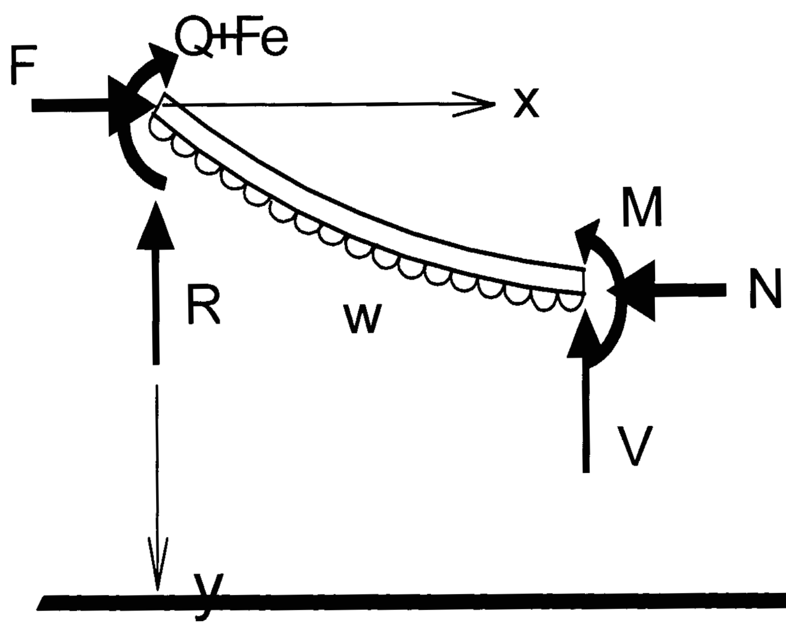


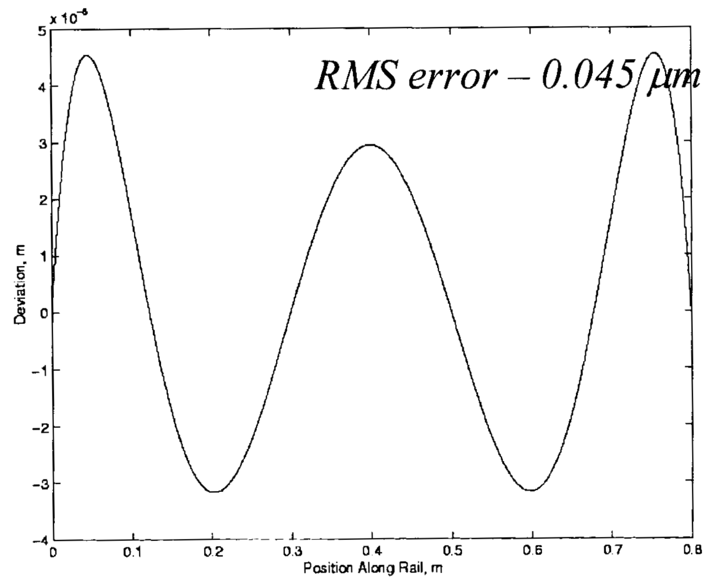
Aperture size	Radius (m)	RMS error(μm)
50 x 50 cm	3.06155	5.50
45 x 45 cm	3.05882	2.87
40 x 40 cm	3.05694	1.88
35 x 35 cm	3.05500	1.13

A rail becomes a parabola within <1 μm

Nonlinear structural analysis was performed on an isolated shaping rail to establish fundamental accuracies for elastically deflecting a beam into a parabolic shape. Euler-Bernoulli beam theory with nonlinear moment-curvature equations were solved numerically to determine the required end forces and resulting shape of the prismatic beam. The results confirm that precision in the sub-micron range is theoretically possible, and further demonstrate the large sensitivity of the rail shape to the specific end actions applied to the beam.

$$\frac{y''}{(1+y'^2)^{3/2}} = -\frac{1}{EI}\left[-\frac{wL}{2}x + Fy + Q + Fe + \frac{wx^2}{2}\right]$$



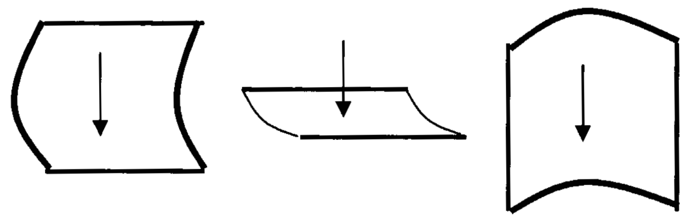


Single Membrane Testbed Design

Objectives

- *Demonstrate the* ***'best' surface*** *we can (1.75 μm rms goal)*
- *Validate predictive* ***models***
- *Develop an* ***understanding*** *of how to shape*

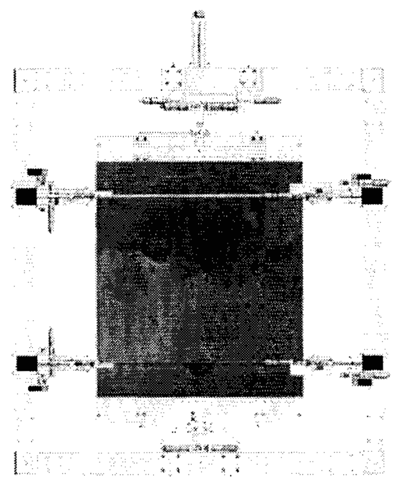
Preload Only	Preload+ Gravity in Y	Preload+ Gravity in Z	Preload+ Gravity in Y
5.8 μm	13.3 μm	110 μm	5.8 μm

