VI.

VERY LARGE TELESCOPE PROJECTS

THE 15-METER NATIONAL NEW TECHNOLOGY TELESCOPE: AN UPDATE

L. D. Barr

Advanced Development Program, National Optical Astronomy Observatories*

I. Introduction

The 15-Meter National New Technology Telescope (NNTT) Program, growing out of the earlier "Next Generation Telescope" studies at Kitt Peak National Observatory(*), is now responding to the recently published recommendation of the Astronomy Survey Committee of the American National Academy of Sciences[1]:

> *"...the construction of a New Technology Telescope (NTT) [NNTT] in the 15-m class on the ground for observations in the optical and in the near- and mid-infrared regions of the spectrum (0.3- to 20μm wavelength). The design studies needed before the NNT can be constructed are of the highest priority and should be undertaken immediately."*

The Survey Committee also established performance specifications for the recommended telescope that have been listed elsewhere[2] and formed a major basis for the NNTT specifications discussed further on. For several years the NNTT Program, with the aid of strongly interested groups at the University of Arizona and the University of California, has been developing telescope concepts to meet the needs set forth by the Survey Committee. A current description of the two final conceptual contenders illustrated in Figure 1 is the principal subject of this paper. In early 1983, the NNTT Scientific Advisory Committee (SAC) was formed to consider the scientific and technical merits of these concepts and to make a recommendation concerning the one to be ultimately developed into the NNTT. The SAC recommendation is planned to be available by Fall 1984. Extensive engineering design will follow.

Considerable attention has been directed by the SAC toward developing the scientific priorities for the NNTT in keeping with the Survey Committee recommendations and without exceeding what can realistically be developed in the next several years by the engineers. Table 1 lists the scientific priorities for the NNTT as seen in early 1984. A complete report on the SAC findings will be available later in 1984. General descriptions of the telescope concepts are given in the next section.

---

* Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

(*) Kitt Peak National Observatory is now part of the newly formed National Optical Astronomy Observatories.

Proceedings of the IAU Colloquium No. 79: "Very Large Telescopes, their Instrumentation and Programs", Garching, April 9–12, 1984.

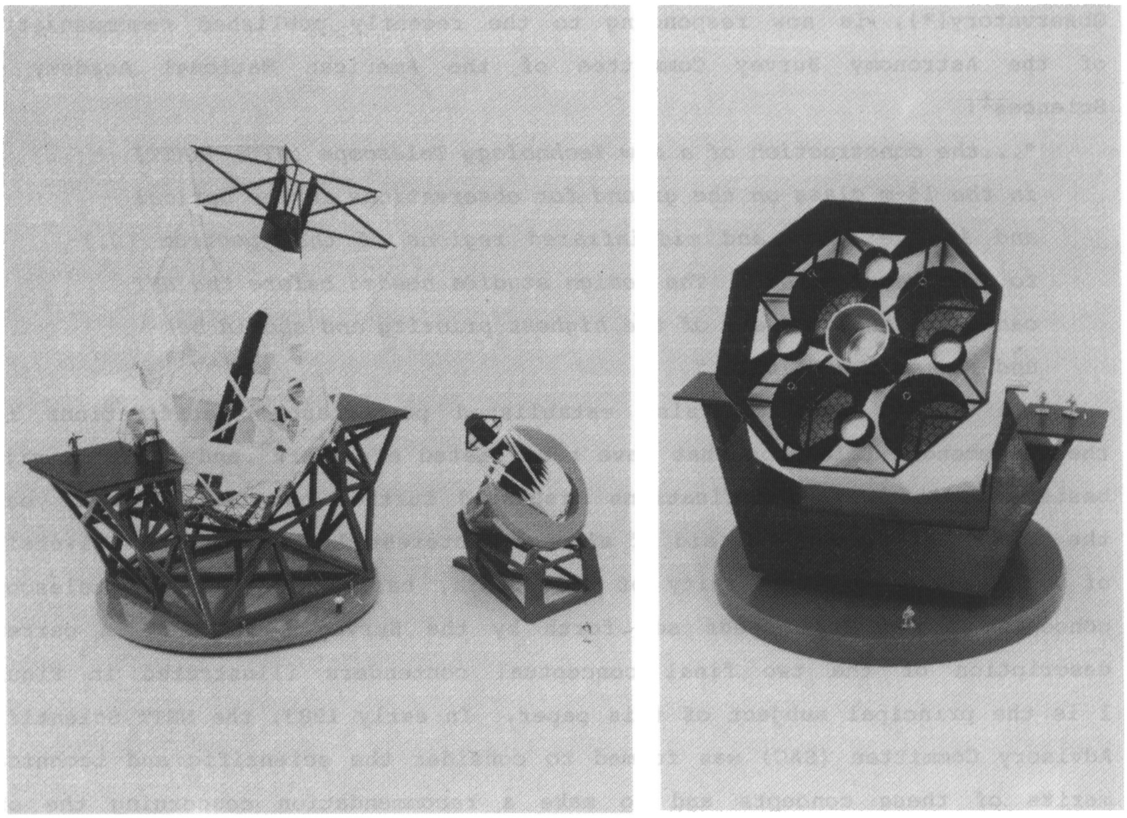


Figure 1

The final design concepts for the 15-Meter National New Technology Telescope (NNTT). **Left:** The Segmented Mirror Telescope (SMT) employing sixty hexagonal mirrors in a controlled mosaic to form the primary mirror. Otherwise, the SMT is a conventional telescope except for size. **Right:** The Multiple Mirror Telescope (MMT) using four 7.5-meter primaries to form a four-telescope array on a common mounting. A two-position rotatable top is used to exchange secondaries. Telescopes can be instrumented separately or at a combined focus. **Center:** The KPNO 4-meter Mayall Telescope to the same scale.

