Quarterly Progress Report

(End of February 2001)

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

NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M010047-00-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 February 2001.

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 97.1 percent complete as of the end of February 2001.

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 are 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. Litigation regarding charges by the subcontractor for sales taxes has been dropped in favor of LIGO.

---

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. An Architect/Engineering firm, NTD Architects of Glendora, CA, has been selected to design additional Office and Laboratory building including an auditorium and other facilities for outreach activities. No additional Construction funds will be required.

Louisiana Civil Construction. Construction of the facilities is complete and the contracts are closed. Erosion control and landscaping are complete. We issued a contract during this quarter to Brunt Construction Company of Independence, LA for the construction of the Staging and Storage Building, and work is in progress.

6.0 Beam Tube Bakeout

We completed the bake of all four Beam Tube modules at Hanford during 1999 and finished the final module at the Livingston site in June 2000. One module at Livingston (LY1) appears to have a very small leak. Attempts to localize and repair this leak were unsuccessful because the leak rate is so small. We will continue to monitor the vacuum in this module to determine if some future action is necessary. At this time, the magnitude of this leak does not present an obstacle to continuing commissioning activities.

7.0 Detector

The Detector group is focusing on installation and commissioning at the observatories. Design revisions based on commissioning experience are being carried out as a parallel activity. The highest priority has been to accelerate the commissioning and testing of the first two interferometers--the two-kilometer at Hanford and the four-kilometer at Livingston--so that lessons learned during commissioning can be incorporated into later installations.

7.1 Installation and Commissioning Progress Overview

The installation highlights for the past quarter are:

- We achieved stable lock of the Hanford two-kilometer interferometer in the full power-recycled Michelson configuration with both Fabry-Perot arms.
- We continued commissioning the Livingston four-kilometer interferometer. The two arm cavities have been separately locked to the laser for periods of up to several hours.
- We participated in the third engineering run held March 9-12, with coincident data collection between the Livingston interferometer locking a single arm and the environmental monitors at Hanford.

- We started installation of in-vacuum components for the Hanford four-kilometer interferometer (see article in the LIGO Newsletter: http://www.ligo.caltech.edu/LIGO_web/0102news/0102han.html#Article_1).

FIGURE 1. Mirror Installation Begins on Four-Kilometer Interferometer at Hanford.

At the end of the quarter, a magnitude 6.8 earthquake (the strongest in Washington State since 1949) struck near Olympia. The shaking was severe enough to break control magnets off some of the suspended optics in the two-kilometer interferometer. Repairs were initiated immediately, and initial estimates indicate a two month delay.

7.2 Lasers and Optics

7.2.1 Pre-Stabilized Laser

Both the Hanford two-kilometer and Livingston four-kilometer Prestabilized Lasers are in regular use and undergoing incremental change and improvement. We have achieved significant improvements in the frequency noise mainly through changes in the opto-mechanical design and the acoustic/vibration shielding. In the most important region of the noise spectrum, vibration and acoustic driven noise sources continue to dominate and are still under investigation.

Using experience gained during the earlier two lasers, we began assembly of the Hanford four-kilometer Prestabilized Laser using a streamlined (simplified) optical layout. The pre-mode cleaner and the reference cavity for the frequency stabilization servo have been installed on the table and locked. Most of the electronics have been installed and are under the control of EPICS[2].

---

[2] EPICS: a set of software tools and applications used worldwide to develop distributed soft real-time control systems for scientific instruments such as a particle accelerators, telescopes and other large scientific experiments (http://www.aps.anl.gov/epics/).

7.2.2 Input Optics

The Mode Cleaners for the Hanford two-kilometer interferometer and Livingston four-kilometer interferometer continue to function reliably supporting other commissioning activities and to play a key role in understanding the prestabilized laser performance.

We revised the servo system for locking the prestabilized laser to the mode cleaner to provide greater margin and to allow us to move the cross-over frequency between the feed back to the mode cleaner and feedback to the laser to lower frequencies. This should improve the filtering of the laser frequency fluctuations by the mode cleaner by more than a factor of 1000 in the most sensitive part of the gravitational wave band. We will resume testing as soon as the two-kilometer earthquake repairs are complete.

We have completed installation of the Input Optics components that modulate and condition the laser beam for the Hanford four-kilometer interferometer before it enters the vacuum system. Installation and alignment of the in-vacuum Input Optics components for the Hanford four-kilometer interferometer has begun.

7.2.3 Core Optics Components

We have characterized all core optics for the three interferometers, and they have been delivered to the sites for installation. Effort continues to characterize the spare optics in the event they are needed.

7.2.4 Core Optics Support

We completed the installation and alignment of all core optics support components for the Hanford two-kilometer and Livingston four-kilometer interferometers last year.