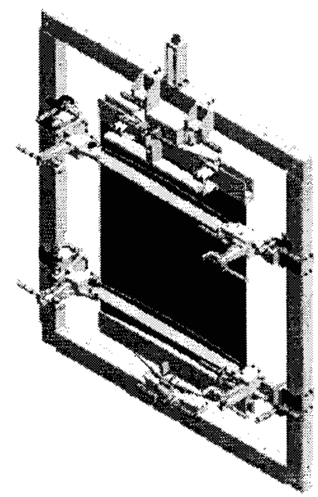


Precurser for a deployable, cryogenic, low mass, flight-practical, scalable design.

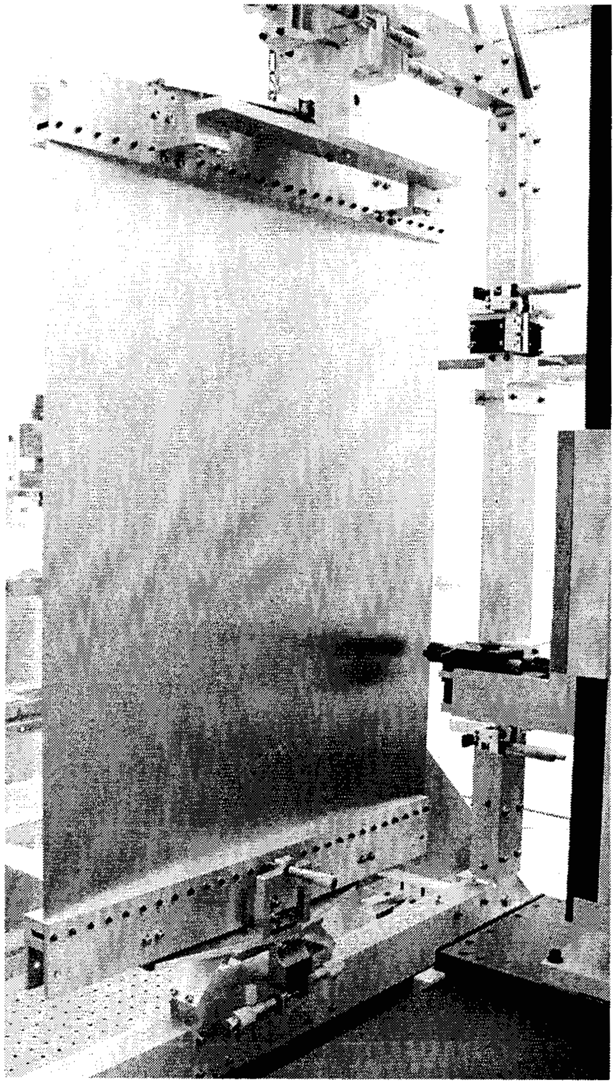
Metrology Requirements

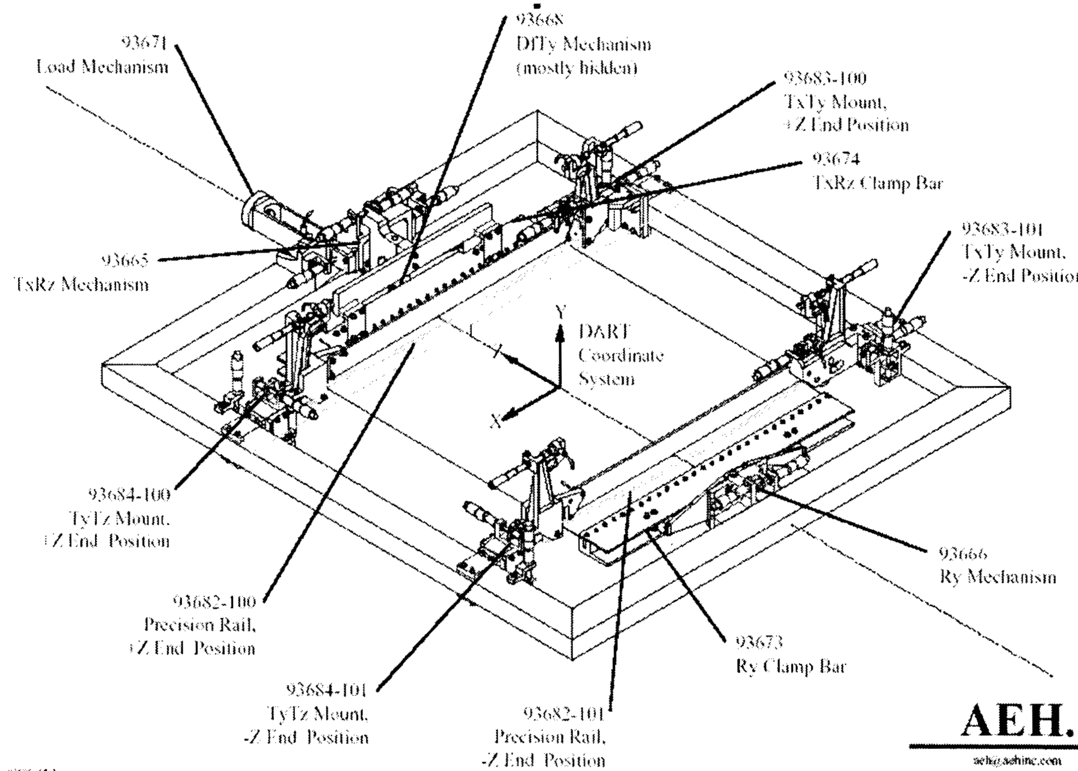
- Resolution 0.15 μm rms
  - -Poisson Effect yields surface error of 1 μm rms
- Dynamic range uncertain
- Not Scaleable to large optics
- Gravity loading constraints





