CALIFORNIA INSTITUTE OF TECHNOLOGY
LIGO Project, 18-34 East Bridge Laboratory, Pasadena, California 91125
(626) 395-2129, Fax (626) 304-9834

Date: October 4, 2000
Refer to: LIGO-L000225-00-P

Ms. Carol A. Langguth
Grants Officer
Division of Grants and Agreements
National Science Foundation
4201 Wilson Blvd.
Arlington, VA 22230

Subject: LIGO Project Quarterly Progress Report, LIGO-M000305-00-P

Reference: NSF Award No. PHY-9210038

Dear Ms. Langguth:

Four copies of the LIGO Project Quarterly Progress Report providing status information for the quarter ending August 2000 are enclosed in accordance with the requirements of the award referenced above. Please forward three (3) copies to Dr. Victor Cook.

Sincerely,

Philip E. Lindquist
LIGO Project Controls Manager

Concurrence for Caltech:

Richard Seligman
Director, Sponsored Research

PEL:pel

cc:

G. Sanders
B. Barish
Chronological File
Document Control Center

Quarterly Progress Report

(LIGO Fiscal Year Ending August 2000)

The Construction, Operation and Supporting Research and Development of a Laser Interferometer Gravitational-Wave Observatory (LIGO)

NSF Cooperative Agreement No. PHY-9210038

LIGO-M000305-00-P

Quarterly Progress Report

(End of August 2000)

THE CONSTRUCTION, OPERATION AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)

NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M000305-00-P

CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1.0 Introduction

This Quarterly Progress Report is submitted under NSF Cooperative Agreement PHY-9210038[1]. The report summarizes the progress and status of the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project for the LIGO fiscal quarter ending August 2000.

Facility construction, including the vacuum system, is complete. All Beam Tube modules have completed vacuum bake and we are installing and commissioning the detectors. The project continues to make excellent progress and is 97.5 percent complete as of the end of August 2000.

2.0 Vacuum Equipment

All Process Systems International (PSI) field activities were completed during the first quarter of the fiscal year. All scheduled payment milestones are complete, and the PSI contract is closed out.

3.0 Beam Tube

All Beam Tube modules have been accepted, and all contract work is complete. Beam Tube module insulation and baking is discussed in Section 6.0.

4.0 Beam Tube Enclosures

Washington Beam Tube Enclosure. Construction activity is complete. The contracts for the fabrication and installation of the Beam Tube Enclosure are closed pending the conclusion of litigation regarding charges by a subcontractor for sales taxes.

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[1] Cooperative Agreement No. PHY-9210038 between the National Science Foundation, Washington, D.C. 20550 and the California Institute of Technology, Pasadena, CA 91125, May 1992.

Louisiana Beam Tube Enclosure. Fabrication and installation of all enclosure segments are complete. The contractor has finished all construction activities along both arms and the contract is closed.

5.0 Civil Construction

Washington Civil Construction. Construction activities for the facilities are complete. This includes the completion of the Staging and Storage Building. We have closed this contract.

Louisiana Civil Construction. Construction of the facilities is complete and the contracts are closed. Erosion control and landscaping is complete. We are soliciting bids for the construction of the Staging and Storage Building.

6.0 Beam Tube Bakeout

We completed the vacuum bake of all four Beam Tube modules at Hanford during the second quarter of FY 1999 and moved the equipment to Livingston last summer.

We started the vacuum bake of the LIGO Livingston Observatory beam tube in August 1999 and completed it in June 2000. All eight kilometers of beam tube were baked in two kilometer isolated modules at temperatures of about 168 C. This successfully concluded the vacuum bake for all LIGO beam tubes. Table 1 below summarizes the vacuum bake results for the Livingston site. Note that one module (Y1) appears to have a very small leak. Attempts to localize and repair this leak were unsuccessful because the leak rate is so small. The vacuum in this module will be monitored to determine if future corrective action is necessary. At this time, the magnitude of the leak presents no obstacle to planned commissioning activities.

TABLE 1. Post-bake measurements of the air signature within two-kilometer modules of the Livingston Observatory beam tube.

Module	Air Leak (torr-liters/second)
Specification per module	$< 10^{-9}$
Livingston X1	$3.5 \pm 1.3 \times 10^{-10}$
Livingston X2	$< 7 \times 10^{-11}$
Livingston Y1	$2 - 3 \times 10^{-9}$
Livingston Y2	$< 10^{-9}$

7.0 Detector

The Detector group is focusing on installation and commissioning at the observatories. Fabrication and design revisions based on commissioning experience are accomplished as parallel activities. We made significant progress this quarter.

7.1 Installation Progress Overview

Highlights for this quarter:

- we completed the installation of the seismic isolation systems at both the Livingston and Hanford observatories,
- we completed the installation of all in-vacuum components for the Livingston four-kilometer interferometer,
- we began alignment of the four kilometer core optics for the Livingston interferometer,
- we completed the installation of the initial complement of the control electronics on the Hanford two-kilometer interferometer,
- we locked the power-recycled Michelson with one arm on the Hanford two-kilometer interferometer--the final step before locking the entire interferometer, and
- we are staging and preparing for the Hanford four-kilometer installation.

Detector installation and commissioning is following the schedule presented in the last quarterly report. The major activities this quarter were the installation of all in-vacuum components for the four-kilometer interferometer at Livingston, and the resumption of interferometer commissioning at Hanford.

7.2 Lasers and Optics

Pre-Stabilized Laser (PSL). Both the Hanford two-kilometer and Livingston four-kilometer pre-stabilized lasers are in regular use and undergoing incremental change and improvement. The current work at the observatories is concentrated on improvements in the frequency noise.