At Hanford, we started installation of the core optics support components for the four-kilometer interferometer. The in-vacuum telescopes for reducing the beams to bring them out of the vacuum system have been installed and aligned. The only components remaining to install are the telescope and baffle at the Y end-station.

7.3 Isolation

7.3.1 Seismic Isolation System

We completed the in-vacuum seismic isolation system installation last year. This quarter we finished the design of the fine actuator system to be used to correct for the tidal motion. We are installing the control electronics for the two-kilometer interferometer and will begin testing as soon as the earthquake repairs are complete.

7.3.2 Suspensions

This quarter we started installing and aligning the large optic suspensions for the Hanford four-kilometer interferometer. These suspensions incorporate a new design for the sensors used for local damping of the suspended optics. The previous design had proven susceptible to stray Nd:YAG light from the main laser, which can cause misalignment of the optics as the interferometer is locked and the laser light builds up in the cavities. The sensors on the other two interferometers will be replaced with the new sensors in conjunction with earthquake repairs for the two-kilometer interferometer and with other planned in-vacuum activities at Livingston. We are also developing a second possible solution to this scattered light problem, a modulation-demodulation technique, in case added immunity is required. Studies of the diagonalization of the sensor-actuator matrices with the new sensor heads have verified that they perform at least as well as the earlier version.

7.3.3 Control and Data Systems (CDS)

The contributions of the Control and Data Systems (electronics and software) group are ongoing and essential during installation and commissioning of the subsystems and during system level testing. The data acquisition system is operating at both sites. A comparison of the timing marks in the data streams from the two sites provided an important test during the recent engineering run. During the three-day run, the timing signals experienced a few steps of up to 50 microseconds. The cause is under investigation.

We have enhanced the two-kilometer length control system servo to support the lock acquisition program. We added the option of damping the angular motions of the optics using optical levers to circumvent the sensitivity of the suspension sensors to the laser light. The length and alignment controls for the Livingston interferometer have been installed and used to lock the arm cavities.

We have redesigned the suspension controllers 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 is digital to increase flexibility. The controller works with the existing suspensions and only minimal incursion into the vacuum is needed. A prototype has been fabricated and tested on one of the Hanford four-kilometer optics. All of the Hanford four-kilometer optics will use this new controller, and the other two interferometers will be retrofitted as opportunities arise.

7.4 Physics Environment Monitoring System

The Physics Environment Monitoring system is now functional and in regular use. Trend data (e.g., seismic activity) are regularly compiled and reviewed for anomalies or correlations with interferometer data. Verification and calibration of signals is ongoing at both sites.

7.5 Global Diagnostics System

We routinely use the Global Diagnostics tools, along with the CDS data acquisition system, to support commissioning activities. We have enhanced these tools to permit their use from outside of the main interferometer computer network.

At the two sites we are also routinely running the Data Monitoring Tool, which is designed to keep up with the full data rate while scanning for signatures of problems and optimizing the instruments. A number of monitors written by LSC collaborators have been integrated into the Data Monitor Tool environment.

7.6 Interferometer Sensing and Control

We improved the length controls for the Hanford two-kilometer interferometer to be used for the full interferometer configuration to enable us to lock the full interferometer. We installed, tested, and began using digital and analog filters to extend the dynamic range of the analog-to-digital converters used to sample the main interferometer locking signals.

We have also started using portions of the wavefront-sensing alignment system for the two-kilometer interferometer to improve the stability and robustness of the lock. Commissioning and testing of the full system continues as an ongoing activity.

We have installed the initial configuration of the Livingston sensing and control system and used it to lock the individual arms of the four-kilometer interferometer. The output beams from the interferometer have been aligned onto the optical tables that contain the various length and alignment photodetectors; verification and characterization of these signals is underway.

7.7 System Level Commissioning/Testing

Commissioning activity was significant at both observatories this quarter. At Hanford, the focus was on improving the locking of the two-kilometer interferometer. The locking of the full interferometer proceeds in steps: first the power-recycled Michelson (PRM), then the PRM plus one arm, then the PRM plus both arms. We improved the automated program to sequence the control system through these stages, resulting in relatively efficient lock acquisition and enough robustness to hold lock for periods up to one hour.

With the two-kilometer interferometer locking stably, we shifted our attention to understanding and improving the noise spectrum. The best noise spectrum obtained prior to the earthquake is shown in Figure 2 along with two known contributors: frequency noise in the light entering the interferometer, and electronics noise in the photodetector (dark noise). Both of these problems were being studied when the earthquake struck.

During this quarter we made the first attempts locking the long arm cavities at Livingston. We first verified initial pointing of the laser beam and correct orientation of the suspended optics. The next step was to lock each arm to the laser separately. This exercises the sensors, the communication between buildings, and the software and hardware for actuating on the test masses. Then we locked the Michelson plus one arm as a first step toward measuring parameters for the lock acquisition program. This work is ongoing. We gained insights into the differences in ground motion between the two sites and have begun to consider how best to tailor the servo systems to deal with these differences.

