1 ppt file folder 05 Mechanical ppt
+ all 5 MPEG Videos

Terrestrial Planet Finder Mission

TPF

A NASA
Origins
Mission

Design Review
TPF Coronagraph System

Timothy Ho

Mechanical Configuration

28 April 2004

Acknowledgements

- This design would not have been possible without the help, guidance and expertise of the following people:
  - Terry Cafferty
  - Gun-Shing Chen
  - Houfei Fang
  - Virgina Ford
  - Tony Hull
  - Louise Jandura
  - Andy Kissil
  - Bill Ledeboer
  - Charles Lillie (NGST)
  - Doug Lisman
  - Mary White

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

Opto-mechanical instrument designs begin with basic inputs:

1. ***Optical Design*** – where are the mirrors placed and rays travel?
2. ***Thermal Design*** – what kind of thermal design is needed to maintain proper alignment and shape of optics within tolerances?
3. ***Structural Considerations*** – how does one design structure around the optical design to maintain proper alignment and shape of the optics within tolerances?
4. ***Volumetric Constraints*** – how much space do the optics and support structure need? Can it all package into the allowable volumes? What deployments are needed?
5. *Mass* – does the design need to be optimized to meet the mass allocation?

TPF-C Minimum Mission Mechanical Design Driving Requirements

1. ***Optical Design***
   - 6m x 3.5m primary mirror
   - 10m primary to secondary mirror separation
   - Back end coronagraph optical system

2. ***Thermal Design***
   - V-groove cocoon surrounding telescope
   - Isothermal enclosure around primary mirror, instrument and secondary mirror

3. ***Structural Considerations***
   - Tight optical alignment and stability tolerances will require stiff supporting structures, kinematic mirror mounting, metrology system, etc.
   - Minimize jitter and vibrations to optics from spacecraft

4. ***Volumetric Considerations***
   - Launch vehicle shroud volume
   - Secondary component sizes (Solar array, propulsion tank, reaction wheel, etc.)

Early Trades That Impacted Overall Configuration

Terrestrial Planet Finder Mission

TPF

Sun Shade Configuration	Advantages	Disadvantages
1. Cocoon-style v-groove	-Deployment includes telescope baffle -Movements - spacecraft reaction wheels -Helps keep primary mirror near RT & secondary support relatively warm -Stiffer sunshield (higher frequencies)	-Can only be 90 degree or greater to light sources, may restrict FOV -Solar pressure is unbalanced -Deployment complicated
2. Flat v-groove (JWST-style)	-More heritage, straight forward deployment (JWST) -May allow larger viewing angle -Solar pressure balanced	-More actuators, mechanisms (gimbal) required to point at all targets in FOV -Deployment difficult to package -Primary mirror passive T too cold -Larger sunshield area- lower frequencies

Spacecraft location	Advantages	Disadvantages
1. Behind primary mirror	-Better CG placement in stowed and flight configurations -No direct view of v-grooves -Support structure for v-grooves can be decoupled from instrument	-Poor load path to booster payload interface -Takes up volume behind primary
2. Side of primary mirror along major axis	-Good load path to booster payload interface -Opens more volume open behind primary	-Raises stowed CG in fairing -Offset CG in flight configuration -Thermal view to v-grooves

A NASA Origins Mission

Note: White colored fields indicate what is in the current configuration

Trades That Impacted Overall Configuration

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

Orientation in Booster Fairing	Advantages	Disadvantages
1. Tilted	-Keeps stowed CG low and centered -Creates wider base support to booster payload interface	-Limits space for v-groove deployment
2. Vertical	-Allows space for v-groove deployment components -CG centered in booster fairing	-Requires clam-shell separation mechanism

Launch Support Structure	Advantages	Disadvantages
1. Interface plate	-Only 1 interface to mate to -Simple interfaces to spacecraft	-Cantilevers system in fairing -Requires large footprint on spacecraft to increase frequency
2. Tilted Support Structure (SIM-like)	-Creates wider base support to booster payload interface -Stiff -Simple interfaces to spacecraft	-Requires tilted spacecraft to get large base footprint -Large mass -Limits space for v-groove deployment components
3. Support Cylinder	-Allows space for v-groove deployment components -Eliminates need for large footprint on spacecraft -Achieves higher stowed frequency -Provides better support access for components not close to booster interface -Lower launch stresses for Observatory structures using support cylinder as primary load path	-Requires clam-shell separation mechanism -Many complicated interfaces on spacecraft and many separables

Note: White colored fields indicate what is in the current configuration

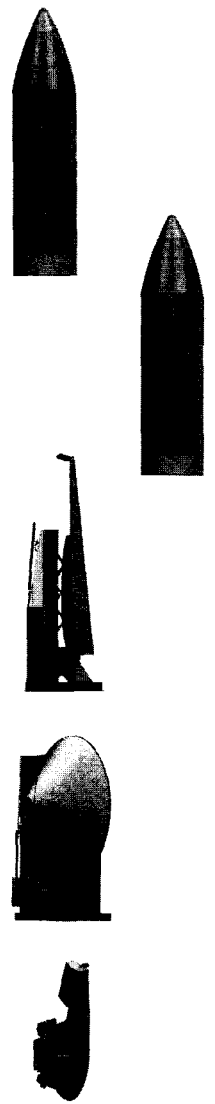
Trades That Impacted Secondary Mirror Deployment

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

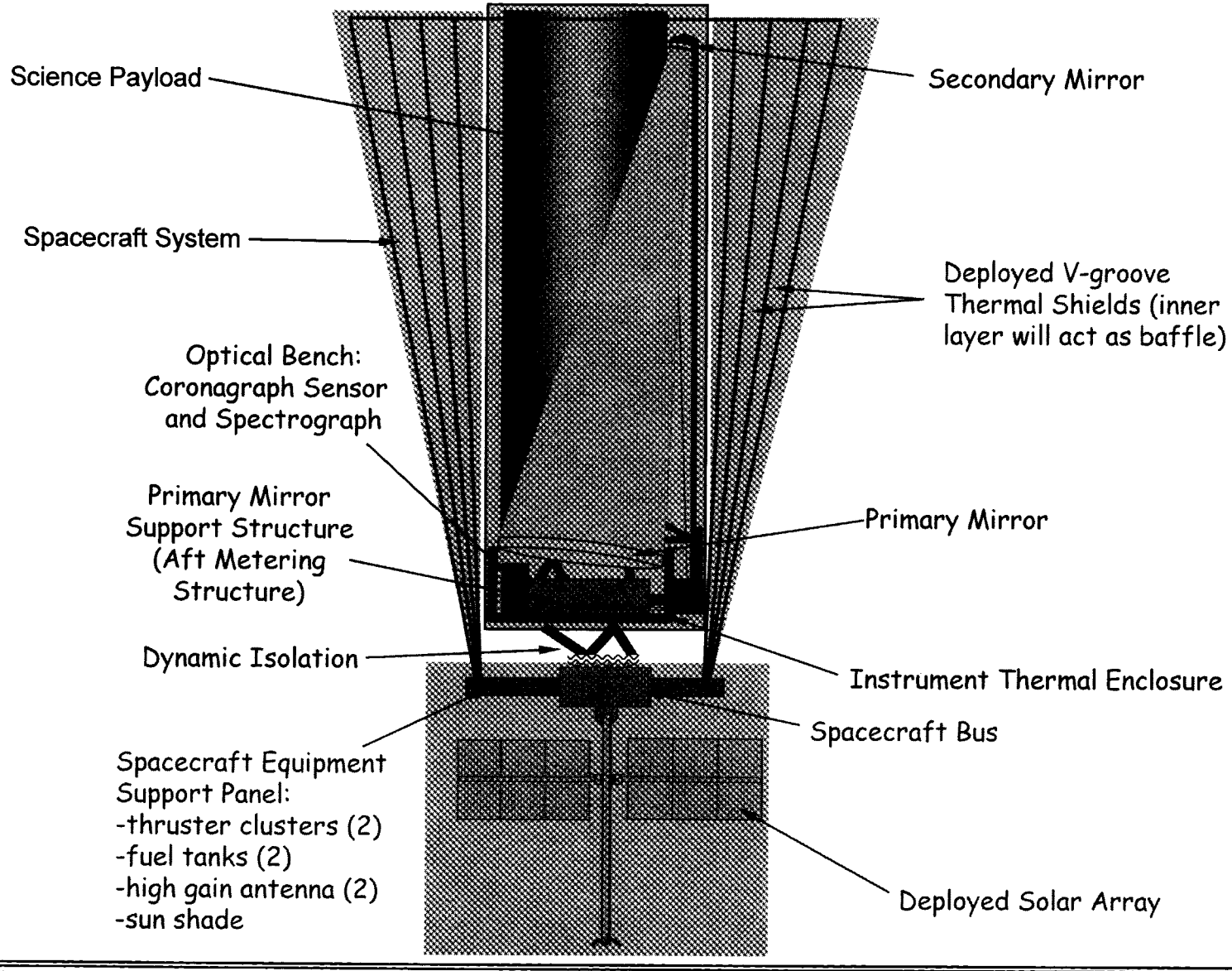
Secondary tower deployment	Advantages	Disadvantages
1. Single compound axis fold	-Single acutation	-Poor primary to secondary tower placement -Limits length of telescope without adding a second pivot -Difficult to carry load to booster payload interface
2. Double compound axis fold	-Favorable primary to secondary tower placement -Allows for growth in telescope length	-Two axis rotation -Difficult motion
3. Single axis fold	-Simple, single acutation	-Pushes stowed CG higher in fairing -Limits length of telescope without adding a second pivot -Offset CG in stowed and flight configuration -Limits base size of tower -Skewed tower to clear light path -Increases size of v-groove shield
4. Double axis fold	-Simple motion - rotation axes are -Favorable position of secondary tower to primary -Allows for growth in telescope length -Better CG placement in stowed configuration	-Pushes stowed CG higher in fairing -Offset CG in flight configuration -Severe limitions on base size of tower -Increases size of v-groove shield
5. Triple axis fold	-Allows for growth in telescope length -Better CG placment in stowed and flight configurations	-Three axis rotation -Limits base size of tower



