Conceptual-Level Cost Estimate for Point Design of a 30-m Giant Segmented Mirror Telescope (GSMT)

prepared for

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ILLUSTRATIONS

1. INTRODUCTION

1.1 Objective

The objective of this study is to develop a conceptual-level cost estimate with supporting information for the Giant Segmented Mirror Telescope (GSMT) using the Point Design as currently configured in our finite element model.

1.2 Scope

This conceptual-level cost estimate includes the following items:

- Telescope Structure:
    - Raft structures that support groups of primary mirror segments
    - Backstructure that support the rafts
    - Transition structure that connects the backstructure to elevation bearings, drive arc, and counterweight supports
    - Drive arc and counterweight supports
    - Counterweight
    - Braced tripod structure that supports the secondary mirror cell
    - Alidade that rotates in azimuth and supports the elevation bearings
    - Instrument platforms
    - Access
- Major Mechanical Components:
    - Azimuth and elevation hydrostatic bearings, including pumps/cooling systems
    - Azimuth bull gear
    - Azimuth motors, brakes, and gearboxes
    - Elevation sector gear
    - Elevation motors, brakes, and gearboxes
    - Actuators for raft structures
    - Actuators for individual mirrors
    - Encoders
- Control Systems:
    - Azimuth and elevation axis motion
    - Raft motion
    - Mirror segment motion

- Miscellaneous Equipment:
    - Cable wraps
    - Stow pin assemblies
    - Buffer stops

This cost estimate does not include the following items:

- Primary mirror segments;
- Whiffletree mechanism that directly supports the primary mirror;
- Secondary mirror and its cell;
- Edge sensing system for primary mirror segments;
- Instrumentation, including acquisition and guiding system, and adaptive optics systems;
- Shipping costs to site;
- Duties and taxes; and
- Costs of preliminary and final designs.

2. COST ESTIMATE

We developed a conceptual-level cost estimate for the GSMT using the Point Design as currently configured in our finite element model. We retained VertexRSI to assist us in the cost estimation of major mechanical components, control systems, and miscellaneous equipment.

The cost estimate includes an estimate of the installation cost and contractor mark ups for general administration and fees. The cost estimate presented in this document is to be considered BUDGETARY. It is based on 2002 rates and prices in the United States and is highly dependent on engineering estimates.

Table 2 – Cost Estimate Summary

Items		Estimated Cost with Installation and Mark Ups
2.1	Telescope Structure	$14,769,000
2.2	Major Mechanical Components	$13,759,000
2.3	Control Systems	$5,800,000
2.4	Miscellaneous Equipment	$291,000
Total		**$34,619,000**

The above cost estimate does not include the following items:

- Primary mirror segments;
- Whiffletree mechanism that directly supports the primary mirror;
- Secondary mirror and its cell;
- Edge sensing system for primary mirror segments; and
- Instrumentation, including acquisition and guiding system, and adaptive optics systems.

This cost estimate also does not include the costs of the preliminary and final designs of the telescope structure, major mechanical components, and the control system. Since the location of the site has not been defined yet, the cost for shipping to the site is not included. No allowance has been made for duties or taxes.

Details on the cost estimate of the above items are presented in Sections 2.1 through 2.4.

2.1 Telescope Structure

Table 2-1 summarizes the estimated cost for the telescope structure. The cost estimate is based on the configuration in our finite element model (Fig. 1). For each portion of the telescope structure, we estimated the fabrication cost based on the weight of the structure and the fabrication cost per unit weight for that type of component developed from actual contract price and detailed cost estimates for similar projects. Except for the instrument platforms and access, we used the weight of the structural members in our finite element model. In addition to the fabrication cost, we assumed the site installation of these structural components would add about 30% to the cost. We also added another 35% to account for shop drawings, alignment, trial assembly, general administration, and fees.