The third Engineering Run (E3) is scheduled in March. This Engineering Run is planned as a coincidence run between the two-kilometer interferometer at Hanford and a single four-kilometer arm at Livingston. Unfortunately, the earthquake occurred just prior to the run and the two-kilometer interferometer became unavailable. We still plan to complete the engineering run, but the data from Hanford will be limited to environmental data (of interest to understand correlated noise). Significant LSC participation is anticipated at Livingston.

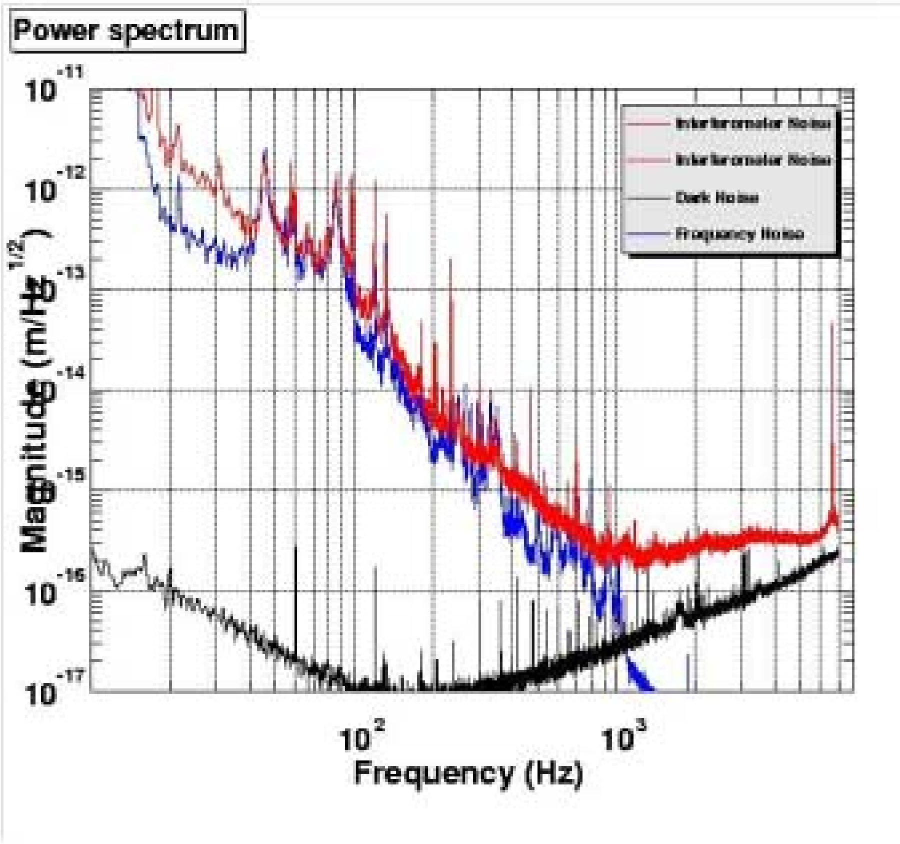

FIGURE 2. The best noise spectrum with two known contributors: frequency noise in the light entering the interferometer, and electronics noise in the photodetector (dark noise).

7.8 Work planned next quarter:

During the next quarter we plan to:

- complete the in-vacuum installation of the Hanford four-kilometer interferometer,
- complete the earthquake repairs to the Hanford two-kilometer interferometer and return it to operation,
- lock the full Livingston interferometer and start its commissioning,
- perform an Engineering Run with the Livingston four-kilometer interferometer operating with recombined arms.

8.0 Data and Computing Group

8.1 Modeling and Simulation

8.1.1 Applications

Lock Acquisition Studies. During this quarter we updated the code used to calculate the control matrix and used it in the two-kilometer interferometer length sensing and control (LSC) servo at Hanford. The new version simplifies the calibration of parameters. With improved control of mirror alignment, we successfully locked the Hanford two-kilometer interferometer without reducing the arm finesse. We are preparing a revision of the document entitled “Automated Control Matrix System.”

We studied lock-acquisition in the presence of uncontrolled fluctuations in mirror alignment. Using the results from a large number of simulation runs, we ordered the effects of zero-mean angular fluctuations of different mirrors (assuming a zero DC angular offset). The resulting order from most harmful to least harmful (in terms of percentage of locked time) is: (i) beam splitter, (ii) input mirrors, (iii) recycling mirror, and (iv) end mirrors. This can be seen in Figure 3 on page 9. If the magnitude of angular fluctuation is small, these distinctions are not important. However, their effects become prominent as the misalignments approach critical values for acquiring lock.

