Robotic Assembly of a 20-Meter Space Telescope
With Extension to 40-Meter Telescopes

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Introduction

This presentation will describe a robotically assembled 20-meter telescope that has evolved from a 10-meter telescope design described in a study entitled "Robotic Assembly Concept for the Next Generation Space Telescope"[1]. In that study, a concept for a 10-meter robotically assembled NGST telescope was compared to the government's 8-meter automatically deployed NGST telescope concept. This showed that there were nine advantages of robotic assembly over automatic deployment. The only negative factors were the cost and weight of the robot.

This report describes concept for a 20-meter telescope that can be launched in the 5-meter diameter Delta IV shroud and then assembled by a robot in space. The capabilities required of the robot system are presented next including a description of the robot's telescope assembly routine. Next, it is shown how the 20-meter design can be extended to telescopes as large as 40 meters. Then the nine advantages of robotic assembly of these large telescopes over automatic deployment are presented and lastly a discussion of the cost and weight of robotic assembly is given. It appears that the cost and weight of robotic assembly becomes less than an automatic deployment at a telescope size between 10 and 20 meters. This is because the cost and weight of an automatic deployment system is proportional to the square of the telescope's diameter, while the cost and weight of the robot system is nearly independent of telescope size,

20-Meter Telescope Packaged for Launch

Figure 1 shows the 20-meter diameter telescope packaged for launch in a 5-meter diameter Delta IV shroud. The 314 square meter primary mirror is composed of 126 hexagonal, lightweight mirrors about 1.92 meters across their longest dimension. Typically, each hexagonal mirror is a relatively thin, somewhat flexible surface that is mounted to a stable supporting structure. The exact mounting details of the mirrors depends on the mirror technology used, but usually many actuators position and shape the mirrors during operation. The actuators usually also provide a caging function so that the mirrors can tolerate launch accelerations and vibrations. The robotic assembly design presented here describes the assembly of the telescope's supporting structure.

For launch, the primary mirror support structure is divided into two sizes of support structure. The 15 Large Primary Mirror Segments (LPMSs) each carry six hexagonal mirrors for a total of 90 mirrors. The 12 Small Primary Mirror Segments (SPMSs) each carry three hexagonal mirrors for a total of 36 hexagonal mirrors. For this design, the LPMS and SPMS thickness was set at 0.15 meters.

During launch, 5 LPMSs and 4 SPMSs are nested together in a "9-Pack". Three 9-Packs are mounted vertically within the shroud in a triangular arrangement. They are mounted above an optical bench that provides the mechanical interface between the telescope and the rest of the satellite.

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[1] The report is available at: http://ngst.gsfc.nasa.gov/public/unconfigured/doc_272_1/RobotDep.pdf
A complementary study that describes a possible robot to do the telescope assembly was done by Spar Space Systems for the NGST project. It is available at: http://ngst.gsfc.nasa.gov/public/unconfigured/doc_337_1/NGSTSPARrobot.pdf

The PMSs of 9-Pack 1 are numbered in the order they will be assembled to become the Primary Mirror. Starting on the innermost PMS and going to the outside they are: LPMSs 1, 2, 27, 4, and 3, followed by SPMSs 8, 7, 6, and 5. Figure 2 shows an exploded view of 9-Pack 1. The 9-Pack 2 is numbered LPMSs 9, 10, 26, 12, and 11 followed by SPMSs 16, 15, 14, and 13 and the 9-Pack 3 is numbered LPMSs 17, 18, 25, 20 and 19,followed by SPMSs 24,23, 22, and 21.

Mounted axially in the central triangular space between the three 9-Packs is a Central Baffle. This is in two sections, one section is mounted to the Optical Bench and the other section telescopes over the first so that when extended, the baffle will reach 11.14 meters above the primary mirror surface. Mounted in the space above the 9-Packs and Central Baffle is the Secondary Mirror. It is suspended below a support structure by a Stewart platform and the support structure is mounted to the top of the each 9-pack. The three folded legs of the Secondary Support Tripod are attached to the to the Central Baffle at one end and hinged to the Secondary Support Structure at the other end.

The Robot System Characteristics

The robot is envisioned to be a seven-degree of freedom device composed of two identical "arms", connected to each other by a "shoulder" joint. Figure 3 shows a robot design by Spar Space Systems. Each arm would have a 3-meter long tube connecting the shoulder joint to a three-degree-of-freedom wrist and the wrist would connect to an end effector. This gives the robot a nominal 6-meter reach. The end effector would be able to mechanically grapple a grapple fitting and, while attached, torque a bolt that is captivated within the grapple fitting. This torque is reacted locally by the grapple fitting. The robot would be thermally insulated and include heaters so that it can operate at any location on the telescope including on the very cold telescope. The robot would be stowed for launch mounted to the outside of one of the 9-Packs.

Three types of grapple fittings complete the robot system. They each have the same mechanical grapple interface but different functions. The grapples are located on the telescope components as necessary.

1. Foothold grapples allow the robot to walk from place to place and to "stand" in a location so that the other end of the robot can do useful work. Foothold grapples are mounted to structure capable of handling the robot's maximum forces and torques and they supply power, command and telemetry signals between the robot and the rest of the satellite.
2. At least one Handhold grapple is provided on each part that the robot is to move. These grapples may be mounted on less robust structure than a Foothold since the stress is much less. When moving a part, the end effector torquer loosens the bolt captive within the Handhold (usually the last bolt holding the part), moves the part to its new position, and then tightens the same bolt to attach the part in its the new position.
3. The Grapple is only used to react the torque of the end effector torquer while it loosens or tightens the captive mounting bolt contained within.

Each end effector includes a television camera with an illumination source used to view a target next to each grapple fitting. The TV images are used in a closed-loop way to eliminate misalignment between the grapple fitting and the end effector as the robot moves to attach to the fitting. These cameras may be used for general viewing when the end effector is not attached to a grapple.

Robot Assembly Routine

Assembly of the Primary After launch, the robot unstows itself and attaches itself to a Foothold on the Optical Bench directly below 9-Pack 1. It then loosens all bolts that connect 9-Pack 1 to 9-Packs 2 and 3. It then loosens all the bolts holding 9-Pack 1 to the Optical Bench except for the one bolt located within the Foothold it is standing on. Then, while holding a Handhold at the bottom of 9-Pack 1, the torquer in the end effector holding the Foothold loosens the bolt under the Foothold. This frees 9-Pack 1 and the robot repositions it in a temporary location about 3 meters up the Central Baffle and attaches it there. This attachment includes a crossed-V guide so that the 9-Pack is accurately aligned. (The first mechanical connection of a PMS always includes an alignment guide.) Figure 4 shows the relocated 9-Pack 1. The robot repeats this process for the other two 9-Packs.

