LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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Procedure for monolithic rehang at LASTI

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1 Introduction

1.1 Purpose and Scope

This document describes the procedure used in going from glass-on-metal wires build of the quad noise prototype at LASTI to the full monolithic build. Version -v1 is an actual procedure to be followed during the operation. After the fact, lessons learned will be incorporated in a -v2.

1.2 References

T080101-00, D. Bridges et al., Notes on Lower Quad Installation at LASTI.
T080165-00, B. Shapiro, Metal Quad Noise Prototype Balancing and Alignment Procedure.
T060040-06, I. Wilmut, Noise prototype Assembly procedure.
G070359-00, K. Mailand, LASTI Tooling (instructional DVD)
E070292-00, H. Armandula, Optics Cleaning Specification - First Contact™
T0900055-v1, M. Barton et al., Rehang of the Quad NP with glass masses but metal wires (January 12-23 2009)
T0900391-v1, M. Barton et al, Pulling/Welding Procedure (LASTI, September 2009)

1.3 Version history

1/31/10: First pre-v1 draft cutting and pasting from T0900055-v1 and T0900391-v1.

2/4/10: Submitted as -v1 by Brett.

2/9/10: Submitted as –v2 by Brett. Revisions include corrections, details, and optic protection measures. Green text is mean to highlight balancing and/or alignment steps. This is not yet meant to be a final version since it is still open for comments and revision.

2/22/10: Submitted as –v3 by Brett. Sections 2.1 to 2.4 updated with work at LASTI.

2 Main procedure

2.1 General setup

Step	What	Where	Time	People	Tools
1	Open tank.	at BSC	0.5 days	3,4	
2	Install the 'hard hat' on the structure over optic and both 'backup plate' on the reaction mass face stops. This is to protect parts of the glass (hard hat only fit with sleeve removed, simple modifications can correct this).	in BSC	5 min	1	9/64'' allen key; 2, 8-32 bolts, 'hard hat', 'backup plate'
3	Record references of suspended quad in BSC. This involves OSEM biases, and optical lever position on a quad photodiode, and bubble level orientation of structure.	in BSC	10 min	1	Bubble level, MEDM screens, optical lever

2.2 Removing structure from tank

Step	What	Where	Time	People	Tools
4	Install the second backup plate on the face stops of the test mass. To protect the face of the optic.	in BSC	1 min	1	'backup plate'
5	Install the lever arm clamps (LACs) below the test mass and reaction mass.	in BSC	5 min	2	LACs
6	Remove the EQ stop brackets below these masses and replace the EQ stops with Teflon line stops.	in BSC	30 min	2	Line stops, 3/16'' allen keys, 9/64'' allen keys, 7/16'' wrench
7	Reinstall the brackets with line stops and remove the LACs.	in BSC	30 min	2	3/16'' and 9/64'' allen keys
8	Lift the test mass and reaction mass enough so that there is room to insert the line stops under the PUMs, but do not yet insert them.	in BSC	10 min	2	3/16'' allen keys
9	Lock the test mass and reaction mass.				
10	Insert PUM line stops.	in BSC	5 min	2	PUM Line stops

Step	What	Where	Time	People	Tools
11	Resuspend test mass and reaction mass.	in BSC	5 min	2	3/16'' allen keys
12	Remove the test mass backup plate.	in BSC	1 min	1	
13	Lock the test mass without changing orientation of optical lever on test mass.	in BSC	10 min	2+1	3/16'' allen keys
14	Replace the second back up plate on the face stops of the test mass.	in BSC	1 min	1	
15	Lock the remaining stages of the quad.	in BSC	15 min	2	3/16'' allen keys
16	Disconnect electrical wiring to lower structure and masses and tuck ends safely out of the way.	in BSC	5 min	2+1	hex keys
17	Lock top stage, lock top mass blades.	in BSC	5 min	2+1	3/16'' and 9/64'' allen keys
18	Raise stops under UIM to touch and overload UIM blade tip by 3mm.	in BSC	5 min	2+1	3/16'' allen keys
19	Raise UIM until top to UIM wires are slack.	in BSC	5 min	2+1	3/16'' allen keys
20	Remove UIM pitch mass (to allow access to screws in next step).	in BSC	5 min	2+1	3/16'' allen keys
21	Disconnect wires from top mass to UIM at UIM.	in BSC	5 min	2+1	3/16'' allen keys
22	Remove X braces, then ¼-20 bolts and spacers at the bottom of the sleeve, then all but 4 of the 3/8-16 bolts up top. When removing the ¼-20 bolts at the bottom of the sleeve loosen them before removing so that removing the spacers behind them is easier with less risk of dropping them on the optics.	in BSC	30 min	3+1	3/16'' and 7/64'' allen keys
23	Remove face earthquake stops and back up plates.	in BSC	5 min	2+1	9/64'' allen keys
24	Remove Sleeve. This step involves two people standing on the BSC floor holding the sleeve while a third person removes the remaining 4 3/8-16 bolts supporting the sleeve at the top. When the bolts are removed the third person will guide the sleeve down as the other two lower it.	in BSC	1 hour	3	5/16'' allen keys and ratchet