Previous studies of frequency noise at both Hanford and Livingston identified a number of peaks in the spectrum associated with mechanical resonances of the optical components and mounts, excited by acoustic pressure. We have simplified the optical path to eliminate unnecessary components and replaced the previous mounts with stiffer designs, less susceptible to acoustic pressure. We are also pursuing a reduction in the acoustic noise in the enclosure, which surrounds the pre-stabilized laser, by introducing acoustic shielding.

Components for the Hanford four-kilometer pre-stabilized laser are being shipped to the site. Assembly will start next quarter.

Input Optics. We suspended the characterization of the Livingston Observatory Input Optics this quarter to allow us to vent to install the remaining in-vacuum components. We modified the suspensions of the input optics to eliminate permanent magnets used for static alignment adjustment, which had caused instabilities in the output beam pointing noted in the last quarterly report.

At Hanford, the Mode Cleaner for the two-kilometer interferometer has continued to be key for understanding the pre-stabilized laser (PSL). We added a notch filter at the frequency of the vertical bounce mode of the mode cleaner optics (14.7 Hz) in the servo that locks the mode cleaner and the PSL together, and this has significantly reduced the residual rms frequency noise.

The in-vacuum Input Optics components for the Hanford four-kilometer interferometer are being suspended and balanced and will be available when installation commences.

Core Optics Components. Metrology of the Hanford four-kilometer interferometer core optics continued. The goal for these optics is a more precise characterization than was achieved for the previous two interferometers. Previous measurements were sufficient to assure that the optics met specifications. However, we wish to perform a detailed comparison of the optical performance with a model based on the metrology of the optics, and recent improvements to the metrology lab will support that. To date, four of the six core optics for the four-kilometer interferometer have been completed and delivered to the site.

Core Optics Support. We installed the final core optics support components in the Livingston four-kilometer interferometer, and alignment is in progress. At Hanford, nearly all components for the four-kilometer interferometer have been delivered and cleaned for installation.

7.3 Isolation

Seismic Isolation System. We completed the installation of the in-vacuum seismic isolation system last quarter. We are now designing and fabricating the fine actuator servo, which will correct for tidal motion.

Suspensions. We installed the large optic suspensions for the Livingston interferometer this quarter and are now aligning them. We also changed the small optic suspensions for the Livingston mode cleaner. We attributed excess beam jitter observed at the output of the Livingston mode cleaner to magnets that had been installed to correct for initial angle errors in the mode cleaner suspensions (this was not required at Hanford.) We eliminated the correction magnets, which required re-suspending two of the components to reduce the initial offset, and modified the controllers to permit greater dynamic range while still meeting noise requirements.

We began the assembly of the large optic suspensions for the Hanford four-kilometer interferometer.

We continued efforts to reduce the sensitivity of the sensors used for local damping to stray Nd:YAG light. We are developing two approaches: a redesign of the sensors to change the wavelength of operation; and a modulation-demodulation technique, which can be used with the existing sensors.

7.4 Control and Data Systems (CDS)

The Control and Data Systems (electronics and software) group is providing essential support during installation and commissioning of the subsystems and during system level testing.

We completed the fabrication and installation of the Hanford two-kilometer full length control system servo modules. Testing with the full interferometer is underway. The first step--locking the power-recycled Michelson with one arm cavity--has been achieved. We are now fabricating comparable modules for the Livingston interferometer, and these will be installed during the next quarter.

With the experience gained at both Livingston and Hanford, we have started a complete redesign of the controller system. The motivation is to reflect a better understanding of the mechanical systems and their imperfections, and to correct for shortcomings in the local sensors. The core of the new controller will be digital to increase flexibility. These new controllers can be employed with the existing suspensions (no incursion into the vacuum is needed), and so will be incorporated and tested as the opportunity arises. Design and testing of prototypes including the software is underway.

7.5 Physics Environment Monitoring System

The Physics Environment Monitoring system is now functional and in regular use. We regularly compile trend data (e.g., dust, weather, and seismic activity) and review it for anomalies or correlations with interferometer data. Verification and calibration of signals is on-going at both sites.

7.6 Global Diagnostics System

We regularly use the Global Diagnostics tools to support commissioning activities. As more people become comfortable with their operation, these tools are replacing the conventional test equipment in the LVEA and increasing the use of the control room. We continue to enhance these tools, and the excitation engine has been activated in the end stations.

7.7 Interferometer Sensing and Control

We are performing the initial alignment of the core optics and installing sensing and control at Livingston. Most of the optical tables are ready. The mode cleaner length and alignment controls are ready for commissioning.

We installed the length controls for the full Hanford two-kilometer interferometer and began testing. We have modeled lock acquisition and prepared low-level real-time code for the first versions of the locking code that will be tested during the next quarter. We also cross-checked the code with the end-to-end (*E2E*) simulation code.

We have addressed the issue of short lifetimes for the optical lever laser diodes, noted last quarter. New longer-lived diode lasers have been ordered for future installations and replacement of existing units.

7.8 System Level Commissioning/Testing

The majority of the commissioning activities were at Hanford this quarter and focused on locking the two-kilometer interferometer. At Livingston, the vacuum chambers in the LVEA were at atmospheric pressure for the remaining installation work, preventing any commissioning beyond pre-stabilized laser testing.

Locking of the full interferometer is accomplished as a sequence of smaller steps: first we lock the power-recycled Michelson (PRM); then the PRM plus one arm; then the PRM plus both arms. Commissioning follows a similar progression, with characterization in each locked configuration.

The PRM was locked early during the quarter using digital servo feedback. Measurements of the recycling factor in this configuration agreed with predictions from the Fast Fourier Transform (FFT) model.

Locking the PRM plus one arm requires feedback to the end test mass transmitted digitally the length of the arm. This was accomplished late in the quarter, with stable locking of the PRM and either arm. We are now testing the servo to lock the PRM and both arms.

