Quarterly Progress Report

(LIGO Fiscal Year Ending August 1999)

The Construction, Operation and Supporting Research and Development of a Laser Interferometer Gravitational-Wave Observatory (LIGO)
NSF Cooperative Agreement No. PHY-9210038

LIGO-M990311-00-P

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Quarterly Progress Report

(End of August 1999)

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

NSF COOPERATIVE AGREEMENT No. PHY-9210038

LIGO-M990311-00-P

CALIFORNIA 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 during the LIGO quarter ending August 1999.

2.0 Recent Progress and Status

Facility construction, including the vacuum system, is complete. At Hanford, all of the four Beam Tube modules have completed vacuum bake. Detector installation is in progress. The project continues to make excellent progress and is 96.1 percent complete as of the end of August 1999.

2.1 Vacuum Equipment

All Process Systems International (PSI) field activities are complete. All scheduled payment milestones are complete, and the PSI contract is in the process of being closed out.

2.2 Beam Tube

As previously reported, all Beam Tube modules have been accepted, and all contract work is complete. Beam Tube module insulation and baking is discussed in Section 2.5.

2.3 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.

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 is complete. The contractor has finished all construction activities along both arms and the contract is closed.

2.4 Civil Construction

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

Louisiana Civil Construction. Construction of the facilities are complete and the contracts are closed. Fabrication of the LIGO Monument Signs for the Livingston and Hanford sites is in progress and on schedule. Proposals for the Erosion Control and Landscaping are in. Award of the contract is pending the NSF approval.

2.5 Beam Tube Bakeout

During the past quarter, following completion of the Beam Tube vacuum bake activities at Hanford Observatory, the bake equipment was packed and shipped to the Livingston site. An electrical contractor, MMR Inc., was retained to assist with setting up the equipment at Livingston. After completing the set up and checking the newly installed equipment, we started the first vacuum bake of a Beam Tube module at Livingston on August 20.

2.6 Detector

The Detector group is in the process of completing the fabrication and assembly on most subsystem components and has shifted to supporting installation and commissioning at the Observatories. There are a few cases where design effort is still in process to complete the Detector system: the length sensing and control electronics and software for the full interferometer configuration, seismic isolation system fine actuator controls for tidal and microseismic motion compensation, and Global Diagnostics System (GDS) software development.

2.6.1 Installation Progress Overview

The installation highlights for this quarter are:

- The input beam was delivered from the Pre-Stabilized Laser (PSL) to the first Input Optics (IO) chamber (HAM7) in the two kilometer interferometer at Hanford. This required the Observatory to go to a "Laser Hazard Condition" in the Laser and Vacuum Equipment Area (LVEA). The transition to this mode of operation with its associated safety constraints went well. This also marks the start of the first system level integration and testing for the interferometer.
- The two kilometer interferometer Mode Cleaner was aligned and locked, both in air and under vacuum. In the high finesse mode (with s-polarization) the fringe visibility is now about 97 percent, and the PSL noise spectrum, as measured by the Mode Cleaner, is only a factor of 10 from the required level.

- All Core Optics for the two kilometer interferometer have been delivered. All but one have been suspended and all but two have been installed and aligned in the chambers. Metrology work was started on the four kilometer core optics for the Livingston interferometer.
- All but one of the seismic isolation systems have been installed for the two kilometer interferometer and work has begun on the installation of the seismic isolation systems within the four kilometer interferometer chambers at Hanford. All seismic isolation systems are installed in the Livingston LVEA (with the exception of one Beam Splitter Chamber stack).
- Installation of the two kilometer interferometer Input Optics system at Hanford has been completed. Assembly of the Input Optics for the four kilometer interferometer at Livingston has begun.
- The Livingston PSL has been installed, and testing and debug are nearly complete.

The installation for the Detector is proceeding reasonably well, though behind schedule. Principal causes for the delay are:

- process control problems for the magnet/standoff assembly adhesion to the optics (which occurred in the first and second quarters of this year and have been solved).
- handling and fixture problems associated with the transport and alignment of completed suspension assemblies (which required reprocessing several suspension assemblies). Reworked fixtures and revised procedures appear to have solved these problems.
- delays associated with the re-manufacture of much of our flourel component stock, as a result of losses suffered from the tornado which devastated regions of Oklahoma in May.
- delay in the installation of seismic isolation stacks recently (mid-August) due to concerns regarding the water outgassing rate for the flourel spring seats used in the stacks. Investigation of the water outgassing load due to the flourel components, and methods to reduce the water load, are currently under investigation.

The effect of these delays is currently under review, as are ways to work around them by accelerating tasks. The overall impact may be as much as five months delay on the start of coincidence operations, but we will know better after the flourel seat problem has been addressed and the single long arm cavity test has started.

The current schedule (which is currently under review in light of the delays noted above) is shown in Figure 1. The next major systems level event is the single long arm cavity test on the two kilometer interferometer, which is expected to start in late October. The Livingston four kilometer interferometer Mode Cleaner commissioning is expected to start in December. While Hanford moves on to explore problems with the first time control of a long arm cavity, Livingston's mission will be the complete characterization and implementation of robust control of the Mode Cleaner. The basic approach is carried forward in each of the subsequent major system level integration and test events. Also note that the installation of the third PSL system, for the Hanford four kilometer interferometer, has been intentionally delayed to gain experience with the use of the first two systems and to permit PSL staff to support other critical activities.

Task Name	Duration	Start	Finish
LHO Detector Infrastructure	80 wks	7/27/98	2/4/00
LHO 2km IFO	**636 days**	**7/1/98**	**12/6/00**
Start Detector Integration	0 days	7/1/98	7/1/98
Install SEI, SUS, COS, ISC	75 wks	9/21/98	2/25/00
PSL	18 wks	9/8/98	1/11/99
Input Optics	41 wks	1/28/99	11/10/99
long arm Fabry-Perot cavity test	16 wks	11/11/99	3/1/00
PR Near Michelson	16 wks	3/2/00	6/21/00
PR Michelson w/ FP Arms	24 wks	6/22/00	12/6/00
LHO 4km IFO	**686 days**	**7/1/98**	**2/14/01**
Install SEI, SUS, COS, ISC	94 wks	7/1/98	4/18/00
PSL	12 wks	2/28/00	5/19/00
Input Optics	16 wks	4/13/00	8/2/00
PR Near Michelson	12 wks	8/3/00	10/25/00
PR Michelson w/ FP Arms	16 wks	10/26/00	2/14/01
LLO Detector Infrastructure	80 wks	12/8/98	6/19/00
LLO 4km IFO	**531 days**	**1/6/99**	**1/17/01**
Install SEI, SUS, COS, ISC	64 wks	1/6/99	3/28/00
PSL	30 wks	4/12/99	11/5/99
Input Optics	36 wks	8/5/99	4/12/00
long arm Fabry-Perot cavity test	12 wks	4/13/00	7/5/00
PR Near Michelson	12 wks	7/6/00	9/27/00
PR Michelson w/ FP Arms	16 wks	9/28/00	1/17/01
Detector Commissioned (h<10^-20)	0 days	2/14/01	2/14/01
NSF Milestone Date (Simultaneous Operation)	0 days	12/15/00	12/15/00
Observatory Operations & improvements	47 wks	2/15/01	1/9/02
Design Sensitivity (h<10^-21)	0 days	1/9/02	1/9/02