Step	What	Where	Time	People	Tools
25	Replace face stops and backup plates. At LASTI we also installed the 'hard hat' for the first time since it fit without the sleeve.	in BSC	5 min	2	9/64'' allen keys
26	Install conveyor, (this was done first in reality, during the Jan 2009 wire hang, which made it not quite impossible but very difficult to get the sleeve off). Measure the position of the conveyor under the quad with a clean measuring tape to make sure it is centered in the BSC. Note it is easy to be off by about an inch.	in, near BSC	1/2 day	4	conveyor
27	Install five-axis table on conveyor trolley. Lift the 5 axis table by screwing 4, ¼-20 eye bolts into 4 corners of the table top and picking up those points with straps hooked on the genie lift forks. Make sure the 3/8 inch bolts sticking out from underneath line up with the clearance holes on the trolley. The 5 axis table is bolted to the trolley from underneath with 4 silver plated bolts in each corner.	by BSC	1 hour	2+1	4 ¼-20 eye bolts, straps, genie lift, 3/16 allen key, 16 silver plated ¼-20 bolts
28	Attach the 5 axis table and trolley to the bicycle chain. The bolts screw in from under the 5 axis table. The bolts engage threads in the 5 axis table.	by BSC	5 min	2	9/16 allen key and 2, ¼-20 silver plated bolts.
29	Install elevator on 5 axis table. Make sure elevator is installed on 5 axis table such that you have +- 180^{o} of rotation. Side 2 is the main chain side (short side) Wrap electrical cabling for elevator in UHV foil. The elevator is lifted with the genie lift. This can be done either by putting the forks directly into the elevator or by wrapping straps around the elevator to the genie lift. The elevator is bolted onto the 5 axis table.	by BSC	½ hour	2+1	Genie lift, ¼-20 flat head bolts
30	Remove side plates on elevator on five-axis tooling and rotate elevator so that it can be slid around structure on the conveyor. When elevator is around structure, rotate so that side labeled "2" is on main chain side.	in BSC	10 min	2+1	wrench
31	Insert halves of (lower structure assembly tooling) LSAT around the structure, hooking them on the pins on top of the fully retracted pushers of the elevator.	in BSC	5 min	2+1	LSAT

Step	What	Where	Time	People	Tools
32	Reinstall side plates on elevator, aligning "1" on corner of first plate to matching "1" on table and "2" on second plate to "2" on other side of table. Bolts are best inserted from centre outwards. Finger-tight is fine. (Doug says: need better tolerancing on holes.)	in BSC	5 min	2+1	Elevator side plates, bolts
33	Remove the top two face stops from both PUMs. They will interfere with raising the LSAT over the lower structure.	In BSC	5 min	1+1	9/64 allen key.
34	Raise LSAT on pushers until it almost engages with the structure about an inch from the final height.	in BSC	5 min	2+1	
35	Adjust the various DOFs of five-axis table as appropriate until the top of the LSAT is well-aligned in position and angle with the lower structure.	in BSC	5 min	2+1	
36	Raise pushers until the LSAT has fully engaged with the lower structure and the weight is off the implementation ring.	in BSC	5 min	2+1	
37	Lock the halves of the LSAT together with plates and bolts, except at the bottom level (where this will cause interference with the sides of the elevator).	in BSC	5 min		2 LSAT connector plates; 4, ¼-20 x 0.5'' bolts
38	Replace face stops and backup plates on both chains.	in BSC	10 min	2+1	hex keys, face stops
39	Unbolt implementation ring from upper structure and remove bolts from upper to lower structure.	in BSC	10 min	2+1	hex keys
40	Retract pushers fully, lowering lower structure.	in BSC	5 min	2+1	
41	Insert translational locking pin into 5 axis table. (This must happen after disconnecting the lower structure because the table position may need to be adjusted to get the pin in place.)	in BSC	5 min	2+1	pin
42	Unbolt implementation ring from lower structure (because otherwise it won't get through the door).	in BSC	10 min	2+1	hex keys

Step	What	Where	Time	People	Tools
43	Move lower structure to door of tank on conveyor.	in BSC	5 min	2+1	
44	Remove side plate on five-axis table on the main chain side ("2").	near BSC	5 min	2	hex keys
45	Bring in Genie (avoiding bumping the HEPI) so that the forks are below the uppermost of the side plates on the LSAT. Use spacers (approximately ½" thick) on top of the forks near the tips to allow for sag of the forks under load.	near BSC	5 min	4	Genie, ½" spacers
46	Lift the LSAT off the five-axis table onto the cart, install remaining (bottom) plates holding together the two haves and clamp it down.	near BSC	10 min	4	cart, LSAT side plates, dogs
47	Cover the LSAT on the cart with a door cloth and wheel to the assembly area.	in transit	5 min	4	door cloth
48	Manhandle Genie past solid stack to assembly area.	in transit	5 min	4	
49	Bring in Genie as before and take LSAT off cart using ½" spacers for sag (but don't set it down yet).	assembly area	5 min	4	Genie, ½" spacers
50	Disconnect lowest set of bolts joining the two halves of the structure (these are difficult to remove later).	assembly area	5 min	4	hex keys
51	Set LSAT down on foil-covered pallet with ¼" spacers. (Use enough spacers that each half is stable independently.)	assembly area	5 min	2	pallet, (lots of) ¼" spacers
52	Remove plates holding halves of LSAT together.	assembly area	5 min	2	hex keys
53	Remove remaining bolts holding halves of structure together.	assembly area	5 min	2	hex keys
54	Bring in Genie as before except placing ¼" spacers near the base of the forks so as to enable just the reaction chain to be picked up.	assembly area	5 min	4	Genie, ¼" spacers
55	Take weight of reaction chain with Genie and remove ¼" spacers under it. Withdraw straight back so as to cleanly disengage pins aligning two	assembly area	5 min	4	Genie

