CELT Report No. 14
Design Team Quarterly Report No. 2
March 2001

Contents

1. Introduction

The University of California and the California Institute of Technology (partners in the W. M. Keck Observatory) are collaborating to build a 30-meter telescope (CELT), designed to be fully steerable and operate on the ground. With its Ritchey-Chretien optical design it will have a large, 20-arcminute, field of view; and with planned adaptive optics, it will produce diffraction-limited images for wavelengths as short as one micron.

A year-long Conceptual Design Phase is described in CELT Report No. 9 "CELT Conceptual Design Plan", Jerry Nelson, Terry Mast, Gary Chanan, Richard Dekany (July 2000). The first quarter is reported in CELT Report #12 which describes many details of the Tasks. **For efficiency we have not repeated them here; we mainly describe here the progress in the second quarter.** Table 1 lists some aspects of the full CELT Observatory Project and organizes the thirty conceptual design phase tasks by aspect.

Table 1. Tasks in context of full CELT program

Observatory Requirements	**Task [1]**
Telescope Design	
Error Budgets	**Task [2]**
External Design Driver: Wind	**Task [3]**
Optical Design	**Task [4]**
Primary Mirror	**Tasks[5 -17]**
Auxiliary Optics	**Tasks[18-19]**
Telescope Structure	**Tasks[20-21]**
Adaptive Optics	
Modes of operation	**Task [22]**
Error budgets	**Task** [**23]**
Alternative Design Concepts	**Tasks[24]**
Conceptual Design Review	**Task [25]**
Preliminary Design Plan	**Task [26]**
CELT Working Groups	**Task [27]**
Conceptual Design Phase Management	**Task [28]**
CELT Website Management	**Task [29]**
Contingency Management	**Task [30]**

Table 2 gives the titles of the 30 conceptual design-phase tasks and serves as a table of contents.

Table 2. Task List

2. Summary

Significant progress has been made on a number of key design issues during this quarter.

We have complete or nearly complete reports addressing segment passive support, segment actuators, and segment interferometric testing. We also have excellent first drafts of the design requirements and the error budgets.

We have hired consultants to work with us on the telescope structure, telescope bearings, drives, and encoders. We have also hired consultants to create an intial design of one of the candidate actuator types.

Tools were created that calculate the CELT segment control matrix, analyze its spatial frequency content, and use it to understand error propagation based on the proposed displacement sensor design.

A Reports and Technical Notes series document the design efforts, and a website provides access to these as well as information about CELT personnel and calendar activities.

A full time engineer has been hired at UCO/Lick who will work on designing a prototype stressing fixture and a test facility for prototype sensors. He will also be available for future testing of candidate actuators and mechanical testing of segment surfaces.

A technical staff member of UCO/Lick is working on CELT sensor design issues and prototypes.

Significant progress was made this quarter on the issues listed below.
Details about these issues and others are given in the Section 6.

- observatory requirements
- error budgets
- segment displacement sensors
- interferometric testing of segments
- segment passive support
- segment support actuators
- spatial frequency response of the primary mirror control

3. Budget

Task	DESCRIPTION	Budget	Q1	Dec	Jan	Feb	Liens	Total	Balance
	ADMINISTRATION								
28	Project Management	20.0	12.8	1.2	2.8	0.1		16.9	
28	Travel	20.0	9.9	0.8	1.6	2.3		14.6	
	TOTAL ADMINISTRATION	40.0	22.7	2.0	4.3	2.4	0.0	31.5	8.5
	OBSERVATORY								
3	Wind influence on telescope	60.0		0.1		0.0		0.1	
27	Working Groups Support	50.0						0.0	
29	Website Management	10.0						0.0	
1	Observatory Requirements	10.0	7.1	0.1	0.1			7.2	
25	Conceptual Design Review	15.0			0.0	0.1		0.1	
	TOTAL OBSERVATORY	145.0	7.1	0.2	0.1	0.1	0.0	7.4	137.6
	OPTICS								
4	Optical Design	5.0						0.0	
5	Segmentation Geometry	5.0						0.0	
6	Segment Material	5.0						0.0	
7	Segment Fab vendor candidates	20.0						0.0	
9	Stress fixture design, fab & test	45.0						0.0	
11	Design segment passive support	55.0		8.4	8.4	0.0	22.5	55.0	
12	Combine Displace /TCWS readings	12.0						0.0	
13	Primary mirror control SFR	19.0						0.0	
14	Segment Displace Sensors	60.0						0.0	
15	TCSE hardware Design	7.0						0.0	
16	Segment Support actuators	45.0		1.0	5.0	0.0	30.8	45.0	
17	Camera design	14.0						0.0	
24	Conceptual AO system optical designs	50.0						0.0	
	TOTAL OPTICS	342.0	23.8	9.4	13.4	0.0	53.3	100.0	242.0
	TELESCOPE								
20	Telescope Structure Design	65.0	35.0		10.0	10.0	20.0	65.0	
21	Prelim design bearings, drives, encoders	30.0					30.0	30.0	
	TOTAL TELESCOPE	95.0	35.0	0.0	10.0	10.0	50.0	95.0	0.0
30	MANAGEMENT CONTINGENCY	128.0							128.0
	TOTAL	750.0	88.7	2.2	14.4	2.6	103.3	233.9	516.1

4. Schedule

Activity	duration	start	end
[1] Observatory Requirements	255 d	22-Sep-00	24-Sep-01
Observatory Requirements Document	51 w	22-Sep-00	24-Sep-01
Quarterly Review #1	0 d	01-Dec-00	1-Dec-00
Quarterly Review #2	0 d	06-Mar-01	6-Mar-01
Quarterly Review #3	0 d	05-Jun-01	5-Jun-01
Quarterly Review #4	0 d	11-Sep-01	11-Sep-01
[2] Error budgets	255 d	22-Sep-00	24-Sep-01
Adaptive Optics on	51 w	22-Sep-00	24-Sep-01
Adaptive Optics off	51 w	22-Sep-00	24-Sep-01
Internal Review	0 d	15-Jan-01	15-Jan-01
Detailed Review	0 d	01-Feb-01	1-Feb-01
[3] Analyze and model wind influence on telescope	125 d	22-Sep-00	26-Mar-01
Caracterize Free Winds at Sites	25 w	22-Sep-00	26-Mar-01
Determine Wind Force on Dome	25 w	22-Sep-00	26-Mar-01
Determine Wind Spectra Inside Dome	25 w	22-Sep-00	26-Mar-01
Determine Wind Dynamics on Primary Mirror	25 w	22-Sep-00	26-Mar-01
[4] Complete the optical design	255 d	22-Sep-00	24-Sep-01
Optical Design	51 w	22-Sep-00	24-Sep-01
Initial Optical Design	0 d	22-Sep-00	22-Sep-00
Revised Optical Design	0 d	02-Feb-01	2-Feb-01
Conceptual Stage Optical Design	0 d	11-Sep-01	11-Sep-01
[5] Establish the segmentation geometry	51 w	22-Sep-00	24-Sep-01
[6] Establish the segment material	51 w	22-Sep-00	24-Sep-01
[7] Establish the segment fabrication vendor candidates	51 w	22-Sep-00	24-Sep-01
[8] Establish the segment fabrication cost	51 w	22-Sep-00	24-Sep-01
[9] Stressing fixture design, fabricate, and test	127 d	22-Sep-00	28-Mar-01
Calculate Conceptual Design & Reqiurements	14 w	22-Sep-00	8-Jan-01
Design Stress Fixture	4 w	04-Jan-01	31-Jan-01
Fabricate Stress Fixture	4 w	01-Feb-01	28-Feb-01
Test Mirror Stress Fixture	4 w	01-Mar-01	28-Mar-01
[10] Define the segment fabrication figure tests	255 d	22-Sep-00	24-Sep-01
Design an LVDT system	4 w	04-Jan-01	31-Jan-01
Test LVDT System	4 w	01-Feb-01	28-Feb-01
Develop Optical Test of Segment Figure	51 w	22-Sep-00	24-Sep-01
[11] Design the segment passive support	236 d	22-Sep-00	28-Aug-01
write requirements	236 d	22-Sep-00	28-Aug-01
write contract and award	2 w	22-Sep-00	5-Oct-00
segment support study	21 w	06-Oct-00	12-Mar-01
Freeze Concept	0 d	14-Mar-01	14-Mar-01
Fabricate Prototype	8 w	14-Mar-01	8-May-01
Test Protype	16 w	09-May-01	28-Aug-01
[12] Algorithms to combine Displacement & TCWS readings	51 w	22-Sep-00	24-Sep-01
[13] Study the spatial frequency response of the primary mirror control	51 w	22-Sep-00	24-Sep-01
[14] Segment displacement sensors (design, fabricate, test)	159 d	03-Jan-01	13-Aug-01
write requirements	2 w	03-Jan-01	16-Jan-01
write contract	4.25 w	17-Jan-01	15-Feb-01
Segment displacement sensor study	25 w	20-Feb-01	13-Aug-01