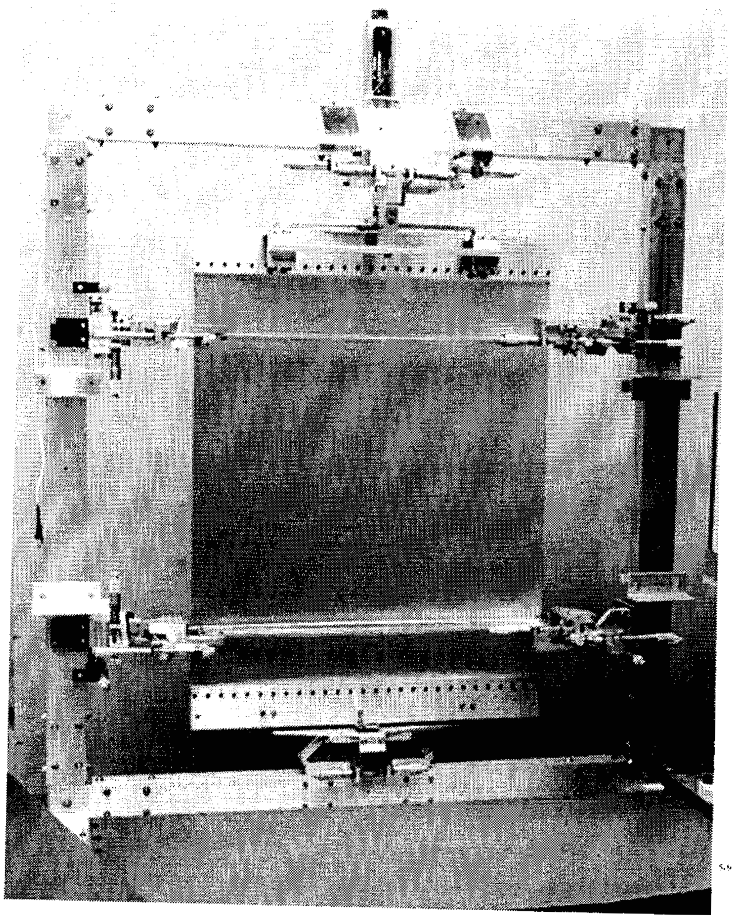
Single Reflector Testbed

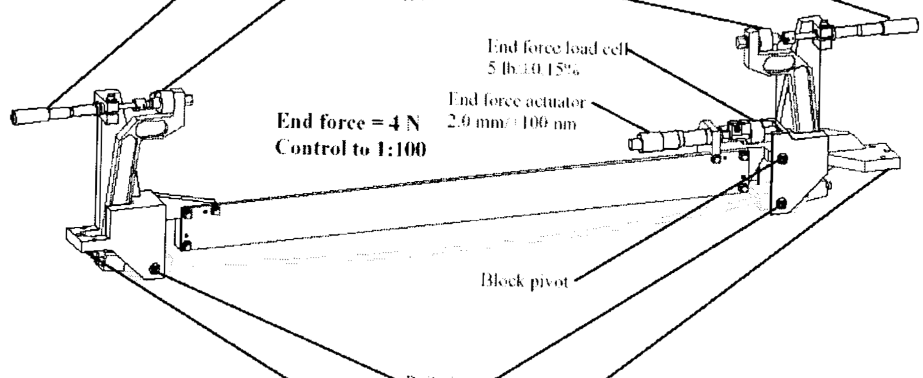




AEH.
aeh@aehinc.com

Precision Rails





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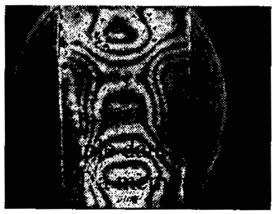
JPL

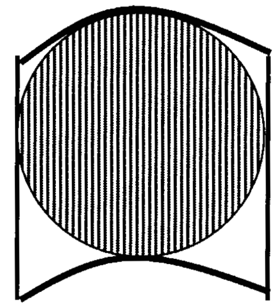
Metrology Instruments for a singly curved Membrane

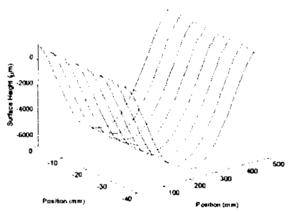
Resolution	Range	Time	Area
0.13 μm	340 μm	10 sec	swaths
1 μm	2 cm	15 min	scans
qualitative	huge	instant	full