Step	What	Where	Time	People	Tools
	halves.				
56	Put the reaction chain in storage until the welding is complete.	assembly area			Genie

2.3 Pre-disassembly characterization

Step	What	Where	Time	People	Tools
57	Install the triple hang tooling on the main chain.				
58	Place main chain half of quad on granite table. Clamp with large C-clamps.	assembly area	20 min	2,3	Genie, turntable
59	Measure the pitch of the structure by placing a precision bubble level on the structure. At LASTI we adjusted the roll of the structure with 0.15 inches of shims on one side.	assembly area	15 min	3	Bubble level
60	Setup total station with the autocollimator. Place reference targets around the room and on the floor under the total station to check for drifts and bumps. Use an optical flat to align the optical collimator and laser collimator to the each other.	assembly area	0.5 days	2	8 inch flat, targets, total station
61	Record the pointing of the optic in the locked position, 'master locked reference'. This will be used as a 'rough' reference for the structure when putting the quad back in the BSC. The goal is to minimize the number of iterations of locking and resuspending when lining up yaw. At LASTI we turned the knobs on the telescope to zero the laser collimator. The reference numbers were the 'horizontal' and 'vertical' pointing of the telescope in degrees, arc-minutes, and arc-seconds. These numbers	assembly area	5 min	2	Total station

Step	What	Where	Time	People	Tools
	provide a greater range than the +-2mrad of the laser collimator.				
62	Suspend the main chain from the triple hang tooling. Record the pointing of the optic again in the same way as the previous step. Make sure no stops or mechanical interferences influence the measurement. This is the 'master suspended reference'. It will be the reference to shoot for when suspending the monolithic on the triple hang tooling.	assembly area	15 min	2	Total staion, 3/16'' allen keys, 7/16'' wrench
63	Relock the main chain.	assembly area	5 min	2	3/16'' allen keys
64	Remove the magnets and magnet jig from the dummy PUM. Weigh what is removed and adjust the weight with addable removable mass so the net weight loss is exactly what was gained when the magnets were installed. The LASTI ilog has the weight change we should shoot for as -761 g.	assembly area	20 min	2	3/16'' allen keys, adjusting weight
65	Add weight to the UIM to cancel exactly what was lost when the PUM magnets were installed. The LASTI ilog has the target change as 764 g.	assembly area	20 min	2	3/16'' allen keys, adjusting weight
66	Resuspend the three lower masses. Make sure no mechanical interferences are present. Note: at LASTI we missed an interference with the ring heater which set us back a couple hours by the time we discovered it.	assembly area	15 min	2	3/16'' allen keys
67	The heights of the UIM blade spring tips will be too high. Bring them back down to the nominal 12mm reference point stated in the assembly and alignment procedures. It may be necessary to loosen the spring clamps.	assembly area	20 min	2	12 mm of slip gauges, ¼-20 allen key

Step	What	Where	Time	People	Tools
68	Check that the blade springs have not rotated, especially if the clamps were loosened. If necessary rotate the springs back. Note: At LASTI we did not need to loosen the clamps, but the lowering of the springs still caused one to rotate about 0.5 mm. We tapped it most of the way back without loosening the spring. The theory is the height adjusting bolt caused the spring to drift when it was lowered.	assembly area	20 min	2	Calipers or ruler
69	If the clamps were loosened tighten them back up with a torque wrench to no more than 100 in-lbs.	assembly area	15 min	2	Torque wrench with 3/16'' hex
70	Resuspend and check the pitch of the test mass against the 'master suspended reference'. Make sure no interferences are present.	assembly area	15 min	2	3/16'' allen key
71	If the pitch is off, especially by large amounts (> 1 mrad), lock the UIM in a level position and recheck the blade springs are truly centered. If not, then adjust. If so, then shift weight around the UIM until test mass is close to the suspended reference. At LASTI we could only get precision to 1 mrad with 50 g increments of addable removable mass	assembly area	20 min	2	3/16'' allen key

2.4 Removing and preparing masses

Step	What	Where	Time	People	Tools
72	Apply First Contact to both sides of the TM using a clean wipe to brush it on.	assembly area	10 min	1	First Contact, clean room wipes
73	Allow First Contact to dry. At LASTI we let it dry overnight.	assembly area	Over night	0	
74	Take quad apart. Test mass goes out for bonding. The dummy PUM, all suspension wires attached to it, and the lower structure faceplates are put	Assembly area	1 day	2+	Ergo arm, allen keys, aluminum foil,