[15] Design Telescope-Control Wavefront Sensor (TCWS) hardware	51 w	22-Sep-00	24-Sep-01
[16] Segment support actuators (design, select, test)	220 d	22-Sep-00	6-Aug-01
write requirements	220 d	22-Sep-00	6-Aug-01
write contract and award	2 w	22-Sep-00	5-Oct-00
actuator study	18 w	06-Oct-00	19-Feb-01
Lorell Study- Write contract and award	19.6 w	22-Sep-00	15-Feb-01
Lorell Actuator Study	24 w	16-Feb-01	2-Aug-01
Accuire Test Acturators	8 w	20-Feb-01	16-Apr-01
Develop Actuator Test Program	6 w	20-Feb-01	2-Apr-01
Test Actuators	16 w	17-Apr-01	6-Aug-01
[17] Design camera required to determine desired sensor readings	51 w	22-Sep-00	24-Sep-01
[18] Define secondary & tertiary physical & performance parameters	51 w	21-Sep-00	21-Sep-01
[19] Algorithms for TCWS control of primary, secondary, & guiding	25 w	01-Mar-01	22-Aug-01
[20] Design the telescope structure	101 d	22-Sep-00	20-Feb-01
Write requirements and contract goals for SJM and award contract	2 w	22-Sep-00	5-Oct-00
Telescope structure study	18.4 w	05-Oct-00	20-Feb-01
[21] Generate strawman designs of the bearings, drives, encoders	145 d	04-Dec-00	3-Jul-01
Write Contract and Award	4 w	04-Dec-00	9-Jan-01
Phase 1 Bearings, Drives, and Encoders Study	16 w	10-Jan-01	1-May-01
Phase 2 Bearings, Drives, and Encoders Study	9 w	02-May-01	3-Jul-01
[22] Identify the candidate AO modes & define requirements for each	51 w	22-Sep-00	24-Sep-01
[23] Develop first order error budgets for AO components	51 w	22-Sep-00	24-Sep-01
[24] Develop conceptual AO system optical designs for each AO mode	51 w	22-Sep-00	24-Sep-01
[25] Prepare for Conceptual Design Review	5 w	15-Aug-01	18-Sep-01
[26] Write the Preliminary Design development plan	5 w	15-Aug-01	18-Sep-01
[27] Support the CELT Working Groups	51 w	22-Sep-00	24-Sep-01
[28] Manage the Conceptual Design phase program	255 d	22-Sep-00	24-Sep-01
Weekly Telecons and Team Meetings	51 w	22-Sep-00	24-Sep-01
CELT Workshop Meeting	0 d	02-Feb-01	2-Feb-01
[29] Manage the CELT Website	51 w	22-Sep-00	24-Sep-01

A Gantt chart will be presented at the CELT Steering Committee meeting.

5. Concerns

Although there has been important and significant progress, there are key issues that are unresolved and are required for many other parts of the study. Their timely resolution is critical.

The effects of the wind are not yet adequately understood,, and the plan for completing this task is vague. The effect of wind **may** be a critical driver for the telescope, but this must be made quantitative. Hence completion of the telescope structural design is seriously hindered by the poor progress on understanding wind.

It **may** be that the most acceptable telescope structures (acceptable due to wind) produce significant blockage of the primary. The likely scientific impact of this blockage needs to be carefully assessed. If it is viewed as a serious problem, and none of the current telescope structure designs are acceptable, then more radical departures in design may be necessary. This could drive the entire design study.

Plausible costs for edge sensors, actuators, and segment fabrication are needed before we can reasonably optimize the segment size and the primary mirror focal length. We will also need the segment alignment error budget and secure knowledge about the mirror cell gravity deformations. Concerted effort needs to be applied here so we can freeze the optical design sooner, rather than later.

Adaptive optics requires technologies not yet availabl,e and building designs around non-existent technology is risky. An adaptive secondary mirror may be extremely challenging, so its value must be carefully understood. If needed, it will influence the telescope structure design. Further, the optical design for MCAO may drive the telescope optical design. The auxiliary requirements of MCAO (number, launch locations, and power of lasers) may have a strong influence on the observatory design, and the requirements are unknown.

Many tasks are either not started or barely begun, and our ability to complete the conceptual design study in 12 months is untested. The fact that many tasks are strongly inter-related and that some key ones are barely begun is a clear cause for concern about keeping to our schedule.

6. Task Descriptions

For each task we briefly repeat from CELT Report No. 9 "California Extremely Large Telescope (CELT) Conceptual Design Plan", the description of the task. Then for each task we describe the progress made this quarter and the plans for the future.

Task [1] Determine Observatory Requirements

Description

We will write the observatory requirements which will form the over riding document that dictates the design objectives. This will evolve with discussions with the working groups and with the Steering Committee.

Inputs

Working Group Reports

Impact on Other Tasks

Fundamental requirements for all tasks

Progress this Quarter

The first draft was written and carefully reviewed by the Steering Committee on 1 February 2001. A second draft has been issued based on comments from that meeting

It has been distributed to the Steering committee for comment.

Plan for Future

The following open issues need to be resolved.

- The value of a prime focus needs to be reviewed in light of very small FOV.
- The short wavelength cutoff of the telescope needs to be reviewed in light of coating concerns.
- The environmental conditions at sites other than Mauna Kea need to be included.
- Sky coverage with laser beacons is not yet known.
- What Strehl degradation vs FOV is required/possible?
- Adaptive secondary specifications need review: number of degrees of freedom and f-ratio.

Task [2] Error budgets

Description

Error budgets for image quality will be completed. These are being constructed for both observing modes; AO-on (in terms of rms wavefront error) and AO-off (in terms of 80% enclosed energy diameters).

Objectives

Construct global telescope error budgets and detailed error budgets for the segmented primary mirror. Also construct error budgets for image motion.

Inputs

Complete Task 4

Initial work on Tasks 5 and 10

Initial values of telescope optical design. Baseline design for primary mirror active control.

Site environmental properties

Impact on Other Tasks

All other tasks will interact strongly with the error budgets. Candidate designs will define the budgeting and the budgeted errors will drive the designs.

Progress this Quarter

Initial draft error budgets for AO-on and AO-off modes have been written and are currently being refined with detailed calculations. The error budgets include both a global telescope budget and a detailed budget for the primary mirror.

