NATIONAL SCIENCE FOUNDATION
REVIEW OF THE COSTS OF THE
LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

AGENDA

Thursday, June 9, 1994

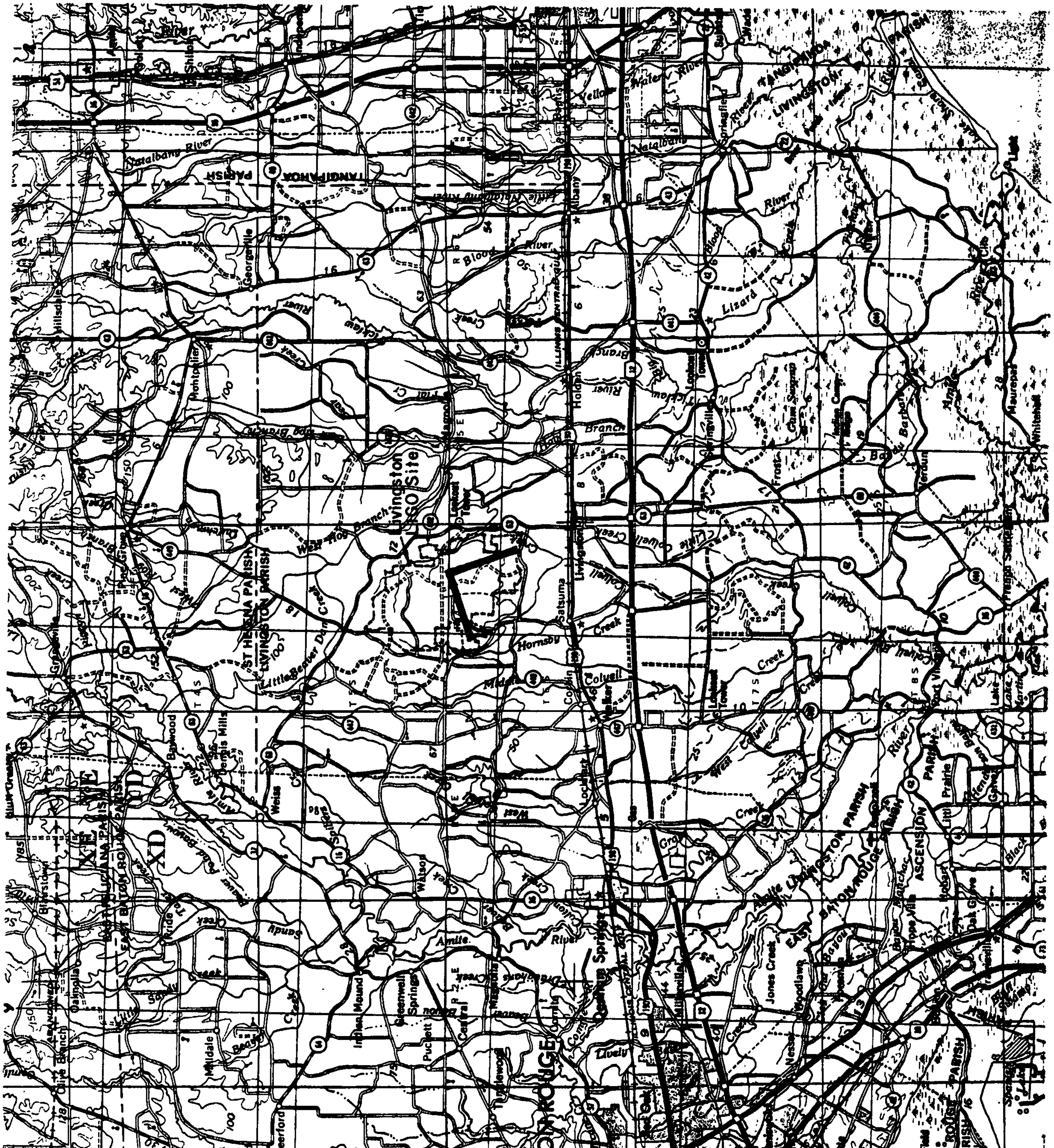
8:30	Barish	Welcome	114 E. Bridge
8:45	Barish	Revised Organization	
9:00	Whitcomb	Revised WBS	
9:15	Stapfer	Revised Milestones/Obligation Plan	
9:30	Aguirre	Cost Estimating Plan	
10:00		Break	
10:15	Schmidt	CDS System Design	
10:45	Bork	CDS Cost Analysis	
11:00	Canizares	MIT/CIT Relationship	
11:30	Fritschel	MIT Program	
12:00		Lunch	
13:00	Raab	40-m Update	22 Bridge Annex
13:15	Asiri	Louisiana Site Status	
13:30	Jones	CBI Final Design Review	
13:45	Stapfer	A&E Solicitation	
14:00	NSF	Executive Session	
15:00		Discussion with LIGO Staff	
16:00		Report Writing	

LIGO-G940008-00-M

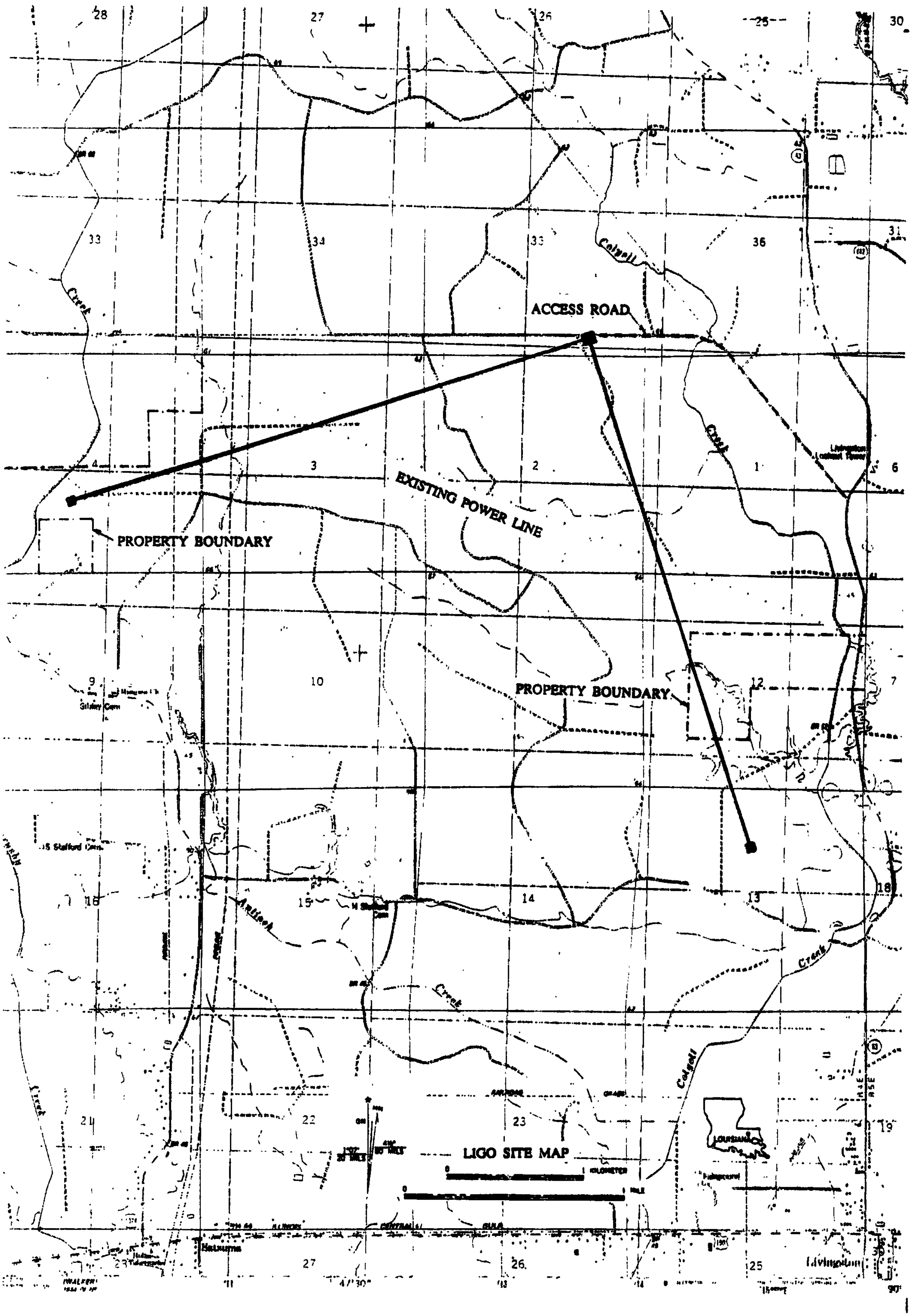
LOUISIANA SITE STATUS

Fred Asiri

June 9, 1994



Livingston
LIGO Site
BATON ROUGE
LIVINGSTON PARISH
ST HELENA PARISH
TANGIPAHOA PARISH
EAST BATON ROUGE PARISH
ASCENSION PARISH
Amite
Natalbany River
Blood River
Satsuma
Holden
Albany
Walker
Denham Springs
Greenwell Springs
Central
Zachary
Deerford
Indian Mound
Hornsby
Colyell
Weiss
Watson
Port Vincent



ACCESS ROAD
EXISTING POWER LINE
PROPERTY BOUNDARY
PROPERTY BOUNDARY
Colgell
Creek
Antioch
Creek
Creek
Colgell
Creek
LIGO SITE MAP
KILOMETER
MILE
LOUISIANA
Livingston
Livingston Lookout Tower
Stafford Cem
N Stafford Cem
S Stafford Cem
Holden
Livingston
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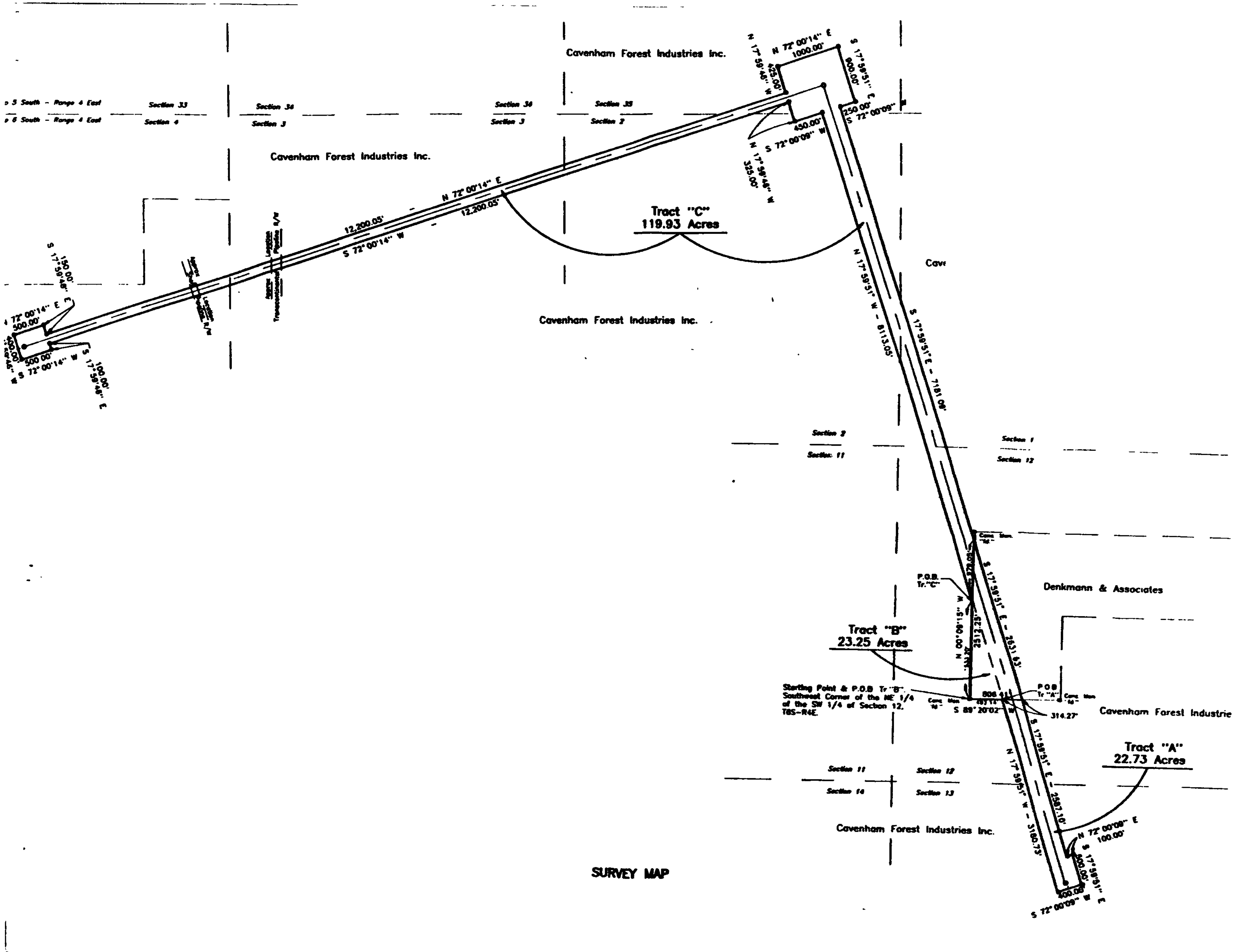
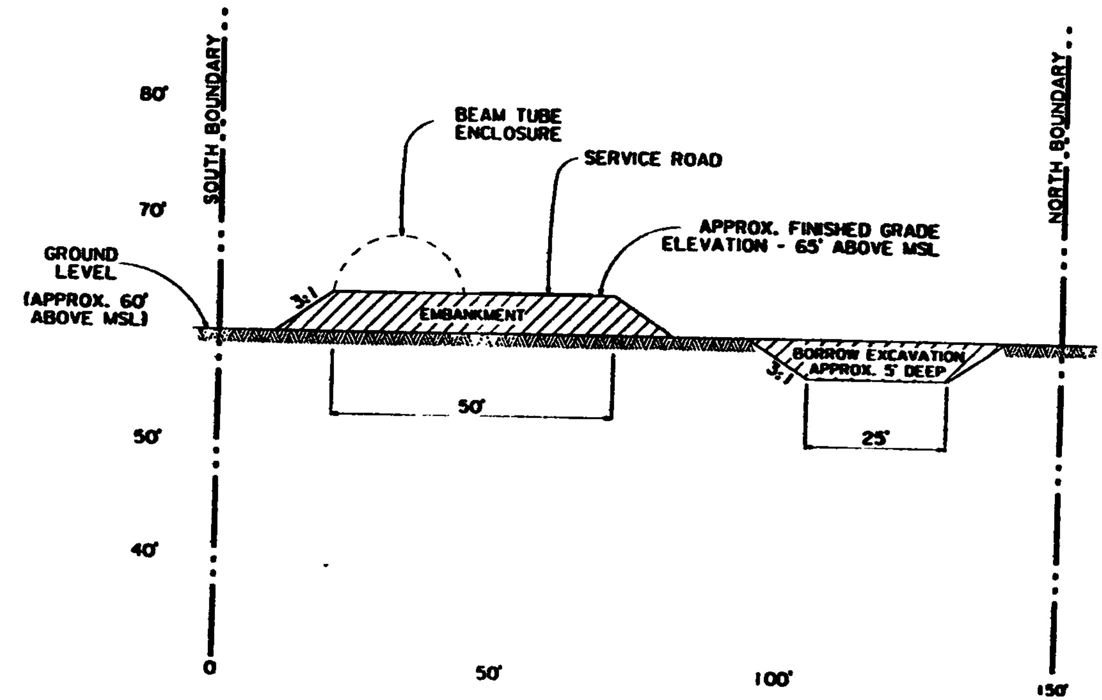