Step	What	Where	Time	People	Tools
	in long-term storage; they are no longer needed. The UIM and all other structure bits are put in temporary storage for safe keeping until the welding is ready. Clean work area.				maristat

2.5 Reinserting masses

Step	What	Where	Time	People	Tools
75	Rebuild lower structure in the new LSAT with the new faceplates. This will include the ring heater and any other parts that need to be installed before the test mass.				
76	Place UIM into structure.				
77	Install PUM wire loop.				
78	Bring in PUM with ergo arm while two people are holding wire loop out of the way. Someone should scope the roll of the PUM with the Brunson while it is being inserted.				
79	Bring in the test mass with the ergo arm. Someone should scope the roll of the test mass with the Brunson as it is inserted.				
80	[?? move structure into CO2 lab]				
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Step	What	Where	Time	People	Tools
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Step	What	Where	Time	People	Tools
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Step	What	Where	Time	People	Tools
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2.6 Welding Alignment

Step	What	Where	Time	People	Tools
131	Move the main chain into the welding lab.				
132	Bring the test mass close to the proper height with the jack and set it on the line stops.				
133	Setup up the total station to scope the face of the PUM.				
134	Check the roll of the PUM using the optical collimator of the total station.				
135	Measure the pitch of the PUM with the laser autocollimator. Does this require changing the height of the total station? The laser collimator is about 6 inches (I think) higher than the optical collimator. Should we adjust the pitch of the structure so that the PUM pitch zeroes on the laser autocollimator?				
136	Bring the total station down to the height of the test mass and realign the				

Step	What	Where	Time	People	Tools
	total station.				
137	Setup an auxiliary optical lever on the test mass in case it goes beyond the range of the autocollimator once suspended.				
138	Check the roll of the test mass with the optical collimator.				
139	Peel back a section of the First Contact and set the pitch with the laser autocollimator to match that of the PUM. Does this require changing the height of the total station?				
140	Turn on the optical lever and mark the 'zero' point of the reflected beam on the projection screen.				

2.7 Welding

Step	What	Where	Time	People	Tools
141	Turn on computer, run LabView program and open welding VM.				
142	Repeat steps down to 115 for each fibre.				
143	Set the appropriate distance between the lower clamp blocks on the fibre cutter and remove the upper clamp blocks.				
144	Lay the plastic tabs on the back of the fibre cutter to the outside.				
145	Make sure the tweezers on the bow are fully retracted and open.				
146	Install the bow on the fibre cutter and rotate the plastic tabs behind it to lock it in place.				

Step	What	Where	Time	People	Tools
147	Select a fibre from storage and lay it in the cutter with equal amounts of neck inside the clamp blocks at each end. Be very careful no fingers or anything else touch the fibre.				
148	Install the upper clamp blocks and screw them down firmly onto the necks of the fibre.				
149	Using a small file or diamond scribe, score each end of the stock at a point immediately to the outside of the clamp. Snap off the stock and fuse-end and, if necessary, clean up the end of the section of stock in the clamp with the file.				file/scribe
150	Using the translation stage, bring in each pair of tweezers with the jaws still open until the groove in the tips is aligned with the neck of the fibre as near as possible to (or even touching) the inside of the clamp and then tighten the jaws to grip the fibre.				
151	Remove the top clamp pieces.				
152	Retract the tweezers so as to move the fibre clear of the lower clamp pieces.				
153	Flip the plastic tabs on the cutter and remove the bow with the fibre.				
154	Bring the bow with the fibre to the structure and attach it to the welding scaffolding. Be very careful not to let fingers or anything else touch the fibre.				
155	Adjust the movable stages holding the tweezers vertically so that the ends of the fibres are inset about 1 mm each from the tips of the ears. (This will cause the fibre to bow slightly in the centre.)				
156	Adjust the movable stages in the direction parallel to the flat on the optic so that the fibre ends are directly opposite the tips of the ears as viewed straight on from the flat.				
157	Adjust the movable stages in the direction normal to the flat until the fibre ends are directly opposite the tips of the ears as viewed from along the flat.				

Step	What	Where	Time	People	Tools
158	Move the adjustable stages vertically until the gaps between the fibres and ears close up. If necessary tweak the other two directions until the alignment is perfect.				
159	Position the V-shaped welding mirror behind the fibre.				
160	Attach the Lexan safety shield to the side of the LSAT.				
161	Repeat steps down to 112 for both ends of the fibre.				
162	Swing the shelf into position and tighten.				
163	Attach the birdcage to the shelf with the business end toward the ear. (Do not move the birdcage with the articulated arm attached - there is a risk of misaligning the arm if the birdcage is dropped or moved in a way that the arm can't follow.)				
164	From the computer, set the galvo mirrors to the middle of their range.				
165	Attach the articulated arm to the birdcage.				
166	Turn the laser on, set the power to zero, and open the shutter to let the pilot beam through to the birdcage.				
167	Adjust the position of the birdcage until the pilot beam is normal to the flat and focused on the welding zone.				
168	Dim the room lights for better visibility of the pilot beam, point the beam at a representative selection of different places as if welding, and position baffle plates to catch all stray reflections.				
169	Don welding goggles.				
170	Set laser to lase, and using laser power and galvo controls, zap the welding zone from three angles. While heating the vertical stage should be used to push the stock end into the ear to ensure proper fusing of the two pieces.				
171	Set the laser power to zero, close the shutter.				