The robot then loosens all but one of the bolts that attach one PMS to the next in 9-Pack 1. It then removes the LPMS 1 and attaches it to the OB with a single bolt from the mirror side of the LPMS. This mechanical interface is located in the shadow of the Secondary Baffle and does not block any active mirror surface. Then the robot tightens two bolts from the backside of the Optical Bench into the back of the LPMSs 1. The robot then makes the electrical connection between the LPMS 1 and the Optical Bench. It does this by attaching to a handhold that carries a electrical cable and connector that is stowed within the back of the LPMS 1. It unscrews the bolt releasing the cable and connector and attaches the connector to its mate on the edge of the Optical Bench. Alignment pins prevent misalignment of the connector. The connector insertion forces are supplied by tightening the bolt within the Handhold. In all the assembly steps below, after a part is mechanically assembled, the robot connects an electrical cable between that part and a part that has already been assembled.

The robot repeats this assembly process with LPMS 2.

The robot then relocates to a Foothold on the back of LPMS 2 that allows it to reach between LPMS 1 and 2 and unscrew LPMS 3 and attach it to the rear of LPMS 1. The robot then connects the bolts between LPMS 3 and LPMS 2. For launch, SPMSs 5 – 8 are mounted to the back of LPMS 3 and they remain attached to LPMS 3 when it is assembled in the Primary.

The robot continues relocates to a foothold on the back of LPMS 1 and continues the assembly process by removing LPMS 4 from LPMS 27 and mounting it to LPMS 1. It then connects LPMS 4 to LPMS 3. The robot then removes SPMS 5 from the back of LPMS 3 and attaches it to LPMS 4. It then moves to the Foothold on LPMS 2 and removes SPMSs 6, 7, and 8 one by one and mounts them in their proper position on the Primary. LPMS 27 remains attached to the Central Baffle at this time.

The robot repeats the above process with LPMSs 9 – 12 and SPMSs 13 - 16. LPMS 26 is left attached to the Central Baffle. Again, the robot repeats the above process with LPMSs 19 – 22 and SPMSs 24 – 25. At this point, the Primary is complete except for LPMSs 25, 26, and 27. The robot then removes LPMS 25 from its temporary location on the Central Baffle and mounts it in the gap between the PMSs from 9-Pack 1 and 9-Pack 3. The robot then relocates itself and mounts LPMS 26 in the gap between the PMSs from 9-Pack 2 and 9-Pack 3. Figure 5 shows the assembly at this stage of completion. Finally, the robot mounts LPMS 27 in the gap between the PMSs from 9-Pack 1 and 9-Pack 2. This finishes the assembly of the Primary Mirror.

Figure 6 is a rear view of the completed Primary showing the order of the assembly sequence. The colors are to help distinguish one PMS from another. In actual practice, the rear of all PMSs will probably be black.

Footholds are placed on the edge of the finished Primary and also at three locations on the mirror side of the Primary about 4 meters in from the edge. These Footholds allow the robot to walk from the back to the front of the Primary so it can assemble the rest of the telescope. All Footholds on the mirror side of the Primary are located between hexagonal mirror segments and will be shadowed by the secondary support tripod legs. No active mirror area is lost because of the mirror-side Footholds.

Assembly of the Central Baffle After the robot walks from the rear of the Primary, it crosses the mirror and then grapples a Foothold on the Optical Bench. From here it loosens all the bolts holding the telescoping part of the Central Baffle to the fixed part. Then, the robot raises the telescoping part of the Central Baffle and fixes it in place. Internal guides align the two parts of the Central Baffle.

Assembly of the Secondary Mirror Raising the telescoping part of the Central Baffle also raises the Secondary Mirror, its Support Structure and the three legs of the Secondary Tripod since they are attached to it. Standing on a Foothold on the upper part of the Central Baffle, the robot loosens the bolts that keep the Tripod Leg 1 joints locked during launch and also loosens the bolt holding Leg 1 of the Tripod to the Central Baffle. (The two remaining legs support the Secondary Mirror assembly.) The robot grapples the various handholds on Leg 1, unfolds the four hinge joints one by one to predetermined angles and then releases the leg. The leg joints accurately retain these angle by means of detents. This configuration is shown in Figure 7. The robot then moves to a Foothold on the Primary, grapples the free end of Leg 1, positions it over a mounting structure attached to the outer edge of PMS 27 and attaches it there. The robot repeats this assembly process with the other two legs. The Secondary Mirror and its Support Structure are now supported by the partially deployed Tripod and is free of the Central Baffle. The robot then moves onto a Foothold on Leg 3 and opens its hinge joints. This also simultaneously opens the hinge joints on the other two Tripod Legs. When a joint is completely open, the robot tightens a bolt that locks it. When the bolt is tightened, the joint is completely aligned because there is a crossed V-guide under each bolt. Note that the joints do not use the hinges for alignment since all hinges must have a small amount of play so that they will move freely at any temperature without lubrication.

After walking up Tripod Leg 3 to tighten all the hinge bolts, the robot walks down Tripod Leg 2 tightening the bolts at each of its joints. It then goes back up Leg 2, moves over to Leg 1 and tightens the bolt at each of its joints.

The telescope is now assembled. This is depicted in Figure 8.

Stow the Robot The robot will walk around the Primary Mirror and go down the isolation mast and onto the warm side of the satellite and attach itself to grapples provided there. It can then be put in a powered off state.

Telescopes Larger Than 20 Meters

The maximum size telescope that can be launched depends on three variables: the volume of the shroud, the thickness of the PMSs and the weight of the mirrors. The Primary Mirror design using 0.15 meter thickness and ~2-meter diameter hexagonal mirror segments allow a 20-meter

Primary Mirror to fit within the 14.8 meter (48 ft) 5-meter diameter shroud and still leave enough room for the instruments and the rest of the satellite. This is the shortest 5-meter shroud available for the Delta IV. The next largest 5-meter diameter shroud is 19.8 meters (65 ft) long and the largest is 22.9 meters (75 ft) long.

The mirror technology selected will determine both the mirror weight and thickness. The robot assembly process is essentially independent of these parameters. For instance, suppose that the selected mirror technology required a thicker mirror. For the same size Primary Mirror, the packaging would change. The PMSs would become longer with more hexagonal mirrors per PMS and the 9-Packs would become 8-Packs or 7-Packs. Conversely, if the Primary Mirror were thinner, the PMSs could become shorter and the 9-Packs would become 10-Packs or 11-Packs. In any of these cases, the robot would assemble the Primary Mirror in much the same way as described above for the 0.15 thick Primary Mirror.