Interferometer

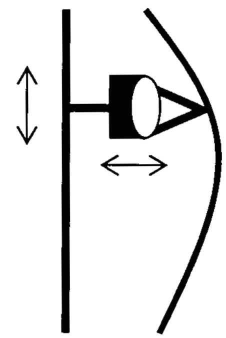
- requires null element
- Sub aperture and
- Whole reflector
- Main model validation work

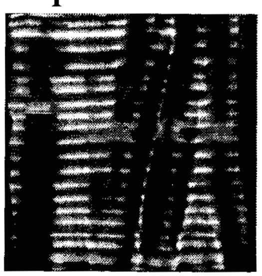




Profilometer

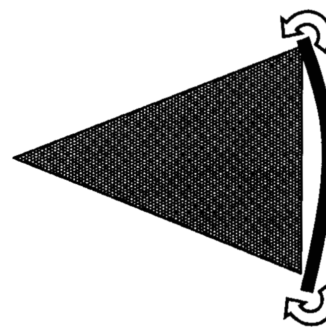
- 0.1 sec settling time
- 30 minutes to scan aperture
- faster lines scans



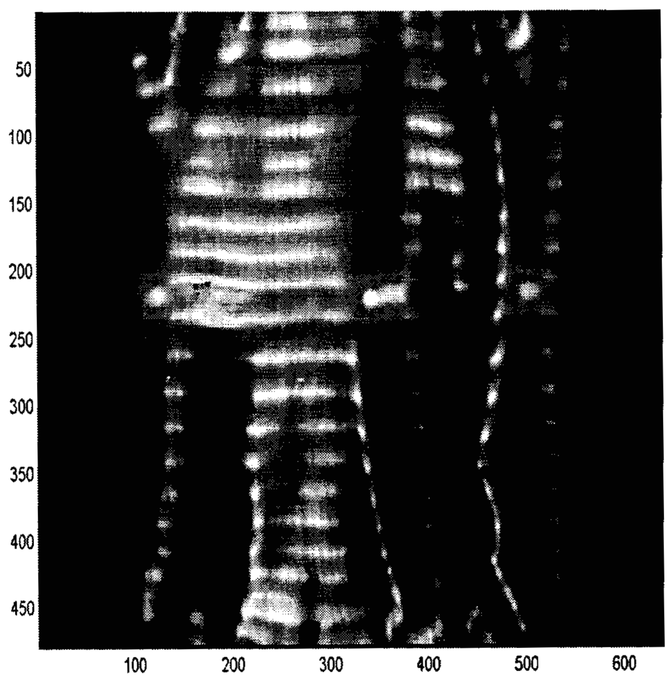


Center of Curvature

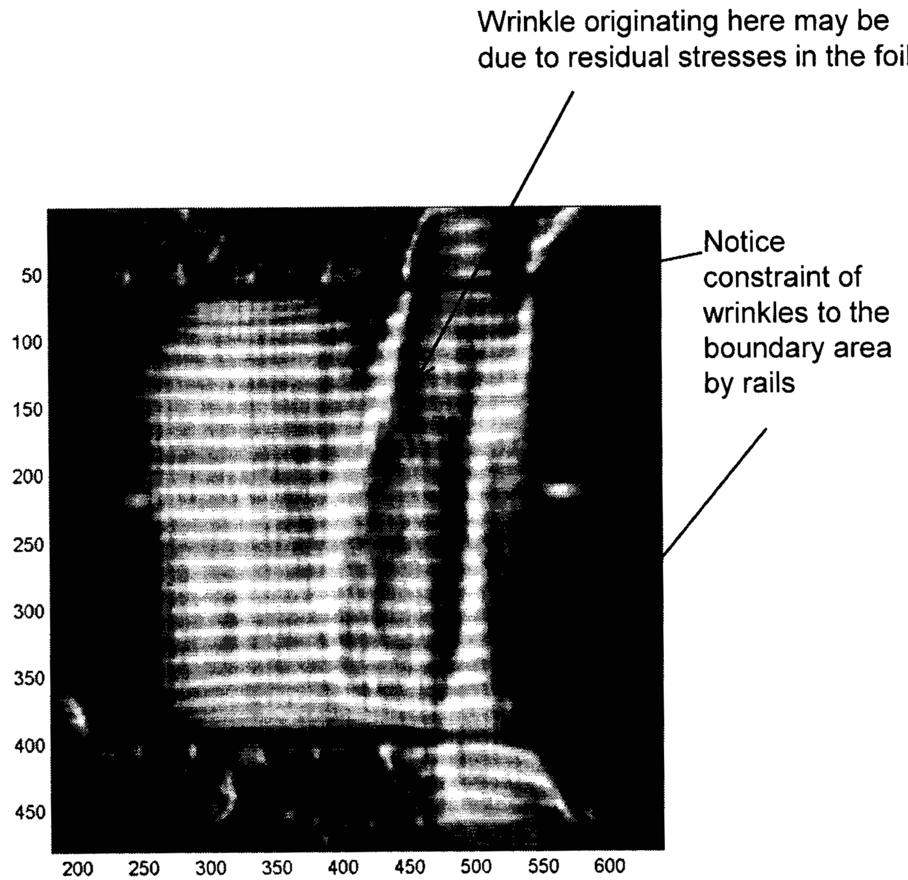
- infrared camera
- IR point sources
- clamp bar alignment
- coarse shaping