Step	What	Where	Time	People	Tools
172	Disconnect the articulated arm, move it to a safe position out of the way and then remove the birdcage.				
173	When both welds have been done, remove the Lexan shield on the side of the LSAT.				
174	Open the tweezers at each end of the bow.				
175	Carefully unbolt and withdraw the bow.				
176	When all four fibres have been welded, continue with stress relieving as below.				
177	Retract each lower earthquake stop screw on the lower mass ¼ turn to lower the mass slightly and put slight tension on the fibres.				
178	Repeat steps down to 121 for each of the top necks.				
179	Set up the birdcage, articulated arm and baffles as previously.				
180	Stress relieve from three angles.				
181	Move the beam down towards the neck and flame polish from three sides where the tweezers contacted.				
182	When all top welds have been done, lower the bottom mass another ¼ turn of the screws.				
183	Repeat steps down to 126 for each of the bottom necks.				
184	Set up the birdcage, articulated arm and baffles as previously.				
185	Stress relieve from three angles.				
186	Move the beam up towards the neck and flame polish from three sides where the tweezers contacted.				
187	Turn off laser and remove all welding apparatus.				
188	Raise jack to take the load off the fibres then screw out the stops to allow for extension of the fibres. The fibres will extend ~6.5 mm when fully				

Step	What	Where	Time	People	Tools
	loaded.				
189	Lower the mass very slowly on the jack until the full weight is suspended. Bring stops back to approx 1 mm from the mass.				
190	[?? stress testing etc]				
191	Retract the line stops and suspend the test mass.				
192	Measure the suspended pitch of the test mass. It should still be within +-10 mrad of the PUM. If it is more than +-2mrad it will go beyond the autocollimator and it will be necessary to read the pitch with the optical lever.				
193	If the pitch is within the acceptable range, install backup plates on the test mass and PUM face stops and put the test mass back on the line stops near its suspended position.				
194	Install fiber guards and Teflon pads under the top stops.				
195	Lock the test mass down and prepare the suspension for travel to the highbay for post-balancing and alignment.				

2.8 Post-balancing and alignment

[?? needs major revision]

Step	What	Where	Time	People	Tools
196	Bring the main chain into highbay and set it on a stand near the granite table.				

Step	What	Where	Time	People	Tools
197	Install the triple hang tooling.				
198	Put the main chain on the granite table in the same location it was in during the pre-balancing. Clamp with large C-clamps. Check level with bubble level referring to orientation from pre-balancing.				
199	Setup the total station in the same location as the pre-balancing.				
200	Remove the backup plate and the First Contact on both sides of the test mass.	assembly area	5 min	2	razor blade
201	Suspend the three masses from top down. Suspending the fibers last will minimize the risk to the fibers.				
202	Measure the pitch of the test mass with the autocollimator and compare it to the master suspended reference created earlier.				
203	Adjustments to pitch at this point can only be made by shifting addable removable mass on the UIM.				
204	Once the test mass is pointing in the desired position, lock the suspension down from the bottom up and replace the backup plate. The test mass should be locked pointing in the direction of the master locked reference created earlier. Install the hard hat only if there is no risk to the fibers.				

Step	What	Where	Time	People	Tools
205	Take the main chain off the granite table with Genie using thin spacers (≈1/4") on tip side to counteract sag.	assembly area	10 min	3	Genie, ¼" spacers
206	Remove the triple hang tooling.				

2.9 Reinstalling structure into tank

Step	What	Where	Time	People	Tools
207	Pick up main chain with tips of Genie forks, using thin spacers (≈1/4") on tip side to counteract sag. Bring over to reaction chain on pallet #1.	assembly area	10 min	4	Genie, ¼" spacers
208	Match height first then bring in horizontally to mate locating pins. Insert ¼" spacers under main chain and then set down.	assembly area	10 min	4	Genie, (more) ¼" spacers
209	Attach plates holding LSAT together.	assembly area	5 min	2	hex-keys
210	Pick up whole LSAT with Genie, using thick spacers (≈1/2") to counteract sag.	assembly area	5 min	4	Genie, ½" spacers
211	Transfer LSAT to cart, clamp down, cover, and wheel to tank.	in transit	15 min	4	cart, hex keys, dogs
212	Manhandle Genie past solid stack to tank area.	in transit	5 min	2	Genie
213	Pick up LSAT with tips of forks using ½" spacers	near BSC	5 min	4	Genie, ½" spacers
214	Take off lower plates connecting halves of LSAT. (These will foul on the elevator of the five-axis table.)	near BSC	5 min	2	hex keys
215	Remove one side-plate ("2") from elevator of five-axis table.	near BSC	5 min	2	wrench
216	Place LSAT into elevator of five-axis table (avoiding bumping the HEPI with the Genie). The LSAT should be positioned vertically a few mm above the floor of the elevator and horizontally with locating holes	near BSC	10 min	4	5AT, elevator

