LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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aLIGO Availability Estimate

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1 Introduction

This is a preliminary estimate of the availability (or uptime) of the Advanced LIGO (aLIGO) interferometer. Updates to this availability estimate will be made as the system FMEA and reliability assessment is completed, and as more operational experience is gained.

2 Applicable Documents

T080160-v1	D. Hoak, B. Bland, "Downtime Accounting in S5", Jul 2008
T1300519-v3	D. Coyne, "Sparing Analysis",
T010075-v2	P. Fritschel, "Advanced LIGO Systems Design"

3 Scope

The scope of this availability estimate is a single aLIGO interferometer (not an estimate of coincidence operation, yet).

This estimate does not (yet) address the impact of non-interferometer, observatory systems on the system availability. For example facility systems such as HVAC and vacuum equipment. The experience from iLIGO/eLIGO is that these systems do not significantly impact the interferometer uptime (see for example T080160).

4 Previous Experience

Some of the experience for Initial and Enhanced LIGO (iLIGO and eLIGO), in particular the S5 and S6 science runs are potentially relevant to anticipated aLIGO operations. Good downtime statistics have been assembled for the S5 run (T080160), but appear to be mostly lacking for the S6 run. (It is worth noting that LIGO operations intends to implement better operational metrics tracking that have been in place in the past.)

5 Terminology

The terminology for the categories of the causes for interferometer downtime (unavailability) used here are very similar to those used in T080160.

5.1 Uptime

Uptime is time the interferometer is in science mode. Science segments of any length are counted.

5.2 Calibration

Calibration is time spent performing calibration studies. These are done periodically throughout the science runs. The same percentage time for iLIGO/eLIGO should apply to aLIGO.

5.3 Hardware Failures

Hardware failures result in downtime due to needed repair or replacement of equipment. Examples are broken seismometers and electronics modules. The repair time includes diagnosis and isolation of the faulty equipment and the subsequent time to repair or replace and verify function (including reboots to computer equipment if appropriate), as well as the time required to bring the interferometer system back to low noise operation again.

Also included in this category is power grid outages.

5.4 Software Failures

Software failures result in downtime due to faults in the software code. Examples are memory leaks and inadvertent triggers of software watchdogs (i.e. when not appropriate due to environmental conditions or equipment faults). The repair time includes diagnosis and re-start/re-boot of processes/computers as appropriate, as well as the time required to bring the interferometer system back to low noise operation again. The time required to isolate of the software fault, or define more appropriate parameter values (e.g. watchdog trigger levels), and then revise and regression test a new version of the code is assumed to be done off-line.

5.5 Maintenance

Maintenance is downtime for planned detector maintenance, including scheduled repairs for failures which do not require prompt repair or replacement. During S5 & S6, four hours were scheduled every Tuesday for invasive, periodic maintenance tasks, such as liquid nitrogen deliveries, grounds-keeping, HEPI pump filter replacement, etc. This period is also used for scheduled detector maintenance such as PSL pump diode replacement, HWS SLED replacement, OptLev laser replacement, etc.

5.6 Commissioning

Commissioning is downtime for planned detector improvements. There were a few extended commissioning breaks at both sites during S5 and S6; these lasted for about a week and occurred once or twice a year. In addition, about 25 hours were allocated every month in S5 for discretionary studies.

5.7 Transition to Low Noise Operation State

In the S5 downtime accounting document (T080160), the “scripts” category covered time spent running the "up" and "down" software scripts that take the instruments from lock-acquisition mode to the low noise detection mode. This required about ten minutes, each time the interferometer lost lock. The Automation System, Guardian, employed for aLIGO serves a similar function, but is more robust and should be more efficient, once the system is fully commissioned.

5.8 Wind

The category “wind” includes downtime due to high winds. At Hanford, for S5 and S6 this is typically wind over 25-30 miles per hour.

In S5 and S6 at Livingston, the seismic pre-isolation system is very sensitive to the low-frequency ground motion caused by wind. Typically, Livingston could not operate in science mode when the wind was gusting more than 15mph. (At Livingston, this category also includes downtime due to Storms.)