Work planned next quarter

During the next quarter we plan to:

- lock the two-kilometer interferometer in its final optical configuration (power-recycled Michelson with Fabry-Perot arms) and begin commissioning,
- perform a one week Engineering Run with the two-kilometer interferometer,
- complete alignment of the optics for the Livingston interferometer,
- start the commissioning of the Livingston power-recycled near-mirror Michelson interferometer,
- start the installation of the suspended optics, and the pre-stabilized laser for the Hanford four-kilometer interferometer.

8.0 Data and Computing Group

8.1 Modeling and Simulation

8.1.1 End-to-End Simulation Environment:

Simulation engine. We added a number of enhancements to make the end-to-end interface more user-friendly. New features include:

- Mathematical expressions, such as $2\ atan(L/z_0)$, and $sin(\pi/3+\varepsilon)$, can now be entered anywhere as settings facilitating entry and comprehension.
- *Macro* is a new special feature which allows users to attribute a descriptive name to frequently used numbers (e.g., the modulation frequency) which may then be referenced by that name. We provide a system-wide macro file containing important LIGO parameters, but the user may also maintain his or her own file, which can then be used to override the system-wide definition.

New or improved modules include:

- *FUNC* is a special group of primitive modules that allows users to relate a number of inputs to outputs by explicitly writing mathematical equations in the settings. In earlier versions, simple mathematical manipulations sometimes needed very complex module connections.
- *Data-reader* reads time-series data from a previous simulation to provide appropriate inputs into the current simulation. This provides numerous advantages, especially for inputs to a fast optics simulation from a slower mechanical simulation.

- New optics modules, *Beam-wiggler* and *Beam-shifter,* perform rotation and transverse shift operations on the input laser beam.
- The module for the recycling summation cavity is important for rapid LIGO simulation. Several software bugs identified during validation have been fixed, and processing speed has been improved.

Mechanical subsystem modeling. We have finalized the interface between the Mechanical Simulation Engine (MSE) components and the end-to-end (*E2E*) environment. Dr. Giancarlo Cella, a VIRGO collaborator, has submitted his software into the *E2E* version control system, including sample codes and documents. A "black box" class was added that may be used to encapsulate a complete mechanical system interfaced in a standard way with *E2E*. Dr. Cella provided two systems wrapped in this new class: a simple suspended mass and the pre-stabilized laser (PSL) reference cavity. We calculated the convolution of the measured motion of the PSL table top and the MSE simulation of the reference cavity and generated a time-series data file of the mirror motion of the reference cavity.

We reorganized the time-domain simulation code and improved the code for thermal noise and structural damping. Unfortunately, limited resources prevented us from completing the full integration of MSE with *E2E*.

GUI Development. Last quarter we released the new version of *alfi* (the graphical user interface (GUI) front-end of the end-to-end environment), which fixes a number of software bugs and is now much more stable. We improved the graphical engine and made it easier to use. For example, a long string of data in settings (say, poles and zeros and their pairs in a digital filter) can now be conveniently entered via pop-up multi-line text-editors. We improved the node-tracking system of *alfi*, which tracks the hierarchy of box files. Code for important editing options, such as node deletion and renaming, has been cleaned up and debugged to make the inheritance of edited nodes more reliable and intuitive. Other user-friendly features have been added such as the addition of command line options where sensible. The hierarchical tree view access of all settings and parameters for individual nodes is nearing completion.

We added a semi-automated *alfi* test suite so that *alfi* can be tested more reliably following modifications.

Hardware/Software issues. The end-to-end software package, including the graphical user interface and the simulation engine, was successfully compiled and executed on a Compaq-Alpha *Linux* machine. The speed of a typical simulation was found to be roughly two times faster than on Sun Solaris platforms of comparable clock speed.

8.1.2 Modeling Applications During Detector Installation:

Lock Acquisition study. We have significantly improved the two-kilometer interferometer lock-acquisition code. It is now installed at the Hanford Observatory and can be run on the LIGO Scientific Collaboration (LSC) real-time front end. We improved the lock acquisition logic by using the ratio of the error signal and the transmitted power, instead of using the error signal itself. The lock acquisition time was dramatically reduced, at least in the simulation. Soon we will attempt to lock the full two-kilometer interferometer using this code.

We have also tested the locking sequence for a number different of mirror misalignments with different seeds in the random seismic noise. The statistics from these preliminary Monte Carlo studies demonstrate that it is possible and robust to lock the two-kilometer interferometer by controlling only the longitudinal motion for dynamic levels of misalignment as large as 10 nanoradians RMS in pitch/yaw in all mirrors with white-noise disturbances.

We have also conducted a number of studies on the detection mode of the locked state.

An “End User's Manual” has been prepared so that anyone interested in using the lock-acquisition code for the two-kilometer interferometer can use the program.

PSL study. We studied the time-domain simulation of the reference cavity in the pre-stabilized laser (PSL). We addressed issues related to shot-noise in reflected light error signals and investigated the contribution to the error signals of higher order modes, the finite-aperture size and non-uniformity of the photodetector, and the motion of the photodetector. Using the mechanical motion supplied by the model for this cavity, we found that the error signal maxima correspond to frequency modulations with amplitudes of the order of a few centiHertz or less. The largest contribution to the error signals is from the Doppler shift due to the longitudinal rigid-body motion of the entire cavity relative to the laser.

Seismic Stacks. We have completed the end-to-end models for Beam Splitter Chamber (BSC) and Horizontal Access Module (HAM) seismic stacks. They employ the pole and zero values (for a six degree-of-freedom transfer function matrix) supplied from a study conducted of the transfer functions of the two stacks.

Noise Curves. We can generate noise curves for the two-kilometer arm from time-domain simulation. They include seismic, shot, and thermal noise (only from the suspension and internal modes). We still need to include additional noise sources. We are presently attempting to generate the total limiting noise curves for full interferometers. This involves obtaining correct parameter values for the interferometer components and servos.