An important contribution to any adaptive optics error budget is the "fitting error" that describes the rms residual wavefront resulting from the limited ability of the deformable mirror to correct all spatial frequencies. Much has been studied and written about fitting errors. At the intersection of AO and a segmented primary, is the fitting error resulting from surface errors in the segments. We have nearly completed CELT Technical Note No. 1 that calculates the fitting error (as a function of deformable mirror actuator spacing) for random Zernike aberrations in an array of hexagonal segments.

Substantial progress was made during this quarter on completing the error budgets. The required ray trace, rms wavefront, and AO fitting error calculation tools were completed. The methods and assumptions were reviewed in a two-hour review with the CELT Steering Committee. With the completion of these milestones we are now poised to rapidly complete the budgets. The calculation of the contribution of each term is described in terms of equations, so that the value can be readily revised when the telescope optical or primary mirror design parameters change.

Plan for Future

In the first half of the third quarter we will complete the Error Budgets, CELT Report No. 10, and the supporting documents.

Task [3] Analyze and model wind influence on telescope

Description

Wind loads on the telescope will be studied. Loads during operations and survival loads on the dome will be addressed. During operations, there is the potential that wind loads directly on the top end of the telescope will cause the telescope to move and oscillate, causing image motion. In addition there is the possibility that wind loads on the primary itself will cause distortion of the primary mirror, occurring at frequencies higher than the bandwidth of the primary mirror active control system (ACS). Finally, wind loads on the dome itself may cause motion of the earth and hence the entire telescope on its pier.

We expect to use a combination of analytic tools, computer simulation, wind tunnel testing, and scaling from other observatories to assess the size of the wind disturbances.

Objectives

We will estimate the static wind speed distribution inside the dome (near the top end of the telescope down to the primary mirror) relative to the outside wind speed. This will be used to calculate the static force on the telescope. This speed distribution will be determined by some combination of

Measurements at Keck or other large telescope
Computer modeling
Wind or water tunnel measurements

We will estimate the dynamic effects of wind on the telescope as well, including spatial and temporal coherence.

Inputs

- Wind statistics for each candidate site
  (probability distribution of wind speeds on clear nights)
- Maximum 100 year wind speeds for each site (for survival study)
- Elastic properties of the soil under the dome for each site.
- Shape and cross section details of the top end of the telescope
- Power spectrum of wind at the site

Impact on Other Tasks

This will influence the telescope design, and the dome design

Status

Wind forces on the telescope may cause image motion in excess of allowed values. This is a critical unresolved issue for the CELT design The central problem is to estimate the dynamic forces on the telescope that may cause the images to move. There are several approaches to becoming informed:

1. Simple calculations of “static” wind force on the telescope can be made, using some assumed wind attenuation inside the dome and appropriate drag coefficients and Reynolds numbers. Then, given an assumed telescope stiffness, image motion can be estimated

2. There exists Gemini data with wind speeds at top of structure structure, along with external wind speed and orientation. Analysis of this data could be informative.
3. Computer-based simulations of the wind power spectrum inside the dome might be made.
4. Wind tunnel tests to estimate the wind power spectrum inside the dome might b e made
5. Wind speeds and turbulent spectrum might be measured at Keck.

Progress this Quarter

We have been exploring different sources of wind information, from books to experts to wind data on Gemini. This education process is continuing, so no definitive conclusions are yet available.

We have had preliminary discussions with Rose McCallan of LLNL concerning the likely effects of wind on structures. She recommends some combination of wind tunnel testing and computer simulations for reliable results.

Efforts to explore the use of an environmental wind tunnel at UC Davis, operated by Bruce White, have led to the conclusion that this wind tunnel is not appropriate.

We have made a preliminary examination of some of the Gemini wind tests (anemometers inside the dome of Gemini S). From this, our view is that wind speeds inside the dome at the top of the telescope will be reduced by about a factor of two from the outside air, with some dependence on the orientation of the dome slit with respect to the wind direction. Further, it appears that the wind speed near the primary mirror is reduced by roughly a factor of 10 relative to the outside wind speed. These results are compatible with those used in modeling Keck.

The upper "tube" of CELT is likely to be composed of trusses, rather than simple tubular beams. Discussions with McCallan and the reading of wind references (Simiu and Scanlan Wind Effects on Structures) suggest that wind forces on these trusses can be estimated by standard methods ($F = C_d \rho v^2 A/2$) and that cross talk between members of the truss will not significantly alter the result.

For some of the telescope designs in progress we have estimated the static wind loads and possible resulting image motion. The results suggest that wind will be a significant issue, driving the telescope design, but also that acceptable solutions might be possible.

Plan for Future

We will examine the Gemini data more carefully to better assess the static and dynamic characteristics of wind inside the dome.

We will work closely with McCallan to check our methodology and to assess which wind tunnel tests should be carried out and which computer modeling should be done.

The power spectrum of the wind will be estimated through some combination of Gemini data, simulations, and wind tunnel tests.

The likely forces on several telescope designs will be produced, and the likely resulting image motion will be estimated and fed back into the telescope structure design.

Task [4] Complete the optical design

Description

We will produce an optical design for CELT that includes a mathematical description of the optical surfaces and locations. The design performance of the system will be produced, including image quality, field of view, focal surface curvature, pupil positions, and sensitivity to misalignment.

Objectives

We will produce a Ritchey-Chretien optical design giving a 20 arc minute field of view with 0.5 arc second image quality (100% enclosed energy). Initial and final f-ratios are critical parameters that will be set, after a trade off study. The compatibility with planned adaptive optics systems for CELT will be carefully assessed and maximized. The sizes of the secondary and tertiary will also be carefully explored to understand their values in the optical design and the tradeoffs against difficulty of fabrication. Focal plane locations will be determined, taking into account the space required for science instruments

Inputs

Requirements on FOV, plate scale, and instrument sizes from working groups

Impact on Other Tasks

The optical design parameters are fundamentally related to the optimization of the segment polishing, mainly though the primary mirror focal length. The requirements of AO are also key inputs to the optical design, through the final focal length, focus position, and possibly special requirements for the secondary mirror. The telescope structure is driven by the optical design.

Status

A conceptual design exists with an f/1.5 primary (k = 90 m) and a back focal distance of 15 m with a final f-ratio of f/15. This design is sufficiently complete for current purposes.

Progress this Quarter

An analysis of the potential for using the prime focus has been completed. A seeing limited FOV of 24 arcseconds is possible. Its value needs to be assessed.

Plan for Future

When we have additional information on component costs and alignment sensitivities we will make a trade study of the value of changing the primary focal length. Information from the working groups may also cause us to re-evaluate the final focal length and back focal distance.

Task [5] Establish the segmentation geometry

As expected, the descriptions for this task status, progress, and plan have not changed this quarter. For convenience they are repeated here from the Quarterly Report No. 1

Description

We will establish the thickness and radius (and thus the number of segments) of each segment. This will involve a complex tradeoff of many issues including predicted effects of thermal and gravitational changes, segment material costs, segment fabrication costs, segment passive support system costs, segment active control costs, impact on adaptive optics, re-aluminizing costs, and handling costs.

Inputs

None required for about six months. Then for a review, and possible revision of the geometry, we will require initial telescope and primary mirror error budgets and initial cost estimates for segment fabrication.

Cost estimates for segment fabrication and tests

Impact on Other Tasks

The definition of the segmentation is strongly inter-related to almost all other tasks.

Progress this Quarter

The segmentation geometry of the primary mirror is mainly defined by two parameters: the hexagonal segment sidelength (a) and the segment thickness (h).

The selection of a segment size, and hence the number of segments, depends on a complex tradeoff of many costs. A larger segment size (radius = a, thickness = h) increases the amount of asphericity required in the surface figure ($\sim a^2$), the gravity-induced deflections on a support, ($\sim a^4 / h^2$), the weight for handling ($\sim a^2 h$), and sensitivity to position errors in the array ($\sim a^2$). A smaller segment size increases the number of active control actuators and sensors, the complexity of a control wavefront sensor, and the complexity of the alignment and control software.