The table below gives the primary mirror diameter of some telescopes that could be robotically assembled using ~2-meter hexagonal mirrors mounted on PMSs of four thicknesses and the three available Delta IV shroud sizes.

Table 1 -- Primary Mirror Diameter for Various PMS Thicknesses and Delta IV Shrouds

Primary Mirror Segment Thickness / # in a Pack	Primary Mirror Diameters for Available Shroud Lengths		
	14.8 meter Shroud	19.8 meter Shroud	22.9 meter Shroud
0.19 m / 7	17.7 m	25.6 m	29.7 m
0.15 m / 9	20.0 m	28.9 m	33.6 m
0.12 m / 11	22.0 m	31.9 m	37.0 m
0.10 m / 13	23.9 m	34.5 m	39.6 m

The robot can easily handle variations of the design. For instance, instead of constant thickness PMSs, PMSs mounted in the middle of the telescope could be thicker than those mounted near the edge of the telescope. Another variant would be to assemble the parts of the 20-meter primary design into a partially filled 40-meter primary. It would have the angular resolution of a 40-meter telescope but with the weight and cost of the 20-meter telescope. Another alternative design would be an offset secondary mirror. In this variant, the robot would build a precision truss from one side of the primary mirror to hold the secondary.

Discussion of Advantages

There are nine advantages for using a robot to assemble the telescope rather than a conventional automatic deployment. These are discussed below:

1. *The Diameter of a Robotically Assembled Telescope will be Constrained Primarily by Cost and Weight, not by Launch Vehicle Shroud Volume*

Conventional deployment requires that the parts to be deployed be located close to their deployed location during launch in order to keep the deployment mechanisms simple and reliable. Robotic assembly allows a large separation of the launch location from the final location of each part and this allows the tight nesting of the PMSs in the robotic design. Such nesting is very difficult if not impossible with an automatic deployment.

The packaging efficiency of a robotically assembled telescope assures that the telescope size will not be limited by launch packaging considerations. Only its mass and/or the cost to build the mirrors will limit its size.

2. *Higher Probability for a Successful Robotic Assembly*

For the 10-meter NGST design, it was estimated[2] that a single robot has a better than 40:1chance to successfully assemble the telescope. To achieve this, the robot would be one fault tolerant. Because robotic assembly is a new technology used in a critical application, it was assumed that two robots would be flown and that either robot could do the job. The second robot virtually guarantees a successful assembly since together they have a probability of a successful mirror assembly of 1600:1. While one robot should be able to assemble the NGST telescope in a few days, to be conservative, the reliability calculation assumed that each robot operated in orbit for 32 days over a 6-month period.

The Spar study came up with similar numbers for their robot to assemble the 10-meter telescope. They estimated the success of one robot to be better than 22:1 and 500:1 for two robots.

For the 20-meter design, the robot's reliability numbers will be reduced slightly because there are more pieces of the Primary Mirror to assemble and this will take a little longer.

An estimate of the probability of a successful conventional automatic deployment of a 20-meter telescope cannot be made without an actual mechanical design to evaluate. Note that all the deployment mechanisms must work properly and completely. Partial operation means a mission failure.

Although the vast majority of conventional deployment mechanisms that have flown have operated successfully in space, there have been a few recent failures. The communications satellite EchoStar 4 has been declared a total loss because its solar panels did not deploy properly. Also, one of the two solar panels on the Mars Global Surveyor did not deploy all the way and lock. In contrast, there have been no recent reports of failed actuators that drive antenna gimbals or solar array drives. These actuators are similar to the joint actuators used in robots.

[2] Reliability estimate based on actuator reliability estimates for the Flight Telerobotic Servicer Program by Moog, Inc., Schaffer Magnetics Division, Report 114177.

3. <u>Packaging Prevents Mirror Contamination</u>[3]

Robotic assembly allows the packaging of all optical surfaces so that they cannot be contaminated during ground handling, launch, and during the deployment of the non-optical parts of the satellite. The robotic packaging I've described places all mirror surfaces so that they face inward. Then the gaps between the backs of the outermost mirrors would be sealed to each other using labyrinth seals. These seals allow flow of clean gas to flow from the inside to the outside through the zigzag path of the labyrinths keeping thereby keeping any contamination from reaching the mirror surfaces. Once the mirror contractor assembles the mirrors to the Optical Bench and the clean gas starts to flow, the mirror assembly can be moved through the various integration and test operations with assurance that no mirror contamination will occur. During launch, the rapid depressurization of the shroud as the rocket ascends above the atmosphere simply increases the flow of gas out through the labyrinth and any particles that are shed by the shroud's acoustic blanket are kept out.

After the major propulsion events are finished and the satellite is on its trajectory to its final destination, the non-telescope telescope deployments would be made. The robotic assembly of the telescope would be delayed for a week or so to give any contamination time to either escape to space or to adhere to some non-mirror surface.

For conventionally deployed telescopes, a similar positive contamination protection is very difficult to achieve. If contamination protection is not part of the mirror packaging design, extreme care and attention to air cleanliness will be required at every point in the buildup of the satellite. Wherever the mirrors are located during the satellite's integration, test, transportation and mating to the launch vehicle, they must be in a high quality clean room. Every component part of the satellite and every handling procedure will require special attention to cleanliness. The acoustic blankets that line the shroud will require special treatment to prevent shedding of particles.

4. A Larger Optical System Will Return More Science

The shroud volume available will typically limit an automatically deployed telescope's diameter. The mass or cost of the telescope typically limits the size of a robotically assembled telescope, not shroud volume. For some tasks, the performance of a telescope is proportional to the diameter to the fourth power[4] giving a robotically assembled telescope much more performance

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[3] If the Primary Mirror or Secondary Mirror becomes contaminated, the telescope will produce poorer signal-to-noise images than it would if no contamination occurred. There are two kinds of contamination: molecular and particulate. A layer of molecular contamination attenuates the amount of starlight reflected from the mirror. The amount of attenuation depends on the kind of molecule, the thickness of the layer, and the wavelength being observed. The main sources for molecular contamination are the rocket exhaust products and outgassing from the satellite itself. Particulate contamination is of special concern for the large telescope because they usually do not have an exterior cylindrical baffle to block most of the off-axis light. Without such a baffle, contaminating particles on the mirrors will be illuminated by off-axis light from Stars, Planets, and the solar thermal shield. The particles will absorb some of this light and the rest will be diffusely reflected. The absorbed light will raise the temperature of the particle and it will then be reradiated in the IR. Some of the reradiated light and some of the diffuse reflected light will enter the instruments as if it were light from the on-axis Star field. This light makes the image noisy and limits the telescope's ultimate performance.