In the presence of DC angular misalignments (in the presence of zero-mean angular fluctuations), power fluctuations in the locked state increase along with a drop in the duration of lock. This is accompanied by an obvious drop in the locked state power. We have systematically studied the tolerance of various states in the lock-acquisition sequence to increasing levels of angular fluctuations.

In-Lock State Noise Simulation. We studied the in-lock state noise using the *Han2k* program (the end-to-end model for the Hanford two-kilometer detector). The model included seismic noise, thermal noise, and shot noise. We simulated the seismic noise by a parameterized seismic motion, a stack transfer function, and a one-dimension pendulum model. The thermal noise simulation is based on frequency domain formulas. We included only longitudinal wire and internal noise in this simulation. A Poisson distribution whose average is determined by the instantaneous power on the photo diode simulates the shot noise.

Due to the steep frequency dependence of the seismic noise filtering provided by the stack and pendulum, the power spectral density (PSD) calculation needed special care. To calculate the PSD efficiently, we developed a new primitive module. For a given frequency range and resolution, this module determines the optimum time step and duration to calculate one PSD. An optional band pass filter can be specified, which is needed for the calculation of a PSD above 10 Hz. As the simulation runs, the primitive module improves the statistical fluctuation of the PSD by repeating the calculation. This emulates the functioning of a spectrum analyzer.

The sensitivity curve was calculated using the length-control force for the region of high gain, i.e., below a few 100 Hz, and using the quad-demodulated dark port error signal for the high frequency region. We calculated the signal-to-displacement calibration using the respective transfer functions. Figure 4 on page 10 shows the sensitivity curve based on these calculations. In the fig-

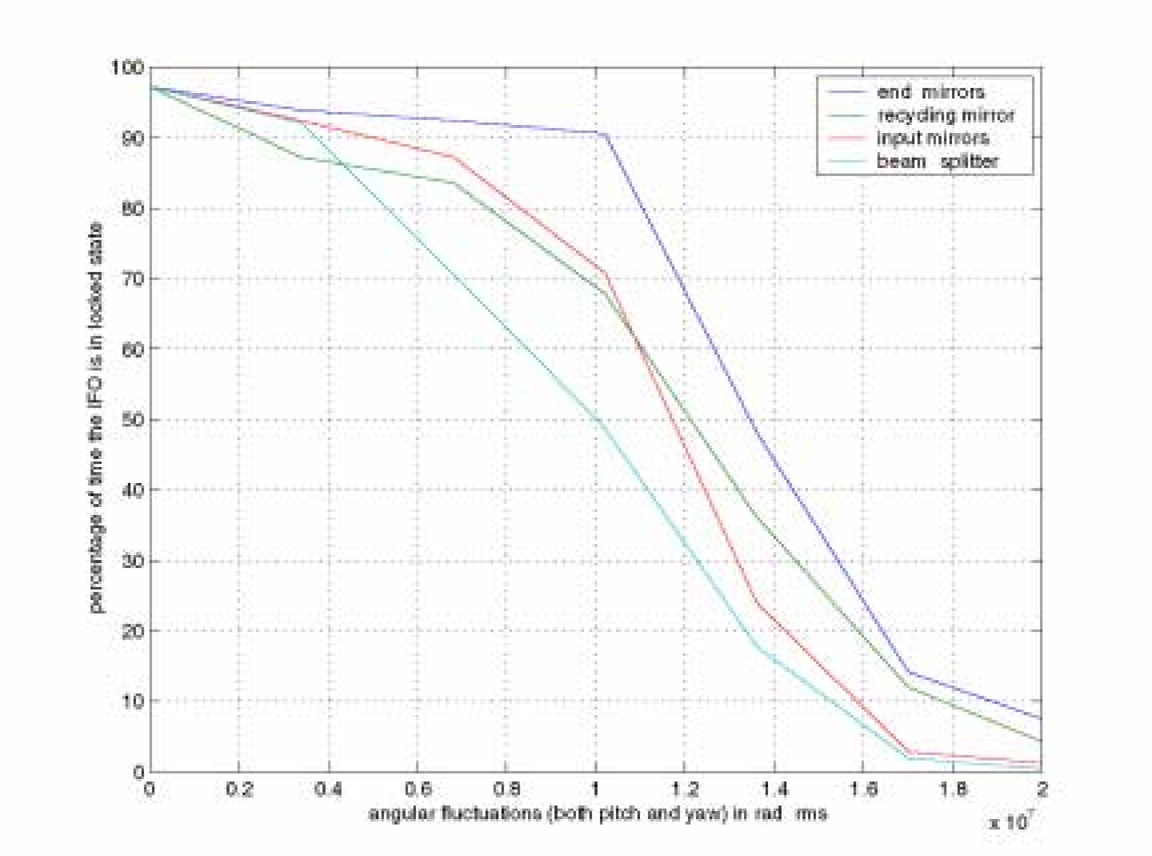

FIGURE 3. Robustness of Lock Acquisition in the presence of uncontrolled mirror alignment fluctuations.

ure, the dashed line shows the sensitivity based on the length-control force, and the solid line shows that based on the dark port error signal.