8.2 LIGO Data Analysis System (LDAS)

8.2.1 Software

System Level Development. We focused on threaded code development this quarter, critical to the successful operation of the *dataConditionAPI*[2] on symmetric multiprocessor (SMP) platforms. We heavily tested the use of threads in preparation for the *dataConditionAPI* mock data challenge conducted during the summer. We identified several conflicts related to our choices for compiler options and the version of TCL/TK being used. We analyzed these and modified common code layers, which handle threaded commands. We encountered an unexpected issue related to using multi-threaded code on Linux SMP platforms, which arises in two distinct classes of LDAS system level testing and appears to have a common origin. We expended significant energy tracking this problem down and have determined that the problem only occurs on multi-CPU Linux platforms (not Suns or single CPU Linux platforms). This may be a bug in the Linux ker-

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[2] API: refers to an Application Programmers Interface.

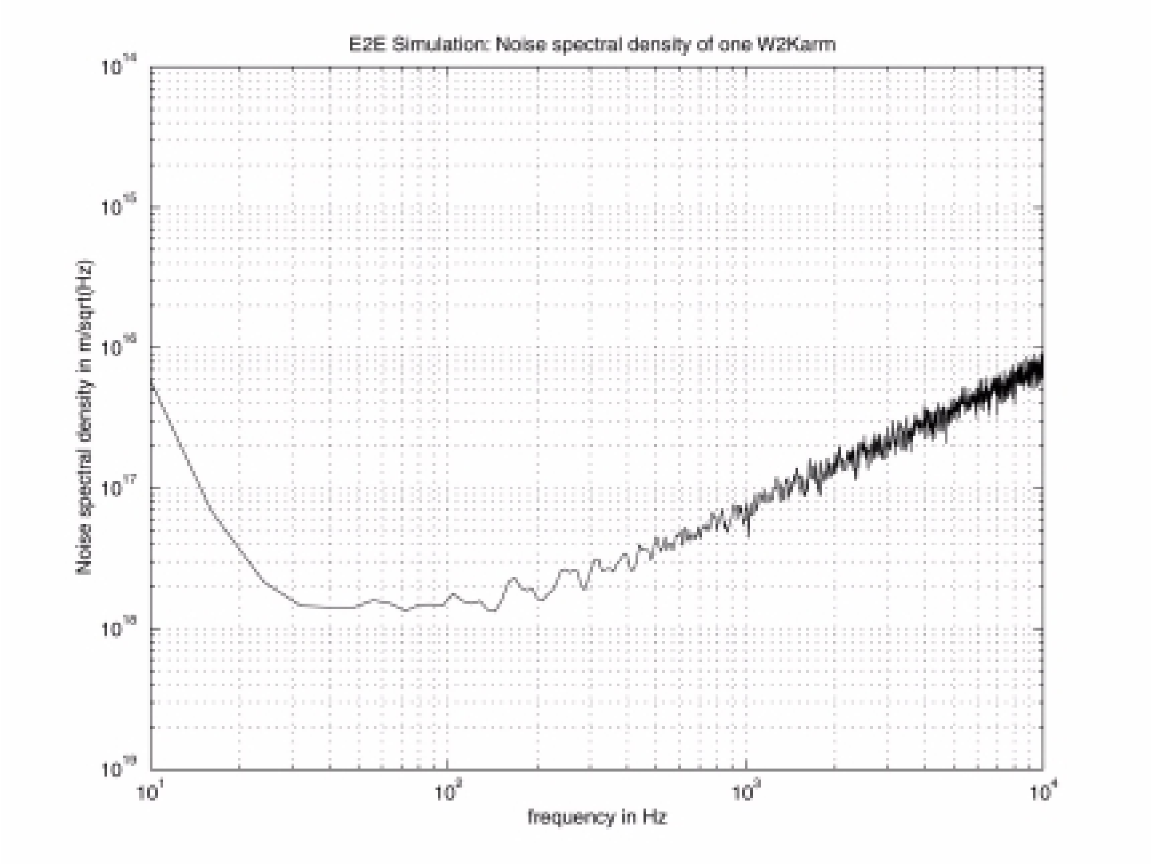

FIGURE 1. Noise curve for the two-kilometer arm from a time-domain simulation. It includes seismic, shot, and thermal noise (only from the suspension and internal modes).

nel. Future releases are expected to be more mature in the multi-CPU/multithreaded environment. The next release of a Linux kernel with superior SMP support is expected later this year.

The *dataConditionAPI* mock data challenge taught us a great deal about how users and operators of LDAS might interact with the system. We have captured this knowledge in enhanced web interfaces and extended the interfaces for data input and output using remote anonymous FTP[3] and URL[4] open *gets* and *puts*. The *controlMonitorAPI* has also matured significantly and now provides a window into the internal operations of the database, the LDAS BEOWULF[5], and individual user jobs. The *controlMonitorAPI* also has new interfaces to contact key LDAS staff members via email or pagers when system parameters or state variables exceed normal ranges.

We increased LDAS staff this quarter with the addition of a new system software test engineer. This staff member is working full time to implement a complete suite of integration and system test scripts which can be use to benchmark our progress and compatibility during this phase of rapid code development. We have tested functionality, performance, configuration, and build

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[3] FTP: File Transfer Protocol.

[4] URL: Uniform Resource Locator

[5] BEOWULF: a computing cluster consisting of PCs.

aspects of the system. As a result of this extra testing support, the LDAS problem tracking database system has experienced a problem reporting rate increase of several-fold over the prior baseline. Early identification of these problems will greatly enhance the team's ability to resolve and improve system reliability well in advance of the LIGO science run.

