Report of the LASTI Technical Advisory Committee

Based on its 2nd meeting, 17 August 2000, at the LSC meeting, LHO

Summary:

The LASTI TAC endorses the overall LASTI plan, and recognizes the progress that has been made to date.

We support the plan not to use LASTI for "heroic" noise tests. This would only be responsible, though, if it is coupled with an alternative plan for ensuring that LIGO II SEI and SUS subsystems can achieve their noise targets. (One such possibility is to replace a single LIGO I interferometer with a LIGO II interferometer, then pause to carry out noise tests before replacing the remaining two interferometers.) This is not a LASTI issue alone, but one that affects all of LIGO. A LIGO-wide testing policy for LIGO II needs to be established.

There is a conflict between the LASTI schedule presented to us and the overall installation schedule for LIGO II, with LASTI not presenting the results of key tests until too late to support the planned installation. LASTI needs to review its schedule and that of the delivery of SEI and SUS prototypes, and then needs to reconcile its schedule with the (possibly revised) LIGO II installation schedule.

Other recommendations:

- *The LASTI program should incorporate a test of the LIGO II IO and PSL subsystems.*
- *The SUS tests at LASTI should include each of the multiple versions of the suspension that will be used in LIGO II.*
- *An early test of the cartridge installation procedure should be carried out.*

Members in attendance: Rolf Bork, Dennis Coyne, Riccardo DeSalvo, Brian Lantz, Fred Raab, Peter Saulson (chair), and Alan Weinstein.

The present state of LASTI and plans for its future were presented by David Shoemaker, Mike Zucker (via telephone), and Ken Mason. The focus of their presentation was an update on the planned scope of the LASTI testing program, and of the schedule for carrying out that program. The meeting was intended to serve as a "Conceptual Design Review", an informal critique and (it was hoped) endorsement of the LASTI program.

1. Scope

1.1 Noise tests

At our first meeting in March, we had considered the goals of LASTI program. The description we gave at that time was as follows: "the goal of LASTI work for LIGO II is to test at full scale the seismic isolation (SEI) and suspension (SUS) subsystems of LIGO II. Those tests can be logically divided into tests of

a) installation and fit,
b) seismic isolation,
c) control function, and
d) noise level."

In our report from that meeting, we flagged the issue that seemed most uncertain in the plans for LASTI (and indeed for all less-than-full-scale LIGO test facilities): to what noise level should the noise tests aspire? The physics reason behind this question is the strong dependence of thermal noise on the size of the beam, which in turn depends on the length of the cavity. The dependence is especially strong for the thermoelastic noise which dominates in sapphire, making the thermal noise so large that any realistic test at LIGO II noise levels is impossible.

Since that meeting, there has been some serious thought about how to deal with this issue. The LASTI program discussed at the 17 August meeting was built around a specific proposal for dealing with the noise dilemma. The idea is to eschew all “heroic” attempts to achieve LIGO II sensitivity levels, and to focus LASTI instead on its other goals: installation and fit, seismic isolation, and control function tests of the SEI and SUS subsystems.

No one doubts the necessity of verifying that LIGO II noise levels can be achieved. The question is how best to gain confidence in LIGO II’s success, where “best” includes the perhaps competing considerations of schedule, cost, and degree of confidence.

The LASTI plan that was presented at the meeting is built around the assumption that there will be a better place than LASTI to verify the noise performance of the SEI and SUS subsystems for LIGO II. More specifically, it is imagined that one LIGO I interferometer might be taken out of service first, while the other two remained operating. (It is simplest to imagine decommissioning the LLO interferometer first, although if there are clever ways to do it at LHO without interfering with the other interferometer, that could have advantages.) The first LIGO II interferometer would be installed and commissioned, with the commissioning operation performing the function of validating the noise model of the interferometer.

This idea was discussed at the LIGO II design meeting held at MIT in May. The idea was considered appealing by many of those present, and it has been taken seriously enough by the LASTI team to form the basis of their present thoughts on LASTI’s goals. Nevertheless, it is a strategy that contains risks, so it is important that LIGO consciously make a choice either to follow this strategy or to choose a different plan for LIGO II noise testing.