5.9 Seismic

For Hanford, the Seismic category includes any source of ground motion that prevents the interferometer from normal operations. Mostly, this downtime is due to earthquakes. The seismic environment is more complicated at Livingston, and this category is expanded into different sources:

Microseism is the term used to describe the low-frequency (0.1-0.35 Hz) ground motion caused by ocean waves striking the continental shelf. This is worst in the winter months, due to storms in the Atlantic.

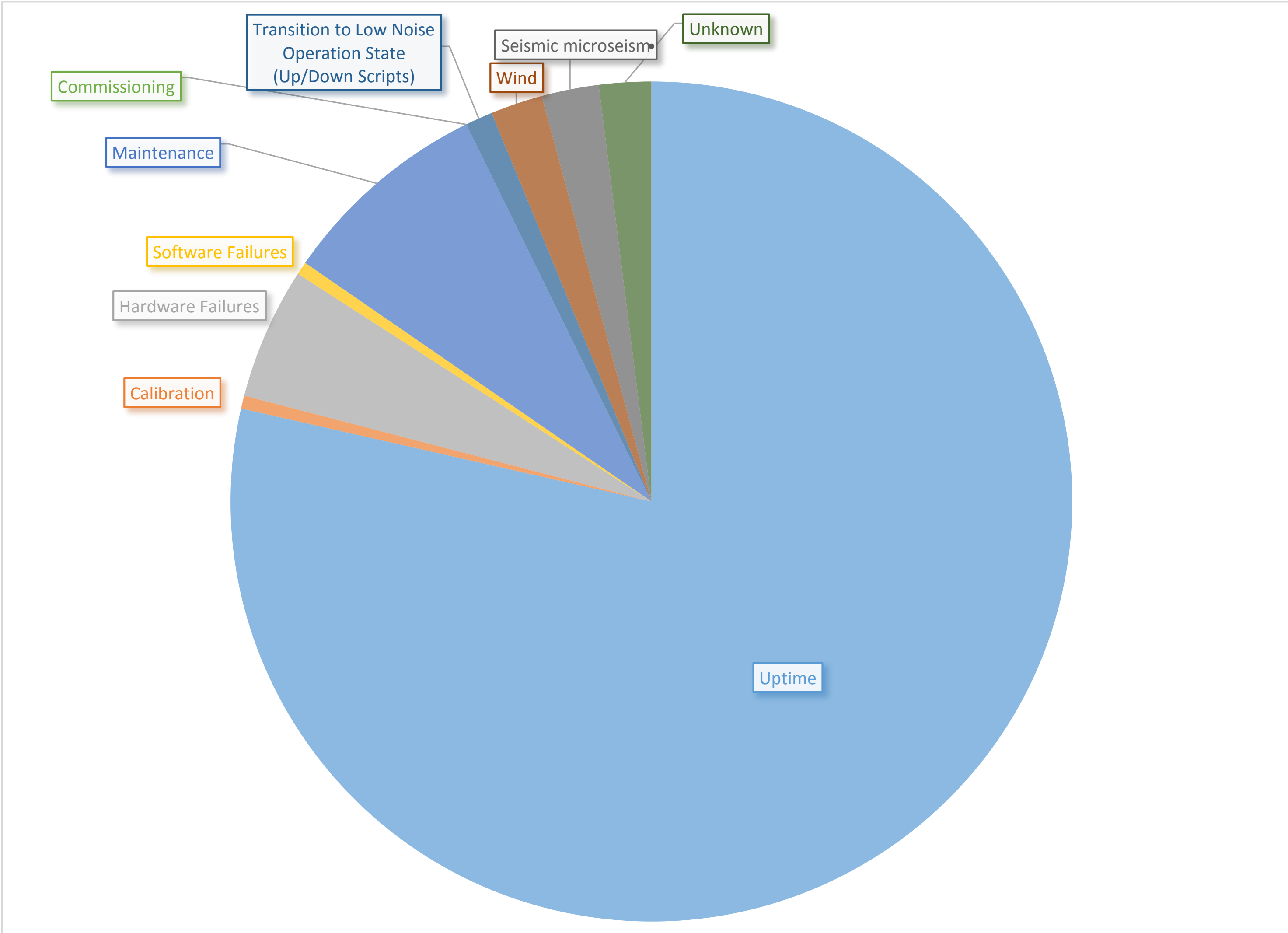
Earthquakes produce large amplitude, low frequency ground motion (0.03-0.1 Hz), although higher frequencies can be driven depending on the earthquake's size and location. Typically, a 6.0-magnitude earthquake on the western Pacific Rim (Russia, Japan, the Philippines, or Indonesia) kept the Livingston interferometer out of lock for one or two hours in S5 and S6. Events like these happen about once every two days.