[4] A discussion of telescope performance is given in <u>The Next Generation Space Telescope – Visiting a Time When Galaxies Were Young</u>, p 30, edited by H.S. Stockman, available on the NGST Website.

than a telescope whose size is limited. This means that during the life of the satellite, a robotically assembled telescope will return much more science.

5. Total Qualification of the Robot and the Telescope Assembly Process Before Launch

The robot would be built from space-qualified components and then thoroughly ground tested. If desired, it could be space qualified on a Shuttle flight or on the International Space Station (ISS).

The robotic assembly sequence would be demonstrated in a neutral buoyancy water tank using simulated telescope components. These components would match the size, shape, and the mechanical interfaces of the actual components, but would have a density equal to water. Since the test is done with simulated telescope parts, it can be run in parallel with the manufacture and test of the actual telescope.

For a conventionally deployed telescope, some testing of the flight deployment mechanisms will be possible before launch. However, it is very unlikely that a test of the full deployment system can be done in 1 g. What testing is done must use actual telescope components and so will be scheduled in series with all the other telescope work. The test conditions must closely simulate the vacuum and temperature that the mechanisms will operated in.

6. No Mechanical Shocks From Explosive Bolts

All robotic assembly operations are made with simple bolts that are operated by the robot. No mechanical shock is created when the robot loosens a mounting bolt. In contrast, conventional deployments typically use explosive bolts that impart shocks in excess of 1000 g. Any telescope components located near one of these bolts, such as mirror actuators, will have to be built to reliably withstand these shock loads.

Besides the damage that may be directly caused, these mechanical shocks can dislodge loosely adhered contamination particles. Once dislodged, they will be free to contaminate the mirrors. The loosening or tightening of bolts by a robot will not dislodge any particles.

7. The Robot's TV Cameras Give Visual Confirmation of the telescope's Configuration

The robots will have dual TV cameras and light sources as part of each end effector. The primary use of these cameras is to view a target that provides fine position control of the robot as it engages a grapple fitting. When not viewing these targets, the robot can position and aim its camera and light to look at any part of the telescope. During telescope assembly, the primary and backup robots would provide visual confirmation of the assembly work as it progresses.

This telepresence could also be used to diagnose other problems. For instance, suppose the solar array did not fully deploy. The robot could show what had happened and perhaps fix the problem. It could also look for micrometeoroid damage to the mirrors or other parts of the telescope.

All TV images could be available for distribution to the public.

8. A Robot on the Satellite Could be Used for Other Assembly Tasks

The present study was limited to just the robotic assembly of the telescope and did not cover any other assembly tasks. However, a robot that can assemble a telescope can assemble anything else. For instance, the robot could assemble (or assist) a conventional deployment of the solar array, the Sun shield and the thermal isolation truss.

9. Some Servicing of the Telescope During its Lifetime is Possible

A resident robot gives the telescope the ability to replace any failed component for which a spare component was provided at launch. For example, the robot could replace a failed mirror actuator with a spare. Because a large number of actuators will be needed to control the many mirrors of a large the primary mirror, the probability of a failed actuator during the life of the mission is high. A robot could replace any failed actuator and thereby restore full operability to the telescope.

Discussion of the Cost and Weight of the Robot System

The Cost of the Robots

The development and production costs of a suitable robot system will be significant. The Spar report states a target cost of US$50M for their robot. However, the development of a suitable automatic deployment system will also be significant, especially if a space test is required. As telescopes become larger, it is important to note that the cost of the robot will be nearly independent of telescope size while the automatic system cost is at least proportional to the square of the Primary Mirror diameter.

One potential way to lower the cost of the robots would be to modify one of the three ISS robot developments. These developments are listed below:

- Spar Aerospace Ltd.[5], under contract to the Canadian Space Agency, is building the Mobile Servicing System (MSS). The MSS can pick up a Special Purpose Dexterous Manipulator. It is a smaller, two-armed robot with tactile capability that will handle many of the servicing and assembly tasks currently performed by astronauts on space walks.
- The National Space Development Agency of Japan is building the Japanese Experiment Module (JEM)[6] Remote Manipulator System. It will change out Orbital Replacement Units mounted on the JEM-Exposed Facility and consists of a main arm that is about 10 meters long and a second, smaller arm that is about 1.5 meters long. The main arm picks up the smaller arm when fine operations are desired.
- Fokker Space B.V.[7], under contract to the European Space Agency, is responsible for the design a robotic arm to be used to assemble the Russian segment of the ISS and to deploy its solar arrays and thermal radiators. It has a reach of 11.3 meters and can “walk” from place to place on the ISS wherever its grapples are provided.

The Weight of the Robots

Without an actual design for both an automatically deployed telescope and a roboticly assembled telescope, the true weight penalty (or advantage) for the robot cannot be determined.

Two robots, including the various grapples that it needs to do its job, will probably weigh as much or a little less than the conventional deployment mechanisms that would be needed to deploy the same telescope. But for a given size robotically assembled telescope, the structure of the individual PMSs can be lighter and less ridged. This is because a naturally high stiffness is provided by the mutual support provided by nested PMSs in their 9-Packs and the triangular

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[5] See the Spar Aerospace Ltd. Website at: http://www.spar.ca/space/mms.htm
[6] See the NASDA Website at: http://jem.tksc.nasda.go.jp/JEM/Jem-j/mfd/mfddoc1_e.html
[7] See the Fokker Website at: http://www.fokkerspace.nl/products/robotics.htm

arrangement of the three 9-Packs. Individually supported mirrors typical of automatic deployment designs have little mutual support capability and are therefore heavier since they individually must meet the mechanical requirements. In most designs, the structural weight is determined by required stiffness, not strength.

It is expected that the structure and mechanism weight of an automatically deployed 20-meter telescope will be more than the weight of the same size telescope assembled by two robots.

Summary

Using a robot to assemble a 20 –meter or larger space telescope is technically feasible and has at least nine advantages over a conventional automatic deployment. The three most significant advantages over a conventionally deployed telescope are:

- The Primary Mirror size will not be constrained by the shroud volume. It will be constrained by mirror cost and size
- The probability of successful assembly will be higher.
- The packaging makes contamination of the mirrors negligible.

Advantages 1 and 3 greatly improve the science that the telescope will return. The larger the telescope and the cleaner the telescope, the higher the quality of the images and spectra that it will produce. The second advantage insures that the telescope actually becomes operational. With a conventional deployment, if any part does not fully deploy, the mission is over.

The potential disadvantage of robotic assembly is the cost and weight of the robot. However, at the 20-meter telescope size and larger, this is not a disadvantage because the telescope parts are lighter and the weight and development costs of the conventional deployment mechanisms and their testing is avoided.