TABLE 1

Preliminary Scientific Priorities for the 15-Meter National New Technology Telescope

PRIORITY	TECHNIQUE	COMMENTS
HIGH	• Multi-object spectroscopy	Requires a large field of view, somewhere in the range 1/2° - 1° from 50 - 200 simultaneous spectra with $\lambda/\Delta\lambda$ from 150 to 10^4 over the spectral region 0.3 - 2.0μm.
	• Thermal infrared spectroscopy	Thermal IR = IR wavelengths at which observations are limited by background noise rather than by detector noise - generally $2\mu m < \lambda < 35\mu m$.
	• High-resolution spectroscopy	Optical/near IR; field of view of a few arcminutes. $\lambda/\Delta\lambda$ to 10^6.
	• Infrared imaging	Imaging and photometry, up to the telescope diffraction limit $\lambda \cong 2 - 40\mu m$.
MEDIUM	• Interferometry	Ultraviolet → 10μm. Including speckle.
	• Wide-field imaging	2-D, broadband direct imaging and slitless spectroscopy; UV → 1.2μm.
LOW	• Polarimetry	Includes spectropolarimetry.
	• Astrometry	Could include work beyond $\lambda = 1\mu m$. Needs modest FOV ($\sim$ 20 arcminutes) with Extremely accurate telescope performance. Specialized telescope are likely to do better for many applications.

II. The Telescope Concepts

II-A General Information and Performance Goals

The number of available telescope concepts is large. After several years of Next Generation Telescope studies, in 1980 we narrowed the selection to versions of the "Multiple-Mirror Telescope" (MMT) and the "Segmented Mirror Telescope" (SMT). The basic considerations in this selection have been reviewed elsewhere[2] and will only be briefly mentioned here. For cost and other reasons we avoided concepts that require building of more than one very large mirror assembly (e.g., Siderostats). Those that required scanning of the primary mirror (e.g., bowls and fixed primary concepts) were avoided because of the potential variability in reflective and IR emissive properties. Arrays of telescope not on a common mounting were found to have extraordinary engineering problems in achieving a phased focus with low IR background over long baselines and were unlikely to produce angular fields at the combined focus of more than a few arcseconds. These restrictions narrowed our choices to some form of SMT or MMT.

During the past year or so, the SAC has developed general telescope design goals for the NNTT that, if achieved, will enable the highest scientific priorities to be met. These are listed in Table 2. Both of the current SMT and MMT concepts appear to be capable of meeting these requirements although it is apparent that much engineering work remains to be done for either design approach.

TABLE 2

General Performance Goals and Requirements for the 15-Meter National New Technology Telescope

* A single telescope mount at a dark site with low water vapor and good seeing.	
* Compensation for field rotation.	
* Optical throughput $\geq$ 75%.	
* Rapid instrument change capability.	
* Remote observing capability.	
* Some daylight observing.	
* Wide field of view for $0.32\mu < \lambda < 1.2\mu m$.	30 arcminute minimum, 1° is a desirable design goal.
* Infrared field of view and combined focus field of view.	1 arcminute minimum, 3 arcminutes is a desirable design goal.
* Image quality for all fields of view.	0.25 arcseconds diameter FWHM at $0.5\mu m$, 80% of the energy within 0.35 arcseconds at $10\mu m$.
* Image scale at the infrared focus.	No less than 0.3 arcseconds per mm with 0.5 arcseconds per mm a desirable design goal.
* Absolute pointing accuracy.	2 arcseconds RMS over the entire sky above 20° elevation angle.
* Offset pointing accuracy.	0.1 arcseconds over 1°.
* Tracking stability.	0.1 arcseconds per second RMS open loop for most applications and 0.05 arcseconds per second during short periods.
* Spatial chopping.	To be provided in the bandwidth 0.3 - 30 Hz with throws up to 30 arcseconds at 90% duty cycle, throws of up to 3 arcminutes with some performance degradation, selectable position on the sky.
* Telescope emissivity.	Less than 5% with stability of 1 part in 10^9 per second.
* Optical phasing stability.	Better than the wavefront differences induced by the atmosphere in best seeing.
* Polarization.	Predictable to 0.1% in optical. Predictable to 0.03% in thermal IR with $\leq$ 1% residual polarization.

After considering different possible SMT configurations, we chose to adopt a "strawman" design for further study that is quite similar to the University of California's Ten Meter Telescope (TMT). This has enabled us to work collaboratively with the UC group (J. Nelson, T. Mast, et al) and to stretch available funds to cover more development activities. Predictably, the designs for the TMT and the 15-Meter SMT have diverged in detail to meet different needs, but there is still great similarity. The present 15-Meter SMT design is based on a primary aperture comprised of four "rings" of hexagonal segments ∿ 2.1m in size arrayed around a central hexagonal hole.

There are many MMT configurations that have been considered. One basic determining factor is the largest individual aperture size that can be achieved without introducing extraordinary problems. Initially this was thought to be in the vicinity of 4 - 5 meters, but the work of Angel, et al, at the University of Arizona on borosilicate honeycomb mirror castings has modified this view. We now feel that castings in the 7 - 8 meter diameter range may be possible[3,4] and have collaborated with the University of Arizona groups (R. Angel, N. Woolf, et al) in developing an MMT design using four 7.5 meter mirrors. A "square" format instead of an "in-line" format is used to maintain higher light concentration in the central image core and also to reduce the overall mount size.

In order to better understand the image potential of the chosen SMT and MMT configurations, K. Shu at NOAO has studied both approaches[5]. Figures 2 and 3 show the unaberrated point spread functions for the two concepts and Figure 4 is a plot of radial energy distribution in the images. As will be evident, for image sizes greater than 0.5 arcseconds there is negligible difference between SMT and MMT images. Below 0.5 arcseconds, the SMT images have more energy in the central core, but the MMT has superior spatial resolution. These differences would exist only on those occasions when seeing is excellent and the telescope is performing very well.

The models of the SMT and MMT shown in Figure 1 were built in early 1983 and are still a reasonably accurate representation of the concepts. However, a few significant modifications have evolved during the past year. One of these is the realization that a "Forward Cassegrain" focus in front of the primary mirror is desirable for the SMT to reduce the size of the required IR chopping secondary. The position is also advantageous for doing wide field work because the corrected angular field size for a given image quality can be greater than at prime focus and the achievable f/ratio is in the optimum range for feeding into fiber optics.