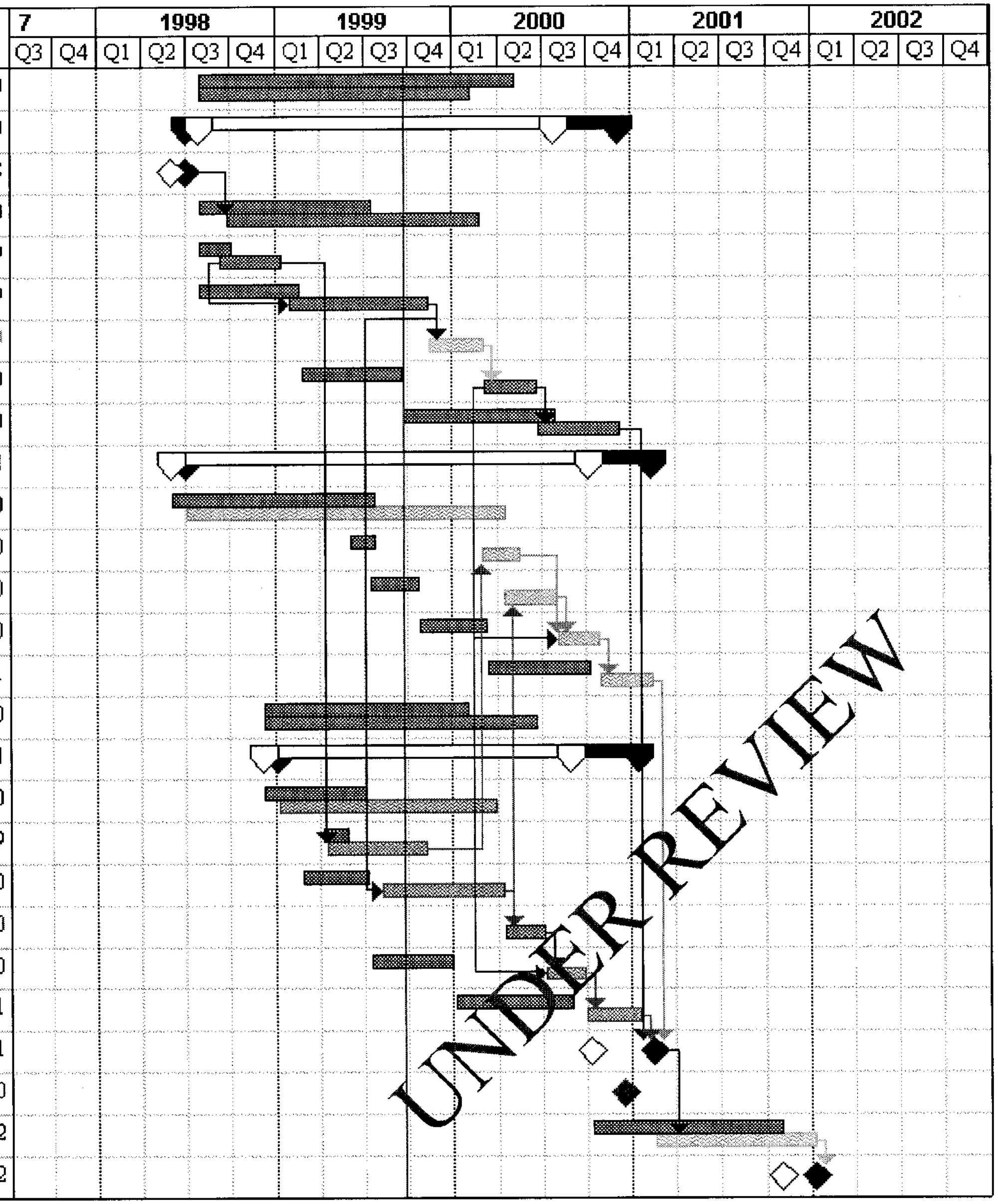

FIGURE 1. Overall Detector Installation Schedule

2.6.2 Lasers and Optics

Pre-Stabilized Laser (PSL). The Hanford Observatory Pre-Stabilized Laser has been in operation for all of the last quarter. Frequency and intensity servos are operational and acquire lock easily and robustly, and have remained in lock for more than 15 days. The PSL output beam is now being supplied to the Input Optics for commissioning and characterization of that subsystem. In addition, the Input Optics suspended Mode Cleaner cavity was used to independently measure the PSL frequency noise spectrum for the first time. The results are being studied. The Livingston Observatory PSL is now installed, with all major hardware and electronics in place. Its servo systems are being characterized and debugged. Finally, we implemented an improvement to the Lightwave Electronics 10W laser to allow direct actuation of the laser amplifier pump diodes for intensity stabilization. This method of intensity actuation will be simpler and result in higher optical transmission than the previous approach of the use of an acousto-optic modulator.

Input Optics. Installation of the Hanford Observatory Input Optics (IO) subsystem is complete and characterization is in progress. The Mode Cleaner routinely holds length servo-control lock overnight. Using the PSL output beam, a number of important Mode Cleaner parameters have been determined, including the length, cavity linewidth and visibility. These parameters are close to the design specifications. The length and frequency control servos operate consistently with the design, and the wavefront sensing alignment servo is now operational. A number of other important issues are currently under study, including a precise characterization of the small optics suspension actuators and sensors, and a measurement of the PSL frequency noise. We recently started installation of the Livingston Observatory IO. Work has begun on assembling and suspending the small optics.

Core Optics Components. Delivery of the Core Optics Components (COC) for the two kilometer interferometer at the Hanford Observatory is now complete, with the arrival of the recycling mirror, beam splitter, two folding mirrors, two input test masses, and two end test masses. We performed metrology on the optics using a phase measuring interferometer to assure that surface figure specifications were met. In addition, we measured the surface scatter of the test masses with a scatterometer. Two of the measured end test masses were rejected because of coating defects that occurred during the coating process. However, sufficient spares were available to replace them. All of the four test masses delivered to the observatory were found to have acceptable scatter levels, and were well matched in terms of their radii of curvature. Characterization of the Livingston observatory COC is now underway. The Livingston recycling mirror is the first optic to have been shipped to that observatory, and metrology of the input test masses is proceeding.

Core Optics Support. We started full scale fabrication of the Core Optics Support (COS) components this quarter. We initiated fabrication of the pick-off and end test mass telescopes as well as production of the beam dumps and conical baffles. We completed the design of the arm cavity baffle and expect fabrication to begin soon. In-vacuum beam dump installation has begun at the Hanford Observatory, and the anti-symmetric port pickoff telescope has been aligned and assembled and is ready for installation.

2.6.3 Isolation

Seismic Isolation System. The isolation group has made outstanding progress this quarter. Installation of the seismic isolation system has been proceeding, with production and delivery of components supporting installation schedule needs. Early quality problems have mostly disappeared. There have been a few problems with the quality of metal seal knife edges, but we have been able to perform the required rework. The Hytec support contract is nearing completion, with final delivery of the remaining two coarse actuation system racks and final sets of scissor table and vertical actuator assemblies due by November. The Beam Splitter Chamber (BSC) first article that was assembled at Hytec has been disassembled and shipped to Allied Engineering for rework and re-cleaning and air baking before shipment to Hanford.

In Hanford, the seismic isolation systems have been completed for all of the two kilometer interferometer chambers with the exception of the BSC chamber in the X-mid station. Work has begun on installation of the seismic isolation systems for the four kilometer interferometer at Hanford. In Livingston, the seismic isolation systems have been installed in the four Horizontal Access Module (HAM) chambers that will be used, and in two of the BSC chambers. In addition, a third BSC chamber has all but the isolation stack installed. The installation of the BSC seismic systems at Livingston went as quickly as any installation at Hanford, indicating that the transfer of experience was successful. The coarse actuation system for the BSC seismic isolation systems has been installed and tested successfully in the LVEA at both Observatories.