The selection of the segment thickness is also a complex compromise between costs. A larger thickness will require larger required forces for intentional deformation during fabrication, greater cost of the blank material, greater thermal inertia in the telescope, and a greater mass for the support structure (the telescope). A smaller thickness will require more support points to reduce deformations due to gravity.

We have not yet gathered estimates of these costs and cost variations. This will be required to make final informed compromises. Based on our experience with the Keck telescopes, we have adopted for now a baseline segment design. During the conceptual design phase this will evolve to final values for the radius and thickness. In the meantime we have adopted a segment radius of a = 0.5 meters and a segment thickness of h = 45 millimeters.

The resulting array contains 1080 segments. A central subset of 19 segments is deleted from the array since the light to them is blocked by the secondary mirror. This baseline array has an area = 702 m^2.

A discussion of some segment fabrication issues that affect the selection of segmentation geometry is given in CELT Report No. 5. "Primary Mirror Segment Fabrication for CELT", Terry S. Mast, Jerry E. Nelson, and Gary Sommargren, Proceedings of the SPIE, **4003**, 2000

The current status is summarized in Quarterly Report No. 1, (CELT Report 12 Progress on this task relies on the completion of other tasks (7-9, 14,16) that are currently being actively addressed.

Progress on the selection of a segmentation geometry is being made through work on other tasks. Definition of baseline designs for segment actuators (Task 16), segment sensors (Task 14), and segment support (Task 9) will allow estimates of these component costs. Definition of the segment fabrication techniques and vendor estimates (Tasks 7 to 10) will provide additional cost estimates. All of these costs are required for the selection of a final segmentation geometry.

Plan for Future

Work on all associated costs will continue. We do not expect to have the required cost estimates until the end of the third quarter.

We also have the option of adjusting the positions of some peripheral segments to keep a closely circular periphery and at the same time to allow for convenient division of the array into subsets (full and partial “rafts” of 19 segments) for ease of handling. This adjustment, the inter-segment gap size, and the segment prism geometry are additional segmentation geometry issues that will be addressed.

Work on all associated costs will continue. We do not expect to have the required cost estimates until the end of the third quarter.

Task [6] Establish the segment material

Description

The choice of segment material is important since most interesting materials are very expensive. The method of creating the optical surface on the segments will influence the options for material. For segment polishing, one needs either a directly polishable material or one that can be effectively plated. Glassy materials such as Zerodur or ULE are well known, but expensive choices. Aluminum is another potentially less expensive option that needs to be explored. More exotic materials such as SiC should also be investigated.

Objectives

Based on collected material properties we will assess the likely impact on segment thickness and mass, resulting telescope mass, and passive segment support. All these will influence, and may strongly impact, the overall telescope cost.

Inputs

Information on the material properties of candidate materials including E, ρ, α, k, internal stresses (needed for evaluating warping from cutting), availability, size limitations, long term stability, polishability, and cost. ESO reports on the evaluation of aluminum.

Impact on Other Tasks

Material choice is closely related to segment fabrication technique, methods of coating segments, segment passive support, telescope structural design.

Progress this Quarter

The baseline material for the segments is Zerodur.

We met with a representative of Hextek Corporation. They are eager to work with us to assess the possibility of Hextek supplying the mirror blanks for CELT. They make light-weighted (hexagonal cell interior with back and front face sheets) blanks of fused Schott borosilicate glass. The clear advantages of these blanks are their reduced mass (possibly allowing a lighter weight telescope structure) and a shorter thermal time constant.

A number of important issues need to be explored in detail together with Hextek technical personnel. These include: the susceptibility to quilting during stressing for stressed mirror polishing, quilting due to pressure and thermal effects during polishing, quilting and other surface deformations induced by temperature changes and thermal gradients during testing and operations, the consequences of cutting after stressed mirror polishing, a design for the segment support system (and its thermal and gravitational characteristics), a design for incorporating edge sensors (and its thermal and gravitational characteristics), and others.

A second general option for using Hextek blanks uses Reactive Atom Plasma Processing to create the final figure in a hexagonal blank. This process uses a traveling "torch" emitting a plasma of chemical species to chemically erode the blank in a controlled and deterministic process. The amount of erosion is controlled by 1) the concentration of the eroding species (usually CF_4), 2) the distance of the torch from the glass surface, and 3) the dwell time. This process allows a large and well-controlled amount of material to be removed from a surface in a deterministic manner and holds the promise of revolutionizing optical polishing.

The initial development work was made at LLNL; and beginning in December, 2001, the development will move to the commercial sector.

Use of this figuring technique would remove from concern some of the issues associated with the Hextek blanks. Use is this technique would allow the creation of the complete aspheric figure without the need for stressed mirror polishing.

We have not explored this quarter, as we had planned, the potential for using aluminum blanks.

Plan for Future

During the third quarter, we will work with Hextek personnel to define the potential for using Hextek blanks. We will define quantitatively the issues associated with using aluminum blanks. The soon to be completed error budgets will allow us to make a quantitative assessment of the viability of these blank materials.

Task [7] Establish the segment fabrication vendor candidates

Description

Based on an initial definition of segment requirements we will discuss with all potential vendors the desired segment characteristics that they would be able to provide at minimum cost. This will require concentrated personal interactions with teams from each candidate vendor. Segment design and fabrication methods will be modified to find a low cost solution to segment fabrication.

Objectives

Definition of potential segment fabrication vendors and characterization of each in a fixed set of categories including experience, infrastructure, depth, etc.

Definition of a baseline fabrication scenario in enough detail to serve as a basis for a credible cost estimate.

Inputs

Documentation of planetary-stressed-mirror-polishing methods and fixtures.

Documentation of an in-process test option, including test error budget

Documentation of an interferometric test option, including test error budget

Initial progress on Task 2 Error budgets, Task 4 Optical Design, Task 5 Establish the segmentation geometry , and Task 6 Establish the segment material.

Impact on Other Tasks

This is a prerequisite for Task 8.

Status

We assume that the segments will be polished by planetary stressed mirror polishing as described in CELT Report No. 5. "Primary Mirror Segment Fabrication for CELT", Suitable vendors are needed.

Progress this Quarter

We visited Rayleigh Optical in Tucson. They are extremely interested in making the CELt segments, and showed a good understanding of the task.

Jeff Carr described a revolutionary technique for polishing optics using Reactive Atom Plasma Polishing (RAP). Clearly still in its nascent stages, it has the potential for revolutionizing polishing by predictable removal of up to 1g/min.

Contact with other optical firms was not made

Plan for Future

We plan to make initial contact with the rest of the candidates in the 3nd quarter, a delay of 3 months from our previous plan

Task [8] Establish the segment fabrication cost

Description

Based on Tasks 5, 6, 7, 9 we will be able to establish an accurate estimate for all the processes required for segment fabrication. Interactions with candidate vendors will allow us to fine tune the processes and to generate a plausible cost estimate. Costs will come from vendor discussions and opinions.

Objectives

Determine a reasonable cost estimate for segment fabrication

Inputs

Design information, extensive vendor discussions and cost estimates.

Impact on Other Tasks

May influence the size of segments if the cost is size sensitive. This in turn will influence many other tasks.

Status

Current plans assume roughly \$30K/m^2 based on earlier discussions with vendors. Their rough estimate was \$15K/m^2.

Progress this Quarter

No significant activity

Plan for Future

In the 3rd quarter we plan to discuss with vendors the contents of the RFQ. We expect to include a stressing jig design, analysis of its performance, a prototype, and results of experiments with it. In the 4th quarter we will initiate detailed discussions with vendors.