Cavenham Forest Industries Inc.
Cavenham Forest Industries Inc.
Cavenham Forest Industries Inc.
Cavenham Forest Industries Inc.
Cavenham Forest Industrie
Denkmann & Associates
Tract "C"
119.93 Acres
Tract "B"
23.25 Acres
Tract "A"
22.73 Acres
Section 33
Section 4
Section 34
Section 3
Section 35
Section 2
Section 1
Section 12
Section 11
Section 14
Section 13
N 72° 00'14" E
12,200.05'
S 72° 00'14" W
N 17° 59'51" W - 8113.05'
S 17° 59'51" E - 7181.08'
S 17° 59'51" E - 2631.63'
N 17° 59'51" W - 3180.73'
S 17° 59'51" E - 2587.10'
N 00° 00'15" W
2512.28'
S 89° 20'02" W
314.27'
N 72° 00'14" E
1000.00'
S 17° 59'51" E
900.00'
250.00'
S 72° 00'09" W
450.00'
N 17° 59'46" W
325.00'
425.00'
N 72° 00'09" E
100.00'
400.00'
S 72° 00'09" W
500.00'
S 72° 00'14" W
100.00'
150.00'
P.O.B. Tr. "C"
P.O.B. Tr. "A"
Starting Point & P.O.B. Tr. "B". Southwest Corner of the NE 1/4 of the SW 1/4 of Section 12, T8S-R4E.
SURVEY MAP



NOTE: ALL EMBANKMENT FILL WILL BE OBTAINED FROM EXCAVATION WITHIN PROJECT BOUNDARIES.

LIGO
TYPICAL CROSS-SECTION
ARM BEARING S72°W

APRIL 27, 1994

REVISIONS

Gulf Engineers and Consultants Inc.

LOUISIANA SITE STATUS

- DRAFT ENVIRONMENTAL ASSESSMENT IS BEING UPDATED
- TRANSFER OF LAND TO LSU IS IMMINENT
- LSU/NSF LEASE AGREEMENT IS IN FINAL DRAFT FORM
- LIGO HAS APPLIED FOR A 404 PERMIT (WETLAND), EXPECTED TO BE GRANTED BY SEPT. 1, 1994
- NATION WIDE PERMIT (CLEARING AN ACCESS FOR GEOTECHNICAL SURVEY) HAS BEEN OBTAINED
- CAVENHAM GRANTED PERMISSION TO LIGO FOR CLEARING THE CENTER STRIP OF LIGO ARM
- RE-STAKING AND CENTERLINE CLEARING FOR GEOTECHNICAL SURVEY WILL START ON JUNE 15

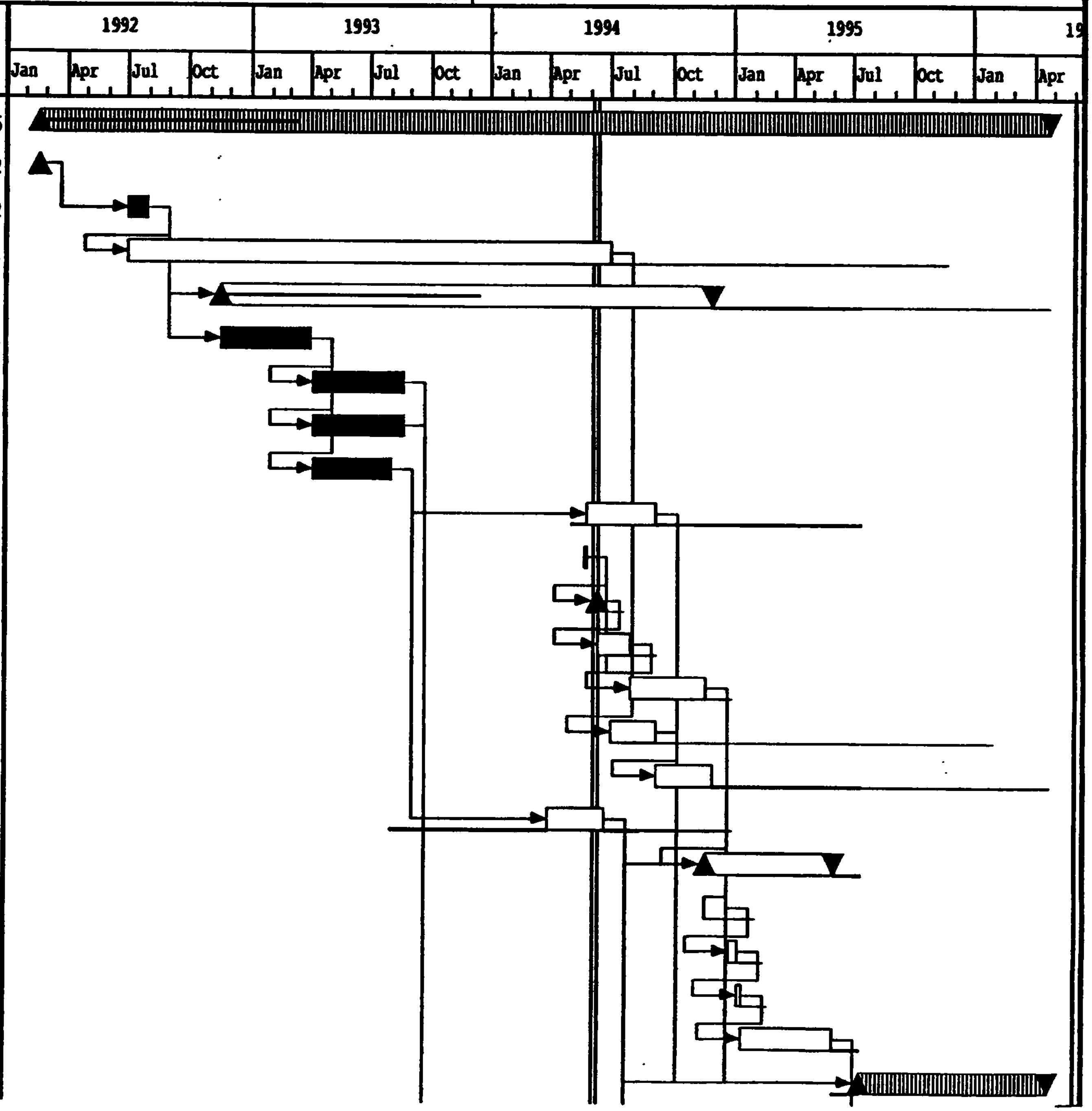
LASITER2 - GANTT CHART

Report Span: 01/01/92 To 06/01/96

Project Span: 02/19/92 To 04/23/96, 43.6 Month(s)

Run Date: 06/07/94

Activity Name	Dur	Start	Finish
SITE ACTIVITIES	43.60	02/19/92	04/23/96
SITE ANNOUNCEMENT	0.00D	02/19/92	02/19/92
ALIGNMENT VERIFICATION	4.00W	07/01/92	07/28/92
LAND ACQUISITION	104.0	07/01/92	06/28/94
SITE INVESTIGATIONS	21.28	11/16/92	11/29/94
STAKING & SURVEYING	4.00M	11/16/92	04/02/93
WETLANDS DELINEATION	4.00M	04/05/93	08/20/93
PRELIMINARY EA	4.00M	04/05/93	08/20/93
DRAINAGE PLAN	4.00M	04/05/93	08/01/93
404 PERMIT PROCESS	3.00M	05/25/94	09/06/94
NATION WIDE PERMIT	1.00W	05/23/94	05/23/94
CAVENHAM'S PERMISSION	0.00D	06/10/94	06/10/94
REMOVING OF SLASH	7.00W	06/10/94	07/28/94
GEOTECHNICAL SURVEYS	16.00	07/29/94	11/17/94
CLEARING	10.00	06/29/94	09/06/94
TOPOGRAPHIC SURVEY	12.00	09/07/94	11/29/94
HYDROLOGICAL SURVEY	12.20	03/28/94	06/20/94
ROUGH-GRADING DESIGN	28.00	11/18/94	06/01/95
SOLICIT BIDS	5.00W	11/18/94	12/22/94
EVALUATE BIDS	2.00W	12/23/94	01/05/95
PROCUREMENT	5.00D	01/06/95	01/12/95
DESIGN PERIOD	20.00	01/13/95	06/01/95
R-G CONSTRUCTION	41.00	07/12/95	04/23/96



A-E SOLICITATION

G. STAPFER

JUNE 9, 1994

LIGO

A-E APPROACHES

TURN KEY OPERATION

DESIGN | CONSTRUCTION

CONSTRUCTION MANAGEMENT

TURN KEY WITH SEPARATE CONSTRUCTION MANAGEMENT

DESIGN | CONSTRUCTION

CONSTRUCTION MANAGEMENT

DESIGN-AWARD-BUILD

DESIGN | CONSTRUCTION MANAGEMENT

CONSTRUCTION

SELECTED APPROACH

DESIGN WITH OPTION TO BUILD

DESIGN | CONSTRUCTION OPTION

CONSTRUCTION MANAGEMENT

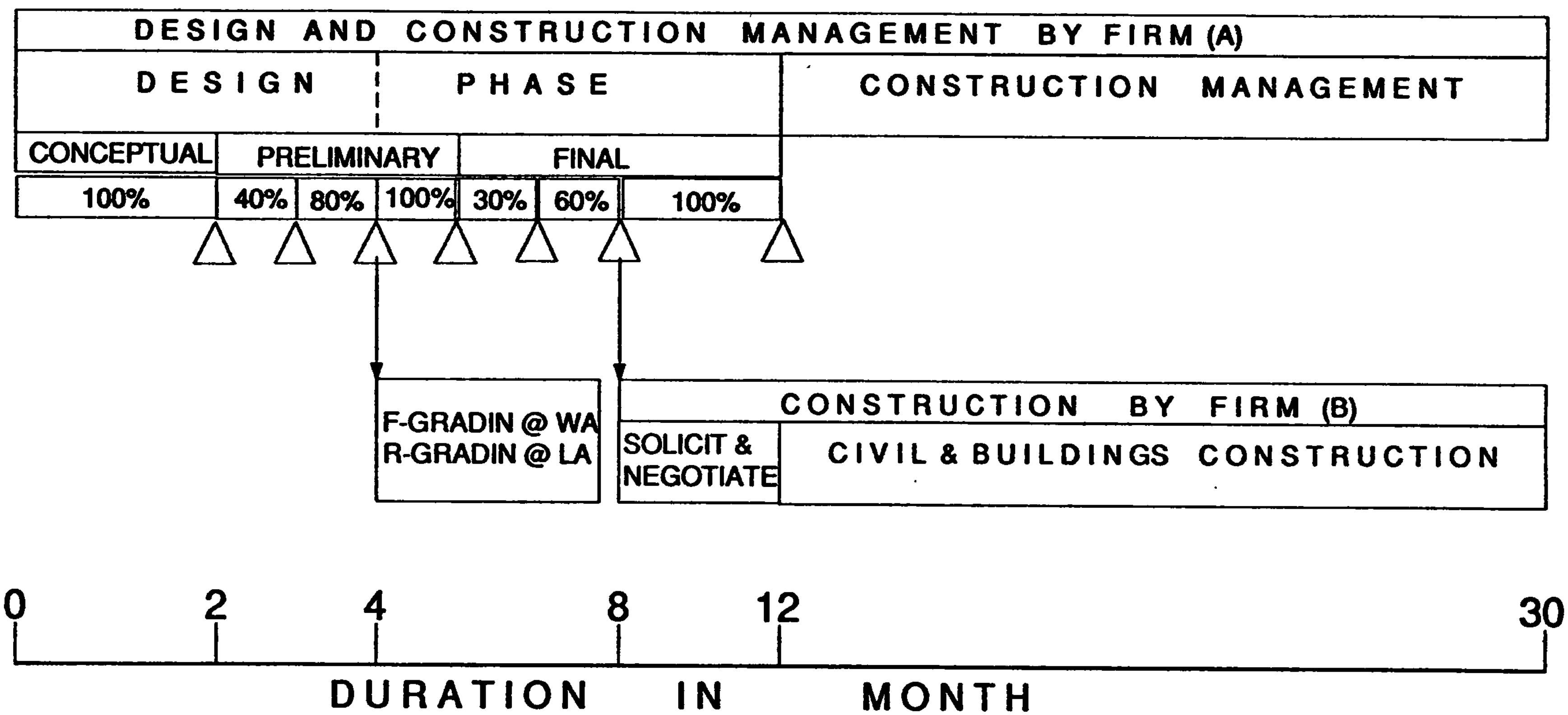
A-E SOLICITATION

SCOPE

- DESIGN SCOPE
  - BUILDINGS
  - ROADS & PARKING
  - DRAINAGE & LANDSCAPING
  - WATER SUPPLY
  - POWER DISTRIBUTION
  - LIGHTING
  - CRANES, ACCESS PLATFORMS
  - HEATING & AIR-CONDITIONING
- NOT INCLUDED IN DESIGN (EXCEPT FOR INTEGRATION)
  - BEAM TUBE MODULES
  - BEAM TUBE SLAB & COVER
  - VACUUM EQUIPMENT
  - HANFORD ROUGH GRADING
- CONSTRUCTION MANAGEMENT