Step	What	Where	Time	People	Tools
	directly above locating pins on pushers.				
217	Raise pushers to engage pins and support LSAT. Remove Genie.	near BSC	5 min	2	
218	Install side plate on elevator on five-axis table (matching corner “1” or “2” and inserting bolts from centre as before).	near BSC	5 min	2	wrench
219	Lower LSAT until it is almost sitting on floor of elevator (so that it will go through door).	near BSC	5 min	2	
220	Roll table into chamber on conveyor.	near BSC	5 min	2+1	
221	Attach implementation ring to lower structure.	in BSC	10 min	2+1	hex keys
222	Raise pushers until lower structure is about to contact, adjusting five-axis table DOFs as necessary to achieve a good mate.	near BSC	5 min	2+1	
223	Connect implementation ring to upper structure and install through bolts, using washers under the through bolts.	in BSC	10 min	2+1	implementation ring, hex keys
224	Remove remaining plates holding halves of LSAT together.	in BSC	5 min	2+1	hex keys
225	Remove upper two face stops on PM on both main and reaction chains, and backup plate on glass PUM.	in BSC	5 min	2+1	hex keys
226	Put two long spacers (1” thick) on floor of elevator.	in BSC	1 min	2+1	1” spacers
227	Lower pushers till LSAT comes to rest on spacers.	in BSC	2 min	2+1	
228	Using two people per side simultaneously, pull the halves of the LSAT out and remove.	in BSC	2 min	4+1	
229	Replace face stops and backup plate on glass PUM.				
230	Remove UIM upper pitch mass (both chains).	in BSC	10 min	2+1	hex keys
231	Connect wires from top mass to UIM (both chains).	in BSC	5 min	2+1	hex keys
232	Install UIM upper pitch mass (both chains).	in BSC	10 min	2+1	hex keys

Step	What	Where	Time	People	Tools
233	Remove five-axis table and conveyor.	in BSC	1 hour	4	??
234	Install two extra planks of flooring in the tank so there are two on each side and bring in the table to give easy access to top mass.	in BSC	1 hour	4	??
235	[This shouldn't be necessary! The ends of the glass rod in the upper half of the ring heater stuck out too far on each side and fouled on the sleeve. Assuming the radius of the curved section in the prototype was right, the welded on sections should be 20-25 mm long to serve their purpose but not foul.] Loosen the set screws holding the glass rod in the top half of the ring heater. Push one end of the rod in about 3 mm and tighten the set screw. Carefully push the other end of the rod in twice as far (bending the glass rod to a tighter radius!) and tighten that set screw.	in BSC	10 min	2+1	hex keys
236	Remove all face earthquake stops on the bottom two levels of both chains.	in BSC	10 min	2+1	hex keys
237	Bring in the sleeve, lift it up around the structure and bolt it on. [Need to rethink washers.]	in BSC	10 min	2+1	hex keys
238	Install X braces.	in BSC	10 min	2+1	hex keys
239	[This shouldn't be necessary!] Restore the upper half of the ring heater to its original condition.	in BSC	5 min	2+1	
240	Reinstall face stops and set at 0.5 mm.	in BSC	10 min	2+1	hex keys
241	Finish routing ESD and OSEM wiring.	in BSC	20 min	2+1	
242	Suspend per Section TBD.	in BSC	??	2+1	
243	Drag wipe per Section 3.6.	in BSC	20 min	2+1	foil, lens tissue, methanol

2.10 Final alignment

Step	What	Where	Time	People	Tools
244	When the quad is back together in the BSC, before it is suspended, measure the yaw of the test mass with the BSC optical lever.	in BSC			
245	If the yaw does not match the previous reference, rotate the structure according to T080230.				
246	Suspend the quad from top down and observe the new pitch of the test mass with the optical lever, checking for interferences along the way.				
247	Adjust the pitch back with the top mass adjustments, checking for interferences simultaneously.				
248	Realign top mass OSEMs and measure TFs.				
249	Suspend reaction chain and check interferences.				
250	Realign UIM and PUM OSEMs.				
251	Measure TFs as a final check.				
252	Check the yaw of the test mass and rotate the structure if necessary,				

Step	What	Where	Time	People	Tools
	according to the rotation procedure T080230.				

3 Sub-procedures

3.1 Aligning the Brunson transit

Step	What	Where	Time	People	Tools
1	Set up the Brunson about 10'-15' from the structure, with the telescope at very roughly the height of the mass to be clocked. If you get too close you won't be able to see both ears/prisms/clamps and if you get too far away, the ears will be too small in the viewfinder to have their height read accurately. If there is a very large difference in height then you need to be careful that the structure is facing the telescope accurately (so that the ears/prisms/clamps are the same distance away), but this is not at all critical. Midway in height between the bottom mass and the penultimate mass is probably good enough, and gets you two clockings for the one setup.		30 min	2	
2	Make sure the lock on the vertical height adjustment is tight and that upper mechanism is firm against moderate horizontal pressure.		5 min	1	wrench: ¾" open-ended
3	Level the upper section as accurately as possible using the circular bubble level in the base of the rotating section.		5 min	1	
4	Turn the telescope pitch adjustment screw until it is roughly in the middle of its range.		1 min	1	
5	Unlock the telescope pitch clamp screw, roughly level the barrel of the telescope, and relock the clamp screw.		1 min	1	
6	Using the pitch adjustment screw, level the telescope as accurately as possible looking by eye at the barrel.		1 min	1	