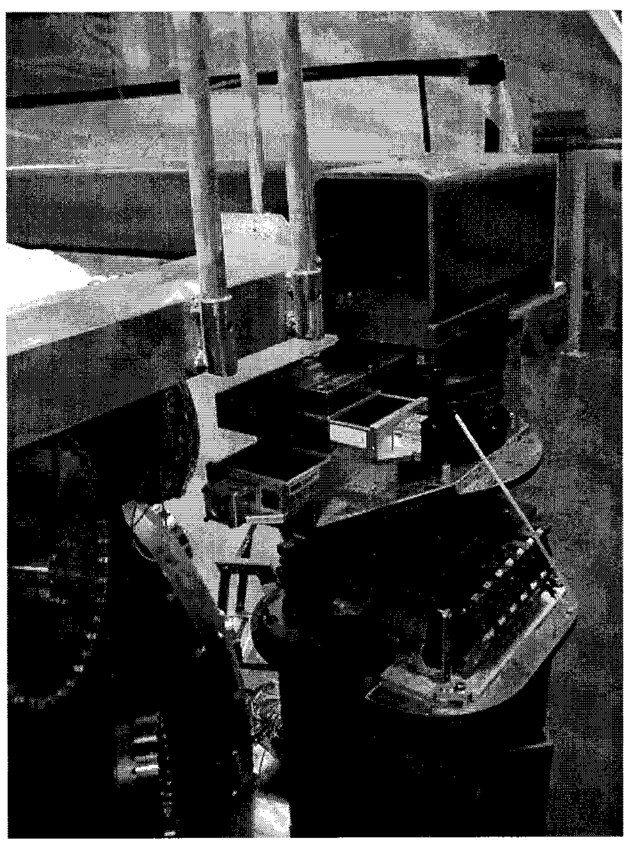

FIGURE 2. Beam Splitter Chamber (BSC) Coarse Actuation System Components. One pier of the BSC at Livingston is shown. The chamber dome is removed for stack installation.

Suspensions. During this quarter, we assembled six core optics into suspensions for the two kilometer interferometer at Hanford (the X- and Y- input test masses, the X- and Y- fold mirrors, the Y-end test mass, and the beamsplitter). All of these have been installed and aligned in their respective chambers, with the exception of the Y-end test mass. The two kilometer interferometer suspension remaining to be completed, the X-end test mass suspension, will be started in September. This is remarkable progress considering two problems that had to be overcome:

- shorting of the sensor/actuator heads coils to the anti-static coating, which required rework of the sensor/actuator assemblies and in-chamber refit of a number of suspensions;
- failure of the magnet/standoff assemblies on three of the core optic suspension assemblies during installation, requiring changes to the fixtures and installation procedures.

Recent suspension assemblies and installations have proceeded flawlessly, so we expect that we are through the initial learning problems.

Component and lab preparation and staging of core optic suspension parts has been underway at Livingston in anticipation of a start of core optic suspension activity in September.

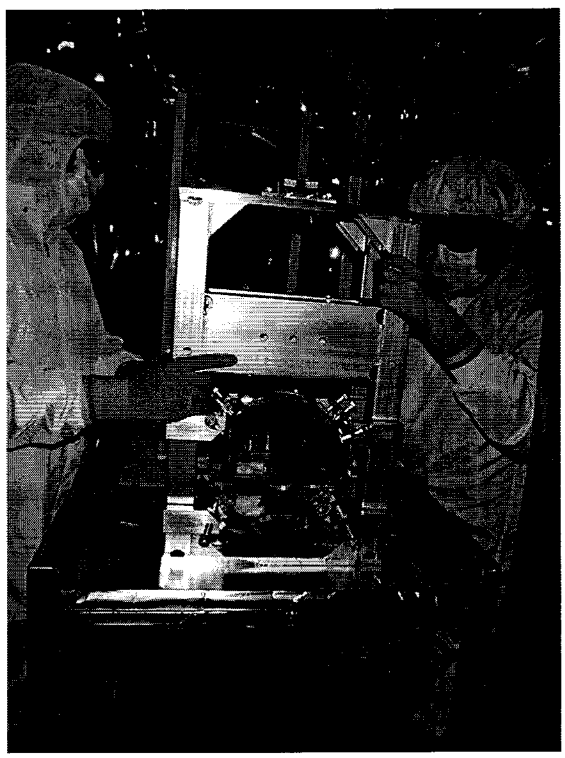

FIGURE 3. Installation of the Y-Arm Fold Mirror Suspension

2.6.4 Control and Data Systems

The Control and Data Systems (electronics and software) group are essential players in all subsystems and have been major contributors to the successful installation and commissioning for the subsystems and of the Mode Cleaner system level testing. The design, hardware delivery and installation accomplishments of the CDS group during this quarter included:

Data Acquisition and Control & Monitoring

- Completed installation of the network server electronics racks at Livingston.
- Installed a data acquisition crate in the Y-end station at Livingston.
- Installed the control and data systems network in the laser and vacuum equipment area in Livingston.
- Completed the installation of the ATM network in the control room in Livingston.
- Installed data acquisition system crates in the mid- and end-stations at Hanford.
- Completed the installation of the video system at Hanford.
- Testing the frame multicast system for the global diagnostics system at Hanford is in progress.
- Anti-aliasing filter boards are in production and a few have been installed at Hanford.
- Started production and installation of the timing system at Hanford.
- Converted from the VIRGO C frame library to the LIGO frame C++ version.

Suspension Controls

- A suspension test stand has been installed in the Livingston optics lab for use in suspension assembly and test.
- All suspension controllers for the input optics and racks have been assembled, tested and installed at Livingston.
- The end test mass suspension controllers for the two kilometer interferometer were delivered to Hanford.

Pre-Stabilized Laser

- Installed and started the test program for the pre-stabilized laser electronics at Livingston.
- Revised the frequency servo control board based on the Hanford two kilometer interferometer experience.
- Revised the intensity servo control board for improved performance (to use the power amplifier current shunt control instead of an acousto-optic modulator).

Interferometer Length and Alignment Sensing and Control

- Installed and tested all electronics and software for length and alignment control of the Mode Cleaner at Hanford.
- Installed electro-optic shutter controls for the Mode Cleaner length sensing photodiodes.
- Installed beam steering pico-motor controls for the Mode Cleaner system.
- Completed the alignment sensing and control electronics rack for the two kilometer interferometer at Hanford (in the corner station).
- Tested the alignment sensing and control software, including interfaces with the excitation engine of the global diagnostics system and the interferometer sensing and control supervisory control software.
- Completed timing tests of length sensing and control servo code on a pentium III VME processor and demonstrated adequate margin.

- Completed design and started fabrication of the length and alignment control boards for the single, long arm cavity test.

The inevitable problems that arise during the course of installation and test of the subsystems and Mode Cleaner commissioning have all been addressed and resolved in a timely fashion. The next major systems level test (which, like the Mode Cleaner commissioning, will require significant participation by the control and data systems group) is the single, long arm cavity test. Most of the custom electronics boards to support this test are prototypes for the full interferometer length and alignment control boards. We are currently fabricating and testing these boards.

FIGURE 4. Mode Cleaner Electronics Racks (Hanford two kilometer interferometer).

2.6.5 Physics Environment Monitoring System

We made significant progress this quarter on installation and check-out of the Physics Environment Monitoring (PEM) System sensors and components:

- All PEM hardware has either been received or ordered.
- All PEM stay clear zones have been established at Hanford for the sensitive equipment.
- The interface plates and accelerometers have been installed on the Beam Tube module to be instrumented at Hanford (X1).
- All accelerometers and microphones have been installed for the two kilometer interferometer at Hanford.

- Seismometers and tiltmeters have been installed at Hanford.
- Seismometer and tiltmeter instrument check-out and calibration has begun.
- Magnetic field measurements have been made within the chambers at both Hanford and Livingston.
- A high frequency transmission test was conducted on a BSC seismic isolation system at Livingston.
- Seismic background characterization and particle count monitoring is on-going at both observatories.