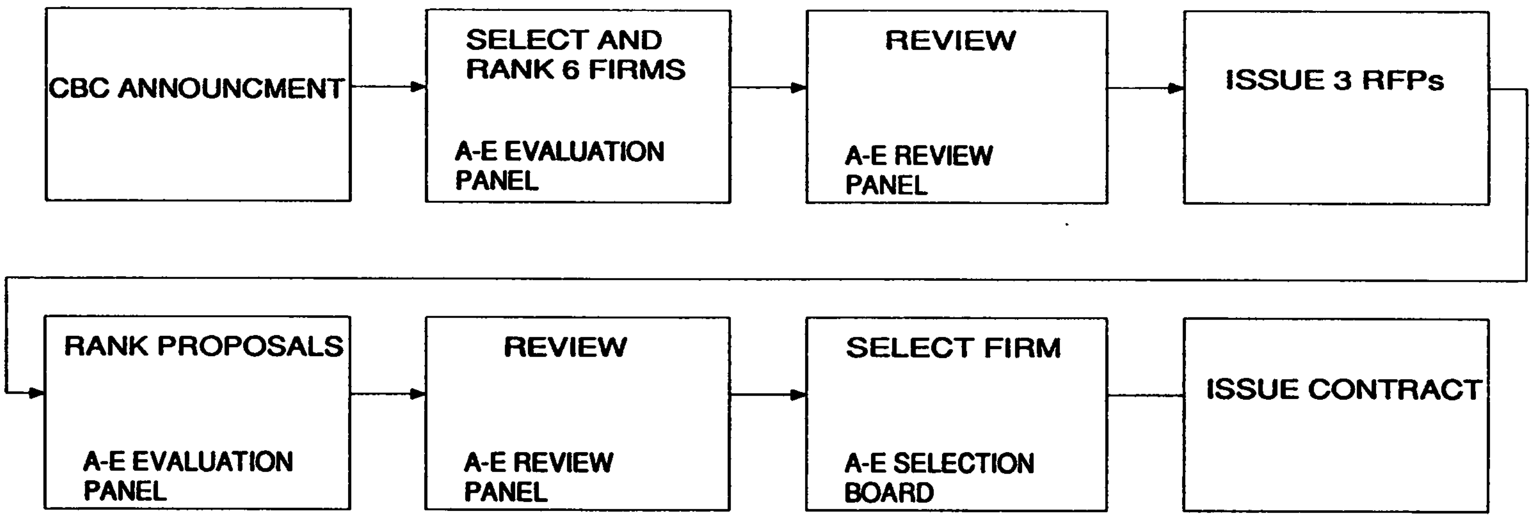
A-E SOLICITATION

SCHEDULE



FAST TRACK DESIGN-AWARD-BUILD APPROACH FOR LIGO FACILITIES

A-E SELECTION PROCESS



A-E SOLICITATION

CURRENT STATUS

- CBD ANNOUNCEMENT HAS BEEN PUBLISHED
- QUALIFYING A-E RESPONSES ARE DUE JUNE 10, 1994
- QUALIFYING CRITERIA FOR A-E FIRMS HAVE BEEN ESTABLISHED
- SELECTION CRITERIA (TO SELECT AND RANK SIX A-E FIRMS) HAVE BEEN ESTABLISHED
- REVIEW PANEL MEMBERSHIP HAS BEEN IDENTIFIED
- SOURCE SELECTION BOARD AND SOURCE SELECTION OFFICIAL HAS BEEN IDENTIFIED

MIT Role in LIGO

Key Issues

- MIT role in oversight of LIGO project

  Structure of Oversight Committee under discussion

- Revised Caltech/MIT MOU

  Draft under discussion

- Revised Caltech/NSF Cooperative Agreement

  Agreement in principle

- Near-term Statement Of Work

  Final FY9~~5~~4 SOW negotiated

- Statement of MIT Roles in R&D and LIGO subsystems

  Draft under discussion

- Statement of MIT Roles in "community outreach"

  Draft under discussion

- Institutional issues: staff, space, technical support

  Under discussion

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
CALIFORNIA INSTITUTE OF TECHNOLOGY (CALTECH)
AND THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)
ON THE
LIGO PROJECT

1) The LIGO project is a collaborative effort by Caltech and MIT scientists to design, build and operate an observatory to measure gravitational waves from astrophysical sources by laser interferometry. LIGO will become a national facility for gravitational wave research.

2) Under the terms of a Cooperative Agreement with the National Science Foundation (NSF), Caltech has prime responsibility to carry out the LIGO project and MIT shares responsibility with Caltech for oversight and execution of the project.

3) The presidents of both Caltech and MIT are responsible for the successful management of the LIGO Project. The presidents will be assisted by a LIGO Oversight Committee composed of members from each institution appointed by their respective presidents after mutual consultation, and chaired by the Special Assistant to the Caltech President for LIGO.

4) The LIGO Principal Investigator is appointed by the Caltech president in consultation with the MIT president and with the concurrence of the NSF.

5) MIT activities on LIGO are classified in two categories listed in the attached Statement of MIT Roles: Core LIGO Science and Technology, and LIGO Interferometer Subsystems. Core activities consist of research, development and project support in specific areas as negotiated with Caltech. Core activities are funded directly by NSF as specified in the Cooperative Agreement. Subsystem activities are funded by multiyear subcontracts from Caltech, with budgets and statements of work as negotiated with Caltech; these will be renegotiated and updated as required.

6) Selected members of the MIT LIGO science team will participate in the scientific and technical management of the project. One MIT member will serve in a senior, leadership role in the LIGO project and at least one will be designated as key personnel in the Cooperative Agreement.

7) The MIT science effort is fully integrated into the LIGO Project. Members of the MIT science team will take responsibility for selected LIGO interferometer subsystems and tasks, as listed in the attached Statement of MIT Roles. The specific tasks and their scope will be

renegotiated as appropriate during the life of the project. The MIT group will also share responsibility for establishing and maintaining interaction with the broader scientific community and for the operations phase of LIGO.

8) MIT will provide institutional, management and technical support to the MIT LIGO project through the Center for Space Research. Further institutional and academic support will be provided through the Department of Physics. The Director of the Center for Space Research and the Head of the Physics Department are the primary points of contact for institutional matters concerning LIGO.

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  Draft under discussion

- Revised Caltech/NSF Cooperative Agreement

  Agreement in principle

- Near-term Statement Of Work

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- Statement of MIT Roles in R&D and LIGO subsystems

  Draft under discussion

- Statement of MIT Roles in "community outreach"

  Draft under discussion

- Institutional issues: staff, space, technical support

  Under discussion

LIGO PROGRAM AT MIT

BROAD ROLES

Scientific and Technical support

- Basic research *
- Design of the interferometers (*)
- Scientific liason to facility design and construction #
- Construction and installation of the initial detector #
- Operation of the initial detector (*)
- Observation planning and data analysis (*)
- R & D of enhanced and advanced detectors *

Management and Project Responsibilities

- Establish project scientific strategy in collaboration with Caltech *
- Scientific liason to facilities/detector systems engineering and integration (#)
- Liason to the external scientific and LIGO users community *

SPECIFIC ROLES

- Development of techniques and instrumentation leading to interferometer subsystems:

  Fringe sensing system #

  Interferometer alignment system #

  Environmental monitoring system ? #

  Seismic isolation system ? #

- Delivery of tested subsystems to the LIGO sites #
- Scientific liason to vacuum system design, construction and operation (#)
- Coordination of LIGO modeling effort *
- Installation and test of the initial interferometer at LIGO sites (#)
- Development of observing strategies and data analysis (*)

* = supported by NSF directly

(*) = supported primarily by NSF directly and in part by LIGO contract

(#) = supported primarily by LIGO contract and in part by NSF directly

\# = supported by LIGO contract

LIGO GROUP AT MIT

Faculty:

Prof Rainer Weiss

Principal Research Scientists:

Dr David Shoemaker

Research Staff

Dr Peter Fritschel   Dr Yaron Hefetz

Graduate Students:

Bret Bochner   Joe Giaime
Joe Kovalik   Brian Lantz
Nergis Mavalvala   Partha Saha

Support Staff:

Tom Evans (Technical)
Susan Merullo (Secretarial and Administrative 1/2)

Undergraduates:

Iosif Bena   Jay Muchnij

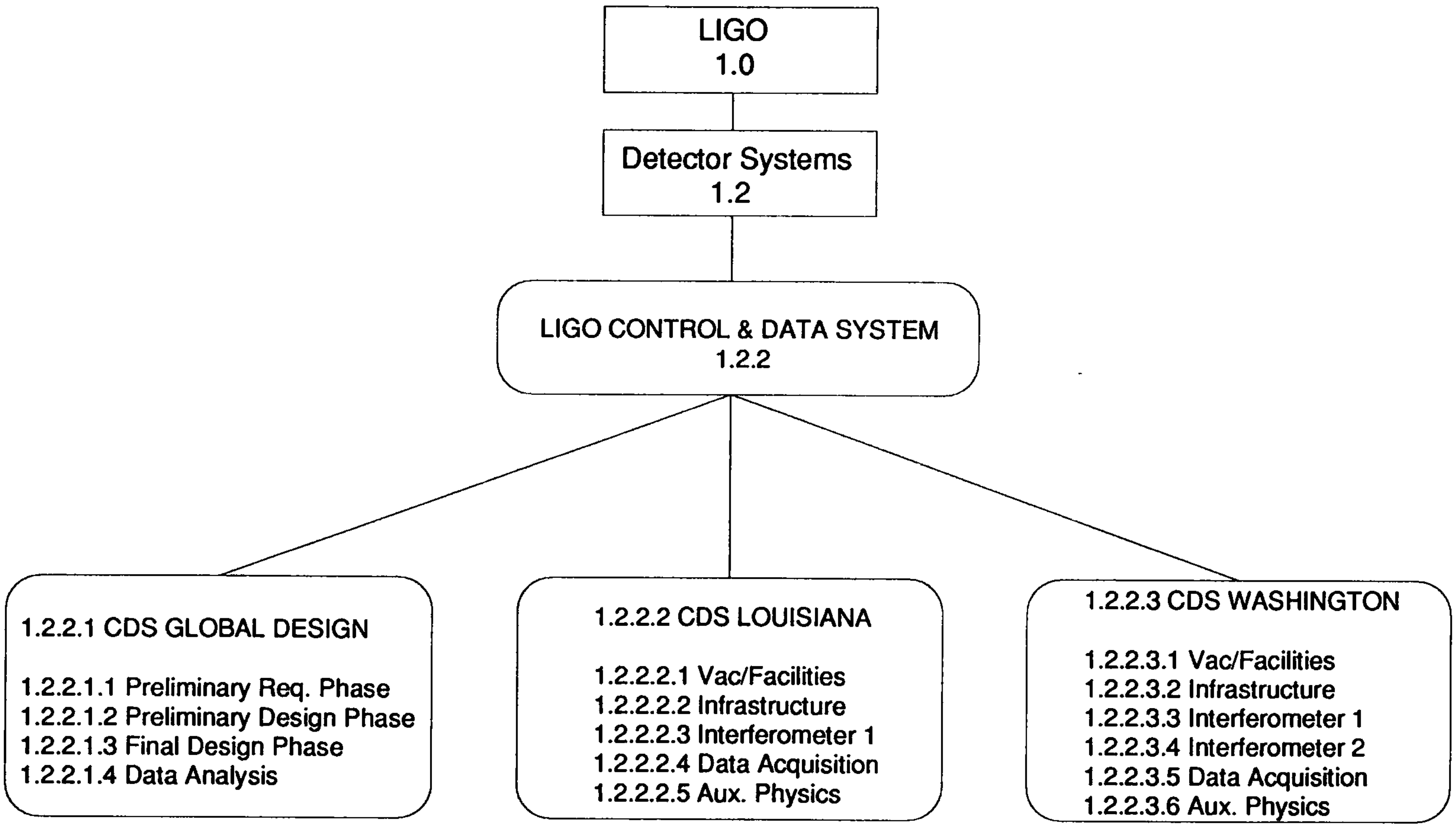
Interested Faculty:

Prof Edward Bertschinger (Physics)
Prof Alan Oppenheim (Electrical Engineering)
Prof James Roberge (Electrical Engineering)
Prof Leslie Rosenberg (Physics)
Prof Gerald Sussman (Electrical Engineering)

CDS COST ESTIMATE

- SCOPE : All labor and procurement costs associated with producing a CDS for LIGO, including:
  - Design
  - Equipment
  - Installation
  - Acceptance testing
- METHOD
  - Bottom-up cost estimate
  - Loaded into and calculated by AutoPlan II™
    - Entered WBS and activities
    - Developed and loaded resources into activities
    - AutoPlan calculated schedule and costs
  - Reconciled with LIGO baseline cost estimate and schedule