Fig. 1 - 20-Meter Telescope Stowed in Delta IV Shroud

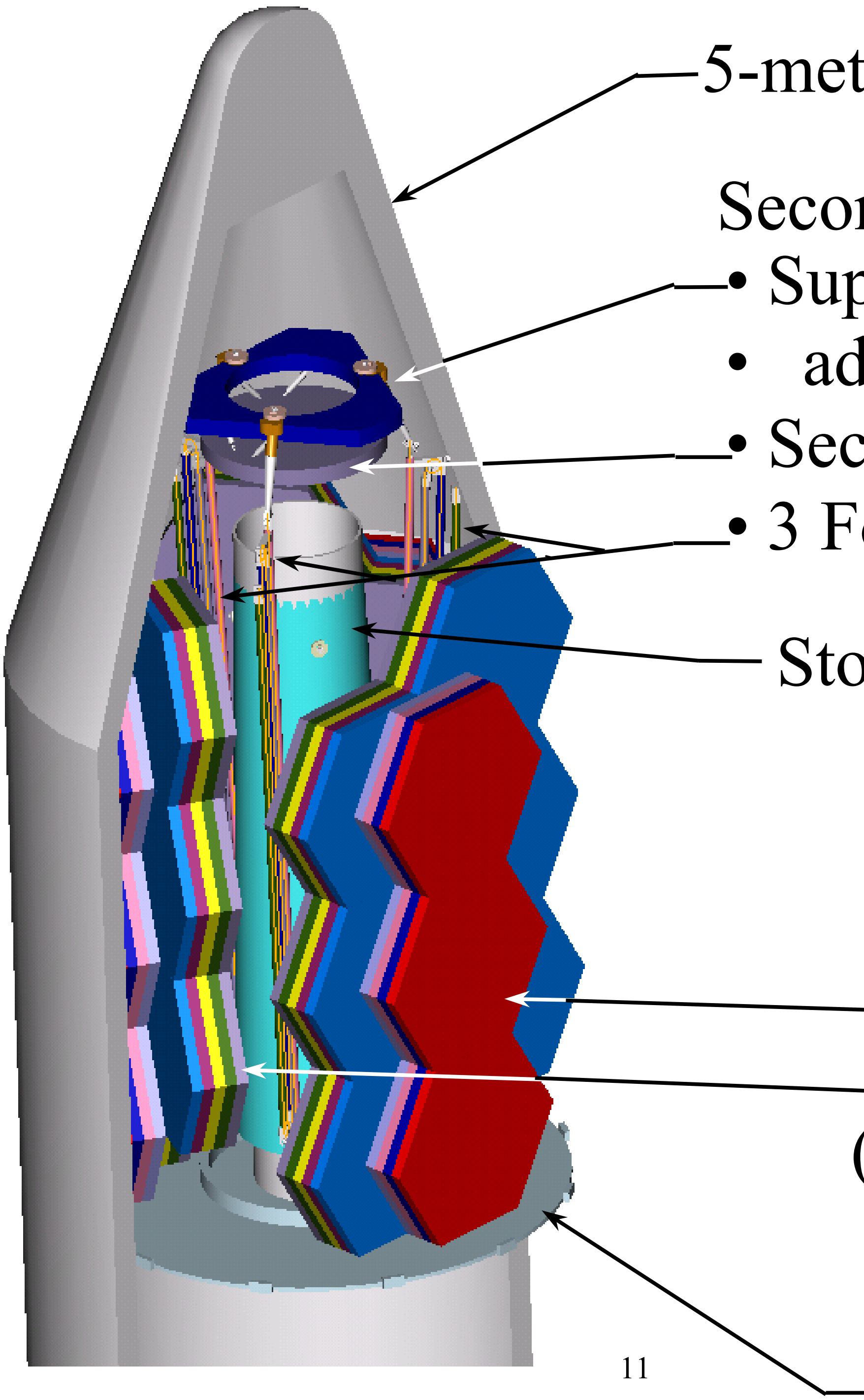

Fig. 2 - Exploded View of 9-Pack 1

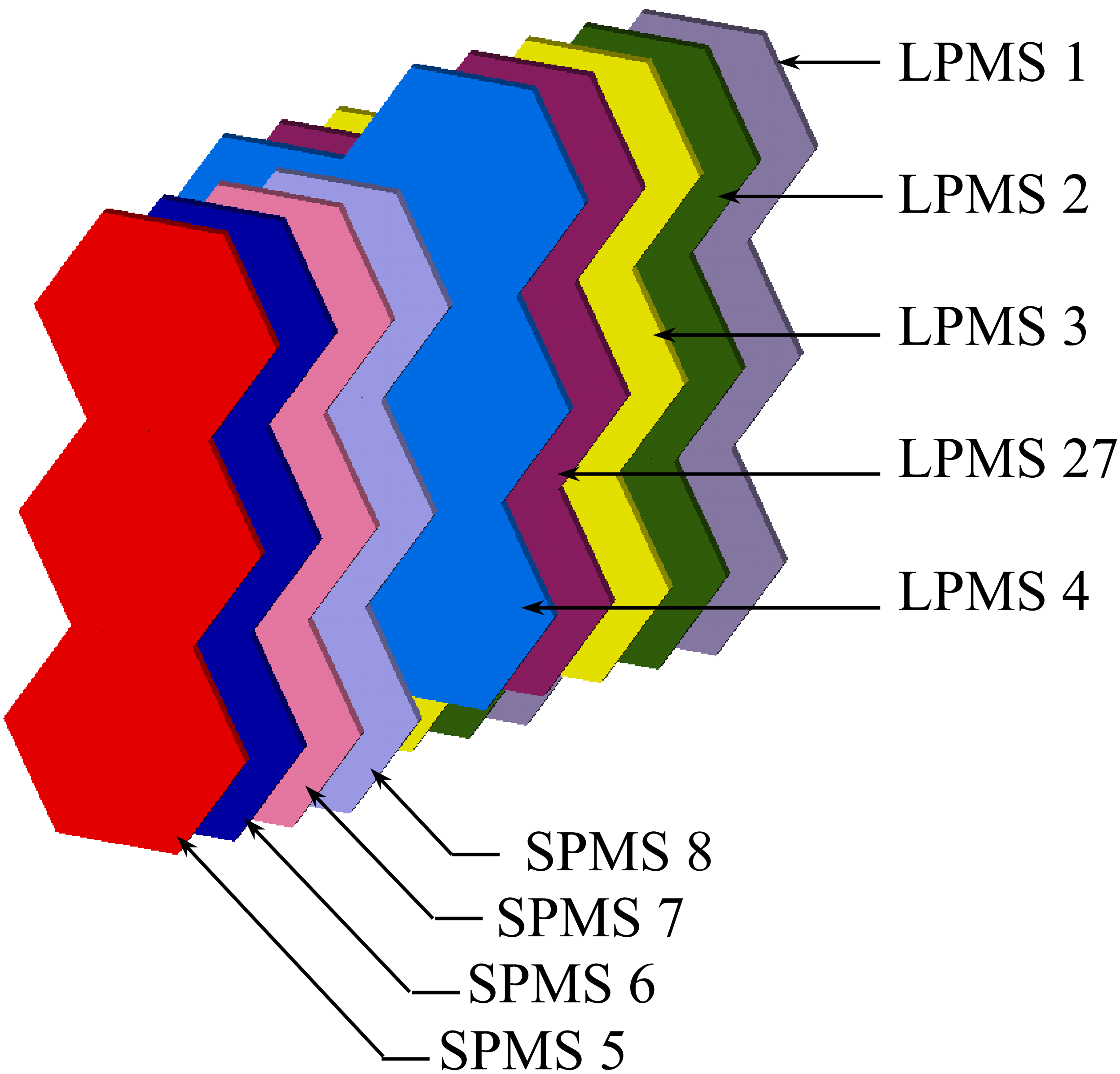