2.6.6 Global Diagnostics System

We accomplished the following this quarter:

- Installed a new version of the data monitoring tool code at Hanford.
- Tested the required high data rate load on the CPUs and network.
- Began testing on some of the diagnostic test software.
- Installed the frame broadcast application interface on the network data server at Hanford.
- Completed the sine response test code and began the swept sine and triggered time series code.
- Expanded the excitation engine in waveform sets and added and tested a digital waveform capability.
- Finished the filter class library and wrote other LIGO specific classes for ROOT, the kernel signal analysis program used for the data monitoring tool.
- Installed the computer server for the data monitoring tool at Hanford.

Development of the Global Diagnostic System is proceeding, and will be available with sufficient capability to support machine diagnostic, characterization and commissioning activities.

2.6.7 Interferometer Sensing and Control

The Interferometer Sensing and Control group has been key to the system level testing and commissioning of the Mode Cleaner (described in the next section). In addition, the Interferometer Sensing and Control group has:

- Installed the optical levers for the all of the currently in-place two kilometer interferometer core optics.
- Performed the initial alignment (using a theodolite and laser autocolimator) of all of the installed two kilometer interferometer core optics.
- Completed the design of the input optics and dark port, Interferometer Sensing and Control optics table assemblies.
- Assembled, installed and checked out the length and alignment sensing and control elements comprising the optics table for the input optics section.
- Started assembly of the length and alignment sensing and control elements comprising the optics tables associated with the long arm cavity test.

- Completed the design and initiated fabrication of the end test mass transmission monitor.
- Performed an initial alignment baseline monument survey at Livingston.
- Developed much of the supervisory control and diagnostics coding.

In addition to these accomplishments for Hanford, the Interferometer Sensing and Control group has delivered a number of basic components (optics tables, optical lever support columns, etc.) to Livingston to support the imminent start of installation of mode cleaner optics and core optics into the chambers.

2.6.8 System Level Commissioning/Testing

The primary Mode Cleaner functions are as follows:

- Frequency stabilization: The Mode Cleaner provides the intermediate level of frequency stabilization and must be more stable than the PSL reference cavity (lower thermal noise). The Mode Cleaner system must stabilize frequency by a factor of ~1000 (over the frequency range 40 Hz to 7 kHz).
- Beam direction stabilization: provide a factor of 1000 passive stabilization of beam direction fluctuations.

The mode cleaner is the first installed system that involves the operation of nearly all sub-systems: Seismic Isolation (SEI), Suspensions (SUS), Interferometer Sensing and Control (ISC), Input Optics (IO), and the Pre-Stabilized Laser (PSL).

Integration of the Mode Cleaner was very successful. The Mode Cleaner locks, fairly easily, and for long periods of time. The length and frequency servo controls work with little modification from the original design. The wavefront sensor alignment servo system also works as designed. The cavity finesse/linewidth is correct (FWHM = 7.4 kHz), mode matching is good, the Mode Cleaner length is measured and set to within 0.5 mm of the desired length, the Mode Cleaner error signal spectrum is clean and behaves properly with gain, and shot noise sensitivity is good. In addition, the internal mode Q's of the Mode Cleaner optics have been measured and meet the specification.

Mode Cleaner commissioning involves the coordinated testing of several different components (see Figure 6):

- the Pre-stabilized laser, the large enclosure and one of the electronics racks to the far right of the photo;
- the Input Optics, which has optical elements on the laser table as well as in the first two vacuum chambers proceeding from right to left in the photo;
- the Suspension Systems, internal to the vacuum chambers with control and read-out eletronics in the racks mid-way between the two input optics chambers;
- and the Interferometer Sensing and Control subsystem, an optics table on the far side of the first vacuum chamber, along with electronics in the center racks.