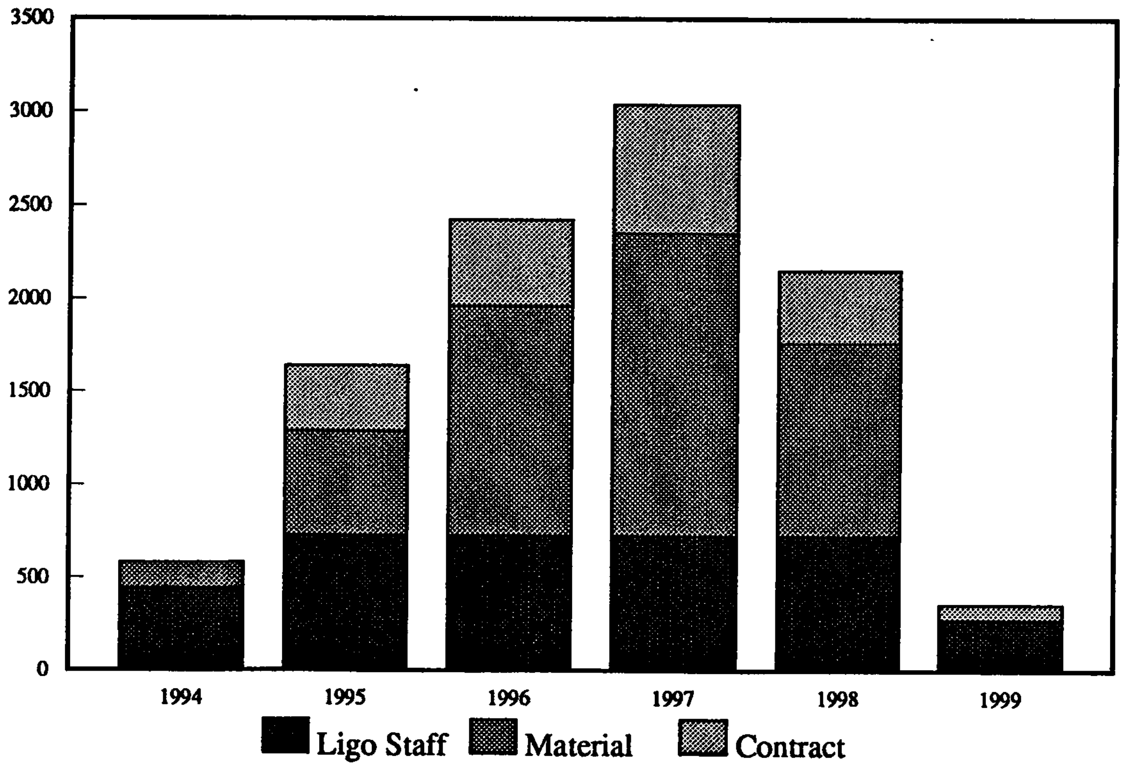
LIGO CDS WBS



LIGO
1.0
Detector Systems
1.2
LIGO CONTROL & DATA SYSTEM
1.2.2
1.2.2.1 CDS GLOBAL DESIGN
1.2.2.1.1 Preliminary Req. Phase
1.2.2.1.2 Preliminary Design Phase
1.2.2.1.3 Final Design Phase
1.2.2.1.4 Data Analysis
1.2.2.2 CDS LOUISIANA
1.2.2.2.1 Vac/Facilities
1.2.2.2.2 Infrastructure
1.2.2.2.3 Interferometer 1
1.2.2.2.4 Data Acquisition
1.2.2.2.5 Aux. Physics
1.2.2.3 CDS WASHINGTON
1.2.2.3.1 Vac/Facilities
1.2.2.3.2 Infrastructure
1.2.2.3.3 Interferometer 1
1.2.2.3.4 Interferometer 2
1.2.2.3.5 Data Acquisition
1.2.2.3.6 Aux. Physics

CDS LEVEL 3 COST ESTIMATE AND DISTRIBUTION (1994 $K)

WBS Number	Name	In-house Labor	Equipment	Contract	Total
1.2.2.1	CDS Design	1525.7	798.0	445.8	2769.5
1.2.2.2	CDS LA	994.8	1658.6	892.2	3545.6
1.2.2.3	CDS WA	1094.1	2148.3	631.0	3873.4
Totals		3614.6	4604.9	1969.0	10188.5



LIGO

Prepared By : R. BORK
Company :
Project : CDS30 - CDS

Page : 1,1
Date : 06/06/94 10:09:54

LIGO CDS - LEVEL 4 ACTIVITY REPORT

Activity Name	*WBS Code*	*Act Type*	*Dur*	*Prf Start*	*Prf Finish*	*Budget Cost*
CDS	0:CDS30	S	267.40W	06/02/94	07/19/99	10188560.00
CDS - GLOBAL	0.1:0012	S	812.00D	06/02/94	07/11/97	2769500.00
PRELIMINARY REQ. PHASE	0.1.1:0016	S	90.00D	06/02/94	10/05/94	262800.00
PRELIMINARY DESIGN PHASE	0.1.2:0022	S	300.00D	07/14/94	09/06/95	1599800.00
FINAL DESIGN PHASE	0.1.3:0043	S	220.00D	09/07/95	07/10/96	807900.00
Data Analysis Sys	0.1.4:0103	S	100.00D	02/24/97	07/11/97	99000.00
CDS - LOUISIANA	0.2:0013	S	556.00D	12/28/95	02/12/98	3545640.00
LA VAC/Facilities	0.2.1:0053	S	396.00D	01/25/96	07/31/97	630320.00
LA INFRASTRUCTURE	0.2.2:0054	S	376.00D	12/28/95	06/05/97	822620.00
LA INTERFEROMETER 1	0.2.3:0056	S	323.00D	08/27/96	11/20/97	939700.00
LA DATA ACQUISITION	0.2.4:0057	S	300.00D	08/27/96	10/20/97	976880.00
LA AUX. PHYSICS	0.2.5:0059	S	140.00D	07/29/97	02/09/98	176120.00
LA CDS COMPLETE	0.2.6:0062	M	0.00D	02/12/98	02/12/98	
CDS - WASHINGTON	0.3:0080	S	561.00D	04/11/97	06/04/99	3873420.00
WA VACUUM	0.3.1:0053A	S	341.00D	04/11/97	07/31/98	583340.00
WA INFRASTRUCTURE	0.3.2:0054A	S	301.00D	04/11/97	06/05/98	780620.00
WA INTERFEROMETER 1	0.3.3:0056A	S	300.00D	11/21/97	01/14/99	939700.00
WA INTERFEROMETER 2	0.3.4:0094	S	240.00D	04/10/98	03/11/99	612960.00
WA DATA ACQUISITION	0.3.5:0057A	S	280.00D	04/20/98	05/14/99	795280.00
WA AUX. PHYSICS	0.3.6:0059A	S	121.00D	10/23/98	04/09/99	161520.00
WA CDS COMPLETE	0.3.7:0062A	M	0.00D	06/04/99	06/04/99	
External Milestones	0.4:0070	S	249.20W	10/07/94	07/19/99	

CDS SCHEDULE

- 1994
  - Preliminary Requirement Specifications / Designs
  - Development systems for “dry” prototyping
- 1995
  - 40M prototype installations/tests
  - Final Vac/Facilities control system and CDS Infrastructure designs
  - Begin final interferometer and data acquisition system designs
- 1996
  - Procure LA Vac/Facilities and infrastructure components; begin installation
  - Complete final designs for interferometer control and data acquisition systems
- 1997
  - Complete LA Vac/Facilities and Infrastructure
  - Procure and begin installation of LA interferometer controls and data acquisition systems
  - Begin WA Vac/Facilities and Infrastructure installation
- 1998
  - Complete LA CDS
  - Complete WA Vac/Facilities and Infrastructure
  - Begin installation of WA Interferometer and data acquisition systems
- 1999
  - Complete WA CDS

LIGO PROJECT
Cost Estimating Plan
PRE-DRAFT COPY
June 9, 1994

Table of Contents

1.0 Scope

The LIGO Cost Review (April 1994) provided an introduction to the cost estimating basis and methods for preparing the latest cost estimate for the LIGO work breakdown structure (WBS). This cost estimating plan (CEP) defines the guidelines and methodology that will be used to update LIGO cost estimates as the conceptual design evolves. Since LIGO is a first of its kind facility requiring a multitiude of specializations and many will participate in preparing a reliable cost estimate, clear guidance is required to assure that the final product is complete, consistent, and well documented.

2.0 Objectives

2.1 Total LIGO Project Cost - A primary objective is to develop a comprehensive estimate of the total LIGO project cost. This includes costs for the necessary research and development activities as well as for the engineering, design, analysis, procurement, fabrication, assembly, installation, start-up and management of the construction project itself. Commissioning and system testing costs for LIGO are part of LIGO Project costs. All costs will be tabulated into a single computerixed relational database.

2.2 Detailed Backup Information - During the cost estimating process it is desired to develop the detailed backup information that will justify all estimates and provide confidence to reviewing organizations that the costs are reasonable. Vendor quotations, engineering calculations, drawings, similarities to other systems and other pertinent data will be collected and organized into Basis-of-Estimate (BOE) report volume organized by WBS. In addition, basic subsystem configuration will be defined along with a list of critical assumptions made during the estimating process. The BOE will be generated according to the guidelines established in this plan and be available for review.

2.3 Contingency - Projects of the size, complexity and challenge of the LIGO Project will have some uncertainty and cost risk. Estimates are being made prior to final design and include projections of expected development and engineering tasks. Thus, "contingency" will be generated to account for these uncertainties. The WBS 3 estimators will perform standardized risk analyses to develop a consistent justification for all contingency costs which are included in the total WBS 3 system cost. These analyses will be performed according to the guidelines established in this CEP.

2.4 Cost Tracking Baseline - The costs of the LIGO will be monitored and must be controlled over the life of the project. This plan will guide the development of a relational database that can provide the basis for this task. The hierarchy used in the CEP establishes costs in a format that can be translated to a formalized project management. Such a system could be implemented to track the actual incurred cost against the projected cost estimates. It is thus vital that the guidelines established by this CEP be strictly followed so that subsequent project monitoring activities may be facilitated.

3.0 Basis

3.1 Detailed Bottom-Up Estimate - The basis for the cost estimate developed according to this CEP will be a detailed bottom-up estimate for the lowest possible (however, advanced the design of a given system) WBS element. These estimates shall be based on current year dollars. Escalation factors will be applied at the top level by the cost estimating manager to adjust costs to required Funding Year basis.

3.2 Cost Estimate Development Approach - Cost estimates will be developed using a relational database (See Section 5.0), that will be based on a system-wide WBS. The WBS hierarchy to be used will delineate all subsystems and divide each of those subsystems into multiple lower levels. Cost items will define the labor and material requirements.

3.3 Basis-of-Estimate Books - In addition to developing detailed cost items each WBS 3 estimator shall develop his/her own basis-of-estimate book. This document shall contain supporting information which substantiates each cost data item. The detailed cost estimate reports for the lowest level of each WBS branch will include memos further describing critical assumptions or reference to vendor quotations, engineering calculations, etc. Hence, to the extent possible narrative information will be integrated into detailed cost estimate report. All other supporting material, including vendor quotations, engineering calculations, graphs, figures, etc. will be organized in basis-of-estimate books. This information will be used during both internal and external reviews of the LIGO cost estimates.

4. Work Breakdown Structure

The WBS is a hierarchy of elements which identifies all and their parent/child relationships. Cost estimators will develop the subsystem WBS hierarchies where it has not already been defined. These will be collected and collated into the LIGO Project WBS.

4.1 WBS Dictionary
The cost estimate for each WBS element is based on a scope of work for that given element. A WBS Dictionary is essential to define the scope of work for each element. A realistic cost estimate can not be developed without a WBS Dictionary.

5.0 Costing Methodology

5.1 Relational Cost Database (SUCCESS) - SUCCESS is the cost estimating program that will be used to collect all information for the LIGO cost estimate. SUCCESS is a relational database application that operates in Microsoft Windows (Version 3.0 or greater). These reports will include, but are not limited to, the following:

- Cost Summary Report
- WBS Summary Reports
- WBS Detail Reports
- Labor Craft Utilization Report
- Subcontract Plan Reports - Design Phase
- Subcontract Plan Reports - Construction Phase

5.2 Collection of Cost Information - Previously prepared spreadsheet cost estimates will be converted into the SUCCESS format. SUCCESS reports will be forwarded to each WBS 3 cost estimator once the data conversion process is complete. The Supporting Data Tables (SDT's), discussed later in the CEP, will also be prepared from previous spreadsheets or an electronic spreadsheet copy (EXCEL Format) of the WBS may be forwarded, upon request, as a starting point. The SDT's should be part of the cost basis books.

5.3 Cost Estimate Report Book - The cost estimate report book for annual NSF submission will consist of the SUCCESS generated reports, supporting data tables (SDT), and basis-of-estimate information. The SDT's shall be generated using EXCEL (Version 3.0 or greater) spreadsheets that are vertically synchronized with the WBS elements. The SDT's will contain (at a minimum) pertinent estimate information that is defined later in the CEP.

5.3.1 Basic Cost Information - The SUCCESS database contains the basic cost information for each WBS element. Material and labor costs driven by quantities, productivity, and unit costs will estimated for each line item component. Roll-ups of total costs from subelements to higher level elements are performed internally within the SUCCESS framework. Labor rates, material estimating strategies, and contingency methodology are defined in subsequent sections.

5.3.1.1. Contingency - Contingency for the LIGO Project cost estimate shall be based on a standardized risk analysis. Each estimator shall perform the risk analysis identified in Section 9.0 and enter the associated contingency in an SDT and for application within the SUCCESS project. Depending upon the particular subsystem being analyzed contingency may be applied at the lowest WBS level or at a higher subassembly level. It is the responsibility of the estimator to make this determination. In any case, the estimators are responsible for assuring that each and every component has appropriate and defensible contingency applied.