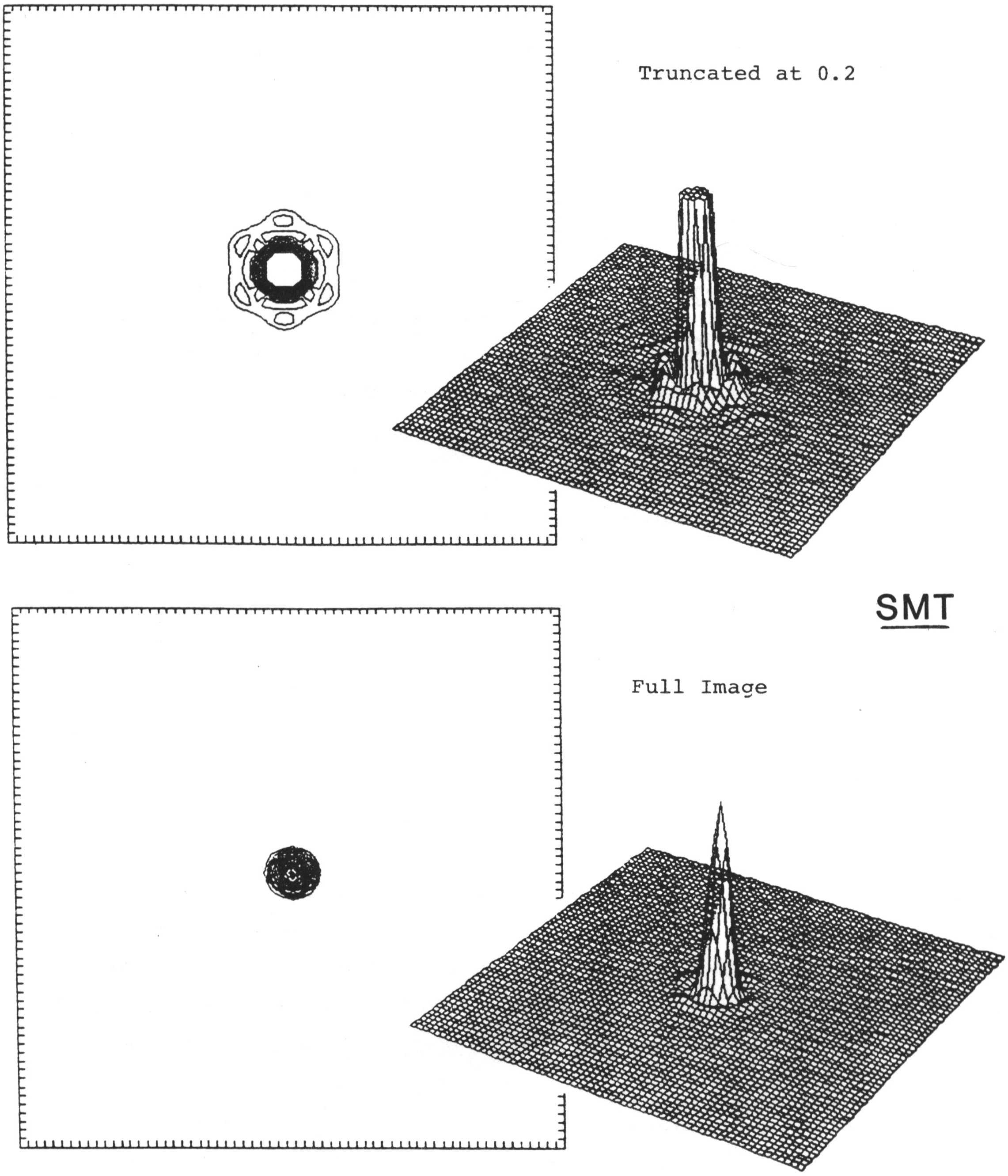


Figure 2 Point spread function for 15-m equivalent area 4-ring hexagonal segment aperture.