Trains are a phenomenon unique to Livingston. Railroad tracks pass by the site about 1.75 miles south of the ETMY end station, and freight trains move through Livingston three or four times a day. The largest trains occur regularly around 2am and around 7am, and typically take the interferometer out of low-noise operations for about half an hour.

6 aLIGO Availability Estimate

6.1 Uptime

The estimated uptime for aLIGO is 79%, as indicated in the Table and Figure below. Each of the factors that are part of this estimate are discussed in the sections below.


Transition to Low Noise Operation State (Up/Down Scripts)
Seismic microseism
Unknown
Wind
Commissioning
Maintenance
Software Failures
Hardware Failures
Calibration
Uptime

Category		S5 H1 (T080160)	S5 L1 * (T080160)	S5 L1 ** last 2 months	aLIGO Estimation	aLIGO comments
Uptime		76.9%	70.9%	76.1%	78.6%	
Calibration		0.5%	0.5%	0.5%	0.5%	same as for S5
Hardware Failures		3.9%	3.9%	2.7%	5.1%	Rate for aLIGO is based on failure rates (from T1300519, Sparing Analysis) for prompt (unscheduled) attention and LLO power outage rate for last year with recovery WAG
Software Failures					0.5%	WAG; should be low after commissioning
Maintenance		6.2%	8.3%	6.1%	8.1%	corresponds to 4 hr/wk, plus one 3 wk vent&pump period per yr Note that for aLIGO the ISC in-vacuum output electronics/detectors are in vacuum volumes separate from the main vacuum volume
Commissioning		4.3%			0.0%	projection to steady-state operations; no commissioning
Transition to Low Noise Operation State (Up/Down Scripts)		2.0%	2.8%	2.2%	1.1%	15 min every 24 hr. with Guardian automation system (less rms motion and better automation)
Wind		2.0%	1.7%	0.2%	2.0%	assume that we don't improve on sensitivity to wind-induced ground tilt senstivity
Seismic	**microseism**		2.4%			should have better isolation from earthquakes and microseism
	trains	2.2%	2.4%	2.3%	2.2%	assume better for L1, but same as H1 S5
	earthquakes		4.2%	6.5%		
Unknown		2.0%	2.7%	3.4%	2.0%	same as H1 S5
		100.0%	100.0%	100.0%	100.0%	

* renormalized to remove the exceptional time on L1 for SEC construction and ITMy repair due to SEC construction

** calibration time assumed to be part of the unknown/other category. Unusually high earthquake activity in this period, but no microseism induced downtime reported.

6.2 Hardware Failures

The impact of availability due to hardware failures was estimated by taking the list of Line Replaceable/Repairable Units (LRUs) that was provided by the subsystem technical experts for each subsystem (and documented in T1300519, Sparing Analysis) and then projecting out the following three categories of failures:

- Repair/replacement of in-vacuum failed equipment [assigned to a once per year in-vacuum incursion event with a duration of 1 week duration, plus a 2 week pump-down period]
- Repair/replacement of in-air equipment which require prompt attention (i.e. failures which impact availability or performance, for which we have no credible early detection/forewarning of the failure)
- Repair/replacement of in-air equipment which can be scheduled (i.e. for which we have an early detection/forewarning of the failure) [assigned to be addressed in the weekly maintenance period]

For each of the failures, an estimate of the time required to diagnose, isolation, repair or replace and confirm function/operation has been made.