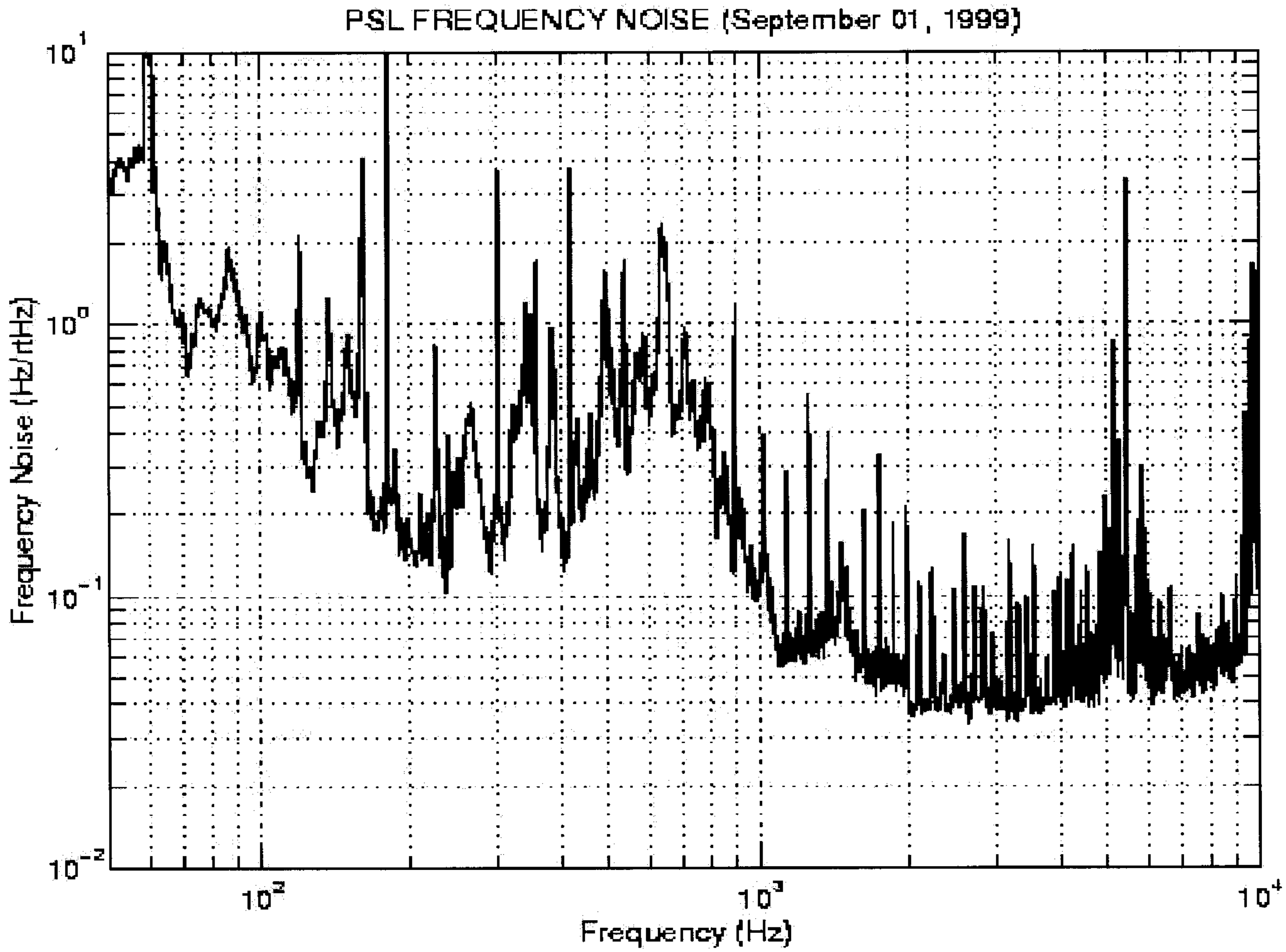

FIGURE 5. PSL Frequency Noise as Measured with the Mode Cleaner Cavity

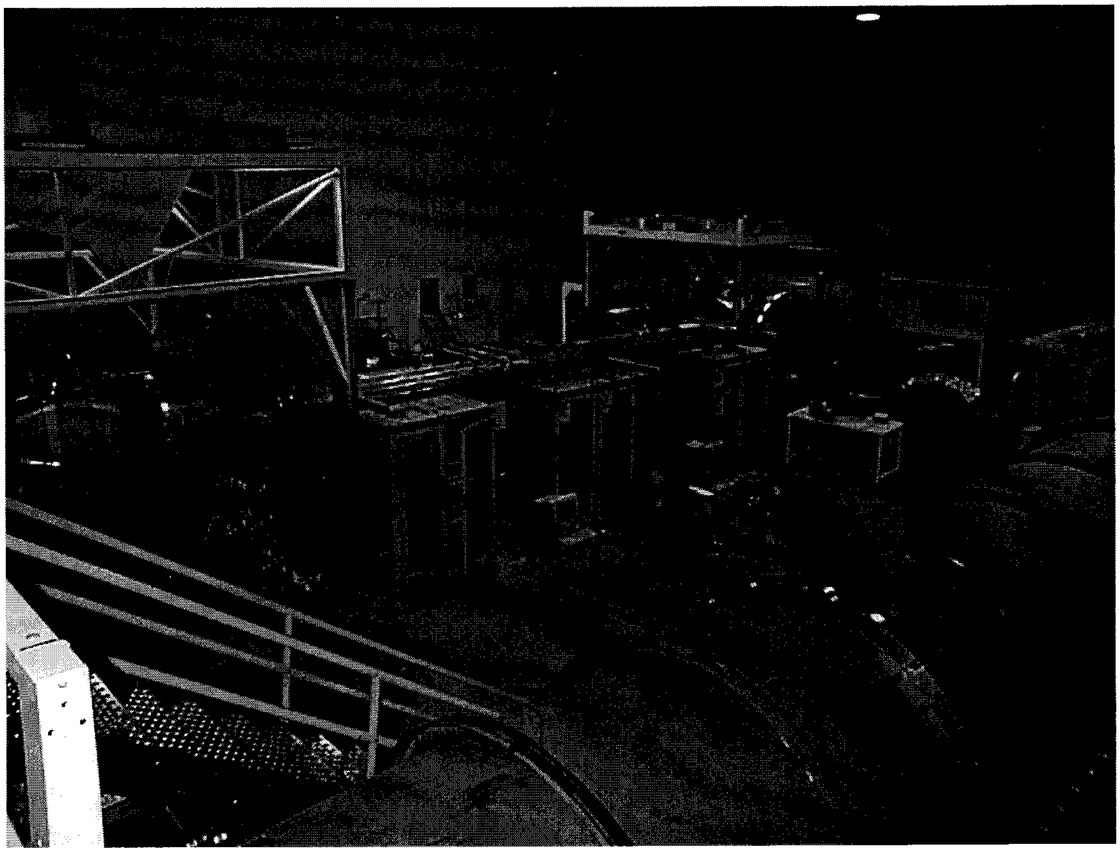

FIGURE 6. Mode Cleaner Commissioning (Hanford two kilometer interferometer).

Work planned to be accomplished during the next quarter includes:

- We will operate at full power (work to date has been at up to 1W of input power.)
- We will improve the pre-stabilized laser frequency noise spectrum (it is currently a factor of 10 above its design requirements.)
- The small optics suspensions must be diagonalized.
- The fluctuations of the input beam direction must be reduced.
- An automatic lock procedure will be developed.
- We will characterize the alignment system.
- We will study length-alignment coupling.
- We will characterize length fluctuations of the Mode Cleaner (15 m baseline).
- We will connect DAQ channels.
- We will investigate radio frequency amplitude modulation (RFAM) at the output of the Mode Cleaner.
- We will measure the PSL intensity noise (in the gravity wave band) at Mode Cleaner output.
- We will test the mode cleaner actuation inputs.

2.7 Modeling and Simulation

Electro-Optical Subsystems. Subsystem development continued mainly at the LIGO Hanford Observatory. We improved the model for the Pre-stabilized Laser (PSL). This includes frequency and amplitude noise generators for the laser and an update of the model parameters to reflect the actual as-built hardware. We completed the length sensing and control part of the Input Optics (IO) subsystem, and development of the alignment control system has started. We made a first attempt at integrating the PSL and IO. We discovered that the individual systems and the integrated system will run if a very small time step is used in the simulation code. However, this time step is too small to be practical when used together with the long arm cavities of the Core Optics Components (COC) subsystem to simulate the entire LIGO interferometer. We are investigating various improvements of the loop algorithms.

Mechanical Systems. We developed a C++ based mechanical systems simulation code, and a draft of the Applications Programmer Interface (API) of this Mechanical Simulation Engine (MSE) was delivered by Giancarlo Cella from the University of Pisa. The design of the interface between the end-to-end model and the MSE was discussed, and it was decided that in the initial effort there would be no Graphical User's Interface (GUI) developed for the MSE. The merits of this approach are the integration can be performed in a much shorter period of time because the GUI development takes a long time to achieve stability; code optimization while integrating the various mechanical elements can be implemented; and debugging the mechanical structure model can be done easily independently of the end-to-end model.

This decision to defer a GUI for the MSE does not reduce its flexibility because the C++ level API is well designed and new mechanical structures can be easily constructed directly. The GUI in Alfi (the graphics toolbox for Adlib, the Gravitational-Wave Detector simulation toolbox) will be enhanced to support the MSE.

Adlib Code. The first phase of development of the time domain modal model is almost complete. We are validating code components under various conditions. The current code is based on legacy code adopted from previous modeling efforts. We have decided to revamp the code related to the dynamics of the electromagnetic field. This includes redefinition of the field and implementation of interactions, and speed enhancements. At the same time, source code is being rewritten to take advantage of the ANSI C++ Standard Template Libraries. Speed improvements of an order of magnitude or greater are expected when all changes have been made. In addition the rewritten code will be much easier maintain. In Adlib and Alfi, parsing code has been revised so that box files and primitive description files can be organized hierarchically. This makes it possible to develop subsystems independently of each other.

2.8 LIGO Data Analysis System (LDAS)

Hanford LDAS Installation. The focus for the LIGO Data Analysis System (LDAS) during this quarter has been the installation of the first components of the LDAS network, hardware, and software at the LIGO Hanford Observatory. In late June, a team of LDAS scientist and software engineers travelled to the site as part of this effort to

- establish the necessary cable runs and optical fiber to connect all LDAS areas to the fast ethernet and ATM networks used by the LDAS on the private “martian” LDAS network;
- setup three Sun workstations and two PC Linux workstations as a data server, a database server, a control and monitor server (and future gateway to the Beowulf compute cluster), one Sun user’s workstation and one Linux user’s workstation;
- configure the Unix systems files on all systems to allow LDAS system resources sharing and user account management, and to properly mirror the LDAS software environment from the main LDAS development server at Caltech;
- configure interfaces to the frame building hardware, allowing access to the newly created frame datasets;
- establish connections for the Global Diagnostics System (GDS) trigger hardware;
- create the DB2 database tables on the metadata server;
- provide LDAS systems level training to staff.

As part of this initial installation, the LDAS private “martian” network was connected through gateways to the Hanford General Computing (GC) network and the Hanford Control and Data System (CDS). The gateway to General Computing allows access to the LDAS network over the internet, while still maintaining a secure private network for LDAS hardware and software. The gateway to the CDS provides the link used by the LDAS to get new LIGO Frame files as they are written by the Framebuilder and the interface to the GDS trigger generation hardware, both on the CDS private network. Figure 7 shows the LDAS rack located in the Hanford Mass Storage room with the ATM network hardware, the metadata server, and the data server.