Data Analysis. In December, at the time of the Gravitational Wave Data Analysis Workshop (GWDAW) at Louisiana State University, we began discussing how the simulation program could be used to provide data analysis support. This is especially important for various upper limit groups in the LIGO Science Collaboration (LSC). We had deferred this due to a lack of resources. We invited input from LSC members and the upper limit study group leaders, and encouraged their assistance implementing the necessary modifications. Preliminary investigations using *Han2k* have started.

8.1.2 Code Improvement

We have undertaken several efforts to improve the code:

- We developed software to permit the simulation engine to perform calculations in parallel using threads.
- The LAPACK (Linear Algebra Package) library, a suite of routines written in Fortran77 to solve systems of simultaneous equations, is available on both our SUN machines at LIGO and on the Caltech Center for Advanced Computing Research (CACR) HP machine. We have com-

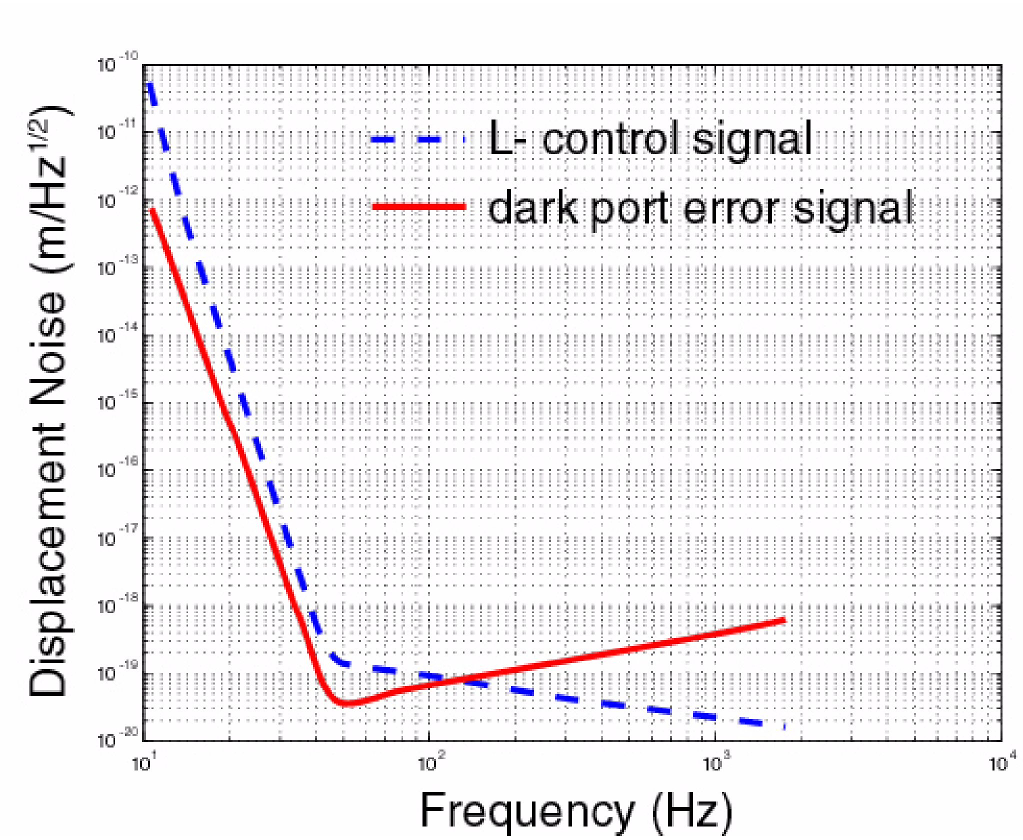

FIGURE 4. The sensitivity curve based on the length-control force for the region of high gain, i.e., below a few 100 Hz, and the quad-demodulated dark port error signal for the high frequency region.

pared the speed of our “home-grown” matrix code and the LAPACK routines. LAPACK outperformed our code, and did so by a large factor for the calculation of large matrices. The speed of LAPACK for calculating a complex matrix is only modestly slower than for real matrices, while our code suffers large performance degradation for complex matrices. We are integrating our matrix class and LAPACK.

8.1.3 Graphical User Interface - *alfi*

We have adopted a new version of *wxWindow*, the underlying graphics library used in *alfi*, and minor *alfi* code problems that resulted were fixed. *wxWindows* has been upgraded to version 2.2.x, an update that was necessary both to support alfi under Solaris 8, and to take advantage of a number of bug fixes. All three sites have the latest version of the end-to-end package installed.