Task [9] Stressing fixture design, prototype and test

Description

We will design, build, and test a full-scale prototype stressing fixture. We will apply it to an aluminum segment, and measure the response, repeatability, and temperature and vibration sensitivities. If discussions with vendors show that this demonstration will have no significant impact on the cost estimates, then we can postpone the prototype and test phases.

Objectives

All candidate vendors have no experience with Stressed Mirror Polishing in a planetary polishing facility. Thus, this is likely to be a high cost-risk process for both CELT and the vendors. A detailed demonstration of the process will allow the vendors to make a credible estimate of the fabrication costs. Experience suggests that without such a demonstration all vendors will be required to provide very high cost estimates.

Impact on Other Tasks

The design (and perhaps the fabrications and tests) on Task 8 Establish the segment fabrication cost

Status

Some initial concepts for stressing fixture design are given in CELT Report No. 1 " Giant Optical Devices" Jerry Nelson and Terry Mast (Proceedings of the Backaskog Workshop of Extremely Large Telescopes, Anderson, T. ed, pp1-11, June 1999, Lund University and ESO) and in CELT Report No. 5. "Primary Mirror Segment Fabrication for CELT" Terry S. Mast, Jerry E. Nelson, and Gary Sommargren, (Proceedings of the SPIE, **4003**, 2000)

Progress this Quarter

No significant activity

Plan for Future

We expect to complete CELT Report No. 11 by April 2001. We have also started work toward building and testing a half-scale prototype of the stressing fixture. Our goal is to design and test this prototype in the first six months of 2001. A suitable glass blank is available for our use at the Lick optical laboratory. Local surface deformations near to the force/moment lever attachment points will be measured using the 6-inch diameter beam of the Lick phase-measuring Zygo interferometer. The full aperture can be measured for a nominal fee using the LLNL 20-inch diameter Zygo. The stressing fixture engineering design will begin now with the hiring of a mechanical engineer at UCO/Lick. The construction and testing of a prototype will follow.

Task [10] Define the segment figure tests

Description

For mechanical measurement of segment surfaces we will build and test a system and use it to measure the performance of the prototype stress fixture of Task 9.

For optical tests of segment surfaces we have defined three possible options. For each option we will make a detailed optical test design, calculate the sensitivity to variations in all possible degrees of freedom and temperature changes. These will be used to construct segment testing error budgets and, if needed, revise the test designs. These and discussions with vendors will be used to establish cost budgets for segment testing.

Objectives

Document the process of selecting baseline options for testing the segments. These must include detailed error budgets that be communicated candidate vendors

Impact on Other Tasks

Significant input to Task 8 Establish the segment fabrication cost.

Progress this Quarter

An initial study of interferometric testing options is given in CELT Report No. 5 "Primary Mirror Segment Fabrication for CELT," Terry S. Mast, Jerry E. Nelson, and Gary Sommargren, Proceedings of the SPIE, 4003, 2000. Since the outermost segment surface surface will contain about 20 microns of astigmatism, the fringe density is expected to be high. Three options for reducing the fringe density were considered in the above paper: A Uses computer generated holograms, B Uses the test configuration geometry of the final segment use, C Uses a tilted lens to create a canceling astigmatic wavefront.

The group at Livermore (under the direction of Gary Sommargren) has pursued the design of this test. They have considerable experience using a point diffraction test to measure X-ray optics surfaces to a precision of about 1 nanometer.

They have worked on a detailed study of using phase shifting diffraction interferometry (PSDI) test to measure the segment surfaces, and they have submitted a nearly complete draft describing their test design. The proposed test is simple conceptually and can be used to measure all segments in the CELT primary.

Based on their experience with the PSDI at LLNL, they have concluded that, although the fringe density directly from the segments is high, it is still low enough to be used without reduction. The proposed test has the following elements.

- Laser ($\lambda = 532$ nm)
- Fiber to provide the diffracting aperture
- Polarization beam splitter
    sends beams to interferometer reference and to converging lens

- Converging lens

  This lens is used to reduce the size of the test from about 90m to about 7m so the test can fit on a single optical table. The lens is placed about 5 meters from the end of the fiber. Depending on the segment under test to distance from the lens to the segment is varied from 75 to 2515 mm. It's position is accurately controlled using a distance measuring interferometer. There are options for the design of this lens; singlet with asphere surface, triplet with spherical surfaces, condensor/compensator lens combination, etc. A study of cost, performance, tolerances needs to be made before selecting a design.
- Camera / Imaging Lens

  A four-element camera was designed to image the surface on the detector (magnification ~ 1/74) and to minimize shearing effects and distortion.
- CCD detector

  A camera used at LLNL for this type of test uses a 1024 x 1024 CCD. With that CCD the fringe density in testing the CELT segments directly would be close to, but not above, the Nyquist frequency, If necessary, it is certainly feasible to acquire or build a camera with more pixels.

Critical issues in the test are

1. Differential optical path errors due to non-common path of the measurement and reference wavefronts for an aspheric segment.
2. Distortion of the local mirror coordinate system in the detector plane.
3. Magnification calibration

They have addressed these issues both in the design and in proposed calibration procedures that use additional fixtures.

1. spherical test mirror (radius nominally = 91 meters).
2. distortion calibration grid
3. magnification calibration mask

The Livermore group has written software to simulate the test; including segment surfaces, coordinate systems, measurement configuration, etc.

No progress was made this quarter (at UCSC), as we had hoped, on the design of a mechanical (surface contact) system for measuring the segment surfaces. We want to design, build, and test a prototype 2-dimensional array of probes to measure a prototype surface.

Plan for Future

The next step in the evaluation of this test will be a complete test error budget. The plan for creating this budget does not yet exist, and CELT and LLNL personnel need to collaborate on this plan. The LLNL simulation software could be used to calculate sensitivities required for the error budget.

Task [11] Design the segment passive support

Description

We will design a passive support for the mirror segments, compatible with the active support system of three actuators and consistent with the thermal and gravitational disturbances. This must include supporting the segment against gravity in any orientation, while maintaining surface errors consistent with the error budget.

Objectives

For a specified segment size and material, we will devise a passive support system. This will include adequate axial support and lateral support. The segment deflections under gravity in any orientation will be calculated, and the design will produce adequately small deflections. The interfaces will be carefully described. This includes attachment to the segments and connection to the active control system actuators and mirror cell lateral support system as needed. The design will also include tolerancing of the support to ensure production is economical. The assembly process will also be addressed for feasibility. Thermal effects will be carefully investigated to ensure that performance is adequate, both for thermal effects between assembly and operations, and during operations. Durability of the system during segment installation, segment handling, segment exchanges, telescope lifetime, mirror cleaning, and mirror coating will be evaluated.

Inputs

Task 5 segment design, Task 6 mirror material, thermal characteristics of the site.

Impact on Other Tasks segment fabrication, mirror coating,

Progress this Quarter

The conceptual design work for the passive support is complete. Steve Gunnels did an excellent job and created a passive support system (axial & lateral) that is acceptable.

He made a study of fabrication and assembly sensitivities that will be used to create the fabrication and assembly error budget. He also calculated the basic deformations required to predict the capability of a Keck style warping harness.

He studied the segment deformations due to wind loads. The deformations will be quite small compared to rigid body motions on the elastic passive support system, as expected.

He completed a detailed cost estimate for the cost of designing, building, and mounting on the segments the passive support system. The estimated cost per segment is $1100, quite a bit lower than our goal of $2000/segment.

Steve calculated the natural deformation frequencies a segment on 3 actuators. The lowest frequency is ~ 350Hz.

Plan for Future

A plan for additional studies and prototype construction and testing needs to be established.

Task [12] Develop algorithms to combine Displacement Sensor and Telescope-Control Wavefront Sensor (TCWS) readings

Initial work on this task were described in Quarterly Report No.1. No additional activity has taken place this quarter.