LDAS Alpha Release Software. The software development team travelled to the Hanford site in late July to begin installation of a pre-alpha release version of the LDAS software. This included the *managerAPI*, the *frameAPI*, and the *metaDataAPI*, with continuing efforts through the summer on the *lightWeightAPI* and *dataConditioningAPI* necessary for the alpha release shown in Figure 8. At the time of installation in Hanford, the *frameAPI* was able to recognize and read new frames into the LDAS system as they were being generated by the CDS Framebuilder. The *metaDataAPI* was able to receive commands to insert data into the database table, which are being managed using IBM’s DB2 commercial relational database. The LDAS system itself was being controlled by the *managerAPI*, which by its location on the LDAS gateway is able to receive requests for data from the CDS or GC networks (as well as the LDAS private “martian” network) and send data products associated with these requests out onto any of the three networks (LDAS, CDS, and GC)

The process at Hanford identified several performance issues associated with both the data server and the metadata server. Frame ingestion into the LDAS system by the *frameAPI* was roughly 50 percent too slow and *metaDataAPI* inserts into the DB2 database were peaking at a few rows of metadata per second. Upon returning to Caltech the LDAS software team focused on performance improvements in these area. As a result the *frameAPI* is now able to ingest frames ten times faster and the *metaDataAPI* can insert over 800 rows per second. These performance benchmarks using the existing LDAS hardware now provide I/O consistent with original LDAS requirements goals.

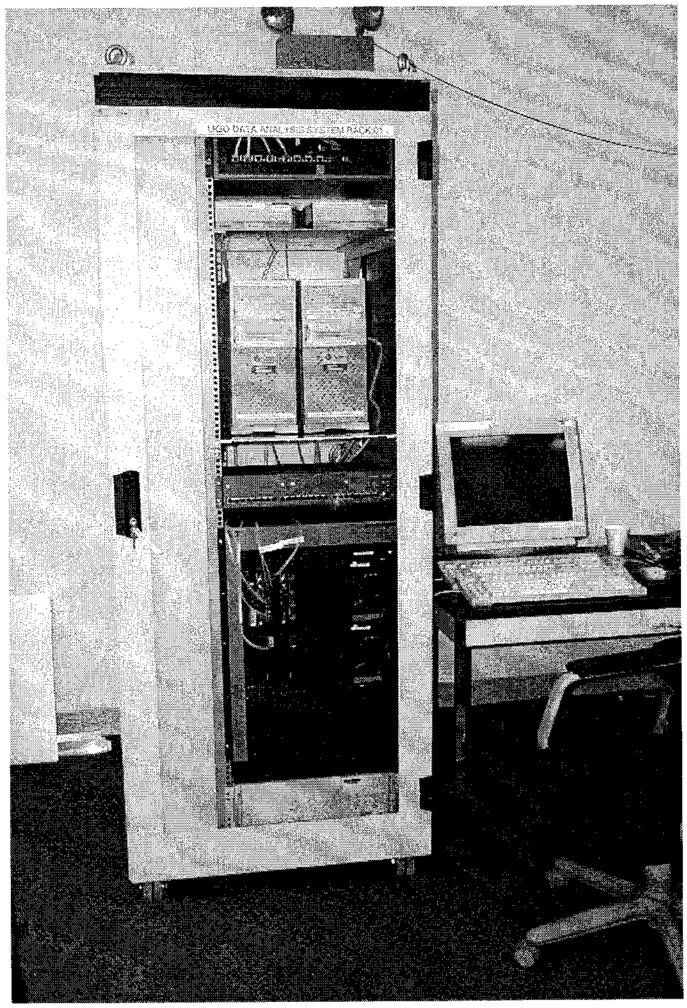

FIGURE 7. The LDAS Rack Containing the ATM and Fast Ethernet Networks and the Data and Metadata servers.

The pre-alpha release of the LDAS software installed at Hanford supported four distinct user requests from the system:

- **getFrameData** - request for data originally contained in frame format,
- **getMetaData** - request for metadata stored in DB2 tables using SQL query,
- **putMetaData** - request to insert metadata into tables managed by DB2,
- **describeMetaData** - request for description of the tables being managed by DB2.

Each of these is initiated by a command line interface to a socket on the managerAPI using telnet (or a more sophisticated GUI once implemented). The exact behavior of each command is customized by a set of parameters of the form:

ldasjob { -name "*" -password "*" -email "*"} {*command* -opt1 "*" -opt2 "*" ...}

where ***command*** is one of the four commands listed above, each of which has its own unique set of options (opt1, opt2, etc.). All options begin with a minus sign and parameter values are con-

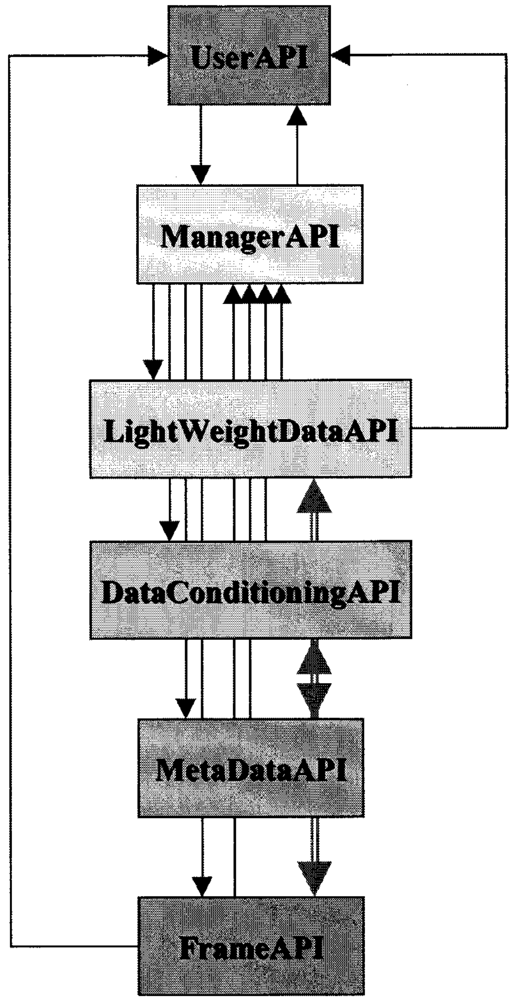

FIGURE 8. LDAS Alpha Release Software Components.

tained in quotes and indicted above by the "*". The *managerAPI* will return a job number if the *ldasjob* is successfully interpreted, or an error if the request fails. The telnet session used to communicate with the *managerAPI* is then dropped and the *managerAPI* assigns an assistant manager to carry out the task. Users are notified by email when the assistant manager has completed the requested task.

Late in the summer, as part of a migration plan back to GNU[2] and to more closely meet the ANSI C++ standard, we received a major new release of the public domain C++ compiler (egcs gcc/g++) that LDAS has been using for development. The new compiler is much stricter about C++ code being ANSI compliant, which will in the long run be a boost for LDAS software portability. However, we were required to update much of the code for compliance with the standard. This upgrade is now finished and new code developed with this compiler will be more closely aligned the ANSI standards.

2. GNU: A UNIX-like Operating System. The name GNU was chosen following a hacker tradition, as a recursive acronym for "GNU's Not Unix." Source: The GNU Project, http://www.gnu.org/gnu/thegnuproject.html.

We also addressed the issue of software release configuration management. LDAS has adopted GNU's automake and autoconfig tools to configure and control the software build and installation process. This allows LDAS to easily maintain the software for Linux and Solaris (our two primary commissioning platforms). The new release of GNU's C++ compiler identified several areas where the configuration was weak, especially when building shared objects. A careful rework of the automake and autoconfig files has provided a more reliable build and install process for the LDAS software.