LDAS Parallel Analysis. A tremendous effort went into the design and development of the *wrapperAPI* this quarter. In mid-July, a dynamically loaded shared object prepared by the University of Wisconsin at Milwaukee ASIS group for conducting a flat binary inspiral search was successfully loaded at runtime and a search was carried out through the LDAS *wrapperAPI*. This was a significant milestone for the group and demonstrated the path for all future search code development between the LIGO Scientific Collaboration (LSC) and LIGO. Later in the summer a second dynamically loaded shared object developed by a Caltech summer undergraduate student to search for instrumental artifacts in arbitrary LIGO detector channels was also run under the *wrapperAPI*. It contained additional functionality to generate events ready for ingestion into the LDAS database as soon as a functional *eventMonitorAPI* is developed.

One of the key problem areas in the initial implementation of the LDAS *wrapperAPI* relates to the communications overhead. All distributed and parallel programs pay a huge nonlinear penalty for communications. As a result of close interaction between the key staff software engineers and staff scientists, the *wrapperAPI* communications overhead was reduced by factors of tens of thousands. Now communications costs can be made almost nonexistent using runtime customization of the *wrapperAPI* communications flow.

Successes achieved this summer during the integration of two unique dynamically loaded search algorithms underscored a need to revisit the overall design of the *wrapperAPI*. A collaboration of senior LDAS staff members, the LSC Software Committee Chairman, and the mock data challenge Chairman accomplished this review. The outcome is a revised *wrapperAPI* that will be developed during the next quarter and should be better suited for the combined needs of LDAS and the LSC users.

LDAS *dataConditioningAPI*. The mock data challenge for the *dataConditionAPI* began the first week of August. Software development staff provided an infrastructure for a “data conditioning command language” with a simple syntax resembling Matlab's to provide an interface between the Tcl[6] layer and the data conditioning classes. For several weeks prior to the mock data challenge we wrote code to interface the C++ data conditioning classes with the Tcl layer via the command language.

We conducted intensive test to check

- the numerical accuracy of the data conditioning algorithms,
- performance (speed of calculation, memory usage),
- pipelining, i.e., performing a series of operations on data, using the output of one as the input to the next,

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[6] Tcl: Tool command language is a simple textual language and a library, intended primarily for issuing commands to interactive programs such as text editors, debuggers, illustrators, and shells. It has a simple syntax and is also programmable, so Tcl users can write command procedures to provide more powerful commands than those in the built-in set. Source: FAQ page at http://www.neosoft.com/tcl/whatistcl.html.

- error handling and error recovery, and
- the ability to handle very large datasets, i.e., “stress tests.”

The components tested were

- basic vector operations, e.g., slicing, vector/vector math, vector/scalar math,
- summary statistics,
- Fourier transforms,
- estimates of power spectral density,
- mixing,
- resampling,
- linear filtering

The tests revealed numerous bugs, most of which were fixed during the mock data challenge; others that were less critical were recorded in the GNATS bug tracking system to be fixed later, and are now being fixed.

Since other LSC scientists may wish to develop code for the *dataConditionAPI*, we have drafted a Developer's Guide describing our conventions and standard practices for writing data conditioning classes. The intent is that all such classes will have a common style and interface where possible to reduce the learning curve for new developers. We have also started revising the LDAS C++ coding standard to conform to current practices. This has a broader scope than the developer's guide since it is applicable to the whole LDAS project.

A student implemented a very fast multidimensional Fast Chirp Transform (FCT) using the LIGO Analysis Library (LAL) standard. We were then able to write code to process frame data. The current LAL code for reading frame data is experimental and only works for 40-Meter frame files, so we are experimenting with modifications to GRASP (Gravitational Radiation Analysis Software Package) to read frame files.

We worked with Professor Bernard Whiting (University of Florida) to convert prototype frequency binning code to the LIGO Analysis Library (LAL) format for eventual inclusion in the LAL. This code will provide the following functionality:

- generic code for efficiently accumulating a variety of data types into histograms (e.g., INT_2S for analog-to-digital conversion counts, REAL_4 for processed data),
- statistics for histograms, e.g., mean, variance, likelihood ratio, chi-squared,
- means for binning frequency coefficients. This is a routine which repeatedly takes a time-series as input and accumulates histograms (one for each frequency) of the power distribution at each frequency.

Commissioning the full LIGO interferometer and doing meaningful scientific analysis will require several different modes of access to LIGO data. In addition to the use of data within the LDAS system itself, we must also make data available to “external” programs and stand-alone tools. Retrieving and distributing data from the archives efficiently is not trivial. We developed a plan to create a “Data Flow Manager” that will unify access to the various LIGO data repositories and provide Unix command-line, C/C++, and Matlab interfaces. In addition, it will support the existing *DataViewer* and Diagnostics Test Tools. Implementation of the Data Flow Manager program and the associated interfaces will proceed over the next several months, with functionality added as needed.

Although graphical interface tools such as the DataViewer and Diagnostic Test Tools are very useful for examining the raw data and processing it in a few standard ways, there is a practical limit to what they can do. Some investigations require processing a larger amount of data, e.g. to investigate a list of transient events or to calculate a sequence of power spectra, while others require more sophisticated manipulation of the data. A common need is for automated access to the data, and the ability to process in a pipelined fashion. LIGO would benefit from choosing a standard “environment” for doing these kinds of investigations, so that software and expertise can be shared. Several possible solutions were evaluated from commercial tools to custom-built software. Based in part on learning-curve considerations, a dual recommendation was made to the LSC to concentrate on Matlab (which is familiar to many LSC members) and on C++ programs using the LIGO Data Monitoring Tool libraries. The latter approach also allows processing to be done within the ROOT environment, which some LSC members favor.

LDAS Database Mock Data Challenge. The LDAS software components related to the “metadata” database have now reached maturity. A “Mock Data Challenge” (MDC) has been planned with the dual primary goals of:

- rigorously testing the functionality and performance of the core database system, and
- implementing a set of user interface tools to facilitate productive use of the database.