Configuration Schematic

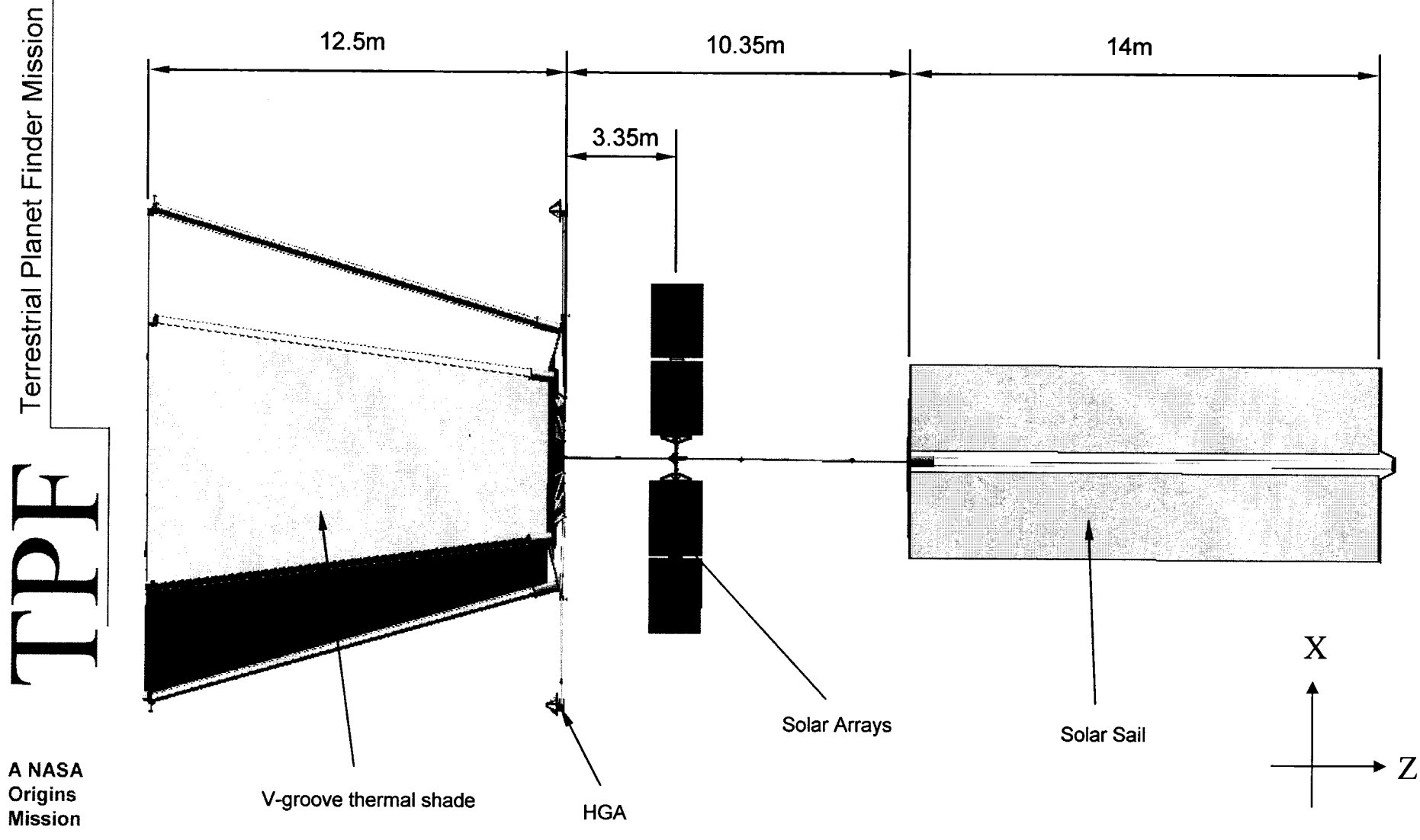
Terrestrial Planet Finder Mission

TPF



A NASA
Origins
Mission

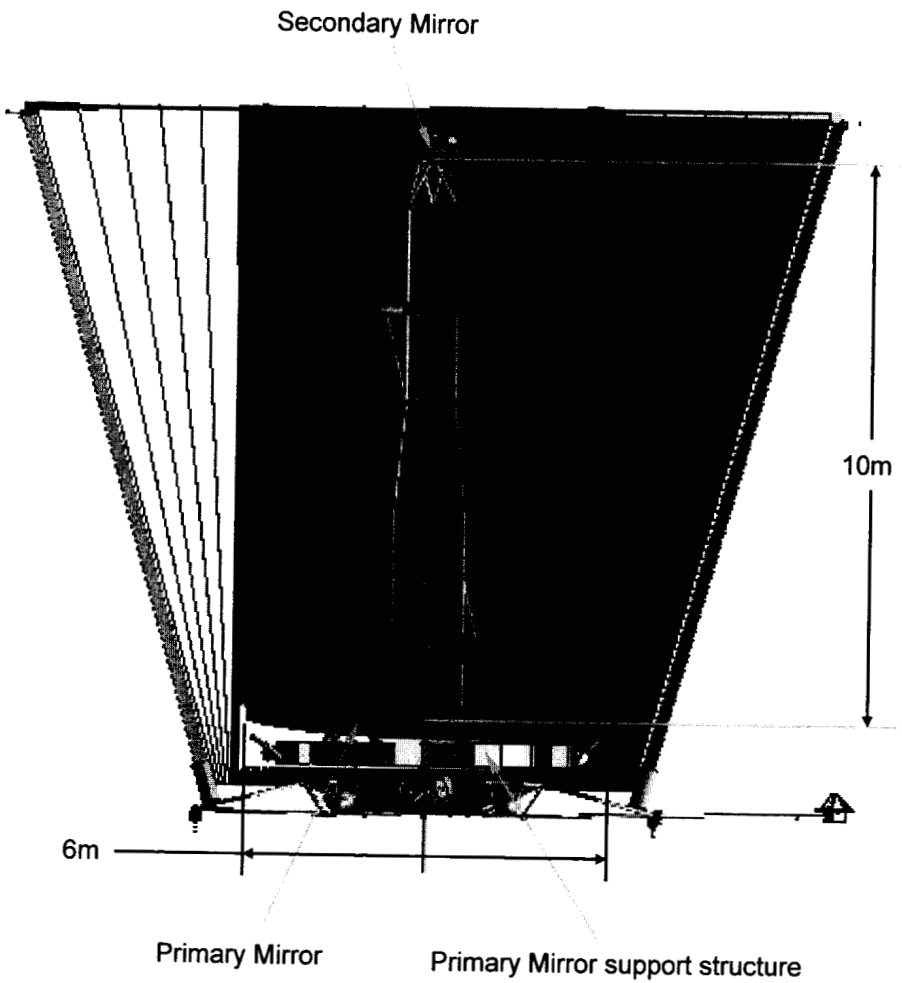
Minimum Mission Configuration

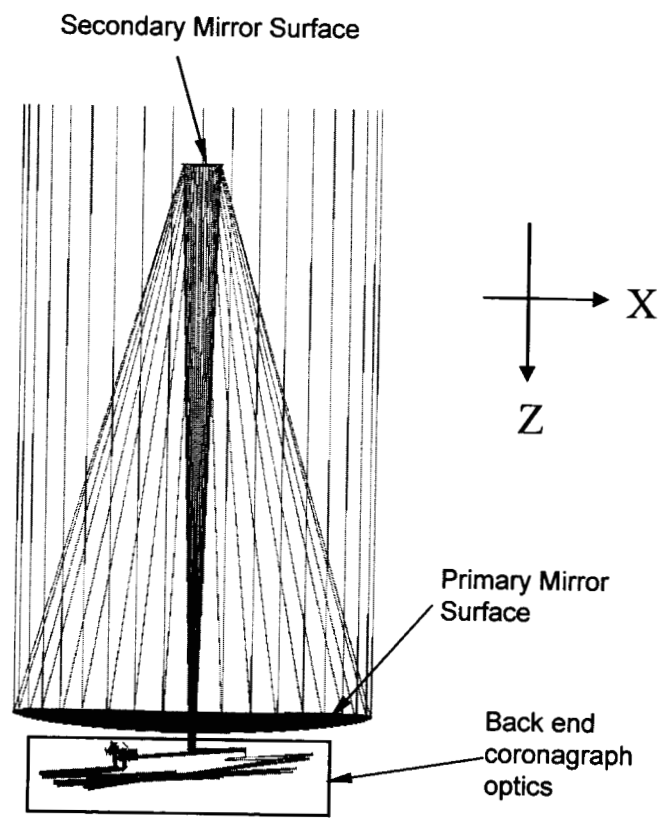


Minimum Mission Configuration

Terrestrial Planet Finder Mission

TPF





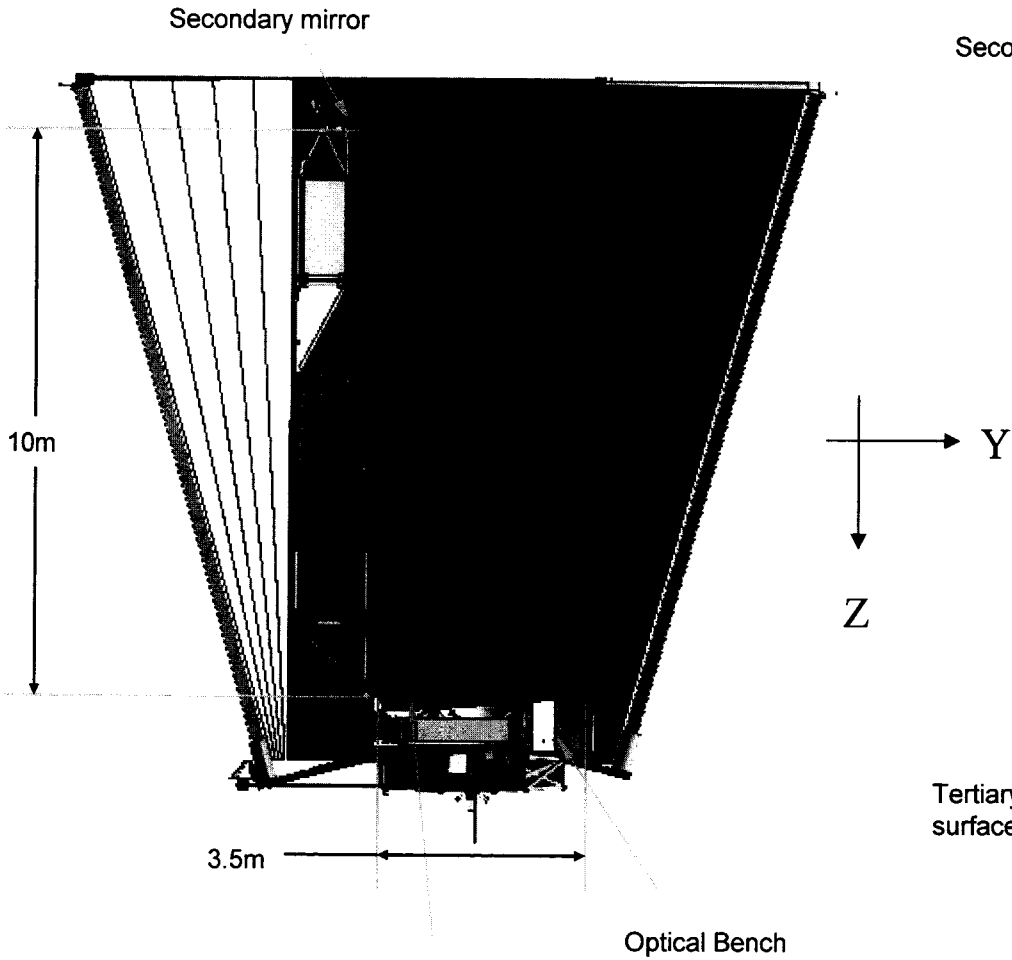
Optical Prescription Reference

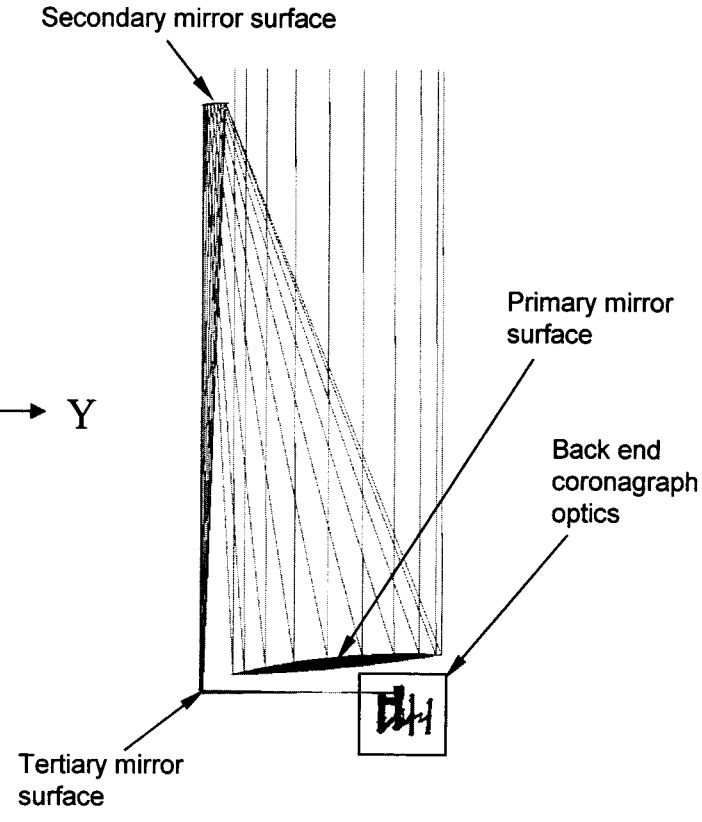
A NASA Origins Mission

Minimum Mission Configuration

Terrestrial Planet Finder Mission

TPF





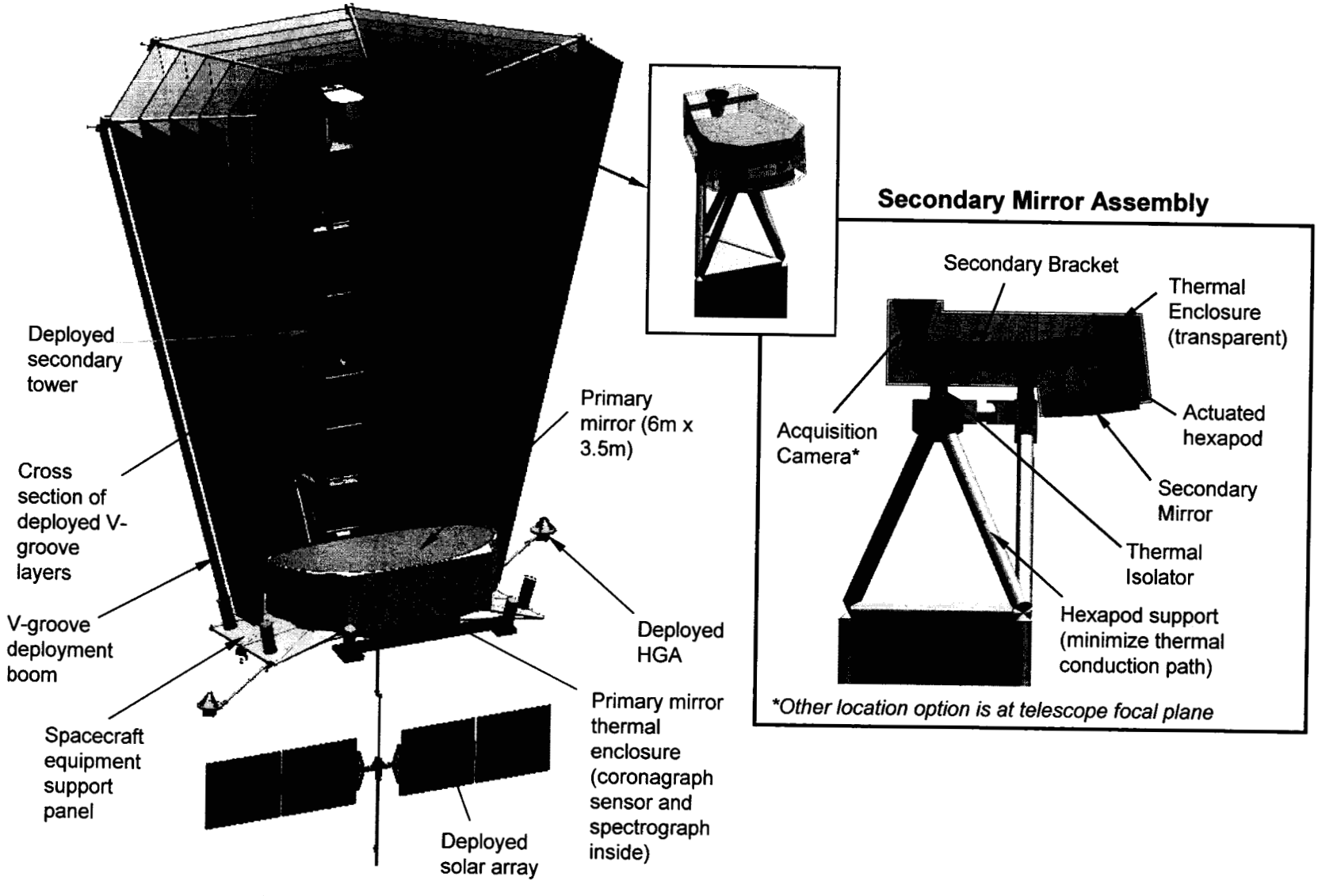