5.3.2 Supporting Data Table - The SDT's, which may be divided into one or more matrices, provide important supporting data to the cost estimates. Estimators are required to provide input to these tables and submit it to LIGO Project Managemnet Group for additional processing into the SUCCESS framework. The information contained in the SDT is essential for interpreting the cost estimates, reviewing them and temporally distributing the costs to permit accurate cost projections to the end of the project. *Please note: The SDT information is only applied to WBS elements. All cost items internal to a given WBS element will be applied the SDT information.*

5.3.2.1 Quantity (QTY) and Units of Measure (UM) - The QTY and UM parameters identify the basic cost unit that was used to determine the cost and the total number of the units that was assumed. Typical values used for units are tons, meters^2, channels, system, assembly, and fibers. For any given WBS element almost anything can be used but the more descriptive it is the more helpful it will be to a reviewer.

5.3.2.2 Estimate Types - Each WBS element shall be tagged with a cost basis descriptor which characterizes the type of estimate that was used. Acceptable data entries are as follows:

1) Bottom-up (BU)
2) Specific analogy (SA)
3) Parametric study (PS)
4) Review and update (RU)
5) Trend analysis (TA)
6) Expert opinion (EO)

Definition of these categories can be found in DOE 4700.1, Project Management System.

It is important that a concerted effort be made to maximize as many WBS elements with BU detail as illustrated below.

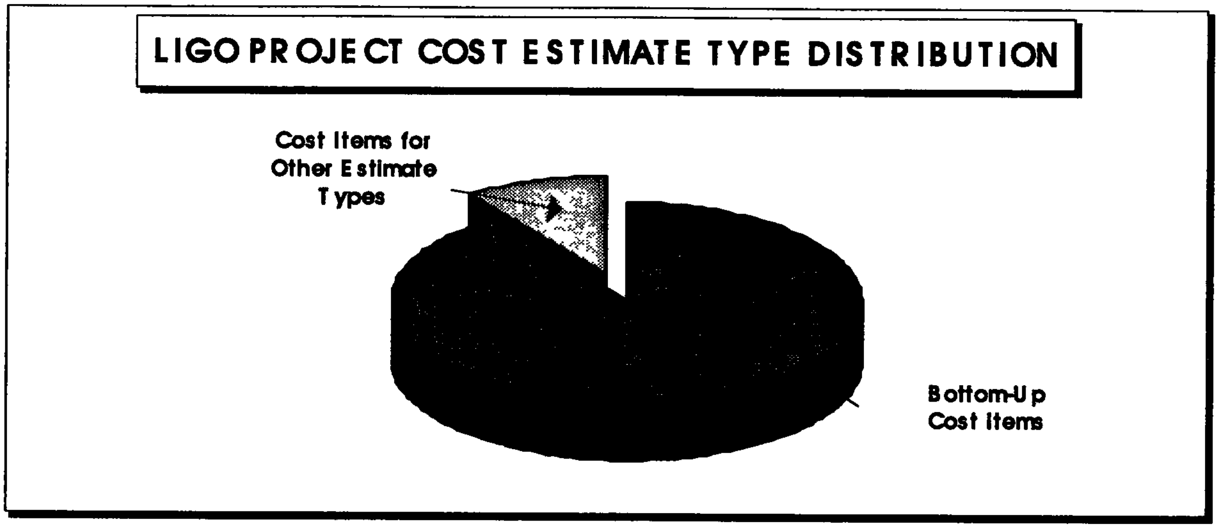


Chart 1. Cost Type Distribution Objective

5.3.2.3 Risk Factors - The risk analysis described in Section 9.0 is used to calculate contingency. In the three columns provided in the SDT, technical, cost and schedule risk factors are input. Standard ranges for these parameters are 1 to 15 for technical and cost risk, 2 to 8 for schedule risk. In some cases the standardized risk parameters may not be appropriate. Higher values may be used as described in Section 9.

5.3.2.4 Risk Percentage - The applied risk percentages are dependent on two factors. The first is whether the risk is associated with technical, cost or schedule concerns. The second is whether these concerns involve design, manufacturing, material cost or labor rate uncertainties. Acceptable values which range from 1% to 4% are defined in

Section 9. These percentages are multiplied by the corresponding risk factor to determine the total contingency which should be applied.

5.3.2.5 Contingency Total - This parameter is the sum of the products of the individual risk factors and corresponding risk percentages.

6.0 Labor Rates

6.1 Labor Rates - Estimators shall use their best discretion in selecting the labor categories and rates that should be used for their subsystem cost estimates. In making their decision, the estimators should determine where the work shall be performed and use the most accurate information available regarding the labor rates for that particular institution. Detailed backup information shall be provided in the cost book supporting any labor classification used. Rates used shall be fully burdened with all associated costs.

6.1.1 Labor Rate Plan - In some cases the subsystem estimators will either know (or establish as a basis) specifically the location where many of the engineering, design development, quality assurance, etc. types of efforts will be performed.

In the remaining cases, exact sources of labor will not be known, thus they will have to be assessed using average rates. Average rates for various categories have been defined in the section below for selective use as required.

In all cases when an appropriate labor category is not predefined a new craft may be appended to the list of labor resources. However, each new resource should be supported with detailed backup information. An SDT shall be prepared listing these labor categories with the minimum associated information.

Craft Name/Description
Base Annual Salary[1] (k$/Yr)
Payroll Burdens[2] (%)
General Overheads[3] (%)

[1] Base Annual Salary is defined as the average payroll compensation for FY 1993.

[2] Payroll Burdens are expressed as a percentage of Base Annual Salary. These burdens will typically include payroll taxes for FICA, unemployment insurance, workers compensation, etc. The aggregate percentage for the payroll

burdens will suffice for estimating purposes. Also, this percentage in most cases will be a constant for all labor classifications at a given institution.

[3] General Overheads are expressed as a percentage of Base Annual Salary. These overheads will typically include cost allocations for vacation pay, sick leave pay, holiday pay, facilities, engineering support burdens, laboratory general expense, laboratory directed R&D, etceteras. The aggregate percentage for the general overheads will suffice for estimating purposes. Also, this percentage in most cases will be a constant for all labor classifications at a given institution.

For instance, if it is known that an effort will be performed at a specific location, then a new craft should be developed and supported with the aforementioned backup information relative to the specific location.

The cost estimating approach may then be streamlined by using crafts, for items of work requiring only one craft, as a means of assessing labor costs in a relational fashion. For other items of work which require a group of crafts, then a team (crew) should be established for this purpose. The team would consist of one or more labor crafts, each with a designated usage or mix. Only predefined and/or new crafts supported with detail information should be used as member(s) of the team. The teams developed for the estimate must be defined in detail. In most cases, only a few teams will have to be developed. Subsequently, systematic application of the crafts or teams will: 1.) streamline the detailed estimate development; 2.) simplify the process of creating a relational database estimate (using SUCCESS); 3.) expedite the normalization process for labor rates to be used throughout all LGIO WBS Elements.

7.0 Productivity (Manpower per Unit of Measure)

7.1 Productivity - Once the subsystem estimators have established crafts, teams, and their associated rates, the next step in the estimating process for assessing cost for any given effort is to assess production. Production in essence may be defined as the total amount of manpower required to perform a given task, effort, work, etceteras. For any given item of work the Unit Productivity (work rate) is defined as the amount of manpower per Unit of Measure (UM). Labor Cost (LC) may then be expressed as follows:

LC= QTY * (Craft or Team Rate) * (Unit Productivity)

Once Unit Productivity values are established they may be used effectively and can become a powerful tool throughout the estimating process.

7.1.1 Full-Time-Equivalent (FTE) Manpower Units - For estimating purposes the CEP has defined a set of conventions for calculating manpower requirements throughout the cost estimate development process. A FTE-Man-year is the equivalent of a salaried person ***actually*** working (and billable) during a 12 calendar month period. The Unit Productivity convention established within the SUCCESS framework for manpower is FTE rates as a baseline. Hence, all cost items should be estimated on an FTE basis. In some instances, conversions from calendar time units to FTE-Man-years will be required. For simplicity, it is recommended that man-hours required be used during the estimating process. The LIGO Project Management Group will then convert to FTE-Man-years. To calculate Unit Productivity of a given cost item we offer the following examples:

8.0 Material Costs

8.1 Material Cost Index - Material costs shall include all hardware costs for the entire LIGO project. WBS elements shall be listed to cover projected requirements for each subsystem. All costs not based on current year dollars will be escalated as appropriate from the estimate basis FY by the LIGO Project Planning & Control Group. All material costs shall have backup details included in the subsystem cost books.

8.2 Material Requirements. - Material costs include all procurement and fabrication for all LIGO assemblies and facilities.

9.0 Risk Analysis/Contingency

9.1 Risk Analysis - Risk analysis shall be performed for each WBS element. Results of this analysis will be related to a contingency which shall be listed for each WBS element. Risk analysis parameters shall be listed in the SDT with equivalent contingency aggregate values also calculated.

9.2 Risk Assessment Methodology - This method is based on estimator evaluation of technical, cost and schedule risk for every WBS element. For technical risk, the value of 1 implies "normal industrial supplied off the shelf item" and 15 is reserved for components "way beyond the current state-of-the-art." For cost risk values, 1 is used to indicate "vendor quote or catalog price for a specific item" and 15 is used for estimates where no data is available. Schedule risk factors range from 2 to 8. The technical risk factor is multiplied by a risk percentage which is categorized below The resulting percentages are added together to establish the total contingency allocation for a particular WBS element. The minimum contingency percentage under this approach is 5% and the maximum is 98%.

Table 7. Risk Factor

Risk factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off the shelf or catalog item	not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive modifications to an existing design	Vendor quote with some design sketches	not used
4	New design within established product line	In-house estimate for item within current product line	Delays completion of non-critical path subsystem item
6	New design different from established product line. Existing technology	In-house estimate for item with minimal company experience but related to existing capabilities	not used
8	New design. Requires some R&D development but does not advance the state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances the state-of-the-art	Top down estimate from analogous programs	not used
15	New design way beyond the current state-of-the-art	Engineering judgment	not used

Table 8. Risk Percentage

	Condition	Risk percentage
Technical	Design or mfg concerns only	2%
	Design and mfg concerns	4%

Cost	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
Schedule		1%

9.3 Good Judgment - There may be special cases where the parameter limitations defined above are inappropriate. Some high risk elements may deserve contingencies greater than 98%. In these cases, at the discretion of the estimator, higher values may be used. Justification for these cases must be provided in the estimator's subsystem cost book.

10.0 Escalation

Escalation factors will be applied to the current year costs identified in each estimator's cost table. Factors to be used will be supplied at a later date and will be implemented into the LIGO Project cost by the cost coordinator. Subsystem estimators do not need to take any action except to include activity start and end dates.

11.0 Responsibilities

Cost estimating responsibilities are as follows:

LIGO WBS Element
Responsible person
?????????
?????????

LIGO PROJECT

PROJECT COST CONTROL

- COST ESTIMATING PLAN
- UPDATING COST ESTIMATES

LIGO PROJECT

COST ESTIMATING PLAN

- DEFINES FOR THE COST ESTIMATING PROCESS

  - GUIDELINES

  - METHODOLOGIES

  - ASSURANCE THAT ESTIMATES ARE COMPLETE & CONSISTENT

LIGO PROJECT

COST ESTIMATING PLAN

- OBJECTIVES

  - DEVELOP COMPREHENSIVE COST FOR ALL WBS ELEMENTS

  - DETAILED BACKUP INFORMATION THAT WILL JUSTIFY ALL ESTIMATES AND PROVIDE CONFIDENCE TO REVIEWING ORGANIZATIONS THAT THE COSTS ARE REASONABLE

  - VENDOR QUOTATIONS, ENGINEERING CALCULATIONS, DRAWINGS, SIMILARITIES TO OTHER SYSTEMS AND OTHER PERTINENT DATA WILL BE COLLECTED AND ORGANIZED

  - CRITICAL ASSUMPTIONS MADE DURING THE ESTIMATING PROCESS WILL BE DOCUMENTED

LIGO PROJECT

COST ESTIMATING PLAN

- OBJECTIVES

  - CONTINGENCY WILL BE ASSESSED AT WBS LEVEL 3 TO ACCOUNT FOR UNCERTAINTIES & COST RISK

  - COST TRACKING BASELINE
    THE COSTS OF THE LIGO PROJECT WILL BE MONITORED AND MUST BE CONTROLLED OVER THE LIFE OF THE PROJECT

COST ESTIMATING PLAN

Table 7. Risk Factor

Risk factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off the shelf or catalog item	not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
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4	New design within established product line	In-house estimate for item within current product line	Delays completion of non-critical path subsystem item
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8	New design. Requires some R&D development but does not advance the state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances the state-of-the-art	Top down estimate from analogous programs	not used
15	New design way beyond the current state-of-the-art	Engineering judgment	not used

COST ESTIMATING PLAN

Table 8. Risk Percentage

	Condition	Risk percentage
Technical	Design or mfg concerns only	2%
	Design and mfg concerns	4%
Cost	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
Schedule		1%

LIGO PROJECT

COST ESTIMATING PLAN

- COSTING METHODOLOGY

  - DEVELOP LABOR & MATERIAL COST FOR LOWEST LEVEL WBS ELEMENTS

  - IMPLEMENT A RELATIONAL DATABASE TO MANAGE ALL GENERATED COST DATA

  - PROVIDE CONSISTENT APPROACH FOR COST DATA COLLECTION FROM VARIOUS PROJECT ESTIMATING CONSTITUENTS

  - CHARACTERIZATION OF COST ITEMS BY ESTIMATE TYPE

    1) **Bottom-up (BU)**
    2) **Specific analogy (SA)**
    3) **Parametric study (PS)**
    4) **Review and update (RU)**
    5) **Trend analysis (TA)**
    6) **Expert opinion (EO)**