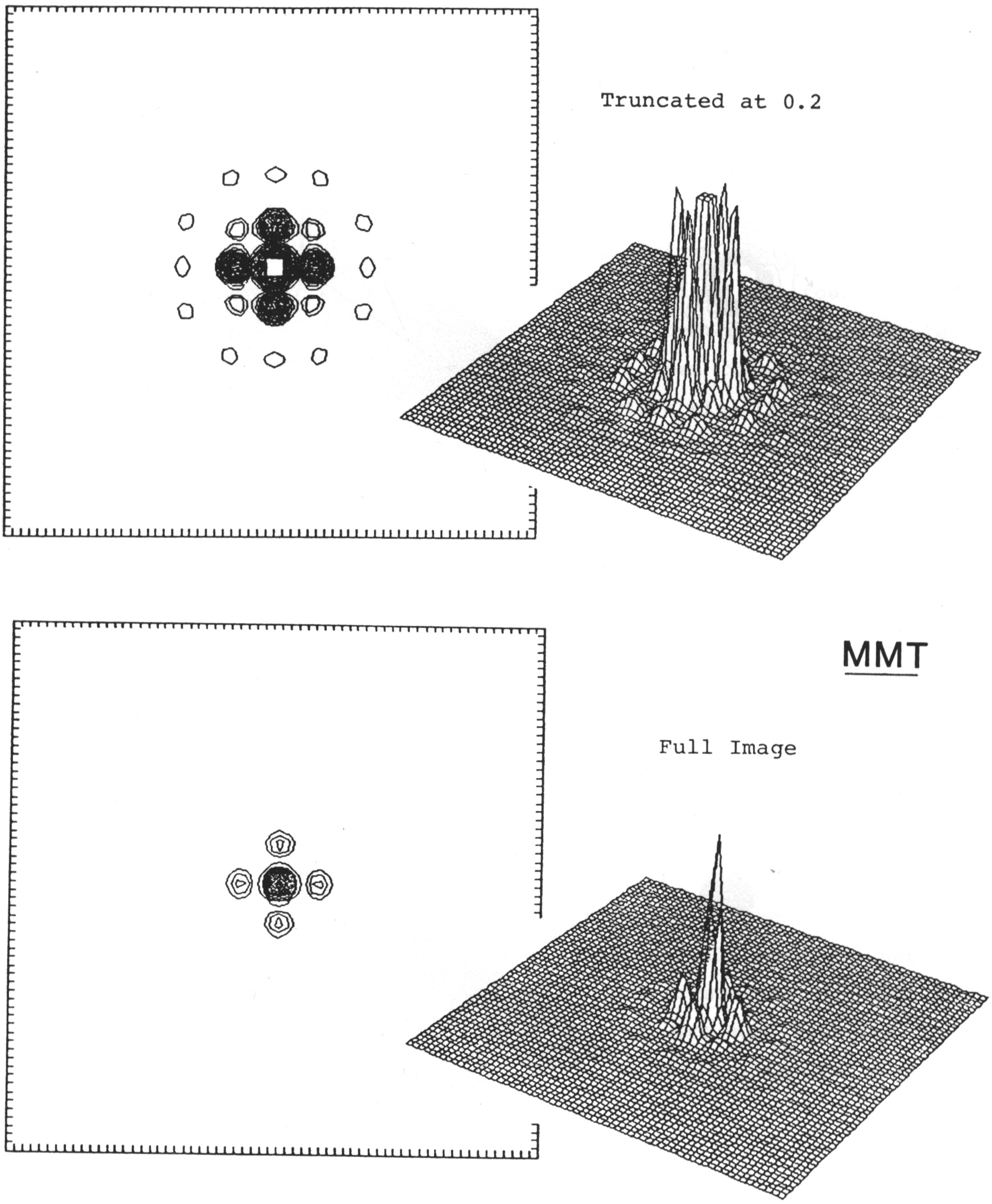


Figure 3 Point spread function for 15-m equivalent area, four circular apertures (mirror separation = 2 meters).

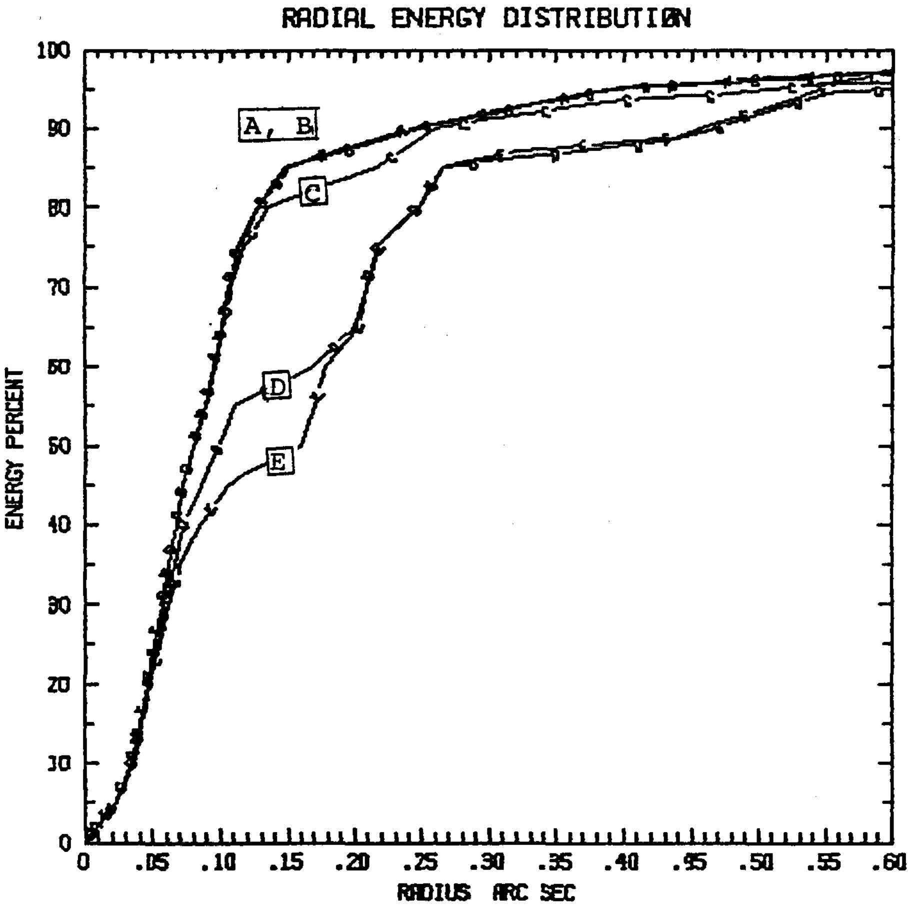


Figure 4

RADIAL ENERGY DISTRIBUTION IN THE IMAGES

A - Single circular aperture

B - Single hexagonal aperture

C - 4-ring hexagonal segment aperture

D - Four circular apertures (mirror separation = 1 meter)

E - Four circular apertures (mirror separation = 2 meters)

These radial energy distributions are based on the energy within a radius of 1".25. The curves are therefore 1-2% higher than for the real case.

Another recent modification, affecting both concepts, is the "distributed altitude bearing" concept evolved by E. Pearson at NOAO. The basic idea is to add an additional support bearing under the primary mirror support structure more or less midway between the elevation (altitude) bearings. The central bearing carries only a portion of the load which allows the two outboard bearings to carry the rest of the load and to maintain mechanical alignment. Figure 5 illustrates an azimuth support yoke with the central bearing. Figures 6 and 7 illustrate the MMT and SMT concepts with such an azimuth support yoke. In both cases, primary mirror deflections are greatly reduced. This configuration also allows the elevation drive to operate against the central journal (i.e., a roller drive) which is mechanically advantageous. Greater resistance to wind buffeting will result.

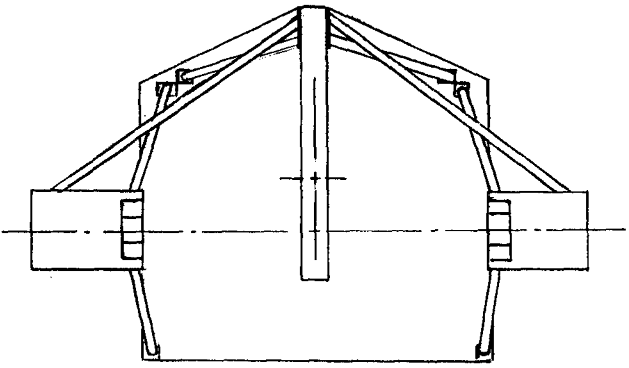
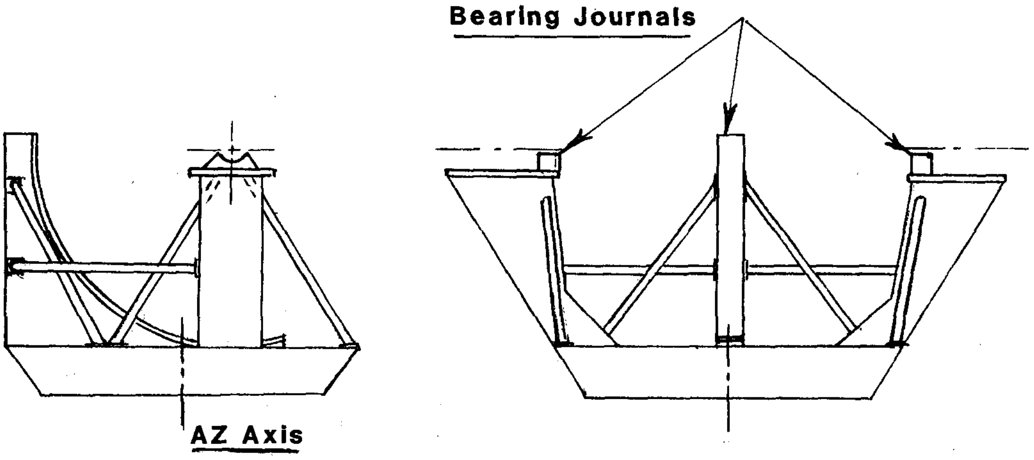