Optical Prescription Reference

A NASA Origins Mission

Telescope and Secondary Mirror Assemblies

Terrestrial Planet Finder Mission

TPF



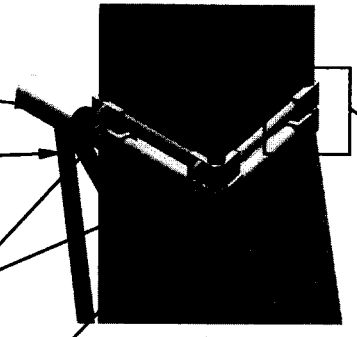
A NASA Origins Mission

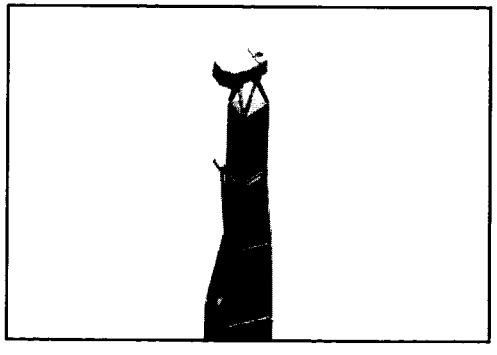
Secondary Tower Hinge and Latching Mechanism Concept

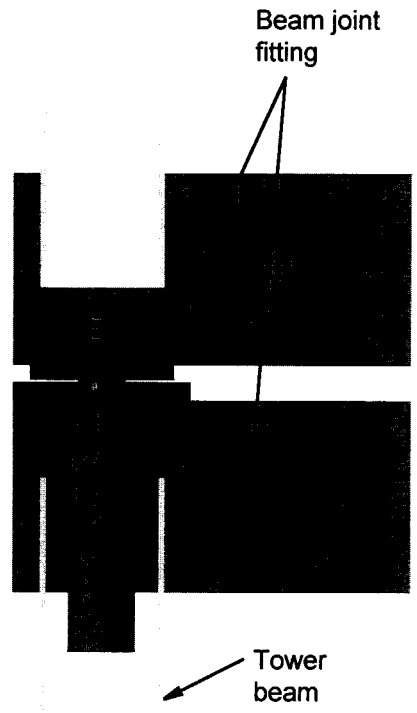
Terrestrial Planet Finder Mission

TPF

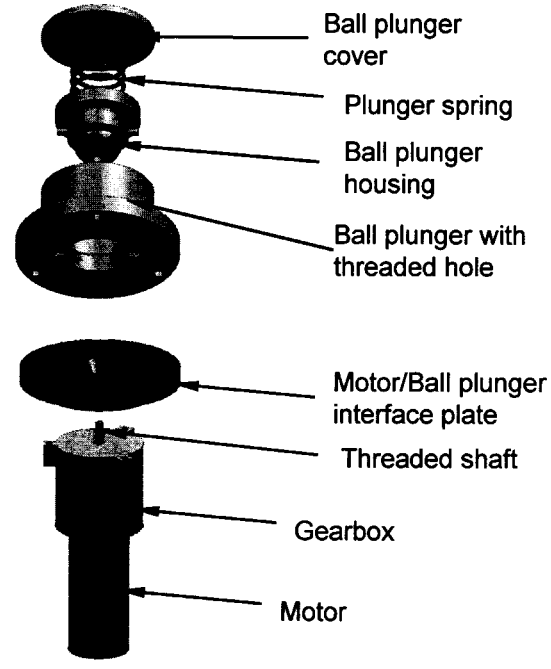
A NASA Origins Mission







Cross-Section View



Exploded View

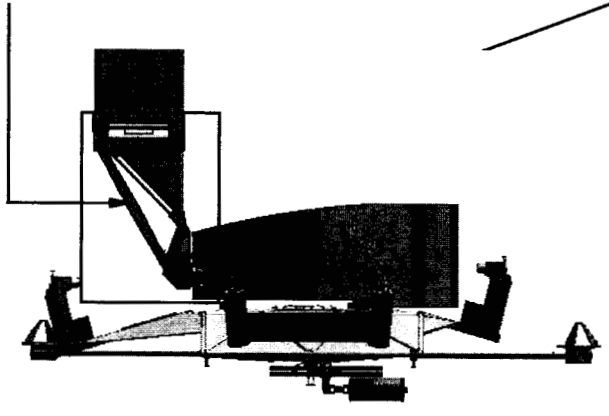
Note: Latching concept based on an NGST heritage concept