LIGO PROJECT

UPDATING COST ESTIMATES

- COLLECT & USE ALL PROJECT INFORMATION
  - TECHNICAL DOCUMENTS & REPORTS
  - DRAWINGS, SKETCHES, ETC.
- CONFIGURE RELATIONAL DATABASE TO:
  - LIGO WBS
  - COST ESTIMATING PLAN NUANCES
  - NSF COST REPORTING REQUIREMENTS
  - PROJECT CONTROL REQUIREMENTS

LIGO PROJECT

UPDATING COST ESTIMATES

- CONVERT EXISTING ESTIMATE INTO RELATIONAL DATABASE (SUCCESS)
- DETERMINE WHICH WBS ELEMENTS REQUIRE A BOTTOM-UP ESTIMATE
- DETERMINE LABOR RATES FOR EACH PROJECT SITE
  -DESIGN
  -CONSTRUCTION
- DETERMINE MATERIAL COSTS FOR EACH PROJECT SITE
- COORDINATE ALL DESIGN AND CONSTRUCTION PHASES ESTIMATES AMONG LIGO ESTIMATING TEAM MEMBERS

LIGO PROJECT

UPDATING COST ESTIMATES

- DEVELOP ESTIMATES FOR ALL WBS ELEMENTS WITH MORE ADVANCED DESIGN
- APPLY RISK ASSESSMENT METHODOLOGY TO ALL WBS 3 LEVELS
- DEVELOP REPORT TEMPLATES & GENERATE NSF REPORTS
- DEVELOP DATABASE QUERY TO UPLOAD INTEGRATED PROJECT SCHEDULE

REVISED MILESTONES/OBLIGATION PLAN

LIGO

G. STAPFER

JUNE 9, 1994

REVISED MILESTONES/OBLIGATION PLAN

ASSUMPTIONS

- MILESTONES AND OBLIGATION PLAN ARE BASED ON THE '93 PROJECT MANAGEMENT PLAN
- FUNDING LEVEL AND SCHEDULE ARE BASED ON LATEST NSF GUIDANCE
- PROJECT STAFFING IS BASED ON THE AUGMENTED STAFFING PLAN
- SCHEDULE IS SUCCESS ORIENTED (NO SLACK TIME)
- LOUISIANA SITE ASSUMES CLOSURE ON LAND TRANSFER
- PIPELINE CROSSING IS STILL A LIEN AGAINST THE PROJECT (BOTH COST AND SCHEDULE)

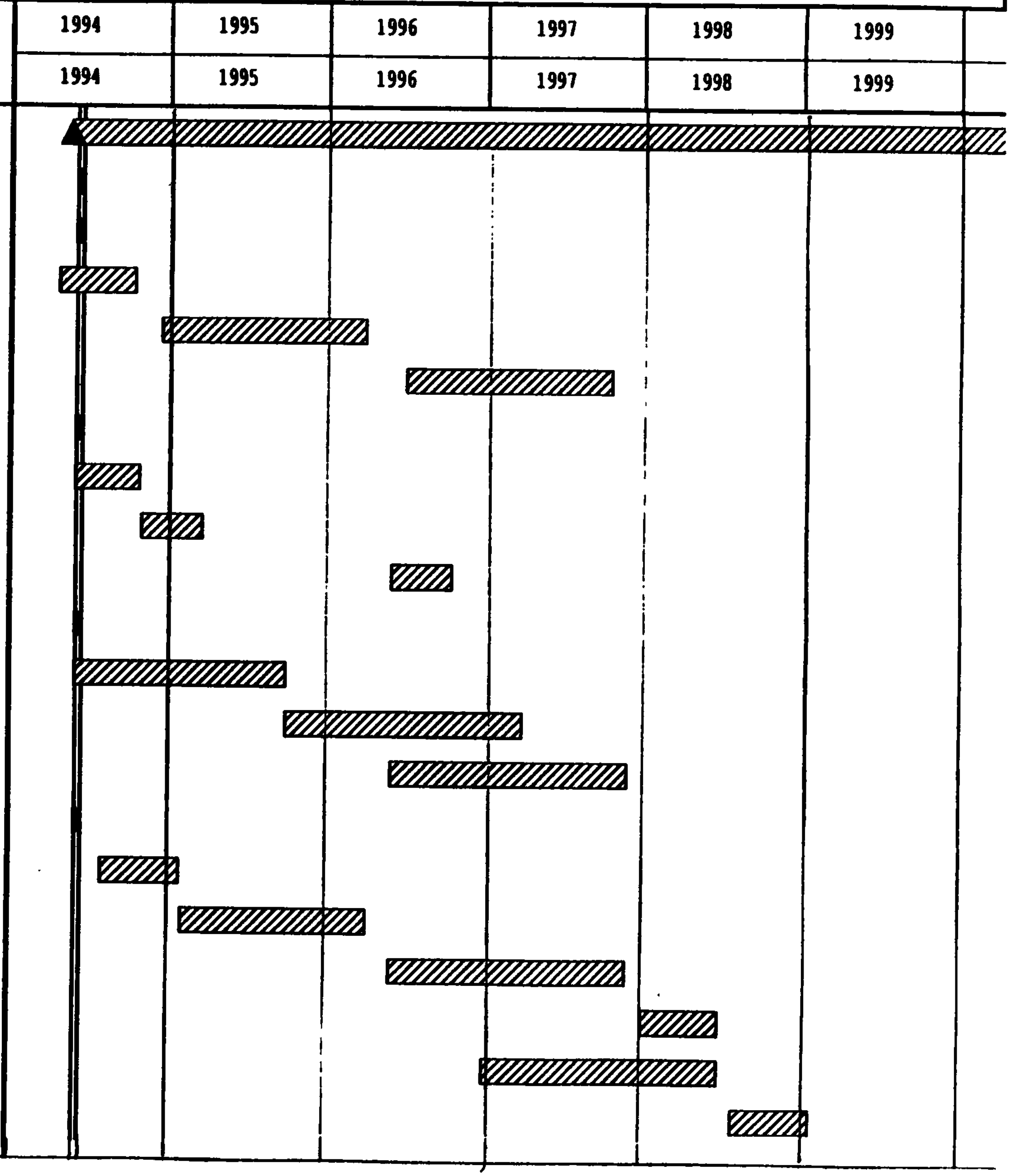
SCH0525 - GANTT CHART

Report Span: 01/01/94 To 01/01/ 2

Project Span: 05/25/94 To 08/28/ 1, 379 Week(s)

Run Date: 06/08/94

Activity Name	Dur	Act Type	Prf Start	Prf Finish
	379.00W	S	05/25/94	08/28/ 1
1.1.X FAC & VAC SYSTEMS	5.00D	N	06/08/94	06/14/94
1.1.1 BEAM TUBES	1.00D	N	06/03/94	06/03/94
DESIGN/QUAL	24.00W	N	04/27/94	10/11/94
FAB/INST WA	68.00W	N	12/13/94	04/01/96
FAB/INST LA	68.00W	N	07/01/96	10/17/97
1.1.2 B T ENCLOSURE	1.00D	N	06/03/94	06/03/94
DESIGN	21.00W	N	06/03/94	10/27/94
CONSTRUCTION WA	20.00W	N	11/01/94	03/20/95
CONSTRUCTION LA	20.00W	N	06/01/96	10/18/96
1.1.3 CIVIL CONSTRUCTION	1.00D	N	06/03/94	06/03/94
DESIGN	69.00W	N	06/03/94	09/28/95
CONSTRUCTION WA	78.00W	N	10/01/95	03/28/97
CONSTRUCTION LA	78.00W	N	06/01/96	11/28/97
1.1.4 VACUUM EQUIPMENT	1.00D	N	06/03/94	06/03/94
PROCUREMENT	26.00W	N	08/01/94	01/27/95
DESIGN	61.00W	N	02/01/95	04/02/96
WA FAB/INST	78.00W	N	06/01/96	11/28/97
WA INTEGRATION	26.00W	N	01/01/98	07/01/98
LA FAB/INST	78.00W	N	01/01/97	06/30/98
LA INTEGRATION	26.00W	N	08/01/98	01/29/99



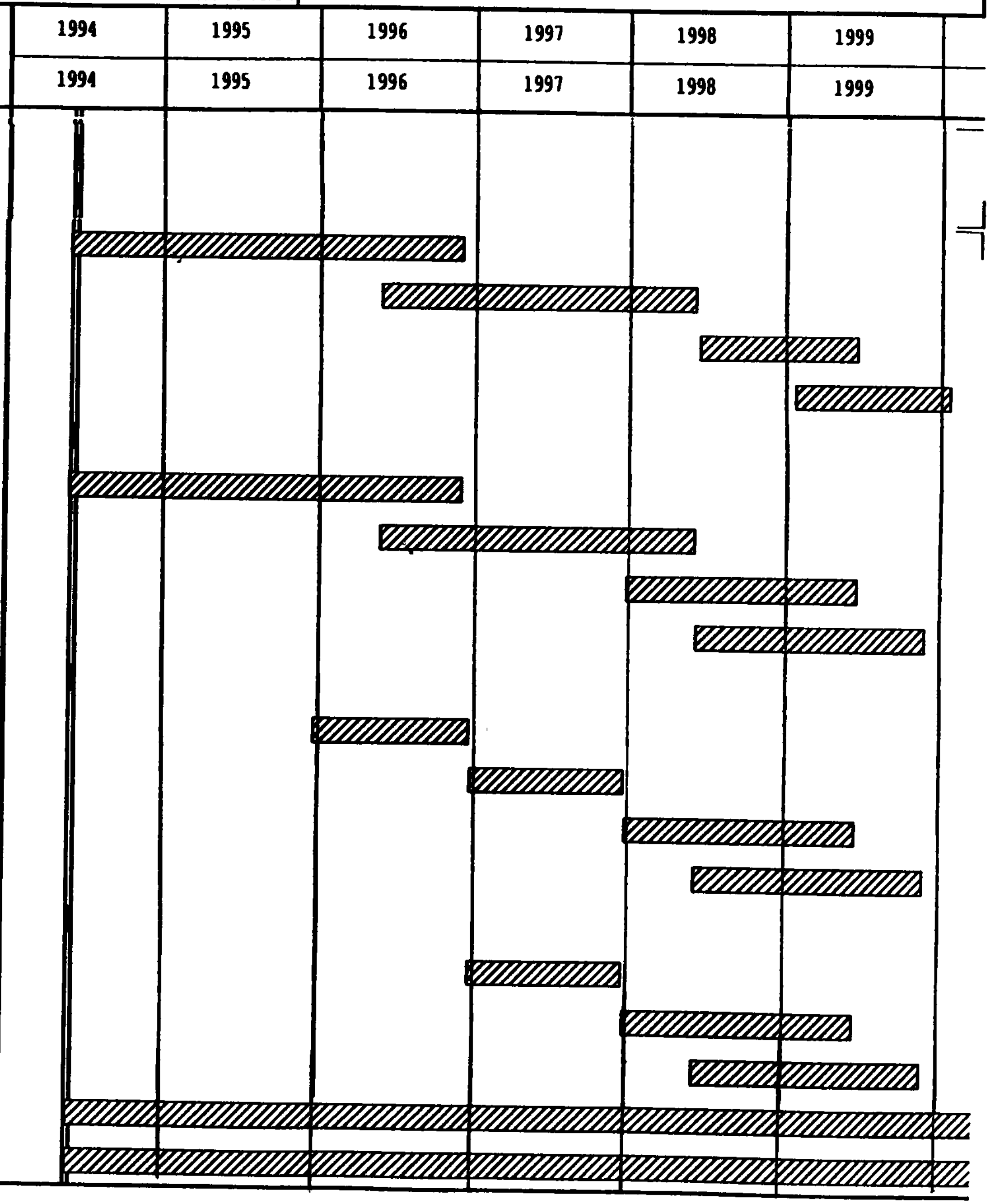
SCH0525 - GANTT CHART

Report Span: 01/01/94 To 01/01/ 2

Project Span: 05/25/94 To 08/28/ 1, 379 Week(s)

Run Date: 06/08/94

Activity Name	Dur	Act Type	Prf Start	Prf Finish
1.2.X DETECTOR SYSTEMS	5.00D	N	06/08/94	06/14/94
1.2.1 INTERFEROMETERS	1.00D	N	06/08/94	06/08/94
DESIGN	131.00W	N	06/01/94	12/03/96
FABRICATION	105.00W	N	06/01/96	06/05/98
INST/INTEGRATION WA	52.00W	N	06/21/98	06/18/99
INST/INTEGRATION LA	52.00W	N	01/29/99	01/27/ 0
1.2.2 CDS	5.00D	N	06/08/94	06/14/94
DESIGN	131.00W	N	06/01/94	12/03/96
FABRICATION	105.00W	N	06/01/96	06/05/98
INST/INTEGRATION WA	77.00W	N	01/01/98	06/23/99
INST/INTEGRATION LA	77.00W	N	06/15/98	12/03/99
1.2.3 AUX PHYSICS	5.00D	N	06/08/94	06/14/94
DESIGN	52.00W	N	01/01/96	12/27/96
PROC/FAB	52.00W	N	01/01/97	12/30/97
INST/INTEGRATION WA	77.00W	N	01/01/98	06/23/99
INST/INTEGRATION LA	77.00W	N	06/15/98	12/03/99
1.2.4 SUPPORT EQUIPMENT	5.00D	N	06/08/94	06/14/94
SPECIFY/PROCURE	52.00W	N	01/01/97	12/30/97
INSTALL WA	77.00W	N	01/01/98	06/23/99
INSTALL LA	77.00W	N	06/15/98	12/03/99
1.3.X RESEARCH & DEVELOPMENT	68.00M	N	06/08/94	12/12/ 0
1.4.X PROJECT OFFICE	68.00M	N	06/08/94	12/12/ 0



REVISED MILESTONES/OBLIGATION PLAN

PROJECT MILESTONES

- 1994
  - INITIATE SITE DEVELOPMENT (HANFORD) 3/94
  - BEAM TUBE FINAL DESIGN REVIEW 4/94
  - SELECT A-E CONTRACTOR 10/94
  - COMPLETE BEAM TUBE QUALIFICATION TEST 10/94 (?)
  - INITIATE TUBE SLAB CONSTRUCTION (HANFORD) 11/94
  - INITIATE BEAM TUBE FABRICATION (HANFORD) 12/94