Task [13] Study the spatial frequency response of the primary mirror control

Quarterly Report No.1 (CELT Report No 12) describes the progress made on matrix inversion time and condition number by Gary Chanan. This work was extended this quarter to include the specific character of the proposed CELT displacement sensors. The error multipliers for the first 30 singular value decomposition normal modes are listed below, and the first 50 modes are plotted in the figure below. These lower SVD modes correspond closely to Zernike deformations of the full primary mirror. The error multiplier is the ratio of the rms wavefront error to the rms sensor noise.

$$M \equiv S_{rms} / \sigma_s$$

Chanan defines a dimensionless parameter, α_s, to describe the ratio of the focus mode sensitivity to normal mode sensitivity and it depends on the details of the sensor design.

$$\alpha_s \equiv b^2/(12\ t\ g)$$

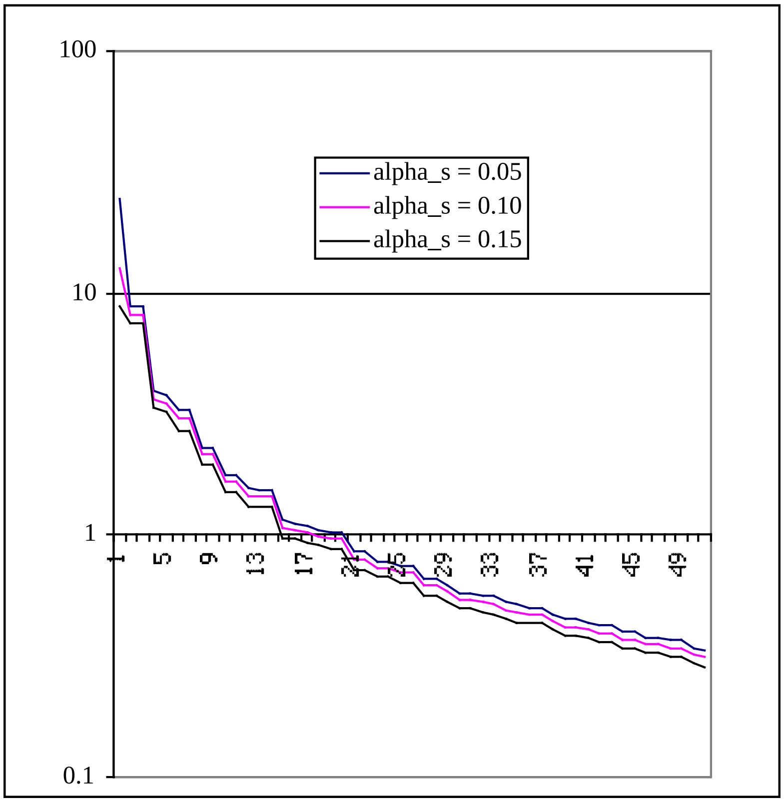
where b is sense capacitor size, t = the radius of the actuator triangle, g = the sensor gap
For a baseline segment / capacitor design (t = 255 mm, g = 2 mm) Gary considered three examples for α_s and calculated the following multipliers, M.

The first mode corresponds to focus mode, or a Z_{20} deformation of the primary. This mode depends strongly on the assumed sensor geometry, and the multipliers for this mode are confirmed with a simple geometric derivation.

α_s =	**0.05**	**0.1**	**0.15**
b =	**17.5 mm**	**24.7 mm**	**30.3 mm**
L_{eff} =	**19.1 mm**	**38.1 mm**	**57.3 mm**
SVD mode	**M**	**M**	**M**
1	24.656	12.694	8.764
2	8.774	8.198	7.541
3	8.774	8.198	7.541
4	3.908	3.656	3.360
5	3.761	3.531	3.252
6	3.287	3.014	2.685
7	3.287	3.014	2.685
8	2.296	2.145	1.964
9	2.296	2.145	1.964
10	1.780	1.657	1.500
11	1.780	1.657	1.500
12	1.551	1.444	1.317
13	1.550	1.444	1.317
14	1.550	1.442	1.305
15	1.149	1.067	0.972
16	1.117	1.051	0.963
17	1.094	1.020	0.930
18	1.045	0.986	0.906
19	1.032	0.964	0.876
20	1.032	0.964	0.876
21	0.851	0.792	0.722

22	0.851	0.792	0.722
23	0.780	0.732	0.670
24	0.780	0.732	0.670
25	0.744	0.697	0.634
26	0.744	0.697	0.634
27	0.665	0.618	0.563
28	0.665	0.618	0.563
29	0.623	0.585	0.535
30	0.572	0.541	0.499
rms of all 3240 modes			
	29.3	19.5	16.1
rms without mode #1			
	15.8	14.8	13.5

The figure below shows the multipliers for the first 50 modes.



These multipliers for the rms surface error and similar multipliers for the rms image blur will be used in the creation of the error budgets.

Task [14] Segment Displacement Sensors (design, prototype, test)

Description

This a potentially very expensive and complex item for CELT. About 6000 displacement sensors are required for segment stabilization. We will create an in-house design and also complete a thorough survey of commercially available devices. If no commercially suitable devices are available and affordable, we will prototype and test the in-house design.

Objectives

Complete a thorough survey of commercially available devices

Create an in-house design. If no commercially suitable devices are available and affordable, prototype and test the in-house design

Status

Initial Sensors design concepts are given in CELT Report No. 6 "Segmented Mirror Control System Hardware for CELT", Terry S. Mast and Jerry E. Nelson (Proceedings of the SPIE, 4003, 2000).

Progress this Quarter

We have begun a program to understand the sources of the larger than expected noise in the Keck sensors. We have also outlined a three-stage program for the coming two quarters for prototyping and testing prototype displacement sensor designs.

Kirk Gilmore made an initial trip to Keck Obsrevatory to learn about their existing sensor/actuator test stand in Waimea. Kirk will return (with Gary Chanan) to Keck to test for RF pickup in sensors at the summit in late March. Kirk has visited LBL and discussed the Keck sensors with Bob Minor. He acquired srawings of sensor and test electronics.

For prototypes we will cut Zerodur blocks, coat them with gold to form the required capacitors, ground planes, and traces; construct or assemble electronics; design and construct a test stand; and test prototype sensors. All this will be carried out in the UCO/Lick shops and clean room. We are currently designing the initial capacitor layout and designing the test stand. A mechanical engineer at UCO/Lick is working on the design of a facility to make controlled moves of a prototype sensor in three degrees of freedom in step sizes of order 5 nm.

We are also completing the theoretical sensor design with calculations of sensitivities to motions in all degrees of freedom and gravity and temperature sensitivities.

Plan for Future

We will pursue the above program for prototype sensors and plan to complete most of this program by the end of the fourth quarter. It is likely we will be able to borrow from Keck and LBNL much of the required electronics and software for the prototype testing, and that will greatly expedite this program. In addition, Bob Minor may be available to participate directly in the some the design and prototype activity.

Task [15] Design Telescope-Control Wavefront Sensor (TCWS) hardware

Description

It will be highly desirable for CELT to have a Gemini- or VLT-style Telescope-Control Wavefront Sensor (TCWS) for monitoring the lowest ten to thirty spatial frequency modes of the primary mirror. The baseline assumption is that the TCWS will be a Shack-Hartmann-type camera in which the primary mirror is re-imaged onto a lenslet array, producing an array of stellar subimages (containing wavefront gradient information) on a CCD. The current task will determine the conceptual design parameters of the TCWS.

Progress this Quarter

Our initial effort on this task is to learn about wavefront sensors being used on large telescopes. Schoeck and Chanan researched the wavefront sensor for the Gemini telescopes. "The Gemini active optics wavefront sensors - guidelines for the CELT telescope-control wavefront sensor" (Schoeck and Chanan, October 2000), CELT Technical Note No 2.