Figure 5

Azimuth yoke with "distributed altitude bearing"



II-B **The Multiple Mirror Telescope (MMT) Concept for the NNTT**

The concept of building an array of telescopes on a common mounting was pioneered by the Smithsonian Astrophysical Observatory and the University of Arizona and culminated in the MMT now operating as an observatory on Mt. Hopkins (MMTO). Many descriptions of that telescope are available[6,7] making it unnecessary to describe very much detail here. The MMT concept for the NNTT deploys four 7.5 meter telescopes on a single Altitude-Azimuth (Alt-Az) mounting in a manner similar to the six 1.8 meter telescopes at the MMTO. However, there are major differences other than size between the MMTO and the NNTT concept. Perhaps, the most important is that the individual 7.5m telescopes will be instrumented separately in addition to the instruments to be available at the combined focus positions where all of the telescope beams are brought together. In order to make the switch quickly from individual telescope operation to the combined focus mode, a rotatable secondary support structure (the "carousel top end") would be utilized. Two sets of secondaries would be carried on the carousel which could then rotate through 45° to make the exchange between sets. The two operating modes presently planned are:

1) The Individual Focus Mode (the "Wide-Field" Mode)

   In this mode, each 7.5 meter telescope uses a relatively large ($\sim$ 2.6m diameter) secondary in conjunction with a 3-element transmission optics corrector and a prismatic atmospheric dispersion corrector. The correctors will ordinarily be left permanently in position just above and inside of the Cassegrain hole in each primary mirror. A telescoping style light baffle surrounding the corrector will be extended/retracted as required. The wide-field image quality goals listed in Table 2 can be met with this system. Image scale is $\sim$ 6 arcseconds/mm. Figure 8 illustrates the optical configuration.

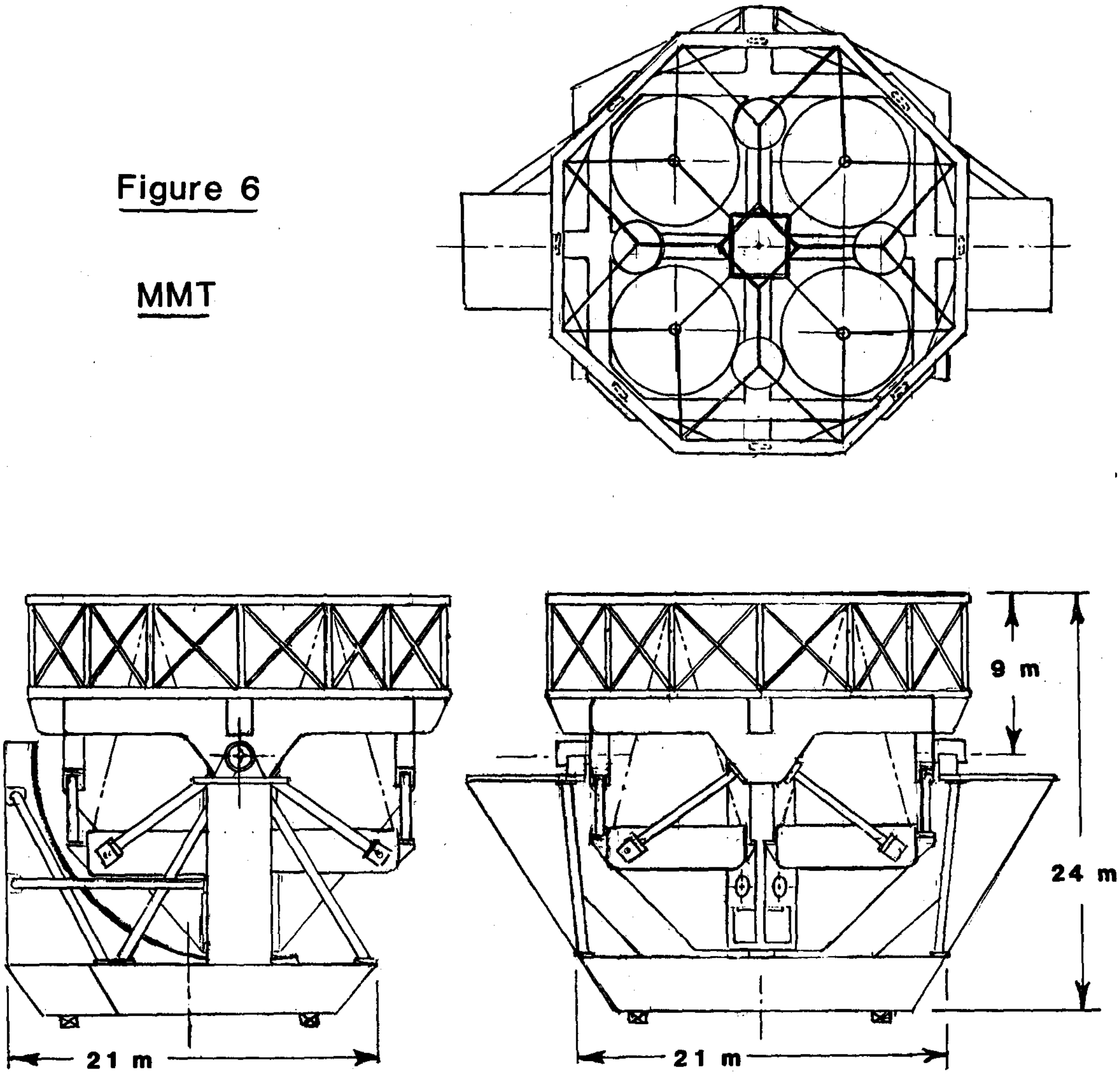
   Major uses of this mode will be multiple-object spectroscopy (MOS) and visible region imaging onto CCD's and photographic plates. Other uses are, of course, possible.