Center of Curvature Testing



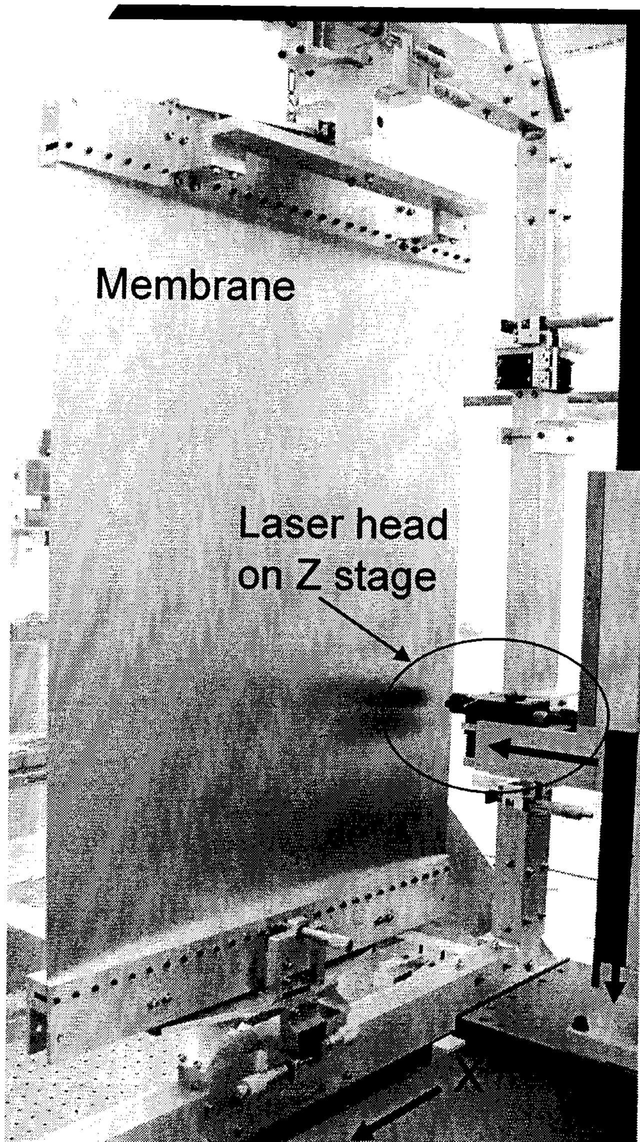
Early attempt membrane figure - preload; no precision rails



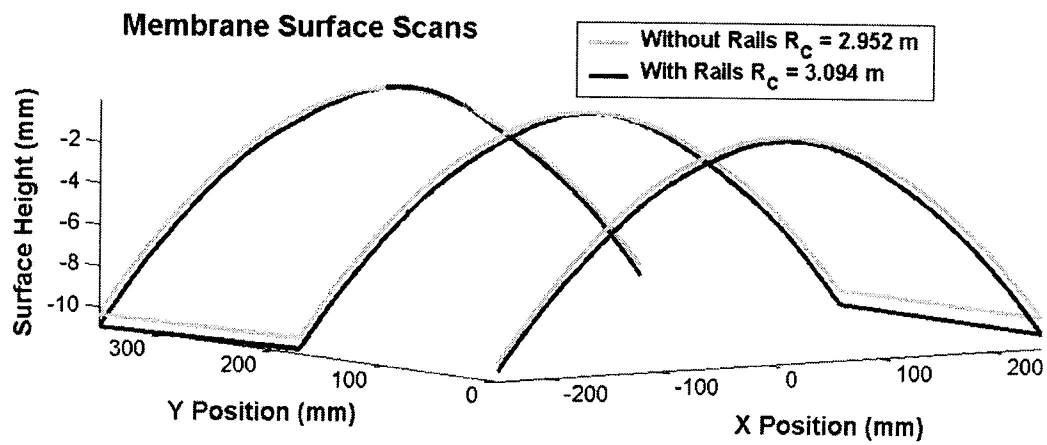
Recent attempt membrane figure - preload; precision rails