The *lightWeightAPI* is nearly finished and is now at the point where it can be used to translate "Internal Light-Weight Format" (ILWD) data to and from the XML[3] based LIGO_LW format. Using a JAVA based XML browser, these LIGO_LW documents can be displayed to users with an intuitive interface. We started work on the *dataConditioningAPI*, which will have an extensible wrapper class to allow additional functionality in the future without significant rewriting.

LIGO Electronic Notebook (iLog). We upgraded the LIGO electronic log a number of ways as a result of requests from those who have been using the software. The additions include:

- Enabled simple pre-formatted tables to keep their format when placed in an entry.
- Modified the XML definition for LIGO entries.
- Defined an ilog entry url reference specification. This enables people to put references to a particular entry in e-mail or a web page (including another ilog entry).
- Created an ilog-users mailing list.
- Compiled an ilog user database to be used for identification and communication to authors of ilog entries.
- Implemented easy access to ilog entry author contact information.
- Created tools for automatically checking the consistency of the various user information databases utilized by the ilog system, including the web authentication database files, the user contact information files and author signatures on all ilog entries.
- Created tools for automatically updating all user database files for adding or deleting users from the system.
- Created tools for the automatic addition of groups to an ilog system.

Videoconferencing Among LIGO Sites. Videoconferencing is an excellent tool to support day-to-day management and technical activities over long distances. Increasingly, the technology to support video conferencing is becoming available to the LIGO Laboratory. We have been exploring options to determine cost and feasibility for LIGO use. One option we have tried and found potentially useful is CERN's Virtual Room Videoconferencing System (VRVS). VRVS was developed under the leadership of the Caltech's High Energy Physics group (HEP) and is already implemented on campus.

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3. XML: Extensible Markup Language, a standard metalanguage based on the SGML standard, but streamlined for use in defining markup languages that can be used on the World Wide Web. XML is defined to be Unicode compliant, so it will fully support multilingual text processing. Source: Offline 62, http://scholar.cc.emory.edu/scripts/Offline/off62.html.

Benchmarking Large Disk Cache

A direct network-attached filesystem from Network Appliance has been benchmarked and prototyped as a possible solution for LDAS disk cache needs. The current product has excellent reliability and administrative performance, and marginal I/O performance for LIGO I. Based on nondisclosure information, the next generation of this product should have comfortable I/O performance for LIGO I. For details see, http://www.srl.caltech.edu/personnel/sba/ligo/raid/netapp.html.

A large 80 disk filesystem from the recently decommissioned Intel Paragon has been salvaged from the Caltech Center for Advanced Computing Research (CACR) and is being attached to several server platforms to test the performance, complexity, and reliability of large software based disk cache systems under Solaris and Linux.

Continued Evaluation of HPSS. A major software upgrade was installed on the CACR High Performance Storage System (HPSS) this quarter to take advantage of the hardware upgrade last quarter. The preliminary impression is that the current CACR system can transfer an order of magnitude more data between processes than the pre-upgrade system. LIGO has installed 15TB of tape into the HPSS and has successfully archived an additional ~10TB of radio pulsar data as a reliability study. Individual file transfers were possible at speeds up to 20MB/s.

The CACR installation is now one minor software release away from supporting the concept of multiple storage subsystems. This would allow LIGO to begin building its own hardware implementation without bearing the significant burden of additional licensing fees from IBM.

2.9 General Computing Infrastructure

Caltech. The move to Caltech's new higher speed backbone (100BT) has been completed. There was a significant improvement in network performance for connections outside the LIGO/CIT internal network.

LIGO has been experimenting with and testing Caltech's VPN system (Virtual Private Network) This software package enables remote sites affiliated with Caltech to preserve their domain identity in order to utilize campus-wide access to resources and licensed software that would otherwise not be available to the LIGO Observatories.

LIGO Hanford Observatory. We are continuing our dialogue with Pacific Northwest National Laboratory (PNNL/Battelle) with regard to expanding LIGO's future network capabilities. A follow-up meeting with Battelle will take place after November. Data were provided by Battelle for LIGO's current network access and usage. Presently it appears that the Observatory usage peaks at approximately 50 percent of the available T1 bandwidth.

Livingston Observatory. The fiber installation for improving the connectivity to vBNS is in process. Discussions of services and costs are continuing. The next meeting with all involved has not been scheduled but is anticipated either the end of this year or early next year.

Preparation is also taking place for the installation of the LDAS equipment. Procurements for prototype servers and an ATM LAN for LDAS are in progress.

3.0 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 in 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. We are currently assessing the potential effect of the schedule delays discussed in Section 2.6.1 on the "Begin Coincidence Tests" milestone.

4.0 Financial Status

Table 3 on page 22 summarizes costs and commitments as of the end of August 1999.

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)	
I/O Optics Final Design Review	04/98		03/98 (A)	
Prestabilized Laser 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		12/00 (P)	

TABLE 3. Costs and Commitments as of the end of August 1999

(all values are $Thousands)

WBS		Costs Thru Nov 1997	Costs LFY 1998	First Quarter LFY 1999	Second Quarter LFY 1999	Third Quarter LFY 1999	Fourth Quarter LFY 1999	Cumulative Actual Costs	Open Commit-ments	Total Cost Plus Commit-ments
1.1.1	Vacuum Equipment	30,517	11,406	1,837	189	9		43,958	121	44,079
1.1.2	Beam Tube	32,978	13,273	769	(17)	0		47,004	78	47,083
1.1.3	Beam Tube Enclosure	13,274	6,145	(3)	29	127		19,571	29	19,600
1.1.4	Civil Construction	44,681	6,563	395	649	310		52,598	910	53,508
1.1.5	Beam Tube Bake	75	3,078	431	536	622		4,742	847	5,589
1.2	Detector	14,340	20,537	4,544	6,117	2,931		48,469	6,482	54,951
1.3	Research & Development	19,681	1,661	211	442	(99)		21,896	224	22,120
1.4	Project Management	22,649	4,914	603	314	281		28,761	972	29,732
7LIGO	Unassigned	1	18	8	17	(12)		32	1	33
TOTAL		178,196	67,595	8,795	8,276	4,170		267,032	9,664	276,695
Cumulative Actual Costs		178,196	245,791	254,586	262,862	267,032				
Open Commitments		62,510	16,422	15,381	11,141	9,664				
Total Costs plus Commitments		240,706	262,213	269,967	274,003	276,695				
NSF Funding - Construction		*$ 265,089*	*$ 291,900*	*$ 291,900*	*$ 291,900*	*$ 292,100*				

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

5.0 Performance Status (Comparison to Project Baseline)

Figure 9 on page 24 is the Cost Schedule Status Report (CSSR) for the end of August 1999. 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 WBS. The schedule variance is equal to the difference between the budget-to-date and the earned value, and represents a "dollar" measure 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 10 on page 25 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. The at-completion overrun forecast reflects payments owed to Process Systems International (PSI) for gate valve rework as well as miscellaneous quality, travel, and labor escalation charges.

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). Civil Construction is complete. Favorable cost variances are the result of normal delays in the payment of invoices.

Beam Tube Bake (WBS 1.1.5). The unfavorable schedule variance is due to a delayed start of the first bake while awaiting completion of repairs to gate valves on the Beam Tube ports (manufactured by VAT, delivered by Chicago Bridge and Iron, and repaired by VAT under warranty).

The unfavorable cost variance is due to increased labor costs associated with the schedule delay plus substantial additional labor resources needed to prevent further delays. These costs are reflected in the estimate-at-completion.

Detector (WBS 1.2). The Detector is behind schedule and under cost. Detector planning continues to emphasize the delivery of hardware to support installation of the first interferometers. Priorities have been adjusted to assure that critical milestones are met.