Table 2-1 – Estimated Cost of Telescope Structure

Items	Estimated Cost with Installation and Mark Ups
Rafts	$426,000
Backstructure	$966,000
Transition Structure	$2,280,000
Drive Arc and Counterweight Support	$1,278,000
Counterweight	$410,000
Tripod	$280,000
Alidade Structure	$7,793,000
Instrument Platforms	$1,093,000*
Access	$243,000*
Total Telescope Structure	**$14,769,000**

* rough estimate

2.2 Major Mechanical Components

Table 2-2 summarizes the estimated cost for the major mechanical components. In estimating the cost, we first developed preliminary requirements for each component based on the overall performance requirements of the telescope. VertexRSI performed conceptual level sizing and, where possible, obtained cost estimates for the major mechanical components from the suppliers. Otherwise, VertexRSI estimated the cost based on information they had for other projects with similar characteristics. No trade-off study was performed during this process.

We assumed the installation of these mechanical components would add about 30% to the cost. We also added another 35% to account for telescope manufacturer mark ups for general administration and fees. Details on the cost estimate of each major mechanical component are presented in sections below.

Table 2-2 – Estimated Cost of Major Mechanical Components

Items		Estimated Cost with Installation and Mark Ups
2.2.1	Az & El Bearings	$4,307,000
2.2.2	Az Gear & Pinions	$693,000
2.2.3	Az Drives (Motors, Brakes, & Gearboxes)	$182,000
2.2.4	El Gear & Pinions	$178,000
2.2.5	El Drives (Motors, Brakes, & Gearboxes)	$88,000
2.2.6	Raft Actuators	$1,802,000*
2.2.7	Mirror Segment Actuators	$6,118,000*
2.2.8	Az & El Encoders	$391,000
Total Major Mechanical Components		**$13,759,000**

* rough estimate

2.2.1 Azimuth and Elevation Bearings

The azimuth bearing axial support consists of hydrostatic-bearing pads located at the four alidade corners and operating on a Ø25.9 m journal. The load per corner exceeds the capacity of the largest SKF pads in production; so two pads per corner were priced. SKF can produce larger pads, but pricing was not available. The bearing journal is assumed to be a 12-in. thick steel cap on top of the support pier, which will be finish machined in place to within 0.010 in. flatness. Azimuth axis radial support is achieved by a roller bearing with Ø3 m bore. The bearing is isolated from thrust and moment loads by flex plate mounting.

The elevation axis is supported at each end by hydrostatic bearings. The bearings operate on a Ø3 m journal with two large radial bearings and one smaller thrust bearing at each end.

The azimuth and elevation hydrostatic bearing systems share the same pumps and oil coolers.

Az Hydrostatic Pad Size	600 mm x 765 mm
Az Hydrostatic Pad Qty	8 (2 each corner)
Az Journal Diameter	Ø25.9 m
Az Journal Width	4 ft (1.2 m)
Az Journal Thickness	12 in. (30 cm) Steel
El Radial Hydrostatic Pad Size	600 mm x 765 mm
El Radial Hydrostatic Pad Qty	4 (2 each end)
El Thrust Hydrostatic Pad Size	225 mm x 290 mm
El Thrust Hydrostatic Pad Qty	2 (1 each end)
El Journal Radius	Ø3 m
Nominal Pad Oil Pressure	1,000 psi
Pump System Power	50 hp
Oil Cooler Type	Oil – Water
Az Roller Bearing Bore	Ø3 m

Estimated Hydrostatic System Cost	$1,040,000
Estimated Az Journal Fabrication Cost	$1,250,000
Estimated Az Journal Finish Machining Cost	$220,000
Estimated Az Roller Bearing Cost	$100,000

Items	Estimated Cost
Estimated Az & El Bearings Cost	$2,610,000
Estimated Installation Cost	$783,000
Estimated Mark Ups (GA & Fees)	$914,000
Estimated Total Az & El Bearings Cost	**$4,307,000**

2.2.2 Azimuth Gear and Pinions

The azimuth final drive is via gear and pinions.

Face width	6 in. (152 mm)
Gear Pitch Radius	508 in. (12.9 m)
Pinion Pitch Radius	6 in. (152 mm)
Pinion Qty	4
Estimated Gear Cost	$408,000
Estimated Pinion Cost	$3,000 ea

Items	Estimated Cost
Estimated Az Gear & Pinions Cost	$420,000
Estimated Installation Cost	$126,000
Estimated Mark Ups (GA & Fees)	$147,000
Estimated Total Az Gear & Pinions Cost	**$693,000**

2.2.3 Azimuth Drives

Azimuth axis motion is controlled by four drives located at the alidade corners. Each azimuth drive consists of a motor, brake, and gearbox. Motors to be used are DC type, with resolver and tachometer feedback. Gearboxes will be multi-stage planetary type to achieve high stiffness.