2) The Combined Focus Mode (the "IR Mode")

   Long focal length secondaries ($\sim$ f/63) mounted on wobbling (chopping) mechanisms will be utilized in combination with folding flats to direct the four telescope beams onto a central pyramid-shaped combiner mirror, thence to the combined focus. (See Figure 9.)

Figure 6

MMT



Major uses of this mode will be infrared imaging, photometry, high-resolution spectroscopy and interferometry. The combined angular field size will be about 1 arcminute unvignetted and ∿ 3 arcminutes with some vignetting at the edge of field. Image scale ∿ .44 arcseconds/mm.

A vacuum chamber with provisions for cryogenic cooling of mirror mounts will be used to enclose the beam combiner mirror and the folding mirrors required to divert the combined beam to two Nasmyth foci or four "bent" central combined foci. It will also be possible to mount small instruments inside the chamber (e.g., IR instruments at the central combined focus). A rotatable turret, with two sets of entrance windows (for different wavelength regions) will mount on top of the vacuum chamber. Transmission windows will be provided as required at the chamber exits. The objective of this system is to reduce air turbulence in the light path and to reduce infrared background noise from the mirror surfaces.

In this mode, the #3 mirrors would be made sufficiently oversized to effectively occult the wide-field correctors and the retracted light baffles. This will prevent IR detectors at the combined foci from seeing unwanted thermal radiation from those sources.

II-C **The Segmented Mirror Telescope (SMT) Concept for the NNTT**

The SMT concept differs from conventional telescopes except for size in only one major respect; the primary mirror is a mosaic of segments held in position by servo-control systems. In particular, the 15-meter SMT concept deploys sixty hexagonal segments in four "rings" about a central hole (i.e., a missing segment). Each segment, positioned by three actuators, can move in piston and tilt. Capacitive sensors located at segment edges at the rear of each segment detect relative motions along the optical axis between segments. Descriptions of the primary mirror and its control have been given elsewhere[8,9,10]. Methods for making and supporting the required off-axis aspheric segments have been under development for several years at UC-Berkeley and NOAO[8,11]. It now appears that making segments and controlling them is an achievable task albeit one that is rather complex.

The optical configurations currently planned for the 15-meter SMT (see Figure 10) are discussed below.

1) Prime Focus - Uncorrected f/1.75 focal ratio. With correctors, a 20 - 30 arcminute field is possible with image scale ∿ 6.7 arcseconds/mm.

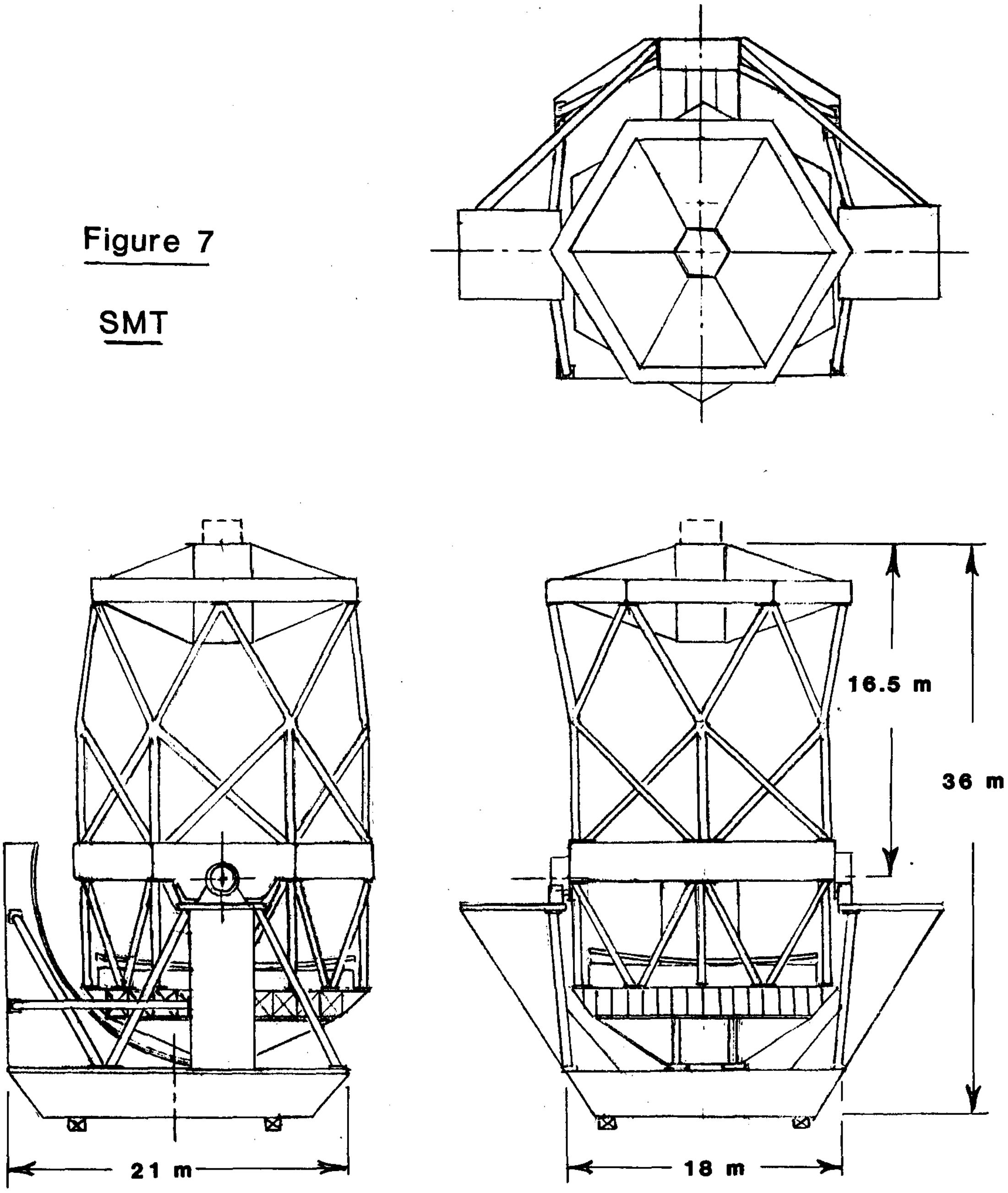


Figure 7

SMT

2) "Forward Cassegrain" - This position is at or near the intersection of the elevation and Azimuth axes and can be used in two ways:

* For "wide-field" work with a large secondary ∿ 2.6m in diameter and a 3-element transmission corrector plus a prismatic atmospheric dispersion corrector. Field sizes up to ∿ 40 arcminutes are possible at f/5 focal ratio and ∿ 2.6 arcseconds/mm image scale

- For IR work with a chopping secondary ∿ 50 cm in diameter and ∿ f/40 focal ratio. Image scale ∿ 0.34 arcseconds/mm with ∿ 3 arcminute unvignetted field.

3) Nasmyth - Using a secondary ∿ 2m diameter with a focal ratio ∿ f/15 and a #3 folding flat at the Forward Cassegrain position. By removing the flat, the conventional Cassegrain position is reached.

All of these configurations require an exchange of secondaries and, in some cases, a change of equipment in the central stack that houses the Forward Cassegrain position. Secondary exchange is planned to be done by exchanging mirror "cartridges" that insert into the central secondary housing. Storage of secondary mirror "cartridges" would optimally be done at the upper level of the telescope enclosure. Exchanging equipment in the central stack would be done from below with a special rising platform mounted on a rail-guided handling carriage. The carriage could be built to store equipment not in use.

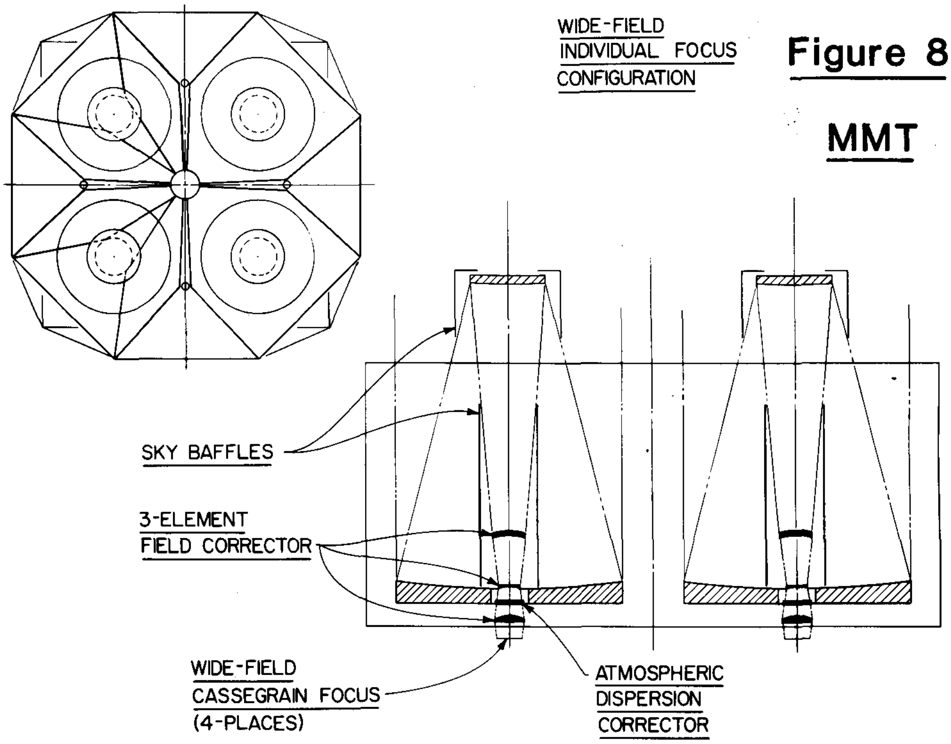


Figure 8

MMT

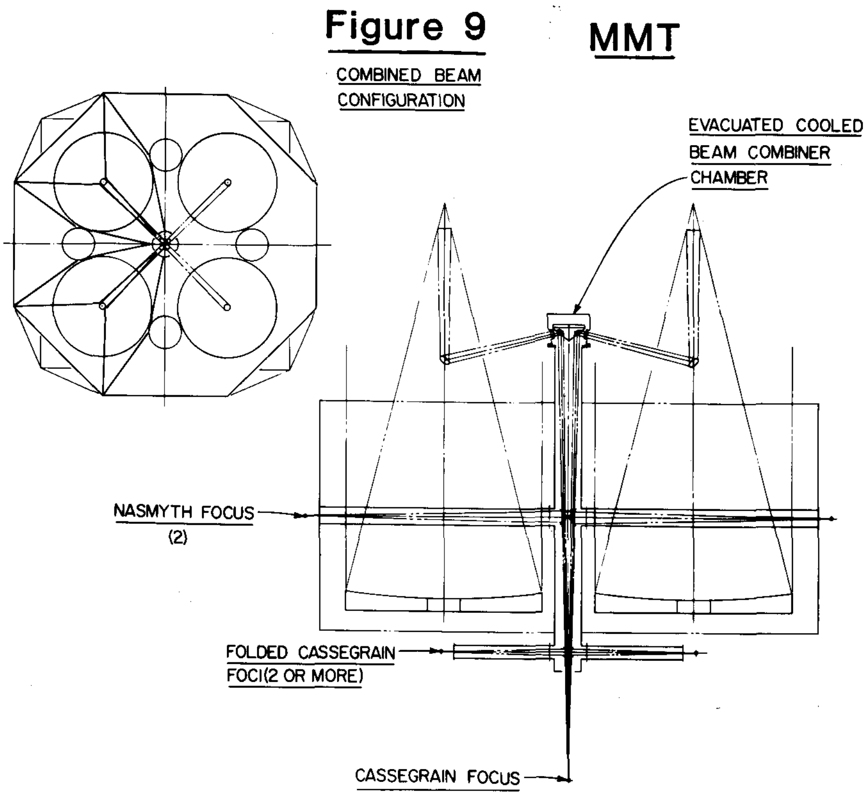


Figure 9

MMT

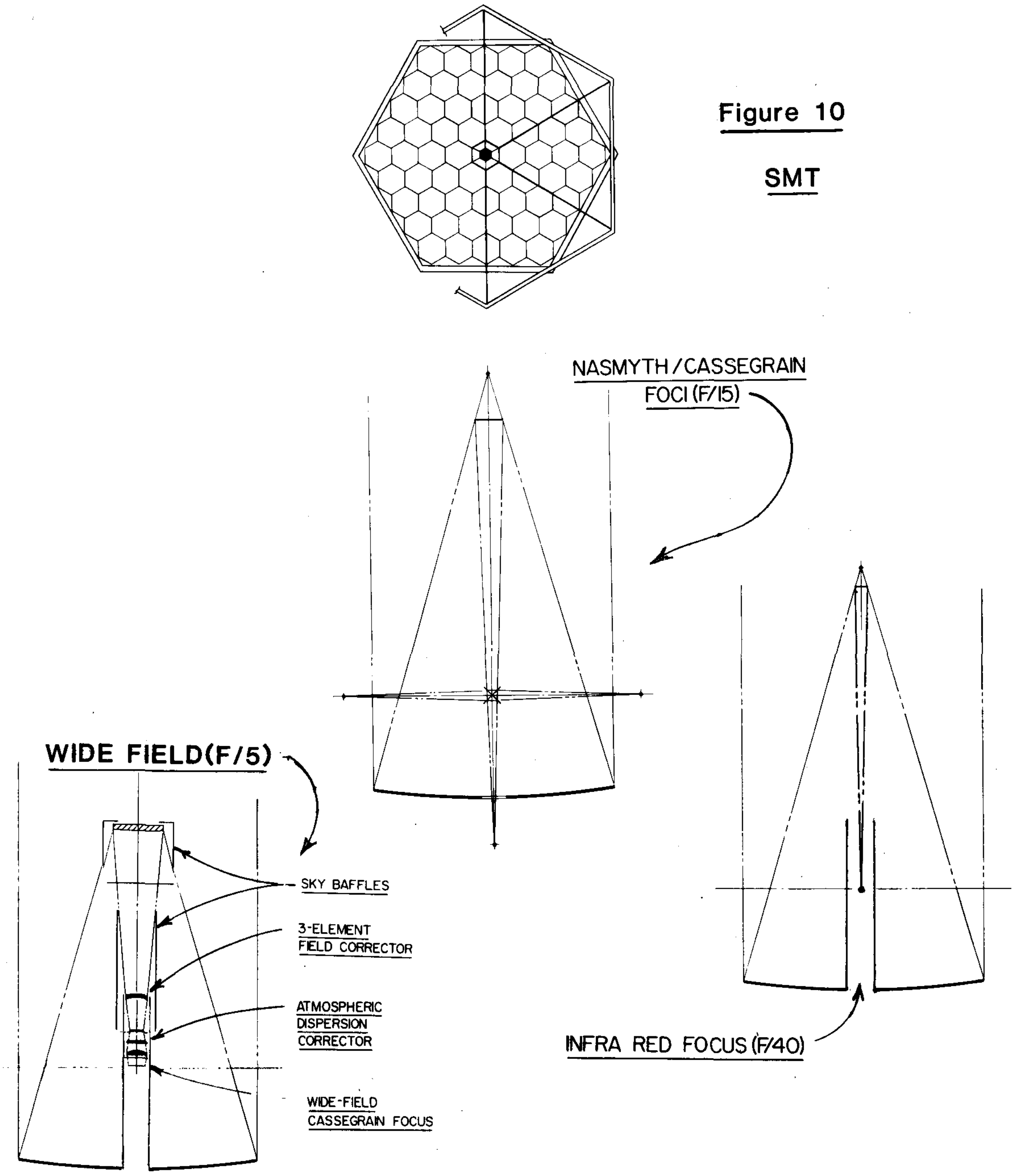


Figure 10

SMT

III. Conclusion

The two telescope concepts currently under evaluation for the 15-Meter NNTT have been presented. A selection between the two will be made by Fall 1984. Engineering design work will be done in the two-year period immediately following.

References