Step	What	Where	Time	People	Tools
7	Pick an opposing pair of the brass leveling discs in the leveling section and rotate the upper section until telescope is parallel with the line between the discs.		1 min	1	
8	Rotate the prism in the knurled housing near the top bubble level so that the aperture is at right angles to the telescope.		1 min	1	
9	Look into the prism aperture and adjust the long mirror to reflect the most ambient light into the side of the bubble level as indicated by the brightest view in the prism.		1 min	1	
10	Adjust the pitch adjustment screw until both ends of the bubble can be seen in the prism and are aligned with each other.		1 min	1	
11	Rotate the telescope by 180°, and then rotate the prism by a further 180° to bring the aperture back to the original direction. Readjust the long mirror if necessary.		1 min	1	
12	Grip the telescope pitch adjustment screw knob and note its position. Keep careful track of the amount of adjustment required in the next step, either by keeping a grip on the knob (if the amount is not too great), or counting the number of quarter turns of adjustment.		1 min	1	
13	Adjust the pitch adjustment screw until both ends of the bubble are aligned in the prism.		1 min	1	
14	Back the pitch adjustment screw off to a point as near as possible to halfway between the initial and final positions.		1 min	1	
15	Redo the second half of the levelling using the the two brass discs identified earlier, rotating them in opposite directions, so as to tighten one as the other is loosened.		1 min	1	
16	Rotate the telescope another 180° and readjust the prism and long mirror. Hopefully the ends of the bubble will be very nearly aligned. Repeat the previous six steps until convergence is achieved.		5 min	1	
17	Rotate the telescope by 90° to align with the other pair of brass discs and repeat the previous seven steps.		15 min	1	

Step	What	Where	Time	People	Tools
18	Rotate the telescope back to the line of the first pair of brass disks and check that the alignment in that direction has not been disturbed.		10 min	1	

3.2 Aligning the total station

[?? Doug writes stuff]

Step	What	Where	Time	People	Tools
1			30 min	2	

3.3 Using the ergo-arm

[?? probably needs revising for redesigned arm]

Step	What	Where	Time	People	Tools
1	Connect ergo-arm reservoir to vacuum pump with hose. [According to Mike Gerfen, the hose should be permanently band-clamped to the reservoir, with the quick release fitting at other end connecting alternately to pump and suction plate. We were doing this backwards, and the following procedure has been revised to reflect what we should have done.]		5 min	1	reservoir with hose, pump
2	Start pump, open valve at reservoir, evacuate reservoir to 30 psi, close valve, stop pump, disconnect hose.		1 min	1	reservoir with hose pump
3	Connect hose to ergo-arm suction plate.		1 min	1	
4	Close valve at suction plate, open valve at reservoir, monitor reservoir gauge for short time (e.g., 1 min) to check for stable pressure (i.e., no leaks in hose or connections).		2 min	1	
5	Bring suction plate near to mass and use horizontal, vertical, pitch and yaw DOFs to match position and angle.		5 min	4	

Step	What	Where	Time	People	Tools
6	Hold suction plate firmly against mass and open valve at plate.		1 min	4	
7	Check that good suction has been achieved (reservoir pressure should still be around 23 psi). If the alignment was poor there will likely be no vacuum at all, in which case, repeat from the beginning, being more careful in Step 5.		1 min	1	
8	Close the valve at the suction plate, and then the valve at the reservoir. (The suction plate has a very slight leak and a small volume, so closing it requires constant attention to the pressure at the suction plate. If it drops it can be topped up by opening both valves momentarily. But if both valves are open and someone trips over the reservoir and pulls the hose off one of the connectors it's an instant catastrophe.)		1 min	1	
9	Raise mass, checking pressures at suction plate and reservoir regularly, and keeping a hand on the crankhandle at all times.		1 min	4	

3.4 Using the triple-hang tooling

Step	What	Where	Time	People	Tools
1	Start with main or reaction chain lower structure with all masses and wires in place, with the UIM approximately 4 mm high of nominal on its stops, and with UIM blades overloaded by 5 mm.				
2	Check UIM is level and if not, adjust earthquake stops till it is.		5 min	2	bubble level
3	Retract upper earthquake stops on bottom mass.		5 min	2	hex keys
4	Screw in lifting screws on lower earthquake stops a tiny amount to ease weight on pad spacers.		2 min	2	hex keys
5	Remove pad spacers.		1 min	2	
6	Retract lifting screws on lower earthquake stops until optic is suspended.		5 min	2	hex keys
7	Check that optic is level relative to structure by eye – debug if not.		1 min++	2	