Motor Type	DC
Motor Power	20 hp
Brake Type	Double C-face
Gearbox Type	Planetary
Estimated Motor Cost	$5,000 ea
Estimated Brake Cost	$2,500 ea
Estimated Gearbox Cost	$20,000 ea

Items	Estimated Cost
Estimated Az Drives Cost	$110,000
Estimated Installation Cost	$33,000
Estimated Mark Ups (GA & Fees)	$39,000
Estimated Total Az Drives Cost	**$182,000**

2.2.4 Elevation Gear and Pinions

The elevation gear is a 152-mm (6-in.) face width, spur tooth, on a 12.9-m pitch radius.

Face width	6 in. (152 mm)
Tooth Form	Spur
Gear Pitch Radius	468.5 in. (11.9 m)
Pinion Pitch Radius	6 in. (152 mm)
Pinion Qty	2
Estimated Gear Cost	$102,000
Estimated Pinion Cost	$3,000 ea

Items	Estimated Cost
Estimated El Gear & Pinions Cost	$108,000
Estimated Installation Cost	$32,000
Estimated Mark Ups (GA & Fees)	$38,000
Estimated Total El Gear & Pinions Cost	**$178,000**

2.2.5 Elevation Drives

Elevation axis motion is controlled by two drives located toward the rear of the alidade. Each elevation drive consists of a DC motor, brake, and gearbox.

Motor Type	DC
Motor Power	6.5 hp
Brake Type	Double C-face
Gearbox Type	Planetary
Estimated Motor Cost	$4,000 ea
Estimated Brake Cost	$2,500 ea
Estimated Gearbox Cost	$20,000 ea

Items	Estimated Cost
Estimated El Drives Cost	$53,000
Estimated Installation Cost	$16,000
Estimated Mark Ups (GA & Fees)	$19,000
Estimated Total El Drives Cost	**$88,000**

2.2.6 Raft Actuators

Based on the overall telescope performance requirements, we developed preliminary requirements for the raft actuators. At this time, VertexRSI has not obtained any cost estimates from vendors. Based on the cost estimates of actuators with similar requirements, we believe that a rough estimate of $2,000 per actuator is reasonable.

Actuator Type	TBD
Number of Actuators	546
Stiffness Requirement	36E6 N/m
Range Requirement	±5 mm
Resolution Requirement	50 μm
Mass Limit	10 kg
Load Capacity	15,000 N
Estimated Cost per Actuator	$2,000*

* rough estimate

Items	Estimated Cost
Estimated Raft Actuators Cost	$1,092,000
Estimated Installation Cost	$328,000
Estimated Mark Ups (GA & Fees)	$382,000
Estimated Total Raft Actuators Cost	**$1,802,000**

2.2.7 Mirror Segment Actuators

Based on the overall telescope performance requirements, we developed preliminary requirements for the mirror segment actuators. At this time, VertexRSI has not obtained any cost estimates from vendors. A mirror actuator survey performed by CELT has reviewed several types of actuators and has selected $2,000 per actuator as a cost requirement. In absence of a better cost estimate, we also used $2,000 per actuator as a rough budget number.

Actuator Type	TBD
Number of Actuators	1,854
Stiffness Requirement	12E6 N/m
Range Requirement	± 0.5 mm
Resolution Requirement	5 nm
Mass Limit	5 kg
Load Capacity	750 N
Estimated Cost per Actuator	$2,000*

* rough estimate

Items	Estimated Cost
Estimated Mirror Segment Actuators Cost	$3,708,000
Estimated Installation Cost	$1,112,000
Estimated Mark Ups (GA & Fees)	$1,298,000
Estimated Total Mirror Segment Actuators Cost	**$6,118,000**

2.2.8 Az & El Encoders

The encoders chosen are optical tape style. The azimuth position will be read by one encoder located near the azimuth bearing. The elevation position will be read by two encoders located near the elevation bearings.