Fig. 3 - Spar 6-meter Robot

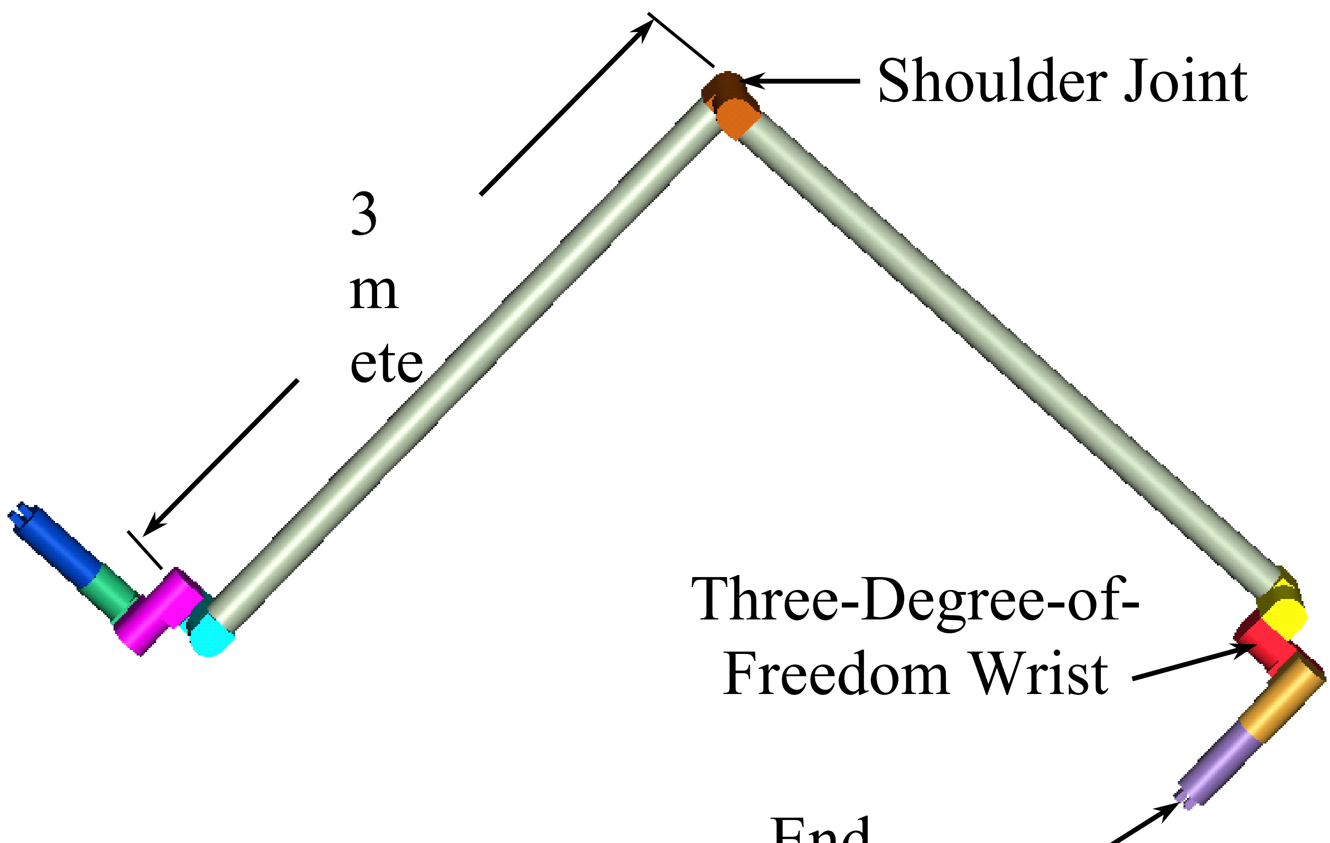

Fig. 4 - 9-Pack 1 Repositioned for Deployment of PMSs

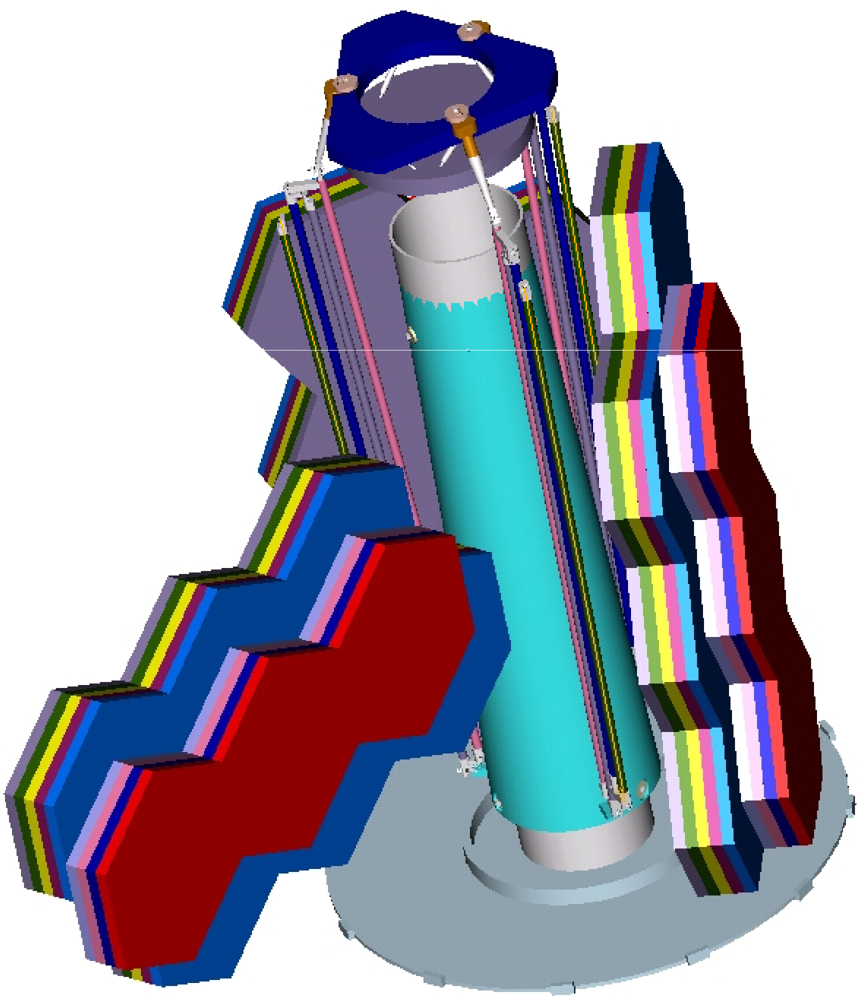