Plan for Future

We plan to make a similar study of the VLT wavefront sensor and write a note describing the design issues and candidates designs for the TCWS.

Task [16] Segment support actuators (design, select, test)

Description

The segment support actuators are potentially very expensive and complex. About 3300 segment actuators are required. We will make a thorough survey of the availability and cost of commercial actuators. We will design a lever-actuator system in order to expand the range of applicable commercial actuators. Every effort will be made to define the actuator requirements to minimize the costs: acquisition, fabrication, and maintenance. Robustness of candidate actuators will be tested, since the active control system has zero redundancy for actuator failure.

Objectives

Develop or acquire an adequate displacement sensor

Status

Quarterly Report No.,1 described the actuator requirements and gave many details of the survey by Alan Schier (The Pilot Group, 3130 Foothill Blvd., Unit 1, La Crescenta, CA 91214, (818)790-7481). At the end of this quarter, Alan submitted a substantial and detailed final report summarizing his survey of many types of actuators and many vendors. After collecting the data and comparing a very large range of potential candidates, he identified six candidates that are likely to meet the CELT requirements and meet a cost goal of less than $2000.

Progress this Quarter

We give a very abbreviated description here; mostly for identification purposes. Alan's report gives many details and thoughts about what we might do in the future to pursue these candidates

Two of these (#1 and #3) use a motion reducer to provide the small resolution (< 4 nm) using commercial actuators.

1. Conventional Lever (Motorized Micrometer and Flexured Lever)

Proposed by: CSEM (Swiss Center of Electro-Mechanics)

Description: Off-the-shelf motorized micrometer
drives a conventional lever (with a flexural pivot).

Micrometer (Physik Instrumente M-230.25)
screw and nut driven by a gearhead and DC motor.

A control loop around a motor mounted encoder
⇒ minimum commanded move at micrometer tip of 50 nm.

Outstanding issues: cost, backlash, life

2. High Resolution Micrometer

Proposed by: Diamond Motion

Description: Motorized micrometer with high ratio internal gearhead.
Stepper motor, micrometer screw, gearhead (> 10,000 : 1)
Pushes against a ruby pad (since micrometer rotates)
Outstanding issues: power, backlash, windup, life, reliability

3. Elastic Lever

Proposed by: The Pilot Group
Description: .Relatively coarse actuator with position feedback drives a flexural motion reducer through a cable drive.
Motion reducer: 2 beams at 90 degrees; 1st converts motion at one end to a moment at the other, 2nd converts the moment to a small motion at the same end (other end is fixed)
Outstanding issues: detailed design not made, mass, cost, life

4. Voice-Coil Actuator

Proposed by: Blue Line Engineering
Description: Voice coil actuator with position feedback around the output.
Diaphragm flexures to support the output shaft,
Eddy-current sensor provides resolution over full range.
Force is off-loaded using air pressure and small control valves.
Outstanding issues: need to air pressure, sensitivity of position sensor to pressure,

5. Magnetostrictive Inchworm

Proposed by: Etrema Products
Description: Inchworm using magneto-strictive materials and a lever mechanism to reduce the output.
Outstanding issues: design not made, transient motions created by application and release of brake, power

6. High- Capacity Inchworm

Proposed by: Greg Carman
Description: Piezo electric inchworm with grooved brake pads to achieve desired axial load capacity.
Outstanding issues: Uncertainty in when grooves are aligned for braking.
Transient motions induced by application and release of brake. cost

Plan for Future

We are holding a CELT actuator workshop on March 8 in Santa Cruz where the above and other candidate actuators will be discussed. At this writing we expect about a dozen attendees including Alan.

We will select two or three candidates to pursue; fund their further development, and acquire prototypes for testing.

Task [17] Design camera required to determine desired sensor readings

At the Keck telescopes, the desired sensor readings are determined by a Shack-Hartmann camera, known as the Phasing Camera System (PCS). In addition to this task, which can alternatively be thought of as aligning the segments in piston and tip/tilt, PCS can also zoom in on individual segments (or groups of seven segments) to determine the segment surface figures which are needed for warping harness adjustments. Although there exist other techniques which can in principle accomplish these tasks (e.g. curvature sensing, the Gerchberg- Saxton algorithm, phase diversity), PCS has the distinct virtue that it has been successfully proved on a large segmented telescope. While we are investigating some alternative techniques in the context of CELT alignment issues, here we explore the issues involved in scaling up Keck PCS to a CELT PCS.

In Quarterly Report No.1 we reported some initial considerations of 1) Tip/Tilt Alignment, 2) Phasing, 3) and Segment Figure Measurements. No further progress was made on this task this quarter.

Additional Telescope Design Activities

CELT Diffraction Point Spread Functions

In the last quarter we wrote code to evaluate the diffraction consequences (in mono-chromatic light) of various CELT segmentation geometries, segment alignment and figure errors, and secondary mirror support structures. The code supports:

- segment piston errors
- segment tip/tilt errors
- segment second order wavefront errors
- global focus errors
- rudimentary secondary support structures
- seeing (in the long term exposure limit only)

To allow better image plane resolution we have now extended the FFT array from 1K x 1K to 8K by 8K.

Task [18] Define secondary and tertiary physical & performance parameters

Description

The secondary mirror or mirrors is a fundamental part of the telescope design. We will assess the need for multiple secondaries, and what their desired optical properties are. We will assess the impact of secondary size on science performance. We will study the tertiary mirror requirements. We will also investigate field rotation issues and conceptual design options for addressing them.

Objectives

We will produce optical designs for two secondaries, one rigid for optical and near IR applications, a second one for an adaptive secondary. Surface and alignment specifications will be produced, and a weight estimate for each, including the entire support system. A cost estimate will be produced.

Inputs

The secondaries are fundamentally related to the primary and final f-ratios, as well as the location of the final focus. The design of the AO systems is also closely related. Size, location, weight, position tolerances will drive the structural design of the telescope.

Progress this Quarter

As a result of the review of the requirements, the secondary has been changed to deliver unvignetted images over a 20 arcminute FOV. This increases the size of the secondary from 3.64m to 3.87m.

There is continuing interest in having an adaptive secondary that is interchangeable with the f/15 secondary. This is likely a 1-meter class mirror with roughly 500 actuators. No further details are available.

Plan for Future

In the next quarter we will generate a strawman support and contact Raytheon (who is fabricating the SOAR primary) for technical comments and a cost estimate.

Task [19] Develop Algorithms for TCWS control of primary, secondary, & guiding

Description

The Telescope Control Wavefront Sensor (TCWS) will provide information required for the active control of each primary-mirror segment's tip, tilt, and piston degrees of freedom. It will also provide low bandwidth information about the primary mirror as a whole, position and orientation of the secondary mirror, and the telescope guiding. We expect that a TCWS will be located at each instrument or each focus.

Objectives

The equations describing all the optical consequences of these degrees of freedom will be derived. The interaction of the degrees of freedom and the expected bandwidths for their control will be described. A baseline control algorithm and process will be created. The possible interaction of this control with the adaptive optics control system will be studied.

Inputs

Telescope optical design

Impact on Other Tasks

Possible impact on the design of the TCWS.

Schedule

This will begin once the telescope optical design is selected and be completed after the requirements for the TCWS have been defined.

Status

As planned, this task is yet to begin.

Progress this Quarter

None. Work on this task continues to be postponed until the error budgets (Task 2) are completed. (Completion of Task 2 planned for mid April.)

Plan for Future

Toward the end of the third quarter we will describe analytically the optical consequences of errors in all six degrees of freedom of the primary, secondary and tertiary. The telescope error budget (Task 2) will be used to set tolerances on all these degrees of freedom, as well as the required control bandwidths. Requirements will be derived for the Telescope Wavefront Sensor measurements for global control.