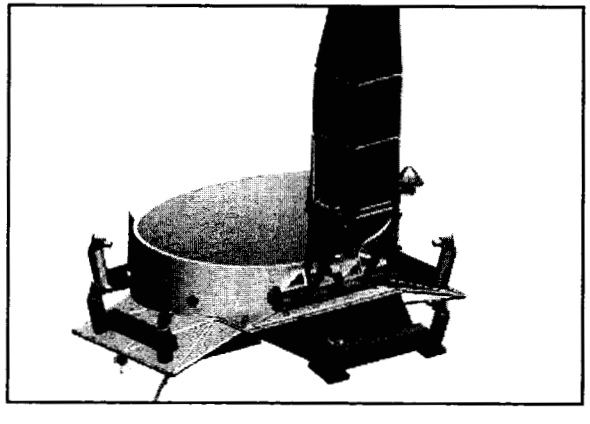
Secondary Tower Lower Support Mechanism

Terrestrial Planet Finder Mission

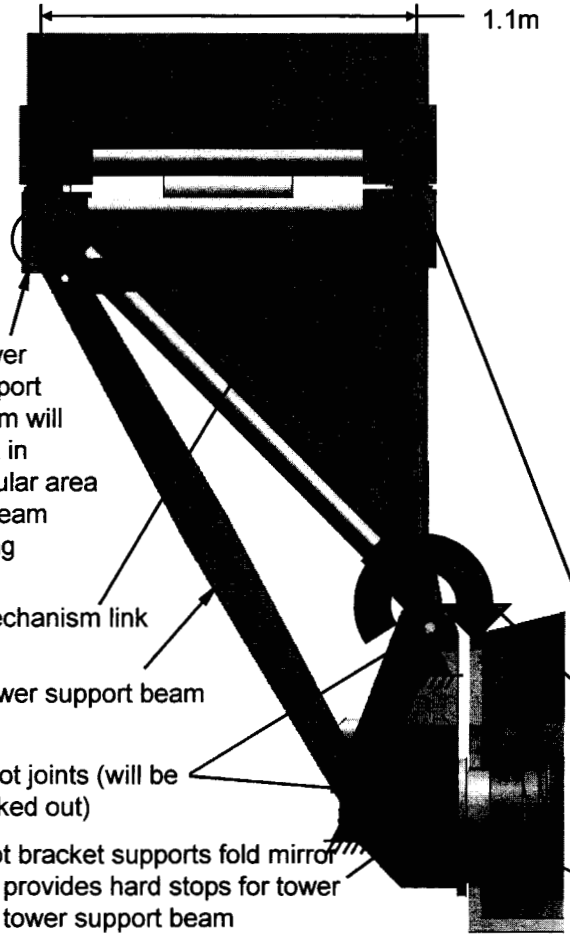
TPF

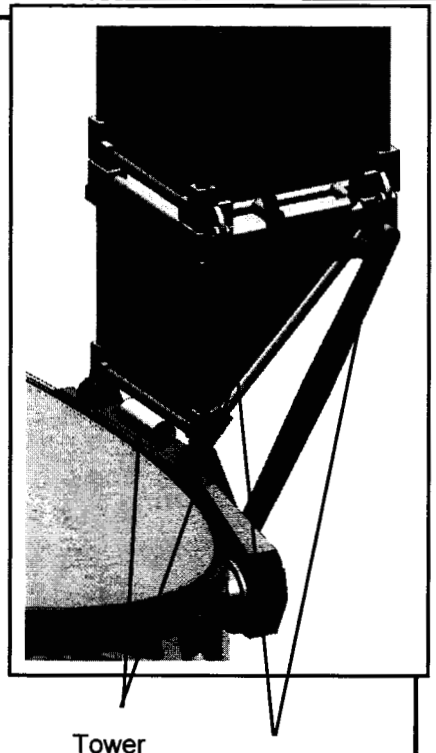
- Lower tower support needed to stiffen tower
- Will not stow in shroud as part of tower - must deploy into place





- Tower support beam part of 4 bar linkage mechanism – deploys when tower deploys



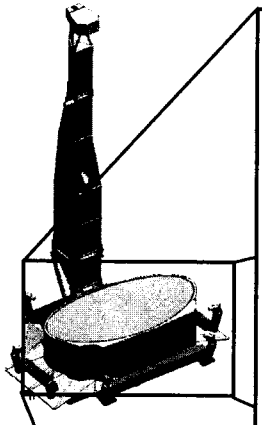


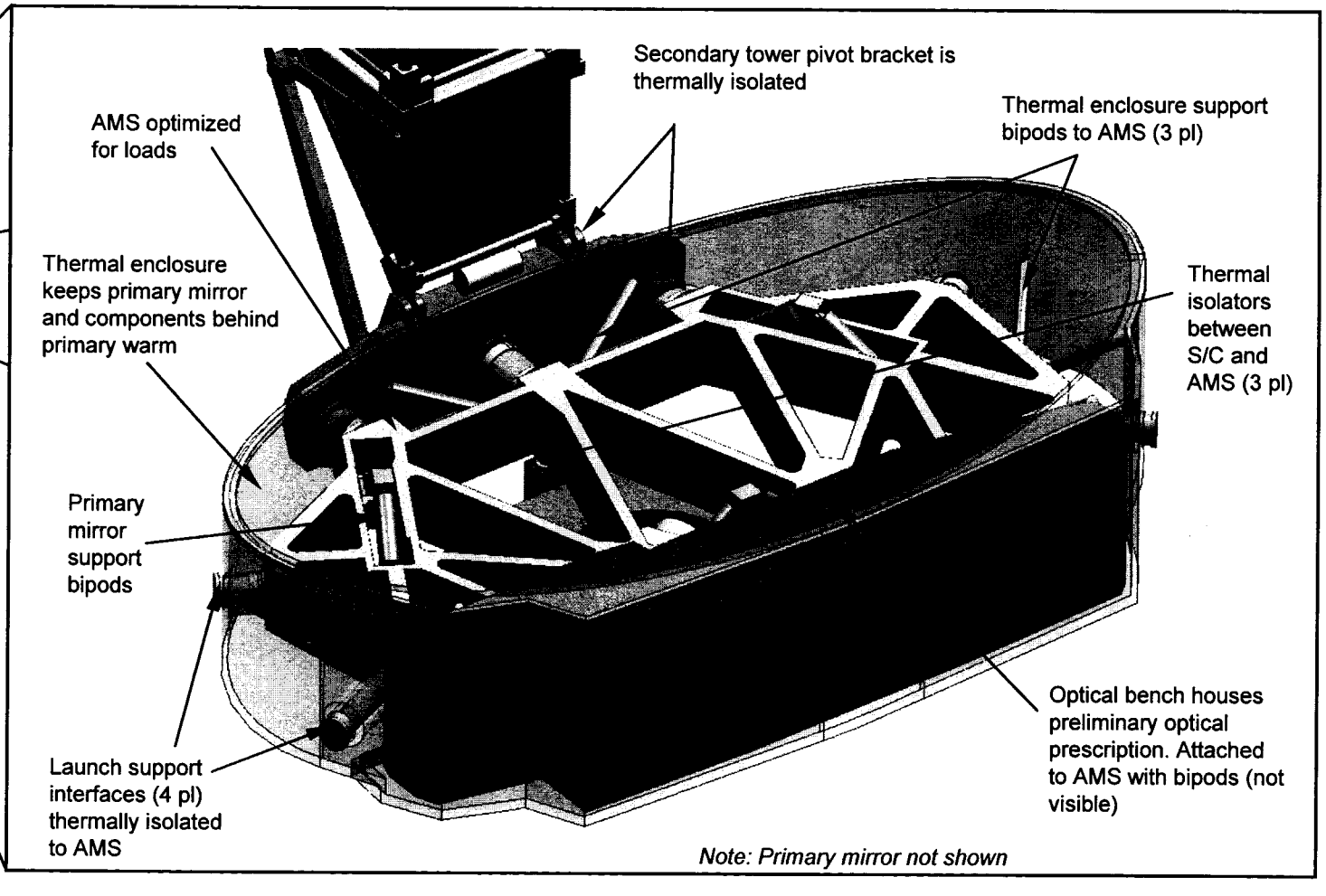
A NASA Origins Mission

Components Behind Primary Mirror

Terrestrial Planet Finder Mission

TPF



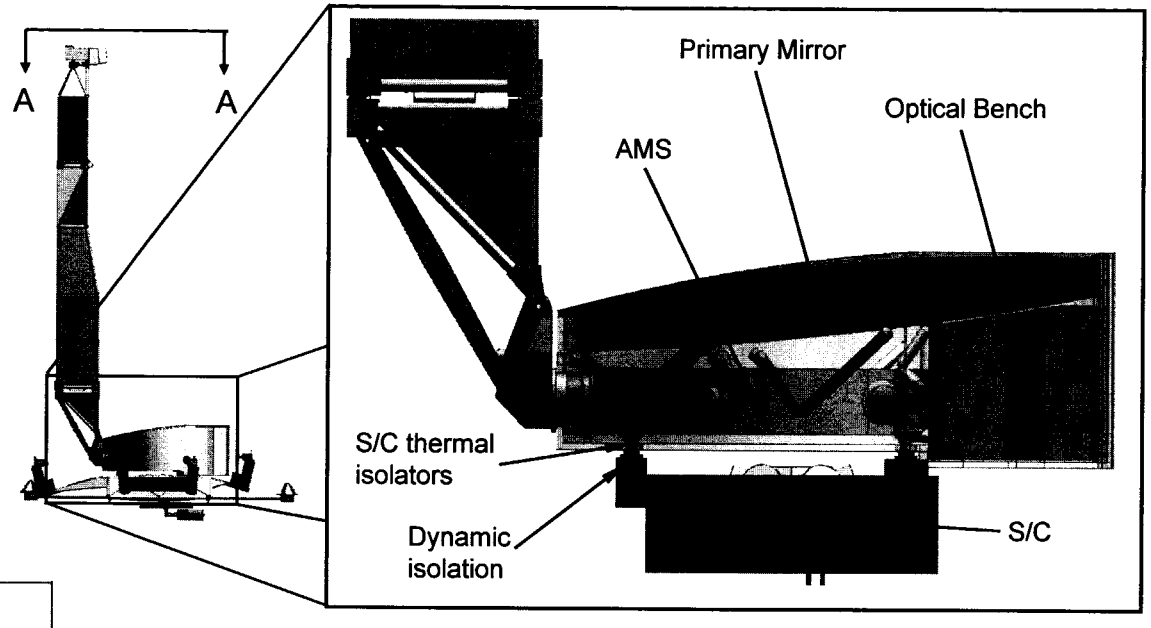


A NASA Origins Mission

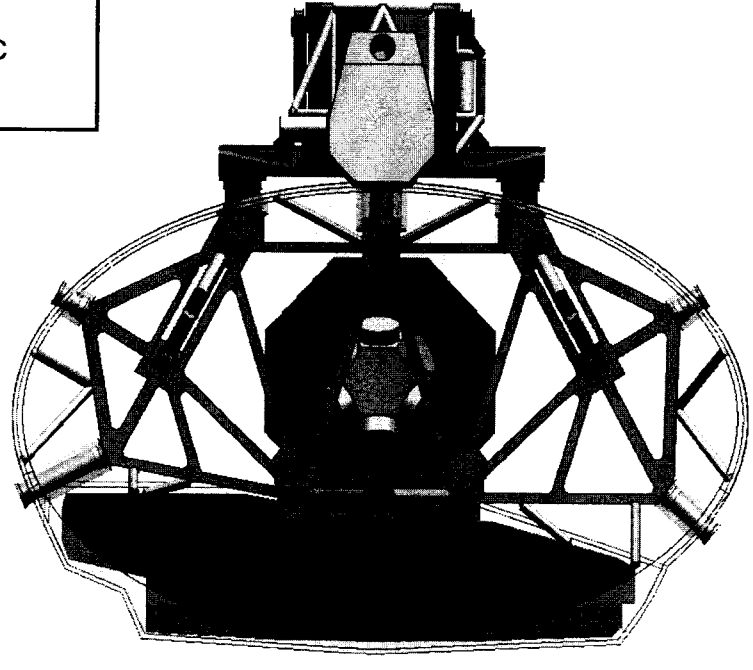
Components Behind Primary Mirror

Terrestrial Planet Finder Mission

TPF



View A-A
(Primary mirror not shown)