Fig. 5 - Primary Complete Except for LPMS 27

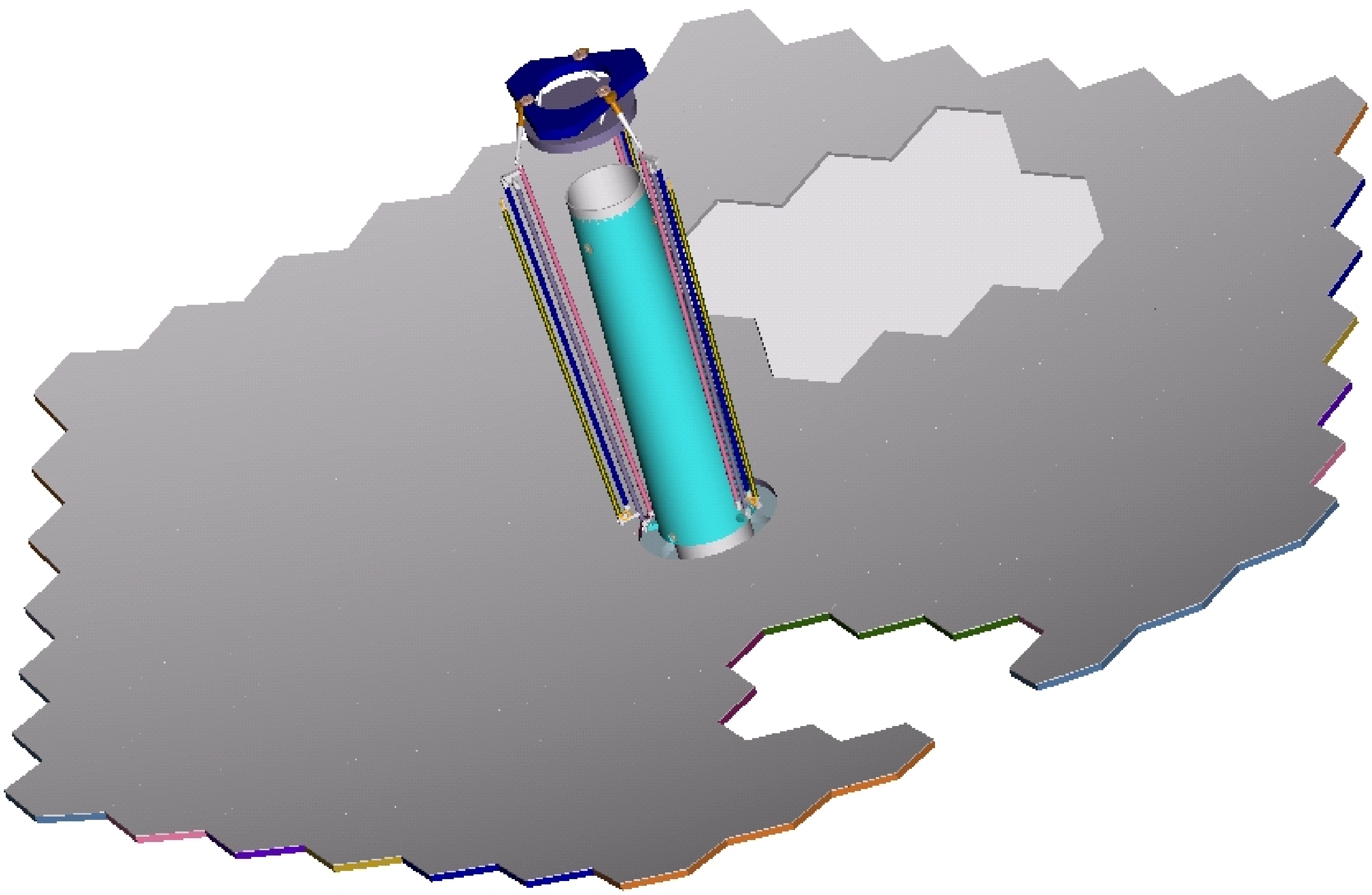

Fig. 6 - Rear View of Primary Showing Assembly Sequence