Other improvements include the ability to manipulate nodes graphically via cut and paste operations. We addressed user requests for ease of use improvements. The code structure was cleaned and is now more robust. Various bugs were eliminated. We continue to develop and expand the test procedures to assure quality and stability.

8.2 LIGO Data Analysis System (LDAS)

8.2.1 Software Systems

LDAS Software Release. We released three new versions of LDAS during the quarter. Version 0.0.13 was used during the MPI (Message Passing Interface) Mock Data Challenge (MDC). Version 0.0.14 was primarily a bug fix release with modifications developed during the MPI MDC. The final release this quarter was 0.0.15. It included bug fixes, and a new *dataConditionAPI* with all signal processing functionality based on the UDT (Unified Data Type) class. We will use this release during the E3 engineering run.

LDAS Parallel Computing. The second LDAS/LSC Mock Data Challenge (MDC) occurred in January and involved testing of the LDAS parallel computing components (*mpiAPI* and *wrapperAPI*) in conjunction with the LSC developed LIGO Algorithm Library (LAL) and *LALwrapper* (a thin layer between the LDAS *wrapperAPI* and LAL code). The MDC tested the ability of the LDAS system to initiate and manage MPI (Message Passing Interface) standard parallel jobs involving preliminary search codes for binary inspirals and the detection of excess power. The MDC also tested user commands that customize the behavior of search strategies. The LDAS team and the LSC participants all considered the MDC to be a tremendous success. The complete test plan and summary report can be viewed on-line in *.pdf* format at http://www.ligo.caltech.edu/docs/T/T010024-00.pdf.

This particular MDC only tested the integration of the *managerAPI* with the *mpiAPI* and *wrapperAPI* using a dynamically loaded shared object library. The next MDC will integrate the parallel computing functions with a broader set of LDAS components including the fundamental pipeline flow from frames to data conditioning into the parallel searches and onto the LDAS database. To accomplish this, we are enhancing the output from the *dataConditionAPI* to support the generic data types used by the *wrapperAPI*. The eventMonitorAPI which parses results from parallel searches and constructs requests to insert metadata into the LDAS database was started late in this quarter.

Fast Chirp Transform (FCT). During this quarter we pursued the following activities relevant to the Fast Chirp Transform:

- We documented a derivation of the Fast Chirp Transform (FCT) for arbitrary functions and estimated the magnitude of the error between the FCT and the (exact) discrete chirp transform for each component.
- We developed code to test the numerical accuracy of Rick Jenet's original FCT implementation (which uses approximations) and compared it to the exact Discrete Chirp Transform (DCT), using the error estimate above. Our intent was to verify that the approximate FCT implementation is accurate to within the analytically determined error bounds. A failure here may indicate a bug in the code. With a generic numerical accuracy test, it will be easier to spot errors (if any) in the code. For example, it may be the case that the FCT fails only for certain phase functions or numbers of dimensions--it is easier to check a large number of cases with this type of test. We also wanted a means of checking changes to the FCT code over time. To verify changes, we need to check the results of FCT vs. DCT as above, but also have a set of results, which we expect the FCT code to reproduce exactly. If a bug is introduced between code revisions it is likely to be picked up here.

- We drafted a timetable for the development of the FCT gravitational-wave chirp search code for the LIGO Algorithm Library and wrapper, with a May 15 target end date.
- We created a “stub” web page for FCT group actions and development information: http://www.ligo.caltech.edu/~charlton/FCT/

Other Improvements. Other LDAS improvements implemented this quarter included conceptual changes in the connectivity from the *metaDataAPI* to the underlying DB2 database server, the development of a loss-less data compression algorithm for LIGO floating-point data in “frame” format, as well as software tools for data access and high level analysis.

8.2.2 Hardware Systems

LDAS continues to archive all trend frames from Hanford and Livingston as well as the full frames from engineering runs. The current archive contains eight terabytes, cf. http://www.srl.caltech.edu/personnel/sba/ligo/hpss.

We have executed the Phase I procurement for LDAS, comprising 28.3 terabytes of disk storage and a 6000-slot tape silo. Beowulf clusters for both Hanford and Livingston Observatory support of the engineering runs planned during 2001 have been fully specified.

8.3 Laboratory Information Technologies Group (formerly General Computing)

Work on a faster Wide Area Network (WAN) to the observatories is progressing slowly. LIGO has become a sponsored member of the Abilene/Internet2 consortium. In Louisiana, Bell South has provided preliminary quotes for an OC3 connection, and we are awaiting the quotes for connection to the State's gigapop server. How OC3 connectivity will be implemented for the Hanford Observatory is not finalized. We are discussing this with PNNL (the Pacific Northwest National Lab) and also considering alternatives. The trade studies at both sites will continue into the next quarter.

The LIGO IT organization is in transition from construction to operations support. Growth is no longer as significant a factor as updating existing equipment. We are working with LIGO Directorship on a draft for a policy and procedures statement.