An estimate of the power outage rate was obtained by looking through the electronic logs for the period 6/1/2013 through 6/1/2014. Even short power "glitches" lasting a few seconds causes many of the interferometer detector systems to shut down and require a careful sequence of re-booting. For L1 there were 16 power outage events in the last year, of which only 5 had significant duration (many minutes or more). For H1 there appear to have only been 4 events.

It is currently difficult to estimate the duration of the impact of a power outage, beyond the duration of the outage itself. Here I have assumed a minimum 4 hour impact (in steady-state operations, once all procedures for re-start are well established). With this assumption, based on the last year of L1 experience, the total power outage impact is 83 hours, or 0.95%. This motivates implementation of adding UPS systems to all interferometer detector systems (not just the mass storage room computers); This is an item on the potential liens on aLIGO project contingency.

#	Subsys	Event	Frequency (#/yr)	Duration (hrs each)	Downtime	Comments
1	All	In-vacuum maintenance	1	504	5.75%	once/year vent, parallel activities; 1 wk vent plus 2 wk pumpdown
2	All	weekly maintenance period	52	4	2.37%	All deferred/planned maintenance
					8.13%	

#	Subsys	Maintenance/Repair	Frequency (#/yr)	Duration (hrs each)	Downtime	Event	Comments
1	COC	Clean optics accumulated hydrocarbon film off of optics	1	8	0.09%	1	duration is set by vertex optics set ETMs cleaned (if needed) in parallel
2	DAQ	electronics failures, incl. all of the I/O chassis and real-time/DAQ computers used by aLIGO	154	1	1.76%	NA	individual, separate events; no early detection
3	IO	clean or replace degraded opto-electronics on the PSL/IO optics table	8.19	4	0.37%	2	clean or replace when convenient during weekly maintenance period
4	IO	replace, align and test EOM when it fails	0.365	4	0.02%	NA	
5	IO	replace, align and test slow & fast PDs when they fail	0.526	4	0.02%	NA	
6	IO	replace, align and test HP beam dump when it fails	0.4	4	0.02%	NA	
7	IO	replace/clean, align and test degraded HAM2 & HAM3 optics	15	24	4.11%	1	very pessimistic MTBF estimates for degradation of the HAM2/3 IO optics; should revise based on iLIGO/eLIGO experience
8	IO	replace/clean, align and test degraded IO table optics	13.538	4	0.62%	2	
9	ISC	replace, align & test ISC in-vacuum electronics	0.04	24	0.01%	NA	HAM1 & HAM6 can be vented & pumped down separately from the main vacuum and turned around in 1 day (3 shifts) if necessary
10	ISC	replace, align & test ISC in-air electronics	6.973	4	0.32%	NA	
11	ISC	replace, align & test ISC in-vacuum optomechanics, picomotors, detectors	1.802	4	0.08%	NA	
12	ISC	replace, align & test ISC in-air optomechanics, picomotors, detectors	8.635	4	0.39%	NA	
13	OptLev	replace, align & test diode laser, optical fiber or Quad PD	6.526	8	0.60%	2	Optical levers are fly-wheels & diagnostic equipment, not critical to operation after commissioning (no downtime hit)
14	PSL	repairs of failures without early detection: FrontEnd: EOM, AOM, shutter, PDs, pump fibers, NPRO driver	0.7	4	0.03%	NA	
15	PSL	scheduled repair/replacement of degraded components: FrontEnd: Faraday Isolator, Amplifier, Diode set, NPRO	1.814	4	0.08%	2	
16	PSL	repairs of failures without early detection: HPO: PD Amp, PD int, PD Iso, PD BP, lock PD, Heads	4.13	4	0.19%	NA	
17	PSL	scheduled repair/replacement of degraded components: HPO: Diode set, etc.	4.904	4	0.22%	2	
18	PSL	Diagnostic Bread Board (DBB)	NA	NA		NA	diagnostic function only
19	PSL	ISS, PMC, FSS	1.9	2	0.04%	NA	
20	SEI	in-vacuum sensors	13.193	16	2.41%	1	ISI can perform (albeit degraded) when a sensor fails due to redundancy (control algorithms/laws and software for re-configuration for graceful recovery are still in development)
21	SEI	SEI repairs of failures without early detection: prompt attention to in-air electronics	12.554	2	0.29%	NA	
22	SEI	SEI scheduled repair/replacement or maintenance	223.083	2	5.09%	2	
23	SLC	NA			0.00%		no maintenance or credible expected failures other than PDs, but they are not essential to operation
24	SUS	in-vacuum OSEM repair/replacement	1.839	4	0.08%	1	Can sustain a single OSEM failure on a stage generally (some redundancy), so schedule replacement in yearly vent
25	SUS	SEI repairs of failures without early detection: prompt attention to in-air electronics	10.022	2	0.23%	NA	
26	TCS	in-vacuum CO2 laser beam relay mirror coating failures	2.608	8	0.24%	1	pessimistic MTBF for CO2 beam coating life note that RH glass former is not a credible failure & RH RTD is not essential
27	TCS	in-air TCS prompt repair	15.516	4	0.71%	NA	NOTE HWS IS NOT ESSENTIAL
28	TCS	in-air TCS scheduled reapir	3.827	4	0.17%	2	NOTE HWS IS NOT ESSENTIAL
29	TMS	in-vacuum	0.876	4	0.04%	1	
30	TMS	in-air, prompt	0.291	2	0.01%	NA	
31	Power	power outage	16	5.1875	0.95%	NA	based on LLO for the period 6/1/2013 thru 6/1/2014 time to recover is a WAG
					19.20%		