Encoder Type	Tape
Tape Diameter	TBD
Azimuth Tapes	1
Elevation Tapes	2
Angular Accuracy	0.2 arc seconds
Angular Resolution	< 0.01 arc seconds

Items	Estimated Cost
Estimated Az & El Encoders Cost	$237,000
Estimated Installation Cost	$71,000
Estimated Mark Ups (GA & Fees)	$83,000
Estimated Total Az & El Encoders Cost	**$391,000**

2.3 Control Systems

Table 2-3 summarizes the estimated cost for the control systems of the telescope. It is difficult to estimate the actual development and design of the control system. For the azimuth and elevation axis control system, VertexRSI provides the actual cost for another project with similar requirements. For the raft and mirror segment control system, since the characteristics of the two tiers' actuation system have not been sufficiently defined, a very rough order of magnitude was provided by VertexRSI considering two separate loops: an open loop system for the raft motion, and a closed loop system for the mirror segment motion.

Table 2-3 – Estimated Cost of Control Systems

Items	Estimated Cost
2.3.1 Az & El Telescope Motion	$1,000,000
2.3.2 Raft & Mirror Segment Motion	$4,800,000*
Total Control Systems	**$5,800,000**

* rough estimate

2.3.1 Az & El Control System

The control system for azimuth and elevation is based on a VertexRSI controller. Installation and mark ups are included in the cost estimate.

Control System Type	VertexRSI

Items	Estimated Cost
Estimated Cost per Control System	**$1,000,000**

2.3.2 Raft and Mirror Segment Actuator Control System

The actuator control system commands the actuators to adjust the raft and mirror positions based on inputs from the structure, look-up tables, and the AO system. Two possible architectures were considered: 1) a distributed type with controllers located in or near the actuators with commands and feedback sent via an industrial communications bus, or 2) a centralized architecture with all electronics housed in a central area of the structure with discrete wiring to each actuator. The distributed approach should enjoy some installation cost and complexity advantages. However, reliability and maintenance realities may necessitate the centralized approach.

A rough estimate of the hardware cost for the open-loop raft control system and the closed-loop mirror segment control system is presented for the centralized approach. The estimate includes a main controller board, subcontrollers, power amplifiers, wiring, connectors, housings, and LVDTs for the raft actuators. Installation, mark ups, prototyping, and some development costs are included in the cost estimate. This estimate does not include the cost of the actuators and edge sensors.

Number of Raft Actuators	546
Number of Segment Actuators	1,854
Estimated Cost Per Actuator	$2,000*

* rough estimate

Items	Estimated Cost
Estimated Total Actuator Control System Cost	**$4,800,000**

2.4 Miscellaneous Equipment

Table 2-4 summarizes the estimated cost for miscellaneous equipment. VertexRSI estimated the cost based on information for other projects with similar characteristics. We assumed the installation of these components would add about 30% to the cost. We also added another 35% to account for telescope manufacturer mark ups for general administration and fees. Details on the cost estimate of each component are presented in sections below.

Table 2-4 – Estimated Cost of Miscellaneous Equipment

Items	Estimated Cost
2.4.1 Azimuth and Elevation Cable Wraps	$198,000
2.4.2 Stow Pins	$66,000
2.4.3 Elevation Buffers	$27,000
Total Miscellaneous Equipment	**$291,000**

2.4.1 Azimuth and Elevation Cable Wraps

The cable wrap design is based on a flexible cable tray system. This system protects the cables from excessive flexure and has been used successfully on other telescope structures.

Cable Wrap Type	Flexible Tray
Estimated Cable Wrap Cost	$60,000 ea.

Items	Estimated Cost
Estimated Az & El Cable Wraps Cost	$120,000
Estimated Installation Cost	$36,000
Estimated Mark Ups (GA & Fees)	$42,000
Estimated Total Az & El Cable Wraps Cost	**$198,000**

2.4.2 Stow Pins

Stow pins are use to stow the telescope at both horizon and zenith pointing.

Stow Pin Type	Stow Pin with Actuator
Stow Pin Qty	2
Estimated Stow Pins Cost	$20,000 ea

Items	Estimated Cost
Estimated Stow Pins Cost	$40,000
Estimated Installation Cost	$12,000
Estimated Mark Ups (GA & Fees)	$14,000
Estimated Total Stow Pins Cost	**$66,000**

2.4.3 Elevation Buffers

Elevation over-travel motion in both directions is arrested by hydraulic buffers.