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 1. **All Facilities milestones have been completed.**

TABLE 1. 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)

---

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

Table 2 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.

9.2 Financial Status

Table 3 on page 15 summarizes costs and commitments as of the end of February 2001.

9.3 Performance Status (Comparison to Project Baseline)

Figure 5 on page 17 is the Cost Schedule Status Report (CSSR) for the end of February 2001. 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 mea-

TABLE 2. 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)	

sure 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 6 on page 18 shows the same information as a function of time for the top level LIGO Project.

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 contracts for both sites are complete.

Civil Construction (WBS 1.1.4). The original scope for Civil Construction has been completed. Additional scope has been budgeted for site improvements initially removed from the plan to conserve contingency. A contract has been issued for the Storage and Staging Building at Livingston and work is in progress. A contract for Architect/Engineering effort for additional space at Hanford is being finalized.

TABLE 3. Costs and Commitments as of the End of February 2001

(all values are $Thousands)

WBS		*Costs Thru Nov 1997*	*Costs LFY 1998*	*Costs LFY 1999*	*Costs LFY 2000*	*First Quarter LFY 2001*	*Cumulative*	*Open Encum-ances*	*Total Cost Plus Commitments*
1.1.1	**Vacuum Equipment**	30,517	11,406	2,114	10	-	44,047	-	44,047
1.1.2	**Beam Tube**	32,978	13,273	753	-	-	47,004	-	47,004
1.1.3	**Beam Tube Enclosure**	13,274	6,145	153	(233)	-	19,338	-	19,338
1.1.4	**Civil Construction**	44,681	6,563	1,513	823	72	53,652	2,123	55,775
1.1.5	**Beam Tube Bake**	75	3,078	1,845	561	11	5,570	1	5,571
1.2	**Detector**	14,340	20,537	17,898	3,614	401	56,791	852	57,643
1.3	**Research & Development**	19,681	1,661	713	46	53	22,153	-	22,153
1.4	**Project Management**	22,649	4,914	1,525	845	75	30,008	23	30,031
7LIGO	**Unassigned**	1	18	13	(1)	-	32	-	32
TOTAL		178,196	67,595	26,527	5,665	612	278,595	3,000	281,595
Cumulative Actual Costs		178,196	245,791	272,318	277,983	278,595			
Open Commitments		62,510	16,422	7,078	1,378	3,000			
Total Costs plus Commitments		240,706	262,213	279,396	279,361	281,595			
NSF Funding - Construction		*$ 265,089*	*$ 291,900*	*$ 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.

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

Detector (WBS 1.2)

Washington Two-Kilometer Interferometer. We had completed installation of the two-kilometer interferometer and were well into the commissioning phase when the earthquake struck the Hanford facility. We had locked the full recycled interferometer with both arms for periods up to an hour, and were working to improve the sensitivity. Sensitivity studies and improvements will resume as soon as earthquake repairs are complete.

Livingston Four-Kilometer Interferometer. We have installed all in-vacuum components including the suspended optics. The laser locks to the Mode Cleaner routinely and robustly. The laser has been locked to each arm cavity individually and we are working toward locking the full interferometer.

Washington Four-Kilometer Interferometer. We have installed the seismic isolation system and the data acquisition system. We are currently installing the prestabilized laser and the in-vacuum optics. The basic strategy has been one of 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 during installation of the first two interferometers.

In spite of encouraging progress, the Detector continues to be behind schedule. Efforts to improve the schedule were set back by the earthquake. The net effect is that detector commissioning is about three months behind schedule. We continue to adjust priorities to optimize progress toward the Science Run.

Favorable Detector Cost Variance. A significant portion of the favorable cost variance in the Detector WBS is due to normal delays associated with processing and recording actual costs.

Research and Development (WBS 1.3). All LIGO 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 pending NSF approval of our procurement plans and also to achieve the most favorable performance per dollar ratio. The NSF approved the procurement plans early in March 2001.

LIGO Project

Cost Schedule Status Report (CSSR)

Period End Date: February 2001

(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	53,780	53,722	53,652	(58)	70	56,226	55,775	451
1.1.5 Beam Tube Bake	5,695	5,695	5,570	-	125	5,695	5,570	125
1.2 Detector	60,252	59,825	56,791	(427)	3,034	60,252	59,752	500
1.3 Research & Development	22,089	22,089	22,153	-	(64)	22,089	22,153	(64)
1.4 Project Office	32,597	30,008	30,008	(2,589)	-	35,509	35,509	-
Subtotal	284,688	281,614	278,563	(3,074)	3,051	290,046	289,148	898
Contingency						-	2,952	(2,952)
Management Reserve						2,054	-	2,054
Total	284,688	281,614	278,563	(3,074)	3,051	292,100	292,100	-

FIGURE 5. Cost Schedule Status Report (CSSR) for the End of February 2001.