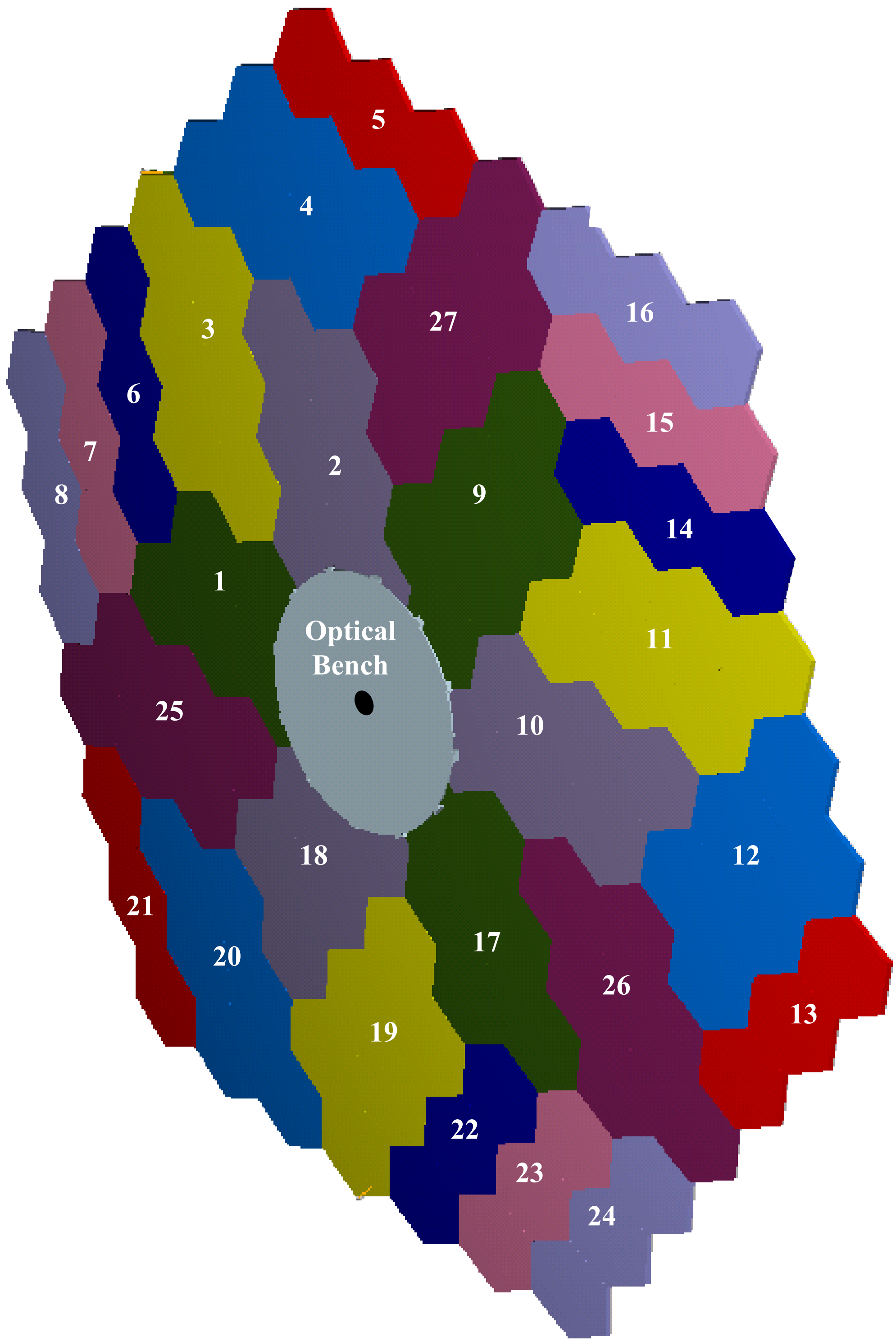

Fig. 7 - Tripod Leg 1 Partially Deployed

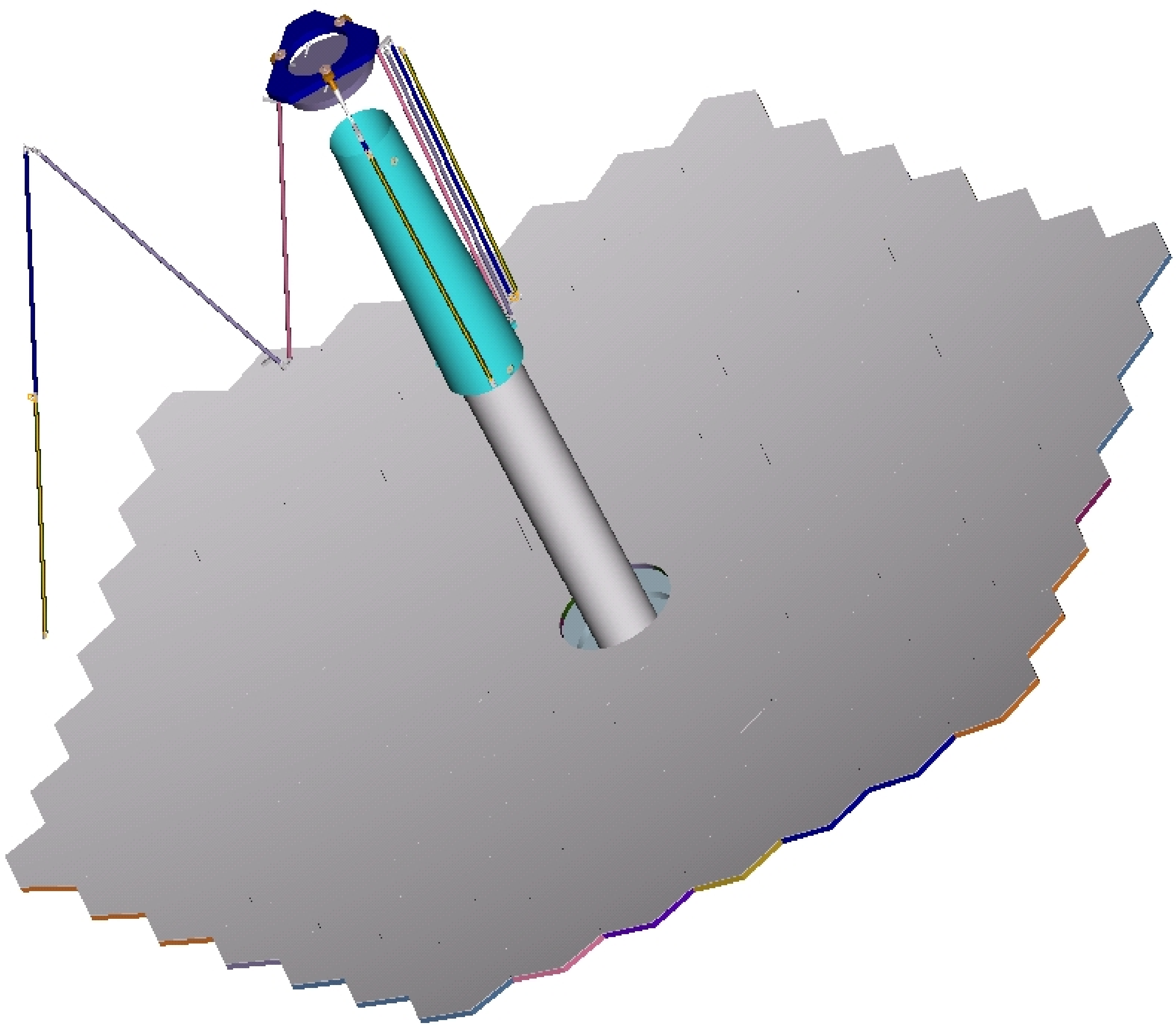

Fig. 8 - The Telescope Completed