Buffer Type	Hydraulic
Buffer Size	Crane Buffer
Buffer Qty	2 per direction
Estimated Buffer Cost	$4,000 ea

Items	**Estimated Cost**
Estimated Buffers Cost	$16,000
Estimated Installation Cost	$5,000
Estimated Mark Ups (GA & Fees)	$6,000
Estimated Total Buffer Cost	**$27,000**

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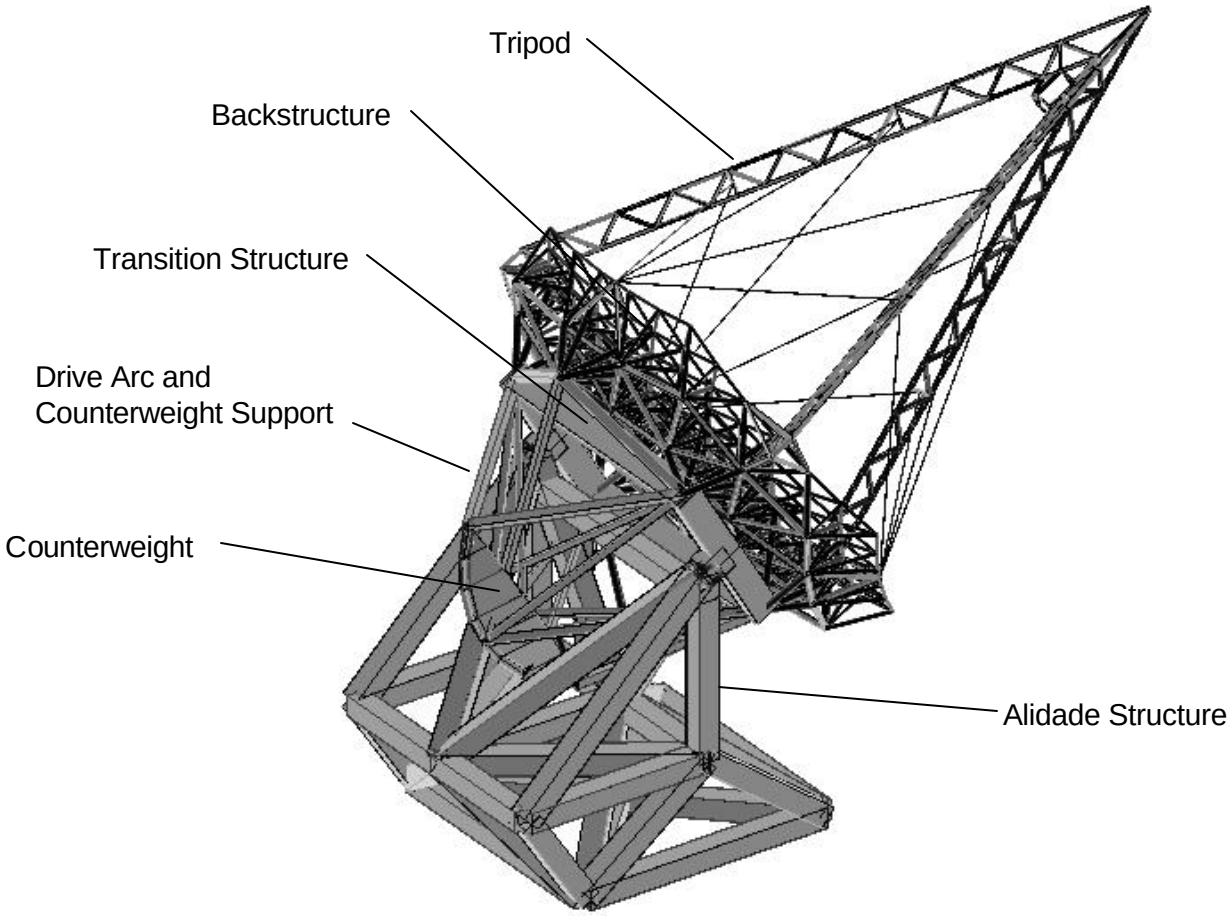

Figure 1 – Point Design of GSMT Telescope Structure