The question is: Is there any other better strategy for noise tests? Alternatives include:

1. Heroic work at LASTI,
2. Heroic work at another LIGO facility (e.g. TNI or 40 m), or
3. Replacement of a single end station (SEI and SUS) at one LIGO I interferometer.

1. The LASTI interferometer, as presently designed, will miss testing the bottom of the LIGO II noise curve at 300 Hz by more than 1 order of magnitude if LASTI uses fused silica test masses, almost 3 orders of magnitude if sapphire test masses are used. It is almost that far at all frequencies lower than that. A fused-silica LASTI

interferometer crosses the LIGO II displacement sensitivity curve (in its storage time limited shot noise region) around 2 kHz.

Two strategies might partially close the gap. Either constructing a long cavity (~16 m) or moving to a less stable cavity could increase the spot size from 0.5 mm to ~5 mm. This would reduce the sapphire thermal noise (thermoelastic dominated) by a factor of 30, or the fused silica thermal noise by much less (around a factor of 5.) A long nearly unstable cavity could do more. Still, none of these options allows for a test at the level of the LIGO II noise minimum.

2. Other LIGO facilities will also play key roles, of course, in guaranteeing that LIGO II will work, but none of them will be able to reach LIGO II sensitivity levels. The TNI's small-beam-spot barrier has been well explored. The longest LIGO facility is the 40 m, so on the face of it would have the best shot at making this test. But its arms are still a factor of 100 smaller than LIGO's (diffraction-limited spot size 10 times smaller). Furthermore, it is designed for other roles than validating the SEI and SUS subsystems, and couldn't do the sort of realistic tests of those subsystems for which LASTI is designed; neither the isolation system nor the suspensions can be fit into the vacuum enclosure.

3. Replacement of a single ETM/SUS/SEI at a LIGO observatory with a LIGO II version would in effect allow a full test of the LIGO II components at LIGO I sensitivity. This makes a very large difference in the level of suspension noise testing if sapphire is the chosen test mass material (2 orders of magnitude in a narrow band around 200 Hz) compared with what LASTI can achieve with a short cavity ("non-heroic"). If silica is the test mass material, LASTI can already beat LIGO I at most frequencies, and in the narrow band where it misses it doesn't miss by much.

At the meeting of the LASTI TAC, Fred Raab proposed another criterion for the displacement sensitivity of LASTI, namely that it should be able to check whether the new SEI/SUS subsystems are at least as quiet as the LIGO I parts that they would replace. This Hippocratic criterion ("First, do no harm.") has a certain appeal. It has different force in different frequency ranges and for different test mass materials, however. For frequencies below about 50 Hz, LASTI is much quieter than LIGO I even if the test does not allow a close approach (for sapphire) to the LIGO II goals. LASTI can also meet this challenge of testing at better-than-LIGO I levels at 2 kHz and above. There is a very large gap in the middle of the intervening interval (up to 2 orders of magnitude at 200 Hz). For fused silica substrates the Hippocratic test is possible in the tests as proposed for LASTI at almost all frequencies, with a small gap (roughly 100 to 300 Hz) in which the worst mismatch is a factor of 2 to 3 at 200 Hz. (These numbers are quoted for the baseline optical design of LASTI, not for any "heroic" alternative.)

This kind of reassurance about the performance of the SEI/SUS systems would be nice to have, especially when it comes as a matter of course in the testing program. The question is whether to tailor the testing program to achieve it more fully. Should more aggressive optics designs be used to improve the quality of this test? Should a fused silica system be tested in LASTI even if sapphire emerges as the LIGO II test mass material, simply to enable a lower noise test?

None of these options would be easy to carry out. And, in the end, they still would not tell us what we want to know, namely whether SEI and SUS actually met their real performance specifications.

It is the recommendation of the LASTI TAC that LASTI not be burdened with carrying out high sensitivity noise tests. The first three goals (installation and fit, seismic isolation, and control function) are valuable and are well-matched to LASTI's capabilities.Only under some circumstances (choice of fused silica plus "heroic" work) could LASTI also perform a high sensitivity noise test.