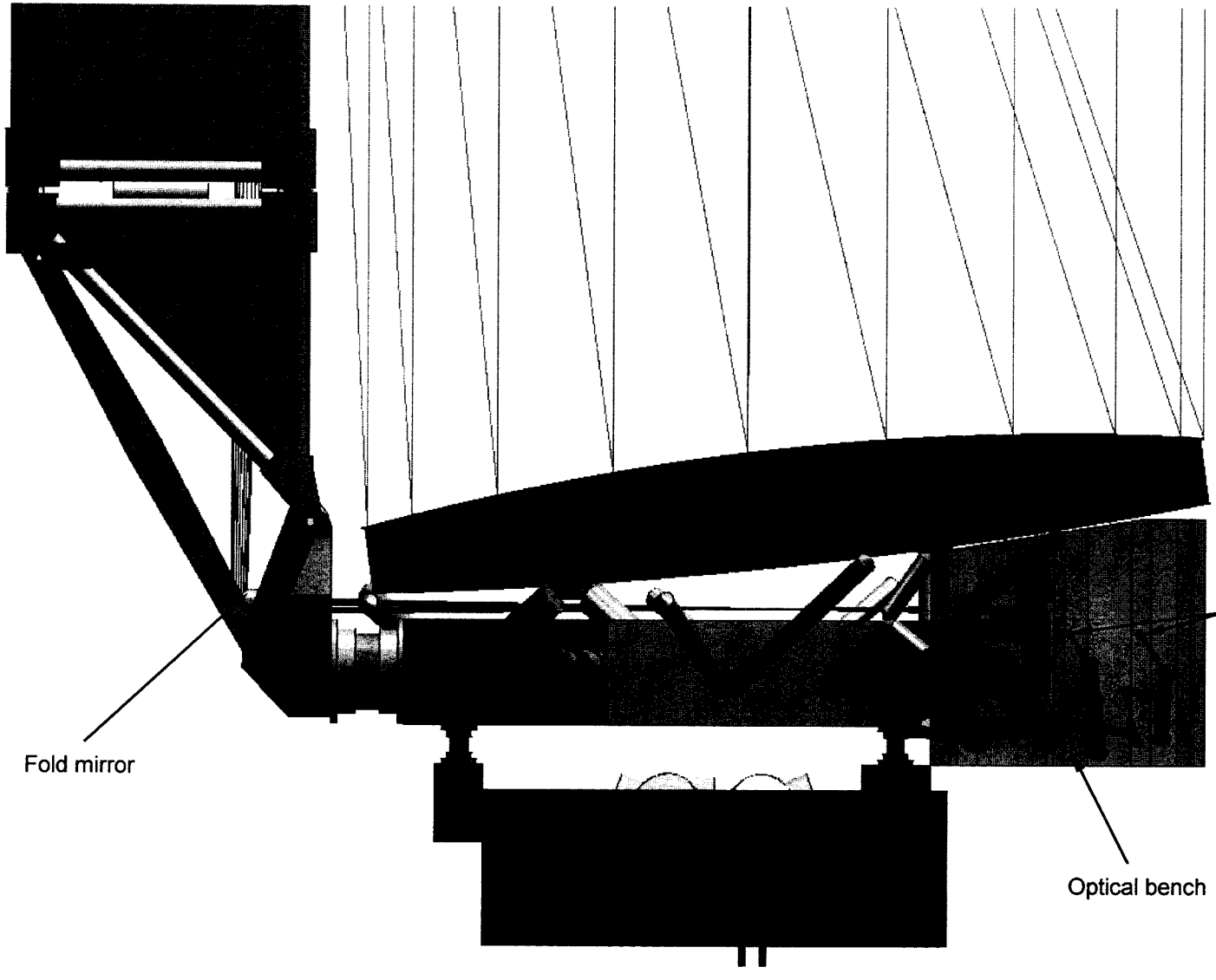
- Optical bench location is ideal from an integration and test point of view as well as helping balance the CG of the system