JPL

Profilometer

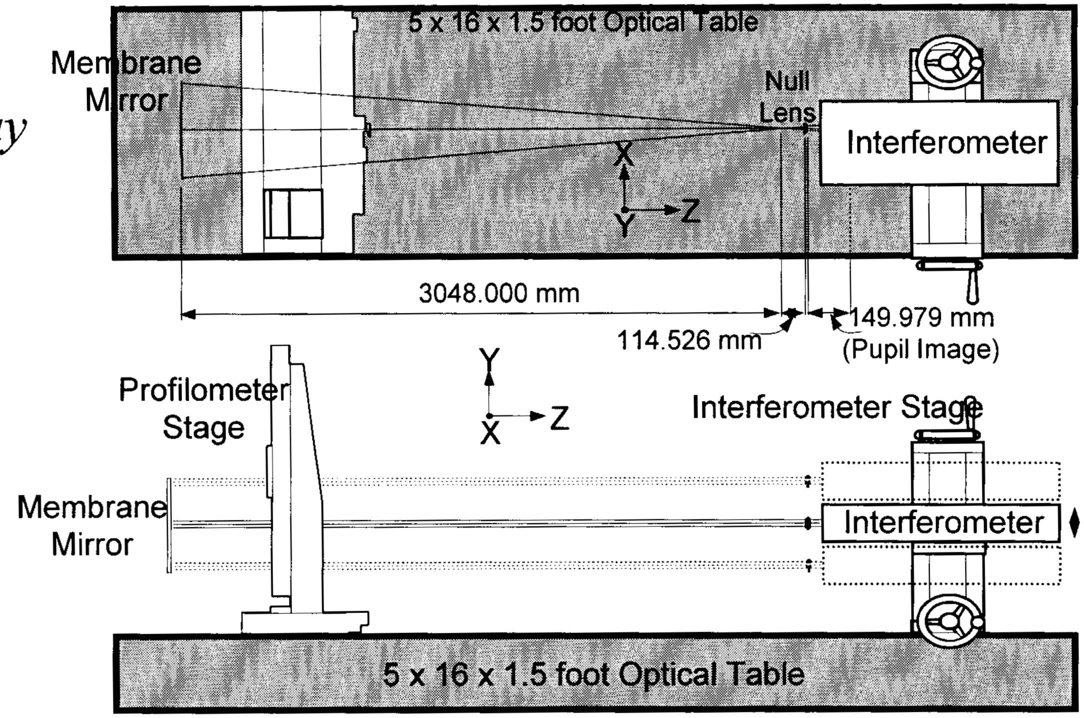


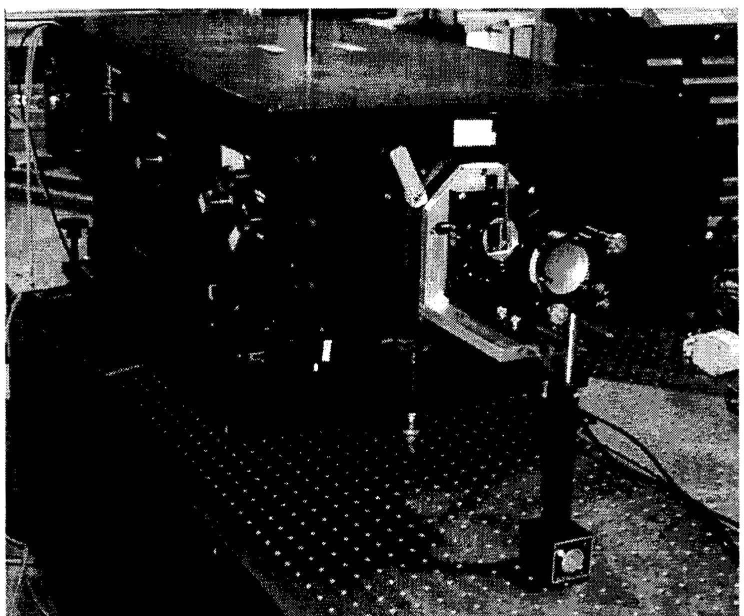
- *Keyence Laser head measures surface height to 0.1 μm rms precision*
- *2 cm range with Z translation stage*
- *Aerotech stage translates XY to 1 μm*
- *Settling time of 0.1 sec*
- *Fast single line scans or*
- *Full membrane scans in 30 minutes*



Infrared Twyman-Green Interferometer

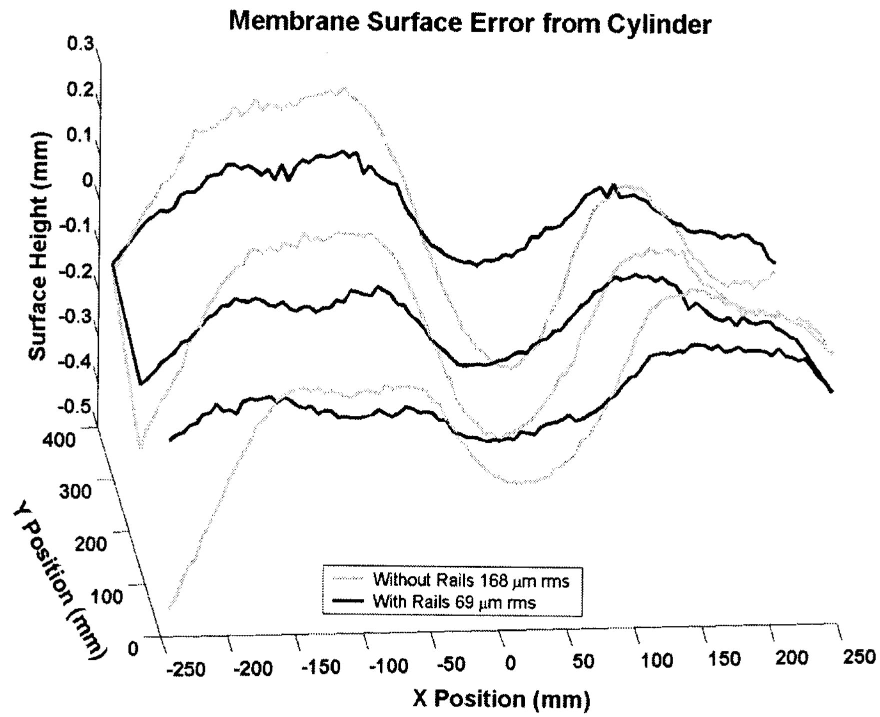
- *10.6 μm wavelength*
- *320x240 microbolometer array*
- *phase shifting PZT*
- *precision of 0.13 μm rms*
- *dynamic range of 340 μm*
- *Video-rate measurement*