A task list has been drafted and an appeal issued to LSC members to participate (especially in the area of user interfaces) alongside the LDAS personnel who are responsible for the core system. The MDC is expected to be complete by December 2000.

8.2.2 Hardware

A resident LDAS staff scientist/system administrator has been hired at the Hanford Observatory.

We prepared the floor plan for the Beowulf cluster. The plan includes space for various tape library systems. We prepared detailed drawings of the layout and obtained site planning information for the installation of various tape library systems. Planning for power and air conditioning requirements is in process.

We have hired an LDAS data archive administrator who is currently working at CACR to gain experience in managing High Performance Storage Systems (HPSS).

We are planning to move LDAS from Asynchronous Transfer Mode (ATM) to Gigabit Ethernet. We plan to install a few kilometers of single mode fiber and test two Foundry Networks Gigabit switches.

We have obtained a suitable machine room with sufficient power, cooling, and raised floor tiles to install the test and main archive LDAS systems.

8.3 General Computing

LIGO has contacted the Internet2 organization to begin the process of upgrading the wide area network (WAN) from T1 to OC3. The plan is for the LIGO Observatories to become sponsored by Caltech/ITS, thereby gaining peering privileges over Abilene and Internet2. Further discussions with BellSouth, the Internet2 representatives, Abilene representatives and Pacific Northwest National Labs (PNNL) are needed over the next several months. These discussions will focus on the logistics and the cost of service for an OC3 link to the internet.

9.0 Project Management

9.1 Project Milestones

The status of the project milestones identified in the Project Management Plan for the LIGO Facilities is summarized in Table 2. **All Facilities milestones have been completed.**

TABLE 2. Status of Significant Facility Milestones

Milestone Description	Project Management Plan Date[a]		Actual (A)/Projected (P) Completion Date	
	Washington	Louisiana	Washington	Louisiana
Initiate Site Development	03/94	08/95	03/94 (A)	06/95 (A)
Beam Tube Final Design Review	04/94		04/94 (A)	
Select A/E Contractor	11/94		11/94 (A)	
Complete Beam Tube Qualification Test	02/95		04/95 (A)	
Select Vacuum Equipment Contractor	03/95		07/95 (A)	
Complete Performance Measurement Baseline	04/95		04/95 (A)	
Initiate Beam Tube Fabrication	10/95		12/95(A)	
Initiate Slab Construction	10/95	01/97	02/96 (A)	01/97 (A)
Initiate Building Construction	06/96	01/97	07/96 (A)	01/97 (A)
Accept Tubes and Covers	03/98	03/99	03/98 (A)	10/98 (A)
Joint Occupancy	09/97	03/98	10/97 (A)	02/98 (A)
Beneficial Occupancy	03/98	09/98	03/98 (A)	12/98 (A)
Accept Vacuum Equipment	03/98	09/98	11/98 (A)	01/99 (A)
Initiate Facility Shakedown	03/98	03/99	11/98 (A)	01/99 (A)

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[a] Project Management Plan, Revision C, LIGO-M950001-C-M submitted to NSF November 1997.

Table 3 shows the actual and projected status of the significant Project Management Plan milestones for the Detector. Every effort has been made to prioritize critical-path tasks as required to support Detector installation. The “Begin Coincidence Tests” milestone has been slipped to March 2001.

TABLE 3. Status of Significant Detector Milestones

Milestone Description	Project Management Plan Date		Actual (A)/Projected (P) Completion Date	
	Washington	Louisiana	Washington	Louisiana
BSC Stack Final Design Review	04/98		08/98 (A)	
Core Optics Support Final Design Review	02/98		11/98 (A)	
HAM Seismic Isolation Final Design Review	04/98		06/98 (A)	
Core Optics Components Final Design Review	12/97		05/98 (A)	
Detector System Preliminary Design Review	12/97		10/98 (A)	
Input/Output Optics Final Design Review	04/98		03/98 (A)	
Pre-stabilized Laser (PSL) Final Design Review	08/98		03/99 (A)	
CDS Networking Systems Ready for Installation	04/98		03/98 (A)	
Alignment (Wavefront) Final Design Review	04/98		07/98 (A)	
CDS DAQ Final Design Review	04/98		05/98 (A)	
Length Sensing/Control Final Design Review	05/98		07/98 (A)	
Physics Environment Monitoring Final Design Review	06/98		10/97 (A)	
Initiate Interferometer Installation	07/98	01/99	07/98 (A)	01/99 (A)
Begin Coincidence Tests	12/00		03/01 (P)	

9.2 Financial Status

Table 4 on page 15 summarizes costs and commitments as of the end of August 2000.

9.3 Performance Status (Comparison to Project Baseline)

Figure 2 on page 16 is the Cost Schedule Status Report (CSSR) for the end of August 2000. The CSSR shows the time-phased budget to date, the earned value, and the actual costs through the end of the quarter for the NSF reporting levels of the Work Breakdown Structure. The schedule variance is equal to the difference between the budget-to-date and the earned value, and is a measure in dollars of the ahead (positive) or behind (negative) schedule position. The cost variance is equal to the difference between the earned value and the actual costs. In this case a negative result indicates an overrun. Figure 3 on page 17 shows the same information as a function of time for the top level LIGO Project.