Task [20] Design the Telescope Structure

Description

We will produce a conceptual design of the telescope that satisfies the constraints of primary mirror and final f-ratio. The location of foci, size of science instruments, support of segments, handling of segments, support and handling of the secondary, rapid exchange of the secondary, cleaning of the mirrors, repair of key active components including replacement of actuators will also be considered in the design. Methods for periodically CO_2 cleaning the mirror will be described. A method for aligning the segments in all 6 degrees of freedom will be addressed.

Objectives

Produce a design that is compatible with all the physical and geometric constraints. The stiffness and natural frequencies will be determined, particularly the lowest modes that influence image location and quality. The possible effects of wind loads will be included in the design choices. The design will be compatible with plausible drive, bearing, and encoder systems. The support and exchange of secondary mirrors will be described.

Progress this Quarter

Steve Medwadowski is working on the design of the mirror cell and cradle structure, and its support of the upper tube. This is proving to be a complex and difficult task. A tripod, a tetrapod, and a Keck-like top end are being analyzed. One problem is that the "natural" center of mass is below that of the proposed elevation axis at 4 meters. The natural center of gravity is 1-2 meters below this.

In additional bending of the tripod/tetrapod legs is also adversely affecting the motion of secondary (horizon pointing). This may require additional cable stiffeners, and these are not yet designed.

Tuning of the cradle has reduced the total mass very significantly. It is now approximately 500 tons.

Results of his analysis are expected early in the third quarter.

Plan for Future

When we receive Steve's report we will list the major concerns. Then, based on money and time limitations, we will decide when to proceed with additional design work.

Task [21] Generate strawman designs of the bearings, drives, encoders

Description

A conceptual design of the telescope elevation and azimuth bearings, the elevation and azimuth drives, and the elevation and azimuth encoders will be generated. Attention will be given to meeting the requirements, and providing a cost effective design. Design alternates will also be given, so options are understood.

Objectives

We will develop suitable designs for all 6 systems and describe their performance. The influence of wind will be given. Alternative designs will be sketched, to provide a start for a more detailed evaluation later in the project.

Inputs

The telescope structure will define the design requirements.

Progress this Quarter

A contract with Vertex/RSI is signed, and they are about to start work on the conceptual design of the telescope bearing, encoders, and drives..

Task [22] Identify the candidate AO modes and define requirements for each mode

Description

Based on the science requirements and potential technologies, systematically identify a set of candidate AO modes. Define the system-level requirements for each mode.

Progress

Quarterly Report No. 1 describes many of the issues in this task. The progress during this quarter is not reported yet.

Task [23] Develop first order error budgets for adaptive optics (AO) modes

Description

> Enumerate, evaluate, and balance error budget terms for the wavefront control performance of CELT. This includes participation in Task 1 error budgets for the entire observatory. Describe error budgets in terms traceable to component-level specification (i.e. rms nm of wavefront error).

Progress

Quarterly Report No. 1 describes many of the issues in this task. The progress during this quarter is not reported yet.

Task [24] Develop conceptual AO system optical designs for each AO mode

Description

> Develop a conceptual optical design for each AO mode for CELT.

Objectives

> Identify key optical technology drivers, as well as any drivers in the telescope structural or configurational design (i.e., number or type of foci and secondary mirrors). Identify potential vendors and/or partners. Evaluate the state-of-the-art of AO component fabrication. Estimate the scope of any technology development programs necessary to realize the conceptual designs and estimate its cost. Provide alternatives for different cost points and describe the technical tradeoffs between these alternatives in terms of error budgets.

Progress

Quarterly Report No. 1 describes many of the issues in this task. The progress during this quarter is not reported yet.

Task [25] Prepare for Conceptual Design Review

Description

All results of this phase will be collected and presented at a Conceptual Design Review (CoDR). At this review, the conceptual design of the telescope, AO, and instrument subsystems should be presented, as well as an update on site selection. A key component of the review will be to understand the level of effort necessary for the Preliminary Design phase, which will address many details not addressed by the Conceptual Design phase.

Inputs

All results from this phase

Schedule

This task will not begin until close to the end of this phase and will not be completed until after the Conceptual Design Review.

Progress this Quarter

None

Plan for Future

This work will be begun in the last quarter

Task [26] Write the Preliminary Design development plan.

Description

We wish to develop the plan for the next phase of work, the preliminary design phase. This will consist of a description of the key tasks, the method for carrying them out, the likely budget and the schedule. Tasks will include more detailed descriptions than the conceptual design, resolution of issued raised in the conceptual design review, progress on key issues that were not undertaken in the conceptual design.

Schedule

This task will not begin until the final month of this phase.

Task [27] Support the CELT Working Groups

Description

The CELT working groups need some funds to operate; travel to meetings, small studies, etc. This task provides those funds.

Other Participants

CELT working groups, including Steering Committee, Telescope, Science, Instruments, Adaptive optics, Site

Progress this Quarter

Working group activities are generally being reported separately. The Telescope and AO progress is included in this document. A substantial report (6 March 2001) by the Instrument Working Group is attached as a separate file.

Task [28] Manage the Conceptual Design phase program

Description

The management of the phase 1 Development program will be begin with the definition of detailed tasks, schedules and milestones. These schedules and milestones will be regularly tracked during the program and updated in response to changing requirements and to changes in the cost-risk assessments. We will also define cost codes corresponding to all aspects of the program and track them against the approved budgets. When required, consultants and suppliers will be contracted for portions of the program. Budget and schedule summaries will be produced quarterly.

Objectives

Manage the conceptual design to a successful conclusion. This means a sound design will be developed, budget will be met, and schedule will be met. Also, preparation for the next phase will be completed.

Progress this Quarter

We currently have three contracts with consultants for work on CELT. Paragon Engineering (Steve Gunnels) has been contracted to carry out the conceptual study of the primary mirror segment support. The Pilot Group (Alan Schier) was contracted to carry out the conceptual study of the primary mirror actuators, and Steve Medwadowski was contracted to carry out a study of the telescope structure. We expect these studies to be completed in the early part of 2001.

Plan for Future

We are planning to contract at least three additional studies in the next few months; a conceptual study of bearing, encoders and drives; a conceptual study of segment displacement sensors; and a conceptual study of one particular type of primary mirror actuator. These contracts will likely be let by the end of the year or early next year.

Task [29] Manage the CELT Website

Description

The CELT website is both a description of the project to the world and an internal communications tool.

Objectives

We will upgrade and maintain the CELT website, so that it announces all project activities, provides an archive for reports describing the results of all tasks, and educates the public about the nature and status of the project.

Status

The CELT web pages are hosted at	www.ucolick.org/~CELT
and there are links to the site at	
The Caltech astronomy site	www.astro.caltech.edu/
and a major existing telescopes site	www.seds.org/billa/bigeyes.html

Progress this Quarter

We have completely revised the organization and appearance of the website. It now includes the general categories of Institutions, Working Groups, Individuals, Calendar, Reports and Notes, and Presentations; as well as some artist concept renderings of the telescope. The Reports and Notes category contain the full text of CELT reports and technical notes. The Presentations category contains, when available, presentations made at internal meetings.

This site is providing both an internal record and a description to the world of the CELT personnel, activities, and progress.

Plan for Future

The website will be updated regularly as additional reports, technical notes, and presentations are created. If resources are available, we will add a section giving the scientific and technical motivation for CELT that is specifically directed to the public at large.

Task [30] Contingency management

Status

$128K is being held as contingency

Progress this Quarter

The contingency has not changed, but it seems likely that we will need to allocate some additional resources for actuator work and for telescope design work.