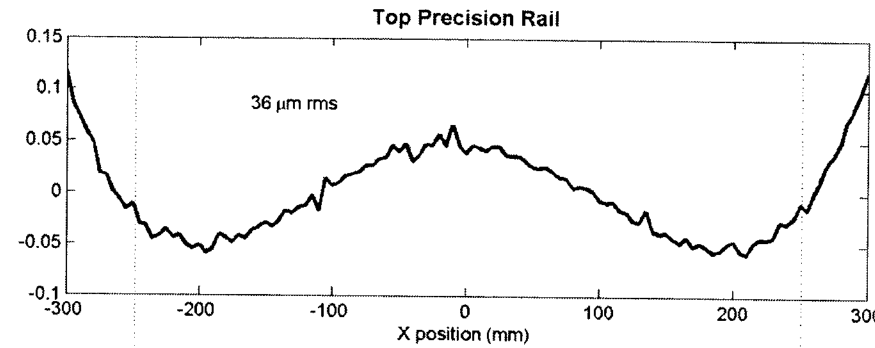


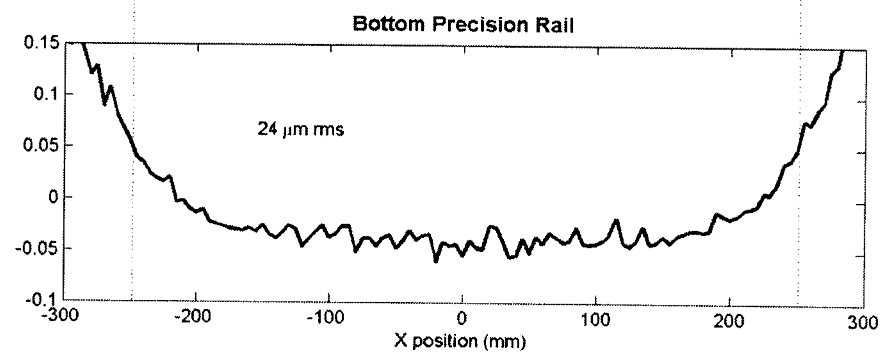


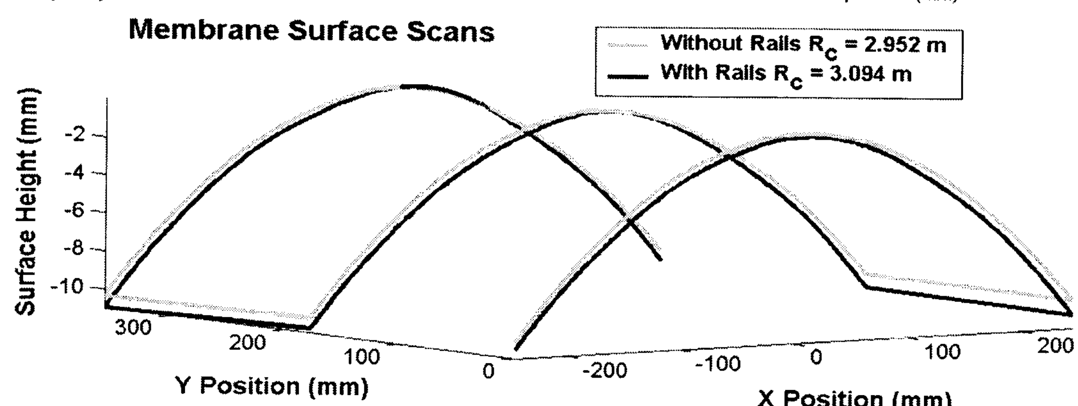
- *Co-aligned to profilometer*
- *Membrane tested at center of curvature*
- *Small ZnSe cylindrical null lens produces a 500 mmx30 mm beam*
- *Upgrade to full-aperture*

Membrane and Rail Figuring





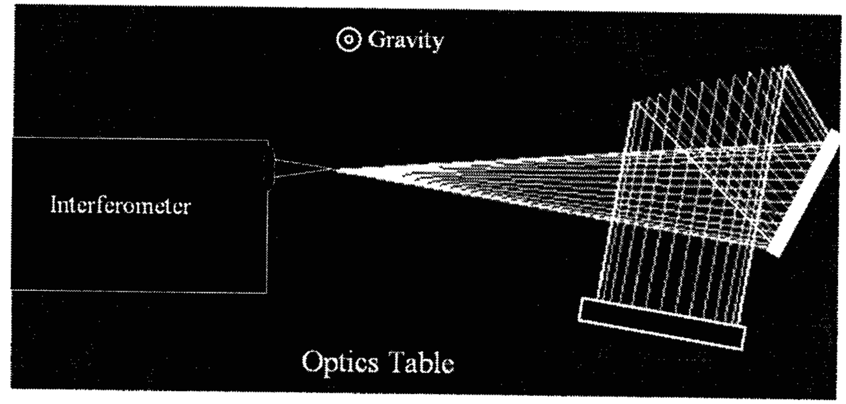




DART TASK – Future Plans
JPL Task Plan No. 71-7856

FY04 Objectives

- Full testbed telescope—Designed, Built, First Light
- Off Axis—Designed, Built, Measured
- ExperimentallyValidated Models--both on-axis and off-axis