TABLE 4. Costs and Commitments as of the end of August 2000

(all values are $Thousands)

WBS		Costs Thru Nov 1997	Costs LFY 1998	Costs LFY 1999	First Quarter LFY 00	Second Quarter LFY 00	Third Quarter LFY 00	Cumulative	Open Encumbrances
1.1.1	**Vacuum Equipment**	30,517	11,406	2,114	10	1	(0)	44,047	0
1.1.2	**Beam Tube**	32,978	13,273	753	-	-	-	47,004	-
1.1.3	**Beam Tube Enclosure**	13,274	6,145	153	-	-	(233)	19,338	-
1.1.4	**Civil Construction**	44,681	6,563	1,513	313	(200)	729	53,598	179
1.1.5	**Beam Tube Bake**	75	3,078	1,845	178	233	88	5,498	143
1.2	**Detector**	14,340	20,537	17,898	1,619	1,156	653	56,203	959
1.3	**Research & Development**	19,681	1,661	713	33	13	(0)	22,100	52
1.4	**Project Management**	22,649	4,914	1,525	343	261	61	29,753	203
7LIGO	**Unassigned**	1	18	13	-	-	-	32	-
TOTAL		178,196	67,595	26,527	2,495	1,464	1,297	277,573	1,535
Cumulative Actual Costs		178,196	245,791	272,318	274,813	276,276	277,573		
Open Commitments		62,510	16,422	7,078	4,726	2,762	1,535		
Total Costs plus Commitments		240,706	262,213	279,396	279,538	279,038	279,109		
NSF Funding - Construction		*$ 265,089*	*$ 291,900*	*$ 292,100*	*$ 292,100*	*$ 292,100*	*$ 292,100*		

Note: “Unassigned” Costs have not been assigned to a specific LIGO Construction WBS but are continually reviewed to assure proper allocation.

FIGURE 2. Cost Schedule Status Report (CSSR) for the End of August 2000.

LIGO Project

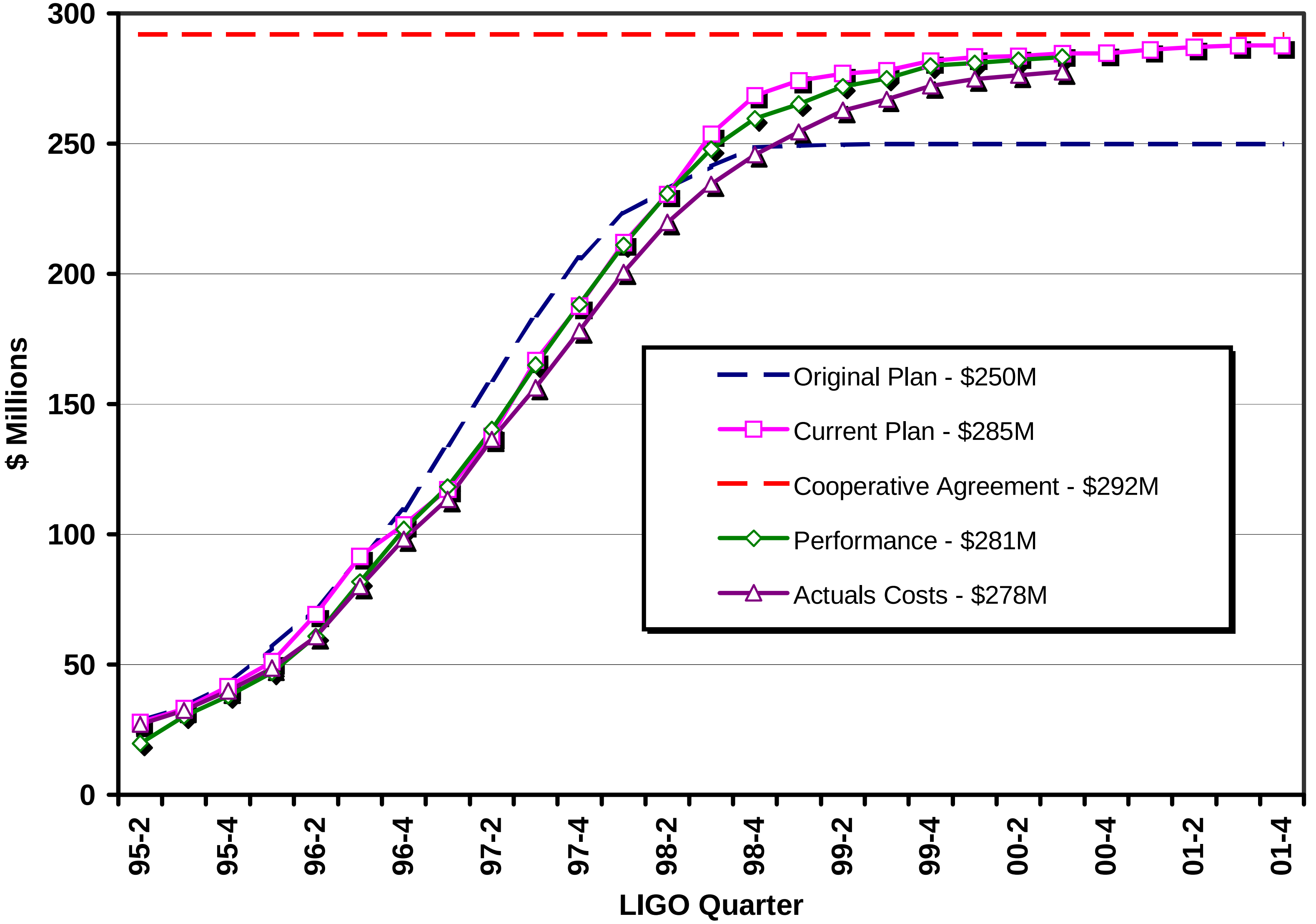
Cost Schedule Status Report (CSSR)

Period End Date: August 2000

(All values are $Thousands)