6.97%	event 1 - in-vacuum maintenance
7.16%	event 2 - weekly maintenance
5.06%	NA - prompt attention

6.3 Software Failures

The rate of software failures in the steady-state after commissioning should be rather low. However given the complexity of the system as well as the need to update/maintain the software as operating systems and hardware platforms are updated, it is not reasonable to assume that there is no impact. For this estimate a 0.5% impact has been assumed until better information, or the basis for a better estimate, is developed.

6.4 Maintenance

Just as for the S5 & S6 runs, a four hour maintenance period has been assumed weekly.

In order to accommodate the scheduled equipment maintenance/repair activities within this weekly 4-hour period, the observatory team would need to address ~3 repairs/tasks associated with the interferometer, on average, each week.

6.5 Commissioning

In the aLIGO availability estimate I have assumed that no commissioning is being performed in steady-state operation.

6.6 Transition to Low Noise Operation

The Automation System, Guardian, employed for aLIGO serves a similar function, but is more robust and should be more efficient, once the system is fully commissioned. The recent aLIGO lock acquisition for L1 using the Guardian takes about 10 minutes. Additional time will be required to bring the system to low noise operation as well. The goal is for lock acquisition lengths of > 40 hr. Here it has been assumed that the Guardian will require 15 minutes every 24 hr.

For the first aLIGO science run, the intent is to operate at 25W. When (eventually) aLIGO operates at high laser power, the time required to get to a low noise operational state, from a cold interferometer state, will be much longer. Even the interruption of high power operation for a short period will cause the interferometer optics to cool and require more time to re-establish the proper “hot” state. The availability estimate in this version does not take into account these considerations.

6.7 Wind

The aLIGO seismic isolation system (SEI) was designed to provide much better seismic isolation performance at low frequencies than we had in iLIGO and eLIGO. Integrated test experience with aLIGO indicates that the promised SEI performance has basically been delivered. However the performance is a trade-off with robustness to environmental disturbances. This trade-off, and optimization for the environmental disturbances, has not yet been completed, and may not until we’re well into commissioning. There is evidence that wind at LHO causes significant ground tilt which the seismometer sensors sense as translation, and limits performance.

For this estimate, I have conservatively assumed that we don't improve on the sensitivity to wind-induced ground tilt sensitivity observed in S5 for LHO. In fact we are likely to improve our robustness to wind as the SEI systems are fully optimized.

6.8 Seismic

As stated above, we fully expect (and have initial integrated test observations in support of this expectation) that we will have considerably better isolation from earthquakes and microseism disturbances. However we don't yet have sufficient data to make assertions on the percentage of downtime with the new seismic isolation systems. For this estimate, I have assumed that downtime due to seismic disturbances is the same as H1 in S5 (and therefore considerably better for L1 than experienced in S5).