- 1995
  - SELECT VACUUM EQUIPMENT CONTRACTOR 2/95
  - COMPLETE TUBE SLAB (HANFORD) 3/95
  - INITIATE SITE DEVELOPMENT (LIVINGSTON) 6/95
  - COMPLETE BUILDING DESIGN 9/95
  - INITIATE BUILDING CONSTRUCTION (HANFORD) 10/95

- 1996
  - COMPLETE BEAM TUBE INSTALLATION (HANFORD) 4/96
  - COMPLETE VACUUM EQUIPMENT DESIGN 4/96
  - INITIATE TUBE SLAB CONSTRUCTION (LIVINGSTON) 6/96
  - INITIATE BUILDING CONSTRUCTION (LIVINGSTON) 6/96
  - INITIATE VACUUM EQUIPMENT FABRICATION (HANFORD) 6/96
  - INITIATE BEAM TUBE SLAB FABRICATION (LIVINGSTON) 7/96
  - COMPLETE TUBE SLAB (LIVINGSTON) 10/96

REVISED MILESTONES/OBLIGATION PLAN

PROJECT MILESTONES

- 1997
  - INITIATE VACUUM EQUIPMENT FABRICATION (LIVINGSTON) 1/97
  - COMPLETE BUILDINGS (HANFORD) 4/97
  - COMPLETE BEAM TUBE INSTALLATION (LIVINGSTON) 10/97
  - COMPLETE BUILDINGS (LIVINGSTON) 12/97
  - COMPLETE VACUUM EQUIPMENT INSTALLATION (HANFORD) 12/97
  - INITIATE FACILITY CHECKOUT (HANFORD) 12/97
- 1998
  - COMPLETE VACUUM EQUIPMENT INSTALLATION (LIVINGSTON) 7/98
  - COMPLETE FACILITY CHECKOUT (HANFORD) 7/98
  - INITIATE INTERFEROMETER INSTALLATION (HANFORD) 7/98
  - INITIATE FACILITY CHECKOUT (LIVINGSTON) 7/98
- 1999
  - COMPLETE FACILITY CHECKOUT (LIVINGSTON) 1/99
  - INITIATE INTERFEROMETER INSTALLATION (LIVINGSTON) 1/99

REVISED MILESTONES/OBLIGATION PLAN

OBLIGATION PLAN

Millions of FY93 dollars

WBS		CY92	CY93	CY94	CY95	CY96	CY97	CY98	TOTAL	Contingency Allocation $M	%	TOTAL
1.	Subcontracted design, construction mgmt, & QA services											
1.1.	Site plans		0.1	1.0	0.3				1.4	0.2	15%	1.6
1.2.	Buildings			1.1	0.2	0.5	0.3		2.1	0.3	15%	2.4
1.3.	Beam tube enclosure			0.8		0.3			1.1	0.2	20%	1.3
1.4.	Vacuum equipment (except tube)				5.6	0.3	1.7	0.4	8.0	1.2	15%	9.2
1.5.	Beam tubes		1.3	1.6		1.2			4.1	0.6	15%	4.7
1.8.	Site investigations	0.3	0.4	0.3					1.0	0.0	0%	1.0
								Subtotal	17.7	2.6		20.3
2.	Washington site facilities & equipment:											
2.1.	Site development			7.3					7.3	0.7	10%	8.0
2.2.	Buildings				14.4				14.4	2.9	20%	17.3
2.3.	Beam tube enclosure			7.6					7.6	1.9	25%	9.5
2.4.	Vacuum equipment (except tube)					12.0	14.0		26.0	5.2	20%	31.2
2.5.	Beam tubes			15.9					15.9	1.6	10%	17.5
2.6.	Support equipment					2.7	2.0		4.7	1.2	25%	5.9
2.7.	Initial interferometers						0.5	5.3	5.8	4.4	75%	10.2
								subtotal	81.7	17.8		99.5
3.	Louisiana site facilities and equipment:											
3.1.	Site development				7.6				7.6	1.5	20%	9.1
3.2.	Buildings					10.1			10.1	2.0	20%	12.1
3.3.	Beam tube enclosure					7.6			7.6	1.9	25%	9.5
3.4.	Vacuum equipment (except tube)						10.0	3.4	13.4	2.7	20%	16.1
3.5.	Beam tubes					15.9			15.9	1.6	10%	17.5
3.6.	Support equipment						2.1	2.2	4.3	1.1	25%	5.4
3.7.	Initial interferometers							2.9	2.9	2.2	75%	5.1
								Subtotal	61.8	13.0		74.8
4.	Manpower, support, operations:											
4.1.	Management & administration	0.8	0.9	1.2	1.7	1.7	1.3	0.7	8.3		0%	8.3
4.2.	Technical staff	2.3	3.1	4.3	6.2	6.6	5.2	2.7	30.4		0%	30.4
4.3.	Travel	0.1	0.1	0.6	0.6	0.6	0.6	0.2	2.8		0%	2.8
4.4.	R&D equipment	1.0	0.6	1.2	1.4	1.4	1.4	0.5	7.5		0%	7.5
4.5.	In-house operations support	0.7	0.9	1.1	1.6	1.7	1.3	0.7	8.0		0%	8.0
4.6.	Remote facilities operations								0.0			0.0
								Subtotal	57.0			57.0
	Subtotal	5.2	7.4	44.0	39.6	62.6	40.4	19.0	218.2	33.3	15%	251.5
	Contingency:	0.0	0.0	5.1	5.3	8.9	6.5	7.4	33.3			
TOTAL (FY93 $M)		5.2	7.4	49.1	44.9	71.5	46.9	26.4	251.5			
NSF (GDP) inflation Factor		--	1.0000	1.0329	1.0668	1.1009	1.1367	1.1736				
TOTAL, GDP-PROJECTED $M		5.2	7.4	50.8	47.9	78.8	53.3	31.0	274.4			
*excluding sales & use taxes												
cum obligation		5.2	12.6	63.4	111.3	190.0	243.4	274.4				
TOTAL FUNDING		19.1	24.0	39.0	54.0	54.0	54.0	42.0				
cum funding		19.1	43.1	82.1	136.1	190.1	244.1	286.1				
cum funding less obligation		13.9	30.5	18.7	24.8	0.1	0.7	11.7				

MIT Technical Program

9 June 1994

Areas of LIGO Research and Development at MIT

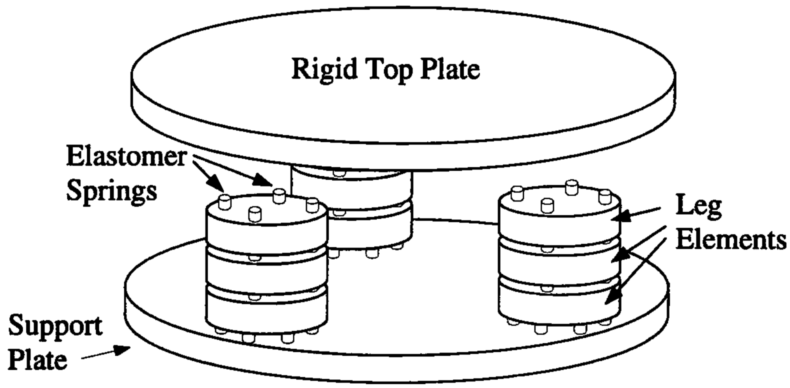
- Seismic Isolation
- Modulation Configuration
- Phase Noise Interferometer
- Interferometer Alignment
- Optical Modeling
- Engineering support

Seismic Isolation

☐ **Prototype passive isolator: built, tested and modeled**

☐ **System:**

- **three legs, three spring-mass elements each**
- **all Fluorel, mixed Fluorel/RTV springs**
- **100 kg steel masses**
- **80 kg top table**



☐ **Measurements:**

- **Mechanical transfer functions: 2×10^{-6} for horizontal → horizontal at 100 Hz**
- **Drift of top table position**

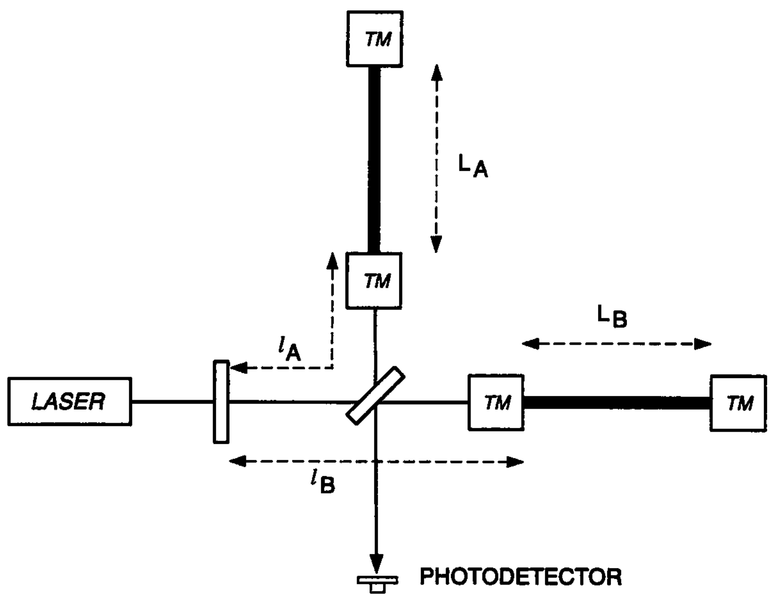
☐ **At the end of the prototype research, this isolator was engineered for the 40 m interferometer, and has given large improvements in its low frequency performance.**

Active isolation system

- ☐ Currently testing an alpha version of an active isolator being developed by Barry Controls
  - 3 mounting feet, each controlled in 3 degs of freedom
  - active band: 0.5–100 Hz; factor or 30 suppression from 2–20 Hz
- ☐ Application to LIGO:
  - facilitate lock acquisition
  - servo implementation: ease requirements on mirror transducers
  - reduction of upconversion effects
  - noise reduction in GW band
- ☐ Future: isolators will be used in MIT's prototype interferometer and evaluated for use in LIGO

Modulation Configuration

- ☐ Part of LIGO's Length Sensing subsystem
- ☐ Given the interferometer optical layout (recycled Fabry-Perot arm Michelson), need a system which generates error signals for controlling the longitudinal degrees of freedom:
  - arm cavity lengths (resonances)
  - recycling cavity length (resonance)
  - output at dark fringe
  - detection of GW signal



- ☐ Parallel research at MIT and CIT to choose between several phase modulation/demodulation schemes
  - experiments on 'fixed-mass' table-top interferometers
  - modeling of these and large-scale interferometers
- ☐ Research converged in September 1993: hybrid scheme chosen as most suitable for LIGO
- ☐ Future work at MIT: GW detection scheme to be further tested in the Phase Noise Interferometer

Phase Noise Interferometer

- ☐ Initial LIGO requires a sensitivity to the Michelson fringe of $10^{-10}\ \mathrm{rad}/\sqrt{\mathrm{Hz}}$
  - requires circulating power of 70 W
  - presently, 40 m uses roughly 0.2 W beamsplitter power
- ☐ Starting (2 yr) research program to build an interferometer that can:
  - achieve this phase sensitivity
  - serve as a 'high phase sensitivity' testbed for technologies and subsystems: complementary to 40 m
- ☐ Interferometer characteristics:
  - LIGO-like system for phase (GW) detection
  - Low displacement sensitivity: simple Michelson
  - LIGO circulating power via recycling
  - Suspended mirrors, seismic isolation, vacuum system
- ☐ Research goals:
  - LIGO phase sensitivity
  - Understanding of noise mechanisms: scattered light, laser amplitude noise, . . .
- ☐ Technology development goals:
  - Photodetection system
  - Modulation system
  - Laser amplitude stabilization
  - Beam absorbers and baffling

Interferometer Alignment

☐ **Consists of:**

- **Initial coarse angular alignment**
  pointing lasers, quad diodes, CCD cameras
- **Centering of beams on masses**
  CCD cameras
- **Maintenance of optimal angular alignment**
  phase-front detectors

☐ **Research and development plan**

- **Establish requirements**
  modeling, including non-ideal optics
- **Develop and test sensor/servo prototypes**
  benchtop setups
  Fixed Mass Interferometer
  suspended cavities & interferometers
- **Develop 'system' (coordination)**
  tests with hardware and software prototypes
- **Complete system test**

☐ **Current work:**

- **Modeling has established requirements for low frequency angular deviations → 10^{-8} radians/mirror**
- **Development of Phase Front Sensor for 'optics/beam — referenced' control signals**
  a. **prototype sensor built**
  b. **being used to control alignment of a 6m suspended cavity in all 4 degs of freedom**
  c. **implements computer processing of sensor signals**
- **Will begin experimental verification of phase front sensor signals on the Fixed Mass Interferometer, in a LIGO-configuration**

Optical Modeling

- ☐ Mode Decomposition Model: TEM_{nm} modes of the system
  - specify alignment requirements for LIGO
  - tool for designing alignment strategy and sensors
- ☐ Perturbation Analysis:
  - analytical solutions for simple mirror distortions
  - useful for determining mirror specifications
- ☐ FFT Numerical Model: what are the effects of imperfect optics?
  - Computer Program:
    a. Divide mirror surface (substrate) into a grid
    b. Apply: [mirror reflection, FFT, propagation, FFT], until field distributions converge and are maximized
    c. Field distributions determine optical performance of interferometer
  - Applications:
    a. Determine mirror specifications by modeling 'fake' mirror surfaces
    b. Simulation of LIGO performance using measured mirror surfaces
  - Status:
    a. Full interferometer code running, with optimizations
    b. Test runs made with: AXAF mirrors; measured substrate inhomogeneity
    c. Interaction with Path-Finder Team