Reporting Level	Cumulative To Date					At Completion		
Work Breakdown Structure	Budgeted Cost of Work Scheduled (BCWS) (1)	Budgeted Cost of Work Performed (BCWP) (2)	Actual Cost of Work Performed (ACWP) (3)	Schedule Variance (2-1) (4)	Cost Variance (2-3) (5)	Budget-at-Completion (BAC) (6)	Estimate-at-Completion (EAC) (7)	Variance-at-Completion (6-7) (8)
1.1.1 Vacuum Equipment	43,970	43,970	44,047	-	(77)	43,970	44,047	(77)
1.1.2 Beam Tubes	46,967	46,967	47,004	-	(37)	46,967	47,004	(37)
1.1.3 Beam Tube Enclosure	19,338	19,338	19,338	-	-	19,338	19,338	-
1.1.4 Facility Design & Construction	53,722	53,656	53,598	(66)	58	54,055	54,000	55
1.1.5 Beam Tube Bake	5,695	5,695	5,498	-	197	5,695	5,498	197
1.2 Detector	60,252	59,122	56,203	(1,130)	2,919	60,252	59,752	500
1.3 Research & Development	22,089	22,089	22,100	-	(11)	22,089	22,100	(11)
1.4 Project Office	32,495	29,753	29,753	(2,742)	-	35,509	35,509	-
Subtotal	284,528	280,590	277,541	(3,938)	3,049	287,875	287,248	627
Contingency						-	4,852	(4,852)
Management Reserve						4,225	-	4,225
Total	284,528	280,590	277,541	(3,938)	3,049	292,100	292,100	-

FIGURE 3. LIGO Construction Performance Summary as of the End of August 2000.



Vacuum Equipment (WBS 1.1.1). All work is completed.

Beam Tube (WBS 1.1.2). The Beam Tube is complete. All Beam Tube installation was successfully completed ahead of schedule.

Beam Tube Enclosures (WBS 1.1.3). The contract for the Hanford site is complete. Contract closeout is pending resolution of litigation regarding state tax issues. The contract for Livingston is complete.

Civil Construction (WBS 1.1.4). The original scope for Civil Construction has been completed. Additional scope has been budgeted for site improvements that were initially removed from the scope to conserve contingency. An invitation for bid has been issued for the Storage and Staging Building at Livingston.

Beam Tube Bake (WBS 1.1.5). The beam tube bake has been completed. The projected favorable completion includes reduced power costs.

Detector (WBS 1.2). Washington Two Kilometer Interferometer--Installation of the Two Kilometer Interferometer is complete. The laser system is installed and operational. We have installed and aligned all suspended optics. All of the output optics are in place. The data acquisition and global diagnostics systems are installed. We have also installed the initial complement of servo control electronics and sensors. The laser locks to the Mode Cleaner routinely and robustly. The vertex Michelson has been locked, by itself and with either one of the two arm cavities. Testing of the control systems for locking the entire interferometer is underway.

Livingston Four Kilometer Interferometer--We have installed all in-vacuum components including the suspended optics. The laser system is installed and operational, and it has been locked to the mode cleaner and characterized. We have installed the length and alignment control systems. Final alignment of the suspended optics is underway. First tests of the Power-recycled Michelson interferometer are expected to begin in November.

Washington Four Kilometer Interferometer--We have installed the seismic isolation system and the data acquisition and global diagnostics systems (shared with the two kilometer interferometer) are in place. The basic strategy has been staggered overlapping installation at both sites focusing on the two-kilometer interferometer at Hanford and the four-kilometer interferometer at Livingston. Installation and commissioning of the four-kilometer interferometer at Hanford has been deliberately delayed to make the best use of available resources as well as lessons learned on the first two interferometers.

In spite of impressive progress, the Detector continues to be behind schedule. There have been a number of minor delays, including start-up problems with the production of seismic isolation components; adhesion problems for the magnet/stand-off assembly for the optics; handling and fixture problems for the completed suspension assemblies; loss of critical-path Fluorel components in a tornado in Oklahoma; a decision to re-bake the seismic stack springs to mitigate water outgassing; and a number of secondary (non-critical path) delays. The cumulative effect is that detector commissioning is approximately three months behind schedule. We continue to adjust priorities to assure that critical milestones are met.

A significant portion of the favorable cost variance is due to normal delays associated with the recording actual costs.

Research and Development (WBS 1.3). All LIGO I Construction Related Research and Development effort is complete.

Project Office (WBS 1.4). All LIGO I Project Office activities are complete with the exception of the procurement of computer hardware associated with the LIGO Data Analysis and Computing System (LDAS). These procurements have been delayed to achieve the maximum performance per dollar ratio.

9.4 Change Control and Contingency Analysis

The following six change requests were approved during the quarter. As a result the budget baseline for LIGO Construction was increased by $330,368 to $287.9 million. This leaves a contingency (relative to the budget baseline) of $4.2 million. We are forecasting a $627K underrun relative to the budget baseline so that the contingency relative to the estimate-at-completion is $4.9 million.

TABLE 5. LIGO Construction Change Control Board Activity During Quarter

CR Number	WBS	Description	Amount
CR-990028	1.1.3	Beam Tube Enclosure Contract Underruns (Unused Overtime, etc.)	(452,432)
CR-000005	1.2.1	Upgrade Prestabilized Lasers	215,000
CR-000008	1.1.4	Cameras and Projection System for Livingston Observatory	26,000
CR-000009	1.1.4	Cameras and Projection System for Hanford Observatory	26,000
CR-000015	1.1.4	Upgrade Roads Along Beam Tube Enclosure at Hanford Observatory	300,000
CR-000016	1.4.3	Early Installation of LINUX Clusters at Sites and Caltech	215,800
		Total	330,368

9.5 Staffing

The LIGO staff currently numbers 139 (full time equivalent). Of these, 24 are contract employees. Eighty-four LIGO staff are located at CIT including seven graduate students. Sixteen are located at MIT including five graduate students. Twenty-three are now located at the Hanford, Washington site, and 16 are assigned to Livingston, Louisiana. LIGO staff is partially paid by the LIGO Advanced Detector R&D Program, PHY-9801158.