Full DART Testbed Telescope

Concerns

•Quality of Membrane, Rail Stock

-Pursuing alternate Membrane Materials (nanolaminates, polymer)

-Stretching copper membranes to eliminate prestrain

-Modeling of preexisting material imperfections

FYO4 Schedule

•LMMSS Study Complete, Dec 2003

•Mid Term Report, March 2004

•Off-axis reflector first light, May 2004

•Experimentally Validated Models, Sept. 2004

•Full Testbed First Light, August 2004

Model-Test Correlation

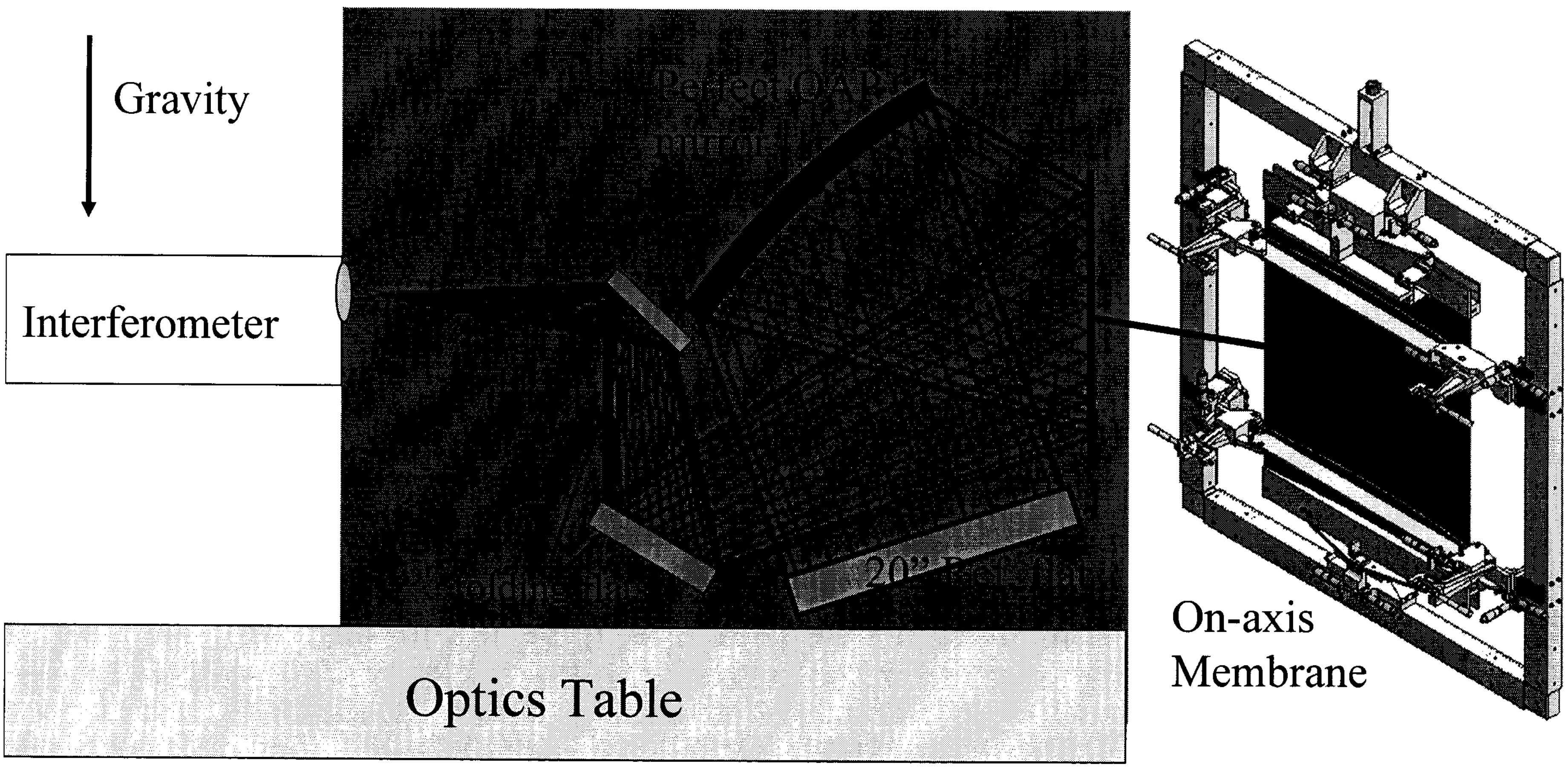
- Two-pronged attack on validating membrane mechanics
  - Make the membranes better by reducing imperfections
  - Add imperfections to the modeling
- Also deforming membrane via boundaries and examining response
  - Deformations "above the noise floor"
  - Based on sensitivity calculations
- Perhaps add a dynamic test to verify frequencies and mode shapes
  - Only gives overall feel

Summary

- The DART architecture will enable low areal density cryogenic telescopes for future NASA missions
- During FY03, the Code R funded task has demonstrated:
  - Nonlinear Membrane analysis with precision rails
  - Design, Fabrication, and Initial Testing of a precision on-axis testbed
  - Development of a robust suite of metrology systems
- During FY04, the task will
  - Design and build the full testbed including an off axis membrane
  - Demonstrate experimentally valided membrane models
  - Complete a SAFIR system study

DART System Test, Membrane is on-axis reflector

Side View



Full DART system, membrane is off-axis parabola

Top View