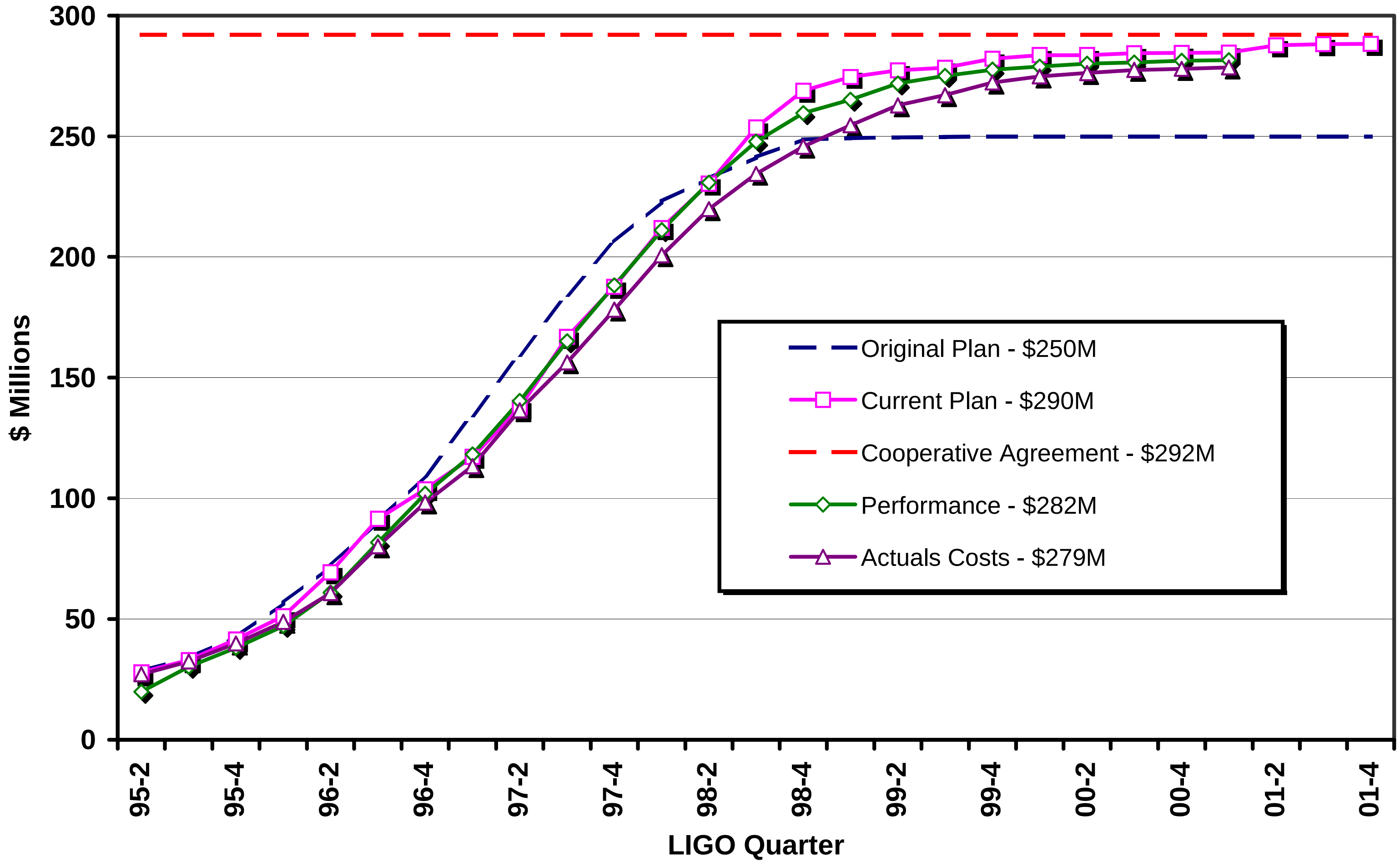

FIGURE 6. LIGO Construction Performance Summary as of the End of February 2001.

9.4 Change Control and Contingency Analysis

There were no change requests approved during the first quarter of FY 2001. The budget baseline for LIGO Construction remains at $290.0 million. This leaves a contingency (relative to the budget baseline) of $2.1 million. We are forecasting a $0.9M underrun relative to the budget baseline for the scope of work currently authorized so that the contingency relative to the estimate-at-completion is $3.0 million.

9.5 Staffing

The LIGO staff currently numbers 159 (full time equivalent). Of these, 32 are contract employees. Ninety-six LIGO staff are located at CIT including eight graduate students. Seventeen are located at MIT including five graduate students. Twenty-two are now located at the Hanford, Washington site, and 24 are assigned to Livingston, Louisiana. LIGO staff is partially paid by the LIGO Advanced Detector R&D Program, PHY-9801158.