A NASA Origins Mission

Optical Prescription

Terrestrial Planet Finder Mission

TPF



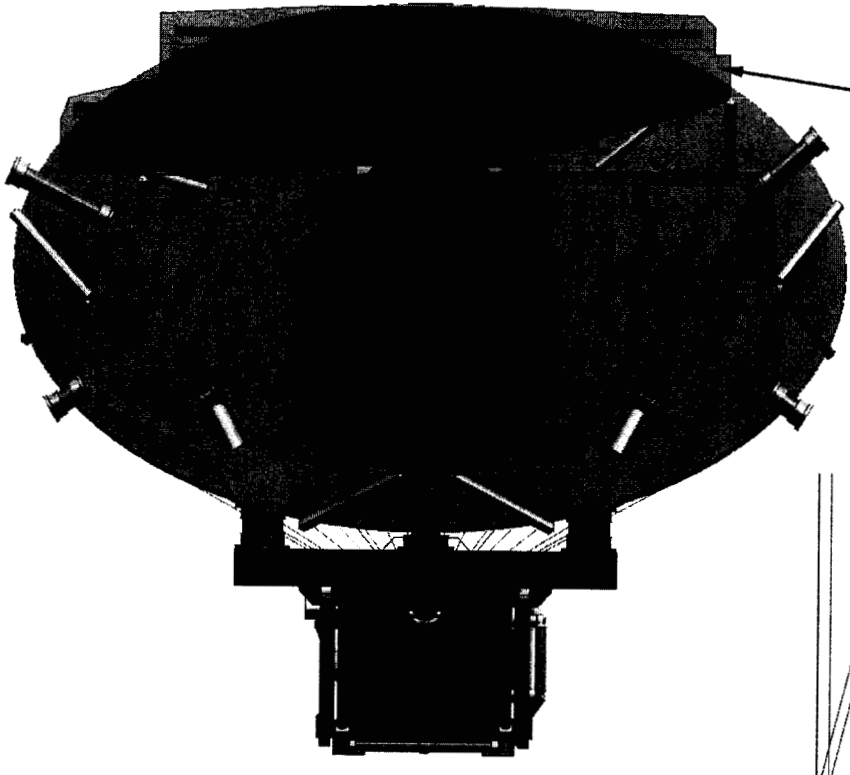
A NASA Origins Mission

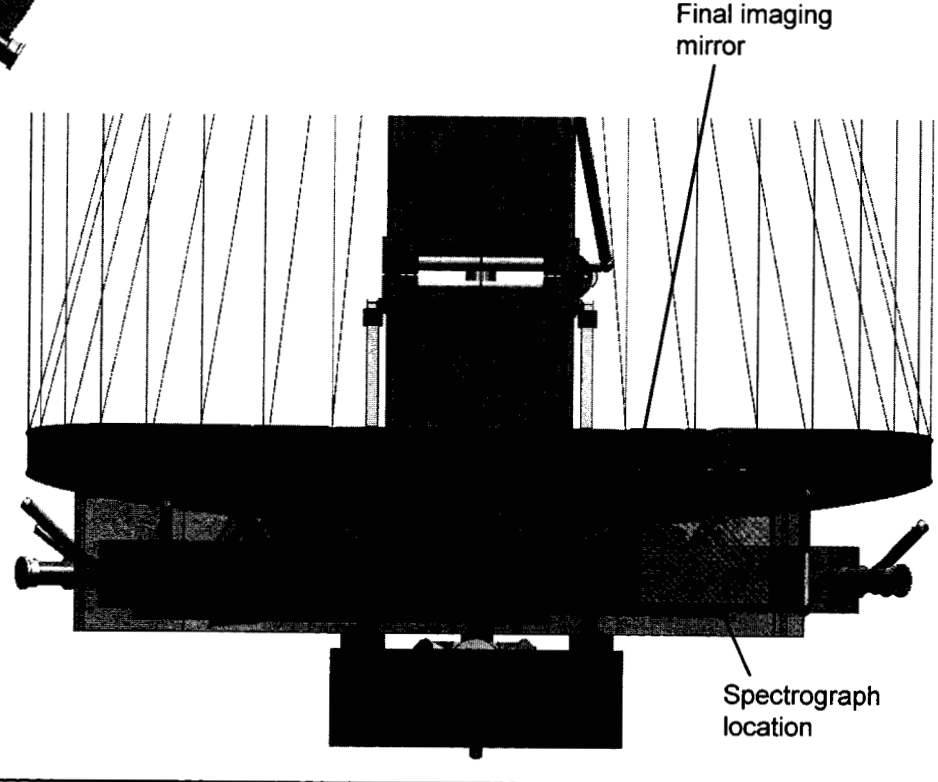
Optical Prescription

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission



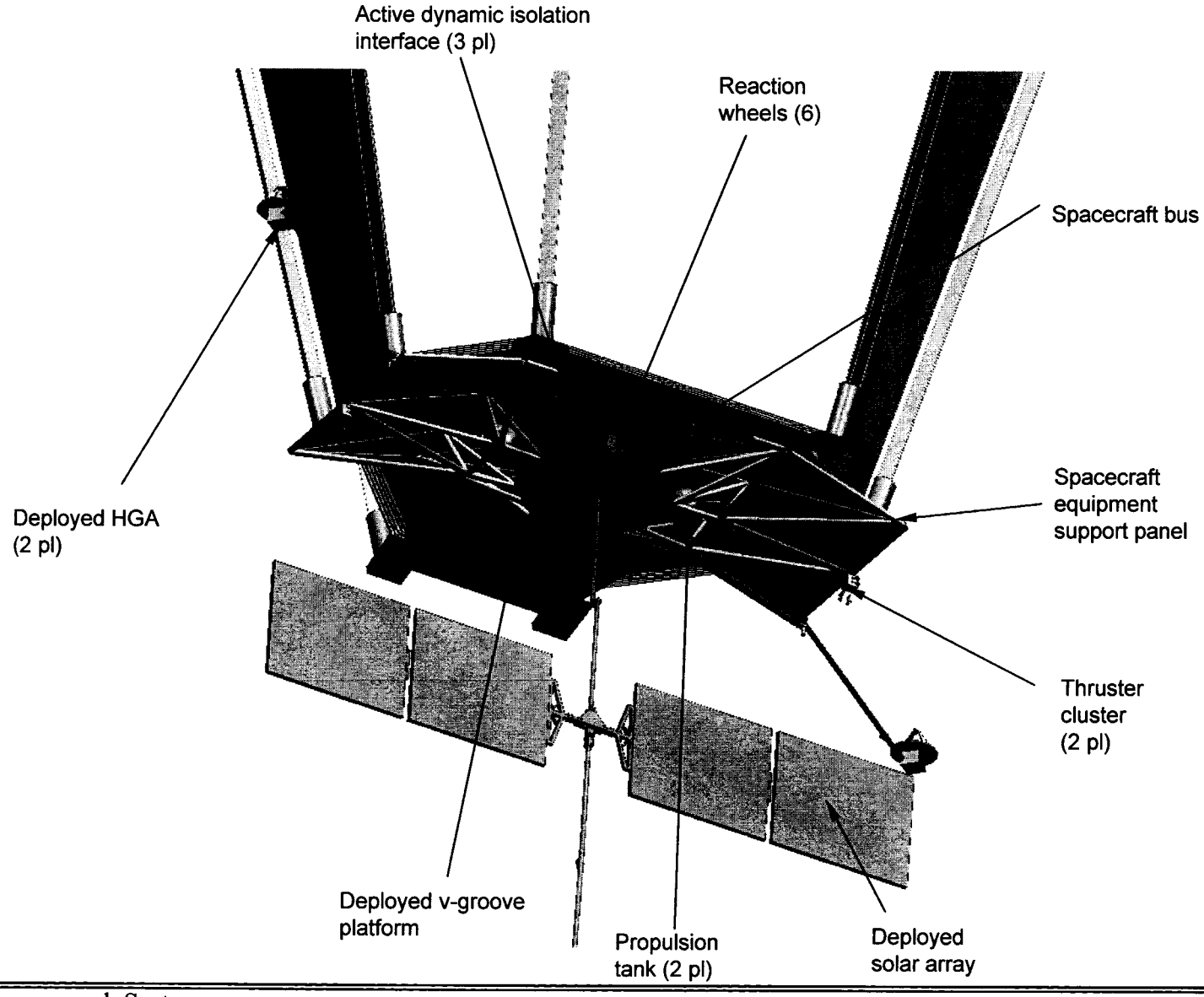


Spacecraft Component Configuration

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission



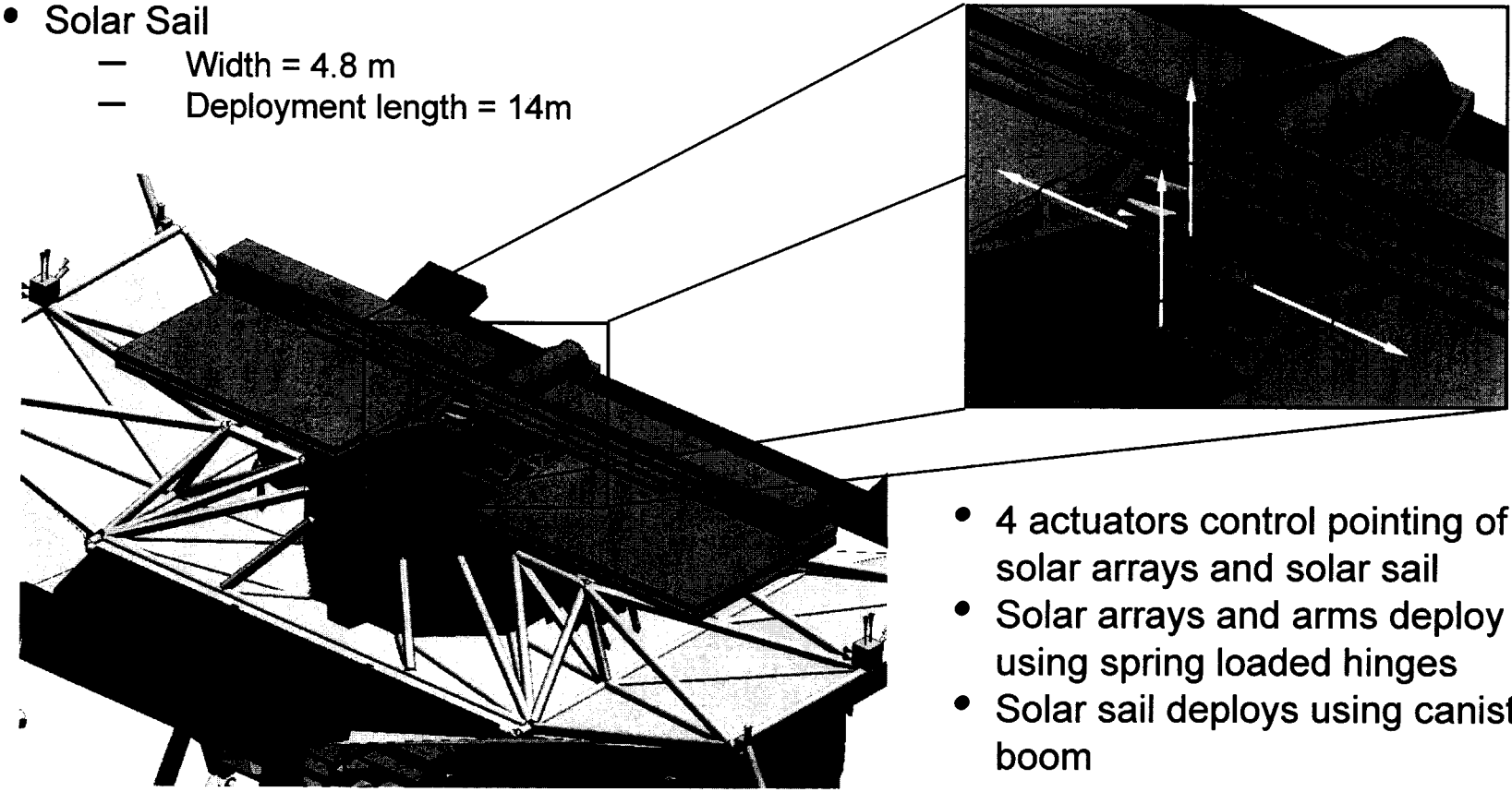
Solar Array and Solar Sail Configuration

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

- Solar Array and Solar Sail are sized and positioned to balance out the solar torque in the deployed configuration.
- Solar Array
  - Total Area = $12m^2$
  - Panel Area = 2m x 1.5m = $3m^2$
- Solar Sail
  - Width = 4.8 m
  - Deployment length = 14m

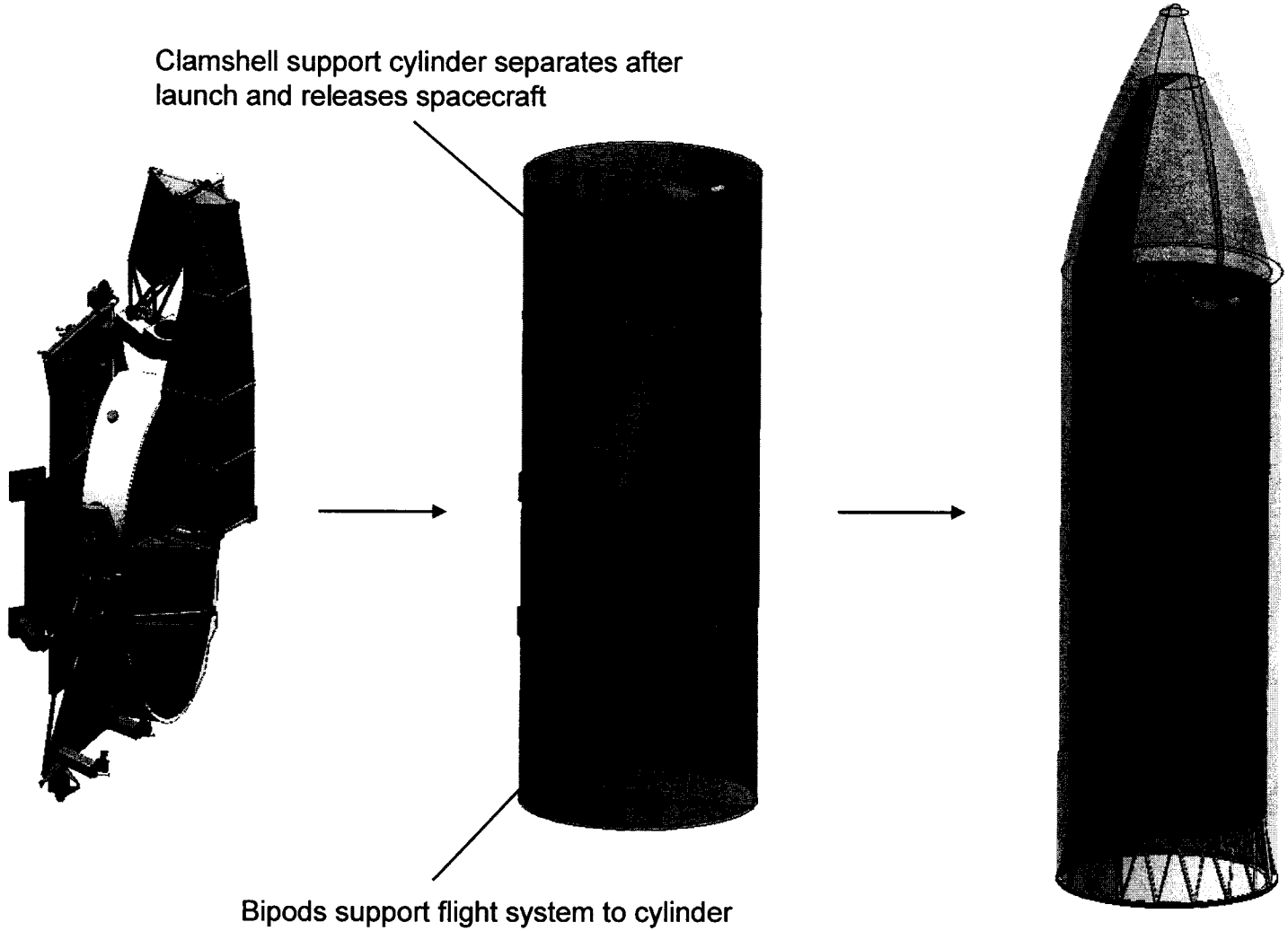


- 4 actuators control pointing of solar arrays and solar sail
- Solar arrays and arms deploy using spring loaded hinges
- Solar sail deploys using canister boom