Step	What	Where	Time	People	Tools
8	Retract upper earthquake stops on PM.		5 min	2	hex keys
9	Retract overload screws on UIM blades, monitoring lower masses. If blade strength is matched to payload, PM should be about 4 mm off lower stops (same as UIM was high to begin with).		5 min	2	hex keys
10	Place 12 mm slip gauge on top of each UIM blade in turn and adjust blade height until top of slip gauge is level with reference notch in upright of UIM blade stop bridge (D060399).		5 min	2	slip gauge
11	Check that PM is level relative to structure by eye – debug if not.		1 min++	2	
12	On reaction chain, remove pitch adjuster, remove cable clamp, refit pitch adjuster.		10 min	2	hex keys
13	Fit wire assemblies from triple-hang tooling to UIM.		5 min	2	hex keys
14	Fit triple-hang tooling spacer blocks to top of lower structure.		5 min	2	hex keys
15	Fit triple-hang tooling top plate to spacer blocks.		5 min	2	hex keys
16	Connect wire assemblies to blades on triple hang tooling.		5 min	2	hex keys
17	Release overload screws on triple-hang tooling.		2 min	2	hex keys
18	Check that all three masses are level relative to structure by eye – debug if not.		1 min++	2	
19	Reapply overload screws on triple-hang tooling until tension is off wire assemblies.		5 min	2	hex keys
20	Disconnect wire assemblies at blades triple-hang tooling.		5 min	2	hex keys
21	Remove triple-hang tooling top plate and spacer blocks.		5 min	2	hex keys
22	Disconnect wire assemblies at UIM.		5 min	2	hex keys
23	On reaction chain, remove pitch adjuster, fit cable clamp, replace pitch adjuster.		10 min	2	hex keys

3.5 Applying/removing First Contact

3.5.1 Applying

Step	What	Where	Time	People	Tools
1	See E070292-00.		3 hours	1	See E070292-00.

3.5.2 Removing

Step	What	Where	Time	People	Tools
1	Carefully shave the entire bevel with a sharp single-sided razor blade to remove traces of First Contact that may have spilled there off the face.		5 min	1	razor blade
2	With the edge of the razor blade leading, scrape from the bevel toward the face to prise up a corner of the First Contact on the face. The corner between the straight and curved sections is a particularly good place to start.		1 min	1	razor blade
3	Grab the prised-up corner with gloved fingers and carefully pull the whole sheet off the face, avoiding tears as much as possible.		1 min	1	
4	If any small patches of First Contact remain, very carefully scrape them off with a razor blade and clean up the area with spectroscopic grade methanol and a lens tissue. (This should not happen if the First Contact was applied thickly enough originally.)		5 min	1	razor blade, methanol, lens tussue

3.6 Drag-wiping

Step	What	Where	Time	People	Tools
253	Pour a little spectroscopic grade methanol into a small foil boat or dish.		5 min		foil, methanol
254	Repeatedly, bend a sheet of lens tissue (3”x5” is good) in half without creasing it, dip the bend in the methanol and drag slowly across the optic. (Doug: This bend technique is particularly good for vertical surfaces.)		1 min		lens tissue

Step	What	Where	Time	People	Tools
255	Work by strips, using a fresh sheet each time. If the lens tissue does not stick to the optic with surface tension, it is too dry. If it leaves streaks of liquid methanol behind (especially from the corners), it is too wet.		10 min		lens tissue

3.7 Pulling a fibre

Step	What	Where	Time	People	Tools
1	Prepare to power up laser: clear area of non-essential personnel, lock door, switch on cooler, ensure all valves are open, turn main wall switch on, check laser warning sign is illuminated.		1 min	1	
2	Install non-fuse-end clamps on pulling machine.				
3	Repeat the next few steps for as many fibres as are required (approximately 6 for welding, 3 for testing and 1 spare).				
4	Measure a 10 cm length of 3 mm stock, scribe with a diamond tipped tool, and snap off.		1 min	1	
5	Clean stock with first an acetone-soaked wipe, then a methanol-soaked wipe.		1 min	1	
6	Install stock in groove of lower clamp and tighten retaining screw gently.		1 min	1	
7	Check that upper clamp is well-aligned with stock, adjust horizontal position if necessary, and tighten retaining screw gently. Wipe with methanol again.		1 min	1	
8	Arm laser: check motorized shutter is closed. Close all doors to laser enclosure except the one convenient to the rear end of the laser. While holding the red interlock defeat button, turn the laser key to the ON position and close the last door.				
9	Open the LabView pulling program on the computer and select the polish-down data set. Press the Labview run button, then click on the software Begin button. The software will now wait for the shutter to be opened		1 min	1	

Step	What	Where	Time	People	Tools
10	From the UC2000 controller, set the power to full and set the laser to lase.		1 min		
11	Open the motorized shutter and the polish program will begin to run. Stop after the display reads approx 40 mm. Close shutter, click on All Stop to end program.		20 min		
12	Select and run the polish-up data set. Stop after the display reads approx 40 mm. Close shutter, click on all stop to end program.		20 min		
13	Run LabView program ???.vi. Use it to move the lower arm down by 10 mm (i.e., to the desired start point for pulling). [This needs to be incorporated into a future version of the pulling program.]				
14	Run the pulling program again.				
15	Select and run the desired pulling data set.		2 min		
16	Close motorized shutter and set laser to off at the UC2000 controller.		1 min		
17	Wait 5 min for fibre to cool.		5 min		
18	Loosen bottom clamp screw.		1 min		
19	Click Motor Advance screen button in pulling program to raise the upper carriage and lift the fibre clear of the lower clamp.		1 min		
20	Hold the upper end of the stock with a gloved hand as near as possible to the clamp, loosen the clamp screw and remove