Laser and Optics - Core Optics Component fabrication is on schedule. The Pre-stabilized Laser for the two kilometer interferometer has been installed in Hanford, Washington and the installation of the laser for Livingston is underway. Input Optics installation is approximately one month behind schedule.

Seismic Isolation - The Seismic Isolation effort is four months behind schedule. Production schedules are being managed to support interferometer installation. Installation is in progress at both sites.

Interferometer Sensing and Control - The Interferometer Sensing and Control effort is behind schedule due to the design of the input optics controls. The Initial Alignment System, needed first for installation, is on schedule.

FIGURE 9. Cost Schedule Status Report (CSSR) for the End of August 1999.

LIGO Project

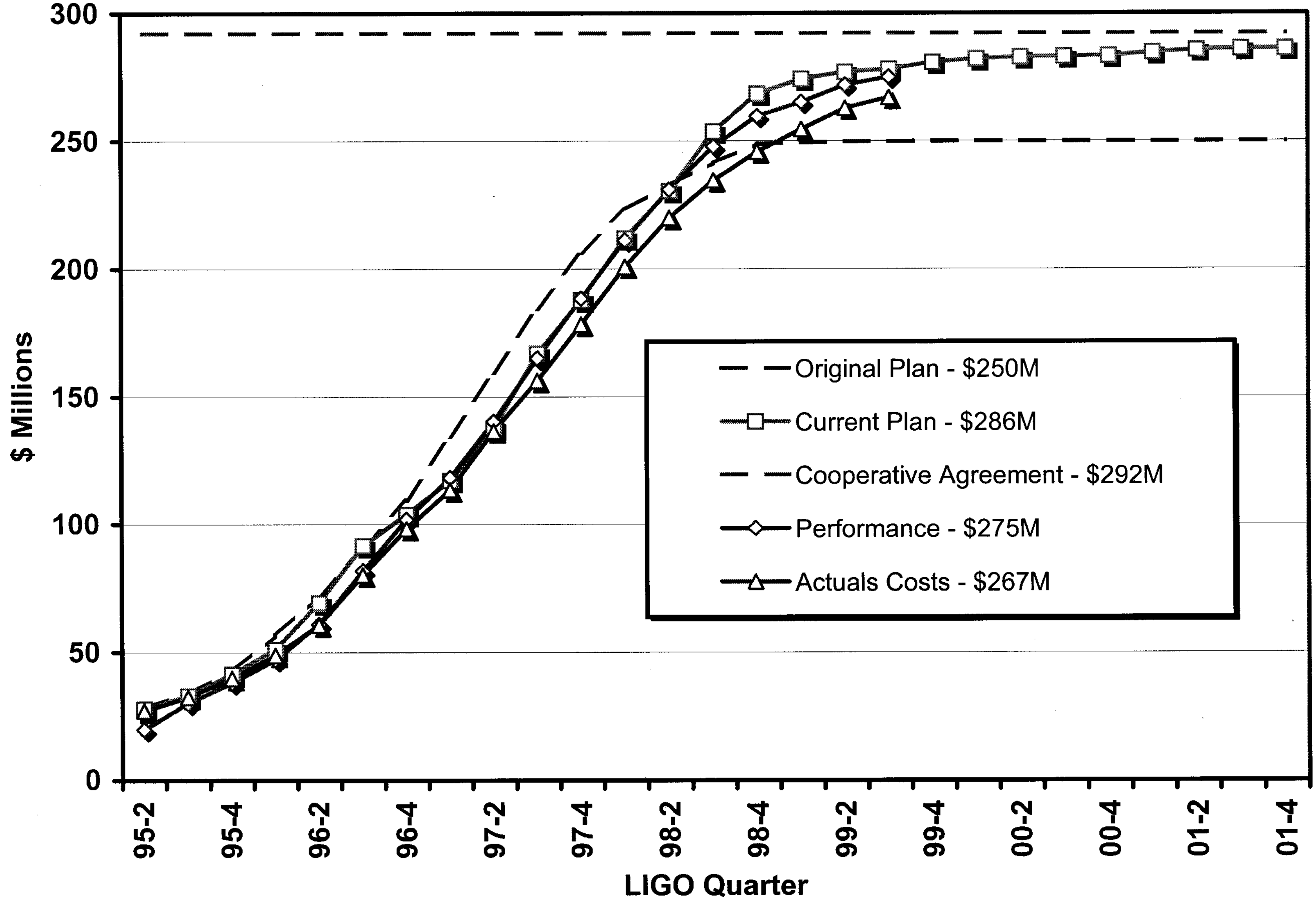
Cost Schedule Status Report (CSSR)

Period End Date: 28 August 1999

(All values are $Thousands)

Reporting Level	Cumulative To Date					At Completion		
Work Breakdown Structure	Budgeted Cost of Work Scheduled (BCWS)	Budgeted Cost of Work Performed (BCWP)	Actual Cost of Work Performed (ACWP)	Schedule Variance (2-1)	Cost Variance (2-3)	Budget-at-Completion (BAC)	Estimate-at-Completion (EAC)	Variance-at-Completion (6-7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.1.1 Vacuum Equipment	43,771	43,771	43,958	-	(187)	43,771	43,956	(185)
1.1.2 Beam Tubes	46,967	46,967	47,004	-	(37)	46,967	47,003	(36)
1.1.3 Beam Tube Enclosure	19,790	19,785	19,571	(5)	214	19,790	19,623	167
1.1.4 Facility Design & Construction	52,891	53,048	52,598	157	450	53,118	53,035	83
1.1.5 Beam Tube Bake	4,199	4,105	4,742	(94)	(637)	4,879	5,600	(721)
1.2 Detector	57,589	54,483	48,469	(3,106)	6,014	60,035	57,213	2,822
1.3 Research & Development	22,089	22,089	21,896	-	193	22,089	22,089	-
1.4 Project Office	30,797	30,797	28,761	-	2,036	35,485	35,568	(83)
Subtotal	278,093	275,045	266,999	(3,048)	8,046	286,134	284,087	2,047
Contingency						-	8,013	(8,013)
Management Reserve						5,966	-	5,966
Total	278,093	275,045	266,999	(3,048)	8,046	292,100	292,100	-

FIGURE 10. LIGO Construction Performance Summary as of the End of August 1999.



Control and Data Systems - There are minor behind schedule positions reported, but the group continues to support immediate needs.

6.0 Change Control and Contingency Analysis

Seven change requests (see Table 4) were approved during the quarter. These change requests allocated $129,200 from contingency with corresponding additions to the budget baseline. The current contingency is $5.2 million.

TABLE 4. Change Requests Approved During Second Quarter LIGO FY 1999

CR Number	WBS	Description	Amount
CR-990001 Revision B	1.3	Return Unused Budget to Contingency	(1,401,000)
CR-990017	1.4.4.1	Project Controls--Administrative Account Closeout	275,000
CR-990019	1.2.1	Detector Systems--Optics Table Balance Weights	42,000
CR-990020	1.2.1	Seismic Isolation System--Material and Subcontract Closeout Costs	156,000
CR-990021	1.2.4	Support Equipment--Additional Clean Rooms and laminar Flow Benches	94,200
CR-990022	1.2	Detector--Extend Contract Labor Support	760,000
CR-990023	1.2.1	Interferometer Systems and Integration Engineering - Cable Tray Contracts	203,000
		Total	129,200

7.0 Staffing

The LIGO staff currently numbers 130 (full time equivalent). Of these, 28 are contract employees. Eighty-four LIGO staff are located at CIT including six graduate students. Seventeen are located at MIT including seven graduate students. Eighteen are now located at the Hanford, Washington site, and 11 are assigned to Livingston, Louisiana.