Sequence For Stowing In Launch Shroud

Terrestrial Planet Finder Mission

TPF



A NASA Origins Mission

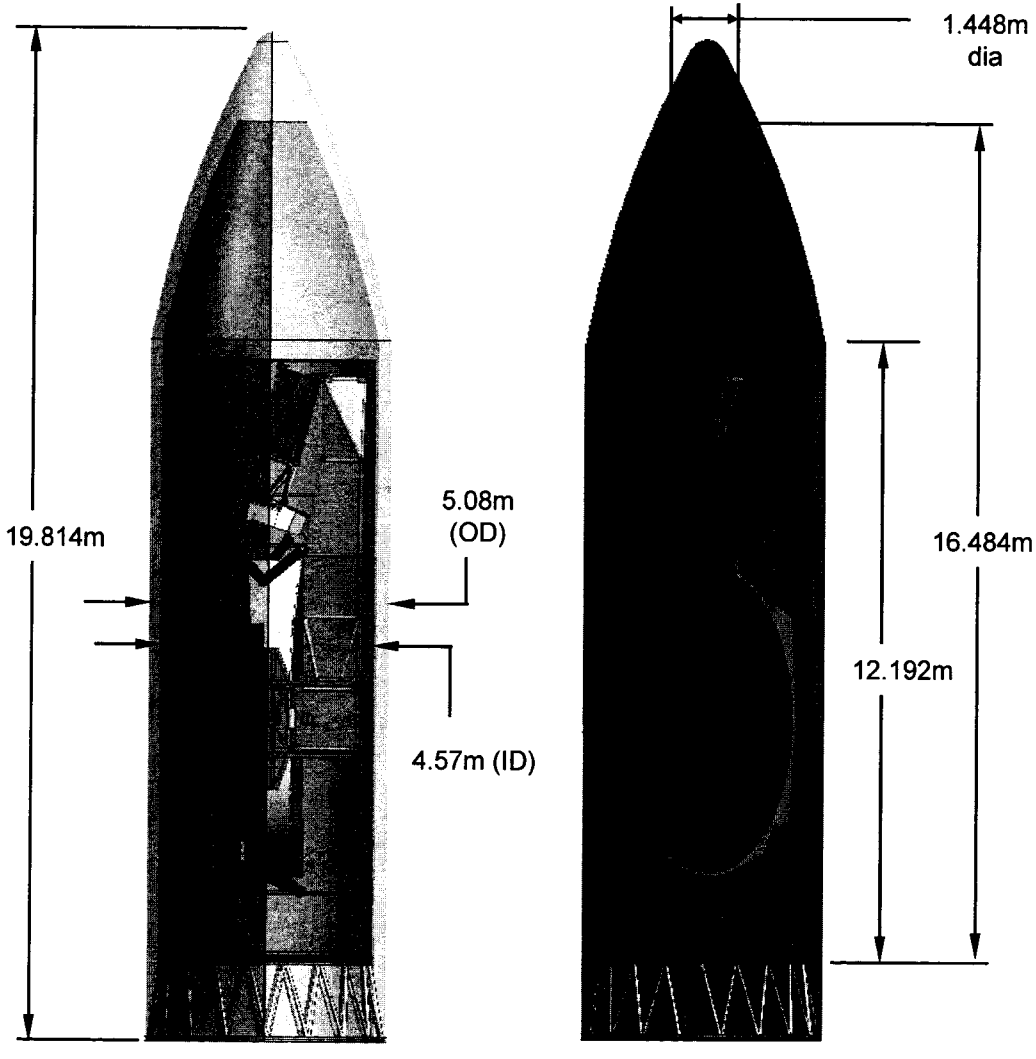
Stowed Mechanical Configuration

Terrestrial Planet Finder Mission

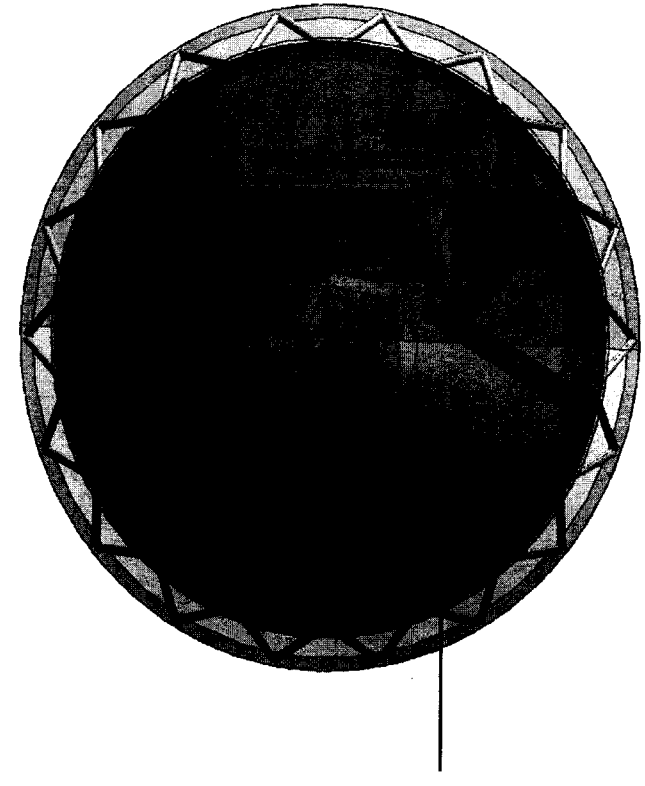
TPF

A NASA Origins Mission

Stowed Configuration in Delta IV-H (19.8m gov't standard)



Top View



Launch support cylinder – closed on both ends to control contamination on primary mirror

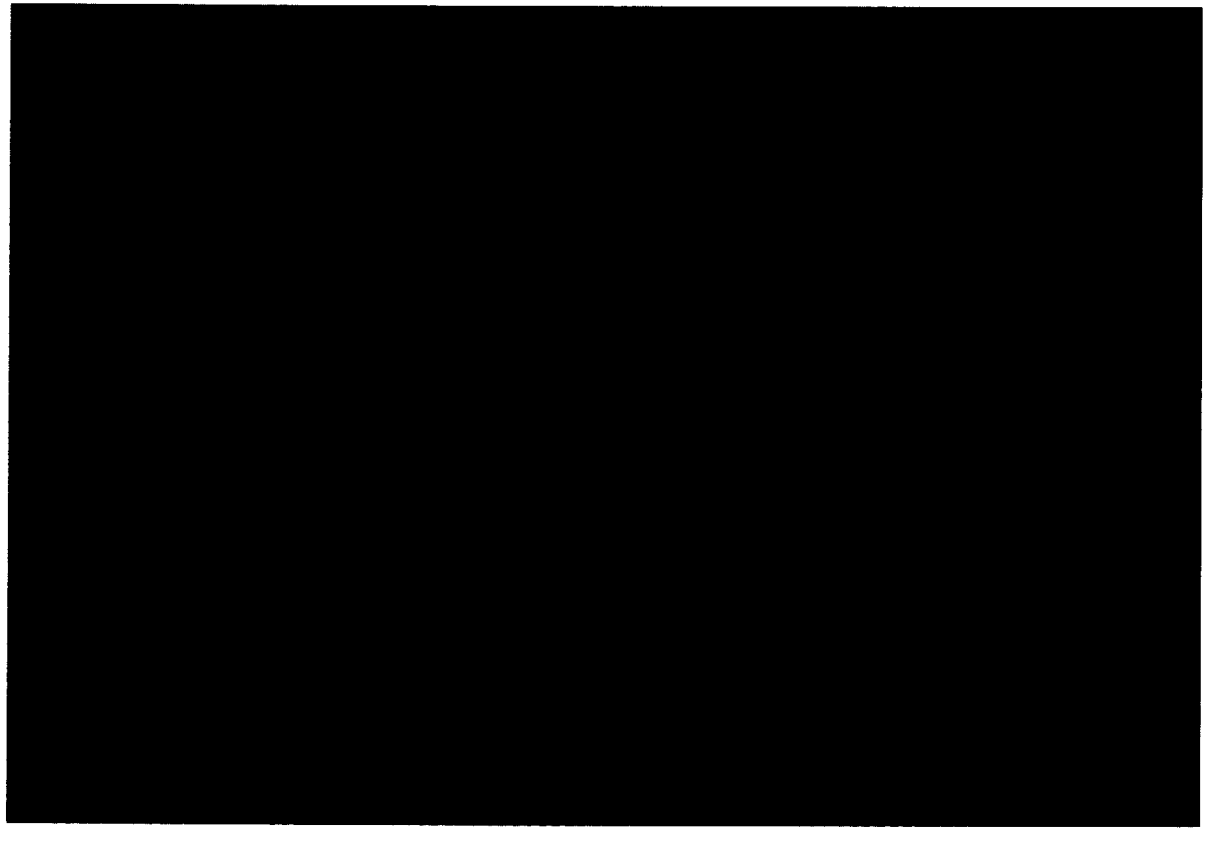
Mission Deployment Sequence Stage 1

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

Launch → Fairing separation → Second stage separation → Support cylinder separation →



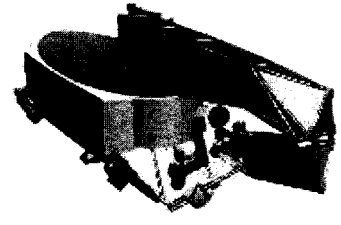
Mission Deployment Sequence Stage 2

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

Solar Array deploy → HGA deploy → Tower deploy → V-groove panel deploy → Solar Sail Deploy → V-groove deploy



Summary

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

- Many early trades performed to find the best overall configuration
- Conceptual configuration for TPF-C minimum mission is solid
  - Top level structural and thermal issues have been addressed
  - Stows compactly in the Delta IV-H launch shroud
  - Major spacecraft components accounted for
  - Viable launch to observation configuration scenario
- Future work
  - V-groove deployment system needs further development
  - Back end optics and optical bench require configuration concept based on optical prescription
  - Accommodation of ancillary science and spectrograph
  - Impacts of analysis (launch and operational) need to be evaluated and incorporated
  - Flowdown of I&T requirements need to be assessed and incorporated
  - Metrology system needs to be accommodated

Terrestrial Planet Finder Mission

TPF

A NASA
Origins
Mission

Backup Slides and Material

Excerpt from "Development of the Terrestrial Planet Finder Coronagraph Membrane V-Groove Sunshield," AIAA 2004-1731, 45th AIAA/ASME/ ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Palm Springs, California, April 2004, p1-6.

Development of the Terrestrial Planet Finder Coronagraph Membrane V-Groove Sunshield

Houfei Fang[†], Timothy Y. Ho[‡], Ubaldo Quijano[§], William C Ledeboer[¶], Andrew Kissil[*], Gregory Agnes[**], Gun-Shing Chen[*]
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099

An innovative architecture for a V-groove membrane sunshield, which serves as both a thermal shield and a light baffle, has been developed for the Terrestrial Planet Finder Coronagraph. A preliminary design analysis has been conducted to determine the major design parameters and to verify the existence of the boom technologies. A packaging and deployment study has been accomplished. A thermal analysis has been carried out to verify the thermal performance of this architecture. A dynamic analysis of the membrane V-groove sunshield has also been performed to validate its dynamic characteristics. Consequently, the feasibility of this architecture has been confirmed.

I. Introduction

The Terrestrial Planet Finder (TPF) mission will study many aspects of planets outside our solar system: from their formation and development in disks of dust and gas around newly forming stars to the presence and features of those planets orbiting the nearest stars; from the numbers at various sizes and places to their suitability as an abode for life[1]. The Terrestrial Planet Finder Coronagraph is a potential architecture under developing at Jet Propulsion Laboratory for this mission. Figures 1 to 2 show the TPF Coronagraph in both packaged and deployed configurations.

To control the coronagraph's thermal environment, a novel V-groove sunshield, which serves as both a thermal shield and as a light baffle, has been developed by this study. This paper will discuss the architecture, preliminary design analysis, packaging and deployment, thermal analysis, and the dynamic analysis of the membrane V-groove sunshield.

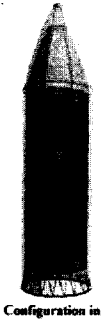


Figure 1. Stowed Configuration in Delta IV-H Fairing

[†] Member of Technical Staff, Mechanical Systems Engineering and Research Division, Senior Member AIAA.
[‡] Member of Technical Staff, Mechanical Systems Engineering and Research Division
[§] Academic Part Time Student
[¶] Member of Information Systems and Computer Science Staff, Observational Systems Division.
[*] Member of Technical Staff, Mechanical Systems Engineering and Research Division.
[**] Member of Technical Staff, Mechanical Systems Engineering and Research Division, Senior Member AIAA
[*] Manager, Science and Technology Development Section, AIAA Member

II. Architecture of the membrane V-groove sunshield

With the development of materials and space gossamer technologies, large membrane sunshields are emerging and gaining more and more attentions[2-3]. This study developed a cocoon type V-groove membrane sunshield. It is composed of six layers of cone-shaped thin-membranes as shown in figure 3. The diameter of the most inner V-groove is 6.5 meters and the functional height of all V-grooves is 11.5 meters. The thickness of the membrane is 1-mil. Major components include: 1) membranes to serve as the sunshield, 2) catenary systems that stretch the membranes to give them stiffness, 3) booms which deploy the membranes and provide structural rigidity, 4) spacer bars to separate membranes, and 5) anchoring cables to stabilize the booms and to prevent bending loads to be loaded onto the booms. Figure 4 is the schematic of the cocoon type V-groove membrane sunshield.