Vacuum System Scientific Support

- ☐ Outgassing models
- ☐ Surface contamination measurements
- ☐ Bakeout strategy
- ☐ Leak assessment and localization strategies
- ☐ Tube alignment strategies
- ☐ Thermal analysis
- ☐ Stray light control and baffling
- ☐ Beam tube qualification test: planning and data analysis

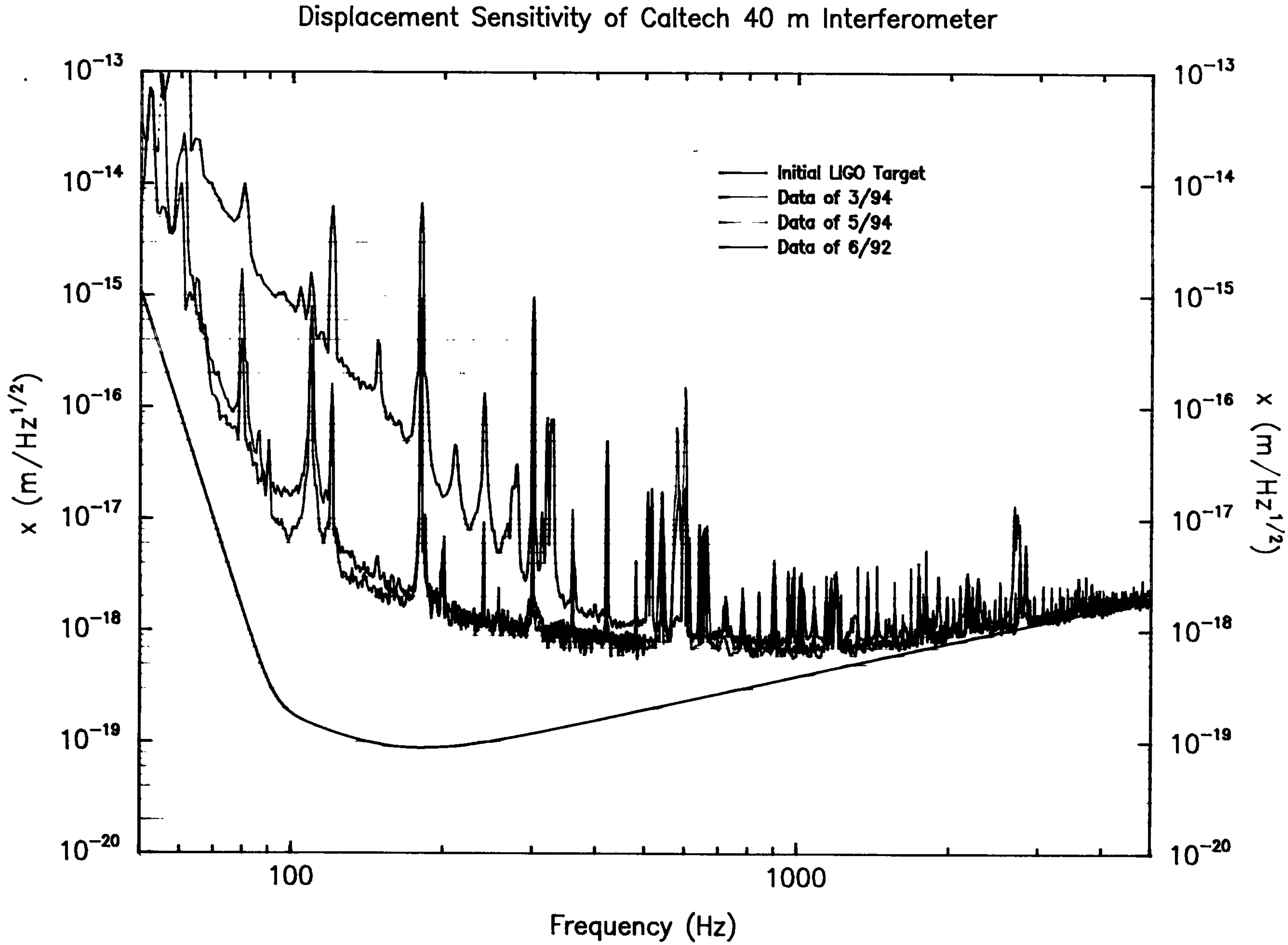
40-Meter Interferometer Update

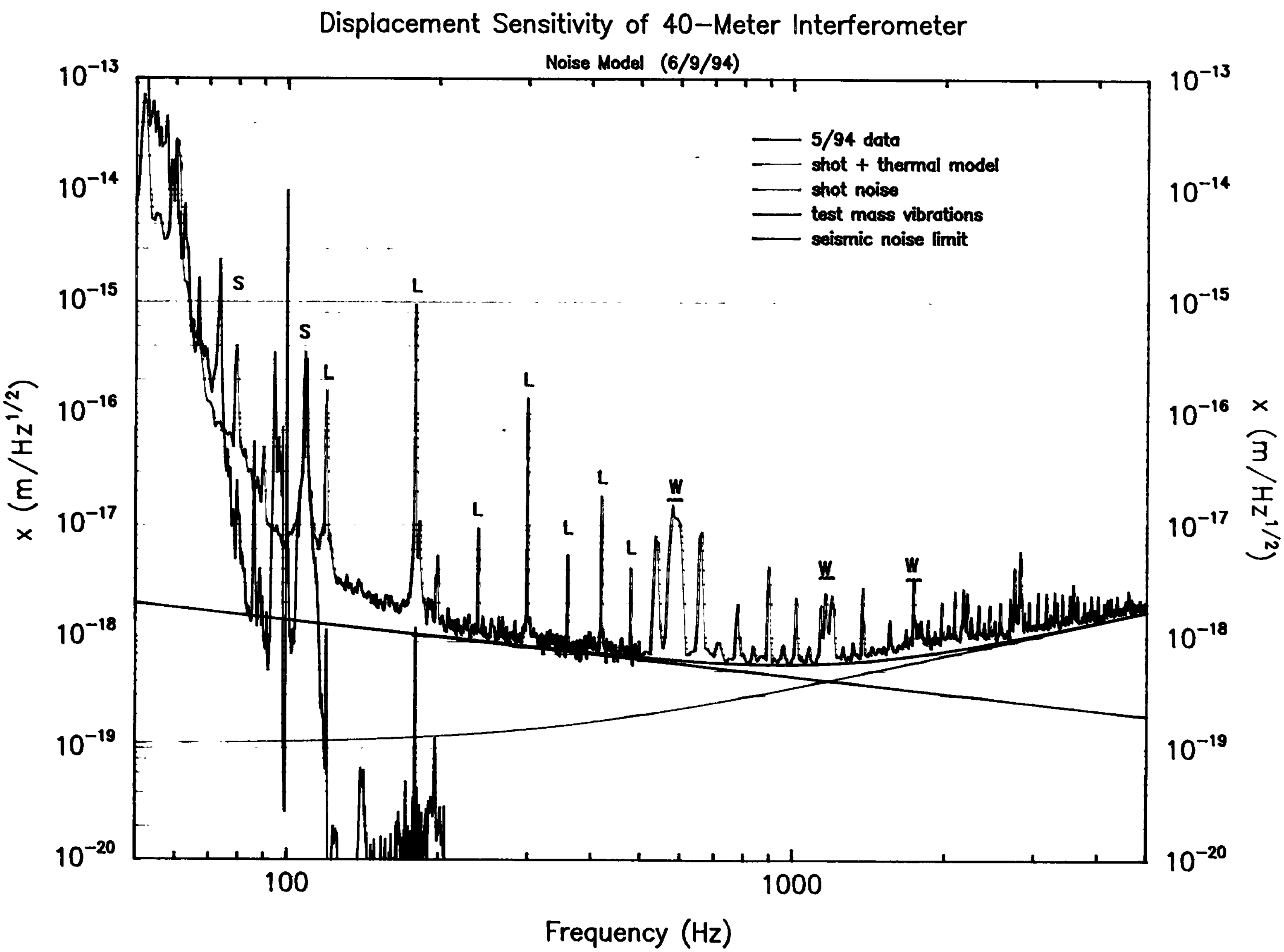
Frederick J. Raab

June 9, 1994

Interferometer R&D Update

- Modifications to Servosystems:
  - Beam splitter control
  - Laser frequency stabilization
  - Laser power stabilization
  - Secondary arm length control
- Reduced Potential Sources of Pendulum Thermal Noise
- Began Monolithic Test Mass Installation
  - seek reduction in thermal noise contribution from internal vibrations
  - evaluate optical properties and any noise sources associated with increased optical aperture or pathlength in test mass
  - gain experience in preparation and handling of larger optics
- Improved Diagnostics for Cavity Optical Properties
- Measured (preliminary) Sensitivity to Pulses
  - calibrate pulse sensitivty
  - evaluate non-gaussian noise
  - develop/test analysis software on real data

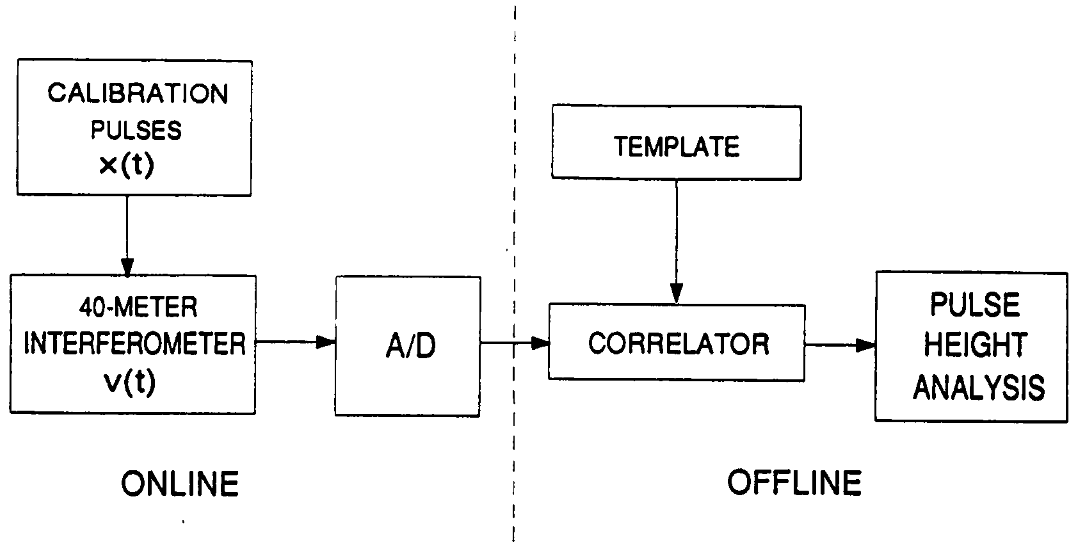

Displacement Sensitivity of Caltech 40 m Interferometer
Initial LIGO Target
Data of 3/94
Data of 5/94
Data of 6/92
x (m/Hz^1/2)
Frequency (Hz)
100
1000
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20

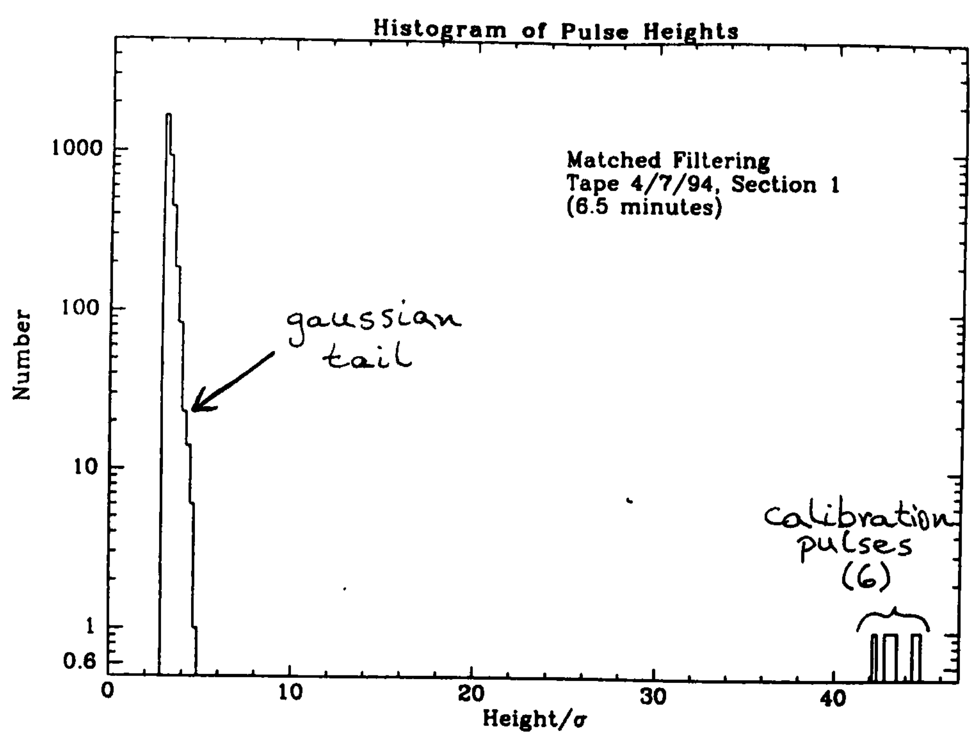


Displacement Sensitivity of 40-Meter Interferometer
Noise Model (6/9/94)
5/94 data
shot + thermal model
shot noise
test mass vibrations
seismic noise limit
S
S
L
L
L
L
L
L
L
W
W
W
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
100
1000
Frequency (Hz)
x (m/Hz^1/2)

Pulse Sensitivity

(preliminary data)





LIGO

Recent Results

- Reduced 40–Meter Interferometer noise at frequencies from 70 Hz to 500 Hz.
- Improved technique for attachments to monolithic test masses.
- Successfully tested chemical cleaning technique on monolithic test masses; should be scalable to large mirrors.
- Sensitivity to benchmark pulses (single sinusoidal cycle at 1 kHz) about 4×10^{-17} m_{rms}. Spurious pulse rates are below a few per hour, well within the allowable rate for triple coincidence searches.