1. "Astronomy and Astrophysics for the 1980's," Report of the Astronomy Survey Committee, National Academy Press, Washington, D.C., 1982.
2. Barr, L. D. , Lynds, C. R., Angel, J. R. P., Woolf, N. J., Mast, T., Nelson, J. E. , "The 15-Meter National New Technology Telescope (NNTT): The Two Design Concepts," SPIE Proc., Vol. 444, pg. 37, 1983.
3. Angel, J. R. P., Hill, J. M., "Steps Toward 8M Honeycomb Mirror Blanks: III 1.8M Honeycomb Sandwich Blanks Cast from Borosilicate Glass," SPIE Proc., Vol. 444, pg. 184, 1983.
4. Angel, J. R. P., Woolf, N. J., Hill, J. M., Gobel, L., "Steps Toward 8M Honeycomb Mirror Blanks: IV Some Aspects of Design and Fabrication," SPIE Proc., Vol. 444, pg. 194, 1983.
5. Shu, Ker-Li, "NNTT Concept Evaluation Notes," Ch. II, NOAO, Tucson, AZ., September 1983.
6. Beckers, J. M., Ulich, B. L., Williams, J. T., "The Multiple Mirror Telescope: A Progress Report," SPIE Proc., Vol. 444, pg. 2, 1983.
7. Beckers, J. M., et al, "The Multiple Mirror Telescope," Annual Reviews Monograph, "Telescopes for the 1980's," edited by G. Burbidge and A. Hewitt, Annual Reviews Inc., Palo Alto, CA., 1981
8. Nelson, J. E., Budiansky, M. P., Gabor, G., Mast, T. S., "The Segmented-Mirror Control System Prototype for the Ten-Meter Telescope: A Status Report," SPIE Proc., Vol. 444, pg. 297, 1983.
9. Gabor, G., "Actuators for a Segmented Mirror Control System," SPIE Proc., Vol. 444, pg. 287, 1983.
10. Mast, T. S., Gabor, G., Nelson, J. E., "Edge Sensors for a Segmented Mirror," SPIE Proc., Vol. 444, pg. 297, 1983.
11. Barr, L. D., Gillett, P. E., Shu, K. L., "Off-Axis Parabola Fabrication at Kitt Peak National Observatory," SPIE Proc., Vol. 444, pg. 261, 1983.