Among these components, the deployable booms are the most critical structural components. They are long (around 15 meters) and must be lightweight. Each boom must be packaged within a 0.3-meter diameter and 0.7-meter tall envelope to accommodate the system package as shown in figure 1. To minimize the bending moment on a boom introduced by the membrane tensioning force, an anchoring cable is employed by this architecture.

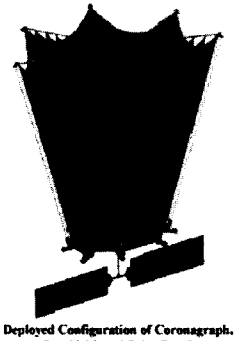


Figure 2. Deployed Configuration of Coronagraph, V-Groove Sunshield, and Solar Panel

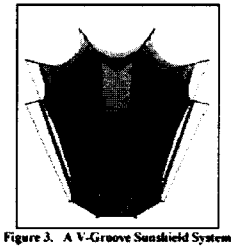


Figure 3. A V-Groove Sunshield System

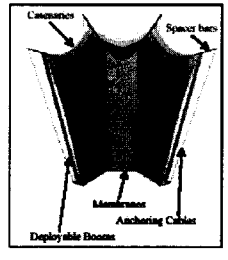


Figure 4. Schematic of the V-Groove Sunshield System

III. Preliminary design analysis

After the architecture was developed, a preliminary design analysis was conducted to determine the parameters of the catenary systems, positions and orientations of booms, positions and orientations of anchoring cables, and forces loading the booms in their axial directions. The ultimate purpose of this analysis is to determine the feasibility of this architecture. 18 different boom technologies were examined to determine the existence of boom technologies

that can accommodate this architecture. References 4 to 9 are some boom technologies that have been published in the public domain.

This study used 1-mil (2.54×10^{-5} meter) thick aluminized Kapton as the membrane material. The membrane tensioning stress is assumed to be 3-psi (20689 N/m^2). Every V-groove is composed of 8 flat membrane sections. The bottom separation between two layers of membrane is given as 2 inches (5.08 cm) and the angle between two adjacent layers of membrane is 3 degrees. The most inner layer is a 6.5-meter diameter and 11.5-meter (excluding the catenary area) tall cylinder.

The preliminary design analysis started from the catenary analysis. A catenary is a cable that is connected to the edge of a piece of membrane. The function of the catenary is to evenly apply tensioning stress to a piece of membrane to stretch it. Figure 5 is an example of a piece of membrane that is tensioned by a catenary. Figure 6 is the curvature of a catenary. In figure 6, L is called the span of the catenary, h is called the sag of the catenary, w is the stress that the catenary applies to the membrane. After the span, sag, and membrane stress are determined, the force along the catenary cable can be calculated.[10] The cable forces of all six membrane are then used to calculate the force transmitted to a boom.

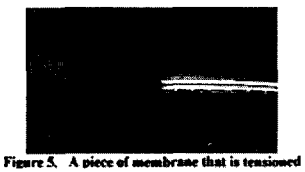


Figure 5. A piece of membrane that is tensioned

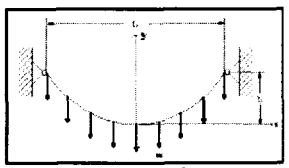


Figure 6. Curvature of a catenary

Figure 7 is a diagram that shows the locations and orientations of six layers of membranes, spacer bar, boom, and anchoring cable. After the catenary analyses, the magnitudes and directions of the forces acting on the spacer bar by catenaries are all determined. By applying force and moment balance with respect to the intersect point of the boom and the spacer bar, both boom force and anchoring cable force can be calculated correspondingly. Most lightweight boom technologies are developed to take large axial buckling loads with very limited bending capabilities. In order to minimize the bending load on a boom, the bending moment load on the boom is assumed to be zero.

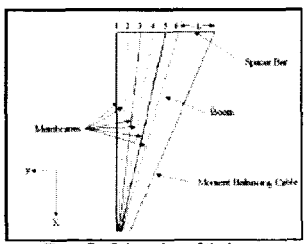


Figure 7. Orientations of the boom, membranes, spacer bar, and anchoring cable

The variables of the preliminary design analysis are:

1. Sag of the catenary system. Since the orientations of different layers of membrane vary, it is required that the projections of all sags on the vertical axis must be at the same height. The dimension of the projections of all sags on the vertical axis is named as "sag of the catenary system".
2. Boom angle. The boom angle is defined as the angle between a boom and the vertical axis. The minimum boom angle is 16.18 deg, which is the angle of the outmost layer membrane.
3. Top offset. The top offset is defined as the distance between the center of the top end of the boom and the anchoring cable. Top offset is indicated as L in Figure 7. The minimum top offset is 0.15 meter.
4. Bottom offset. The bottom offset is defined as the distance between the center of the bottom end of the boom and the anchoring cable. The minimum bottom offset is 0.2 meter.
5. Boom force. The boom force is the force loaded on the boom in the axial direction of the boom.
6. Boom length. The boom length is the function of the sag of the catenary system as well as the angle of the boom.

7. Required boom bending stiffness. The assumptions made for analyzing bending stiffness are: the boom failure type is Euler buckle, bottom of the boom is fixed, top of the boom is free, and the safety factor is 4. The required boom bending stiffness is calculated as:

$$EI = \alpha P \frac{(2L)^2}{\pi^2} \qquad (1)$$

Where, L is the length of the boom, P is the applied boom force, α is the safety factor.

Figures 8 to 11 are some of the preliminary design analysis results. Figure 8 shows the top offset as the function of the bottom offset while the sag of the catenary system is kept at 1 meter. Figure 9 shows the boom force and the

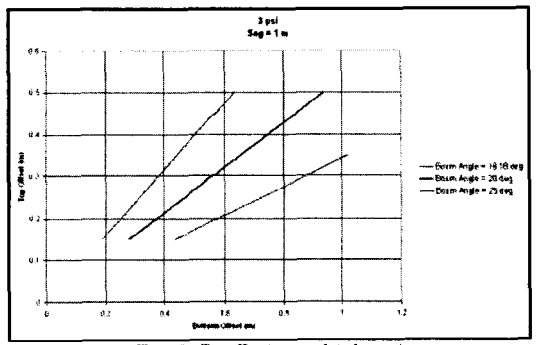


Figure 8. Top offset (sag equals to 1-meter)

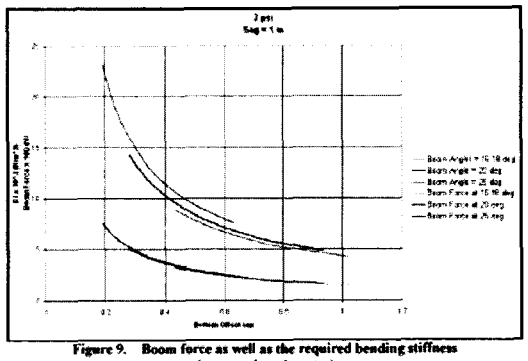


Figure 9. Boom force as well as the required bending stiffness (sag equals to 1-meter)

required bending stiffness (EI) as the function of the bottom offset while the sag of the catenary system is kept at 1 meter.

Figure 10 shows the top offset as the function of the bottom offset while the sag of the catenary system is kept at 2 meter. Figure 11 shows the boom force as well as the required bending stiffness (EI) as the function of the bottom offset while the sag of the catenary system is kept at 2 meter.

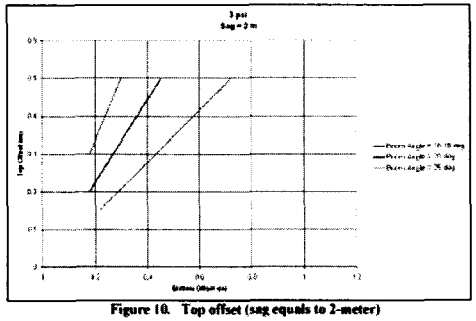


Figure 10. Top offset (sag equals to 2-meter)

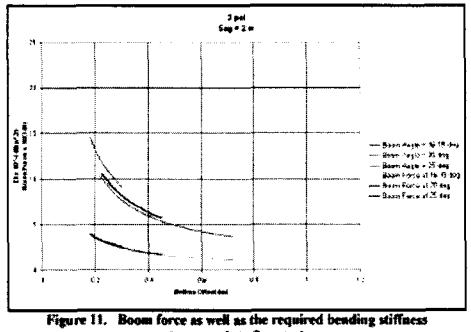


Figure 11. Boom force as well as the required bending stiffness (sag equals to 2-meter)

Following observations can be obtained from figures 8 to 11:

1. Smaller sag of the catenary system results in a bigger force that is loaded to the spacer bar by the catenary. The force loaded to the boom by the catenary via the spacer bar also becomes bigger. On the other hand, bigger sag requires longer boom. In order to minimize the required boom bending stiffness, shorter boom length and smaller boom force are preferred.
2. Smaller bottom offset is desired for packaging. Smaller bottom offset results in a smaller top offset and the system is more compact. However, smaller bottom offset is also associated with undesirable bigger boom force as well as bigger boom bending stiffness.

3. Bigger boom angle results to preferred smaller bottom offset as well as undesired boom force.

It is concluded by this analysis that multiple boom technologies exist which can be developed to accommodate this architecture. The potential boom technology, which can be further developed for this application, has also been identified consequently.

IV. Packaging and in-space deployment

Figure 12. Both coronagraph and sunshield are packaged in the fairing of a Delta IV-H

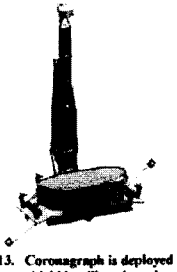


Figure 13. Coronagraph is deployed while sunshield is still packaged

One of the challenges of this study is to package the coronagraph and the membrane sunshield into a Delta IV-H fairing. Tremendous efforts have been made to accomplish this as well as to avoid any possible conflict between the coronagraph and the sunshield during the deployment process. Figure 12 shows both coronagraph and sunshield, which are packaged in the fairing of a Delta IV-H. The first step of the deployment process is the deployment of the coronagraph as shown in figure 13. The second step of the deployment process is the deployment of the sunshield as shown in figure 2.

Another challenge of this study is how to package a membrane cylinder as a whole piece without introducing too many creases after it is deployed. The deployment process of the membrane cylinder should not have any confliction with the deployed coronagraph. An origami technology was invented by this study and demonstrated in figures 14 to 16.

Figure 14. A packaged paper cylinder

Figure 15. A partially deployed paper cylinder

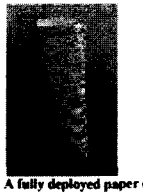


Figure 16. A fully deployed paper cylinder

V. Thermal analysis of the V-groove sunshield

A thermal analysis was conducted to verify the thermal performance of the sunshield. Figures 17-18 give results of this analysis. It is concluded from the results of this analysis that this sunshield can control the thermal environment of the coronagraph.