The LASTI TAC is fully aware that this recommendation is only defensible in the context of an overall LIGO plan for ensuring minimum risk of excess noise in LIGO II. We favor the strategy of using the first LIGO installation of LIGO II components as the LIGO II noise test. However, we are well aware that it is not up to LASTI's TAC to make such an important decision. <u>We urge LIGO as a whole to establish a LIGO II noise testing strategy.</u> Only in the context of such a strategy can plans for facilities like LASTI be meaningfully judged.

1.2 PSL and IO tests

Another question of scope was discussed at our meeting. A suggestion was made last May that LASTI be the testbed for the PSL and IO subsystems, in addition to serving that role for SEI and SUS. There were several arguments in favor of this suggestion:

1. There is no other testbed identified.
2. LIGO I commissioning experience has demonstrated that it would have been helpful to have more realistic full-scale installation and commissioning tests, before moving the subsystems to the LIGO Observatories. For example, the problem with IR sensitivity of the OSEMs would have been uncovered earlier, and much of the debugging of subsystems would have been out of the way before arriving at the observatory.
3. A frequency stabilization cavity and mode cleaner is part of the planned LASTI configuration.
4. LASTI will need to test mode cleaner suspensions in any event, most conveniently and completely in a cavity arrangement resembling the LIGO II mode cleaner.

Given arguments #3 and #4, it seems natural to include tests of the LIGO II mode cleaner in LASTI's test program. The question of tests of the LIGO II PSL, and of the test of SUS at full power, is more subtle. For most of LASTI's work, 100 W or more of laser power would be of no use, and would even be a nuisance (such as from additional safety concerns.) On the other hand, one would certainly like a pre-LIGO II opportunity to catch any problem similar to the interaction between the PSL and SUS in LIGO I. One possible solution would be to use a LIGO I PSL for most work, and to swap in a LIGO II PSL late in the testing program.

One might be concerned that this is an example of "scope creep". If so, it could overtax the efforts of the MIT group, and/or cause the schedule to slip. Two arguments point the other way:

1. LASTI's scope will have been substantially reduced if it is not asked to perform "heroic" noise measurements.
2. The PSL (like all LIGO subsystems) is to be engineered by a dedicated group. Installation and tune-up of the PSL would be carried out by the PSL group as LASTI visitors, in the same style as the installation and test of SUS and SEI.

We recommend that the LASTI program incorporate tests of the LIGO II mode cleaner. We also recommend that an integrated test of IO, SUS, and SEI at the full power of the LIGO II PSL be carried out late in the LASTI test program.

1.3 Tests of multiple suspension versions

One other small issue of scope was discussed. Instead of simply two suspension designs (LOS and SOS), it appears that LIGO II may include several more variations. *To fulfill its role as the testbed of SUS, LASTI needs to ensure that it uses at least once copy of each variation on the SUS design.*

2. Schedule

2.1 Overall pace

The schedule presented by the LASTI team showed key results on the "noise prototypes" of the suspensions only arriving at the middle of 2005, and other key tests not even starting until after that time. This does not mesh with the present overall ("top down") schedule for LIGO II installation.

This is a very important conflict, and needs to be resolved. The schedule needs to be re-examined at all levels. The key pacing items in the LASTI schedule are the deliveries of SEI and SUS prototypes, so a review of those subsystems' schedules should be made. At the top level, it may turn out that recent events at the NSF or elsewhere preclude a mid-2005 installation anyway, reducing or eliminating LASTI's schedule discrepancy.

We recommend that LASTI re-examine its schedule and that of its key subsystems, so that it can be reconciled with the (possibly revised) overall LIGO II schedule.

2.2 Early test of cartridge installation

One of the items postponed to 3Q05 in the present schedule is a first article installation test of the combined SEI/SUS system ("cartridge installation".) The TAC thought this was too late to be useful, and would be disruptive of any sensitive work that was ongoing at the time. *We recommend an early test of the cartridge installation, using the "controls prototype" if possible. This will require that installation procedures and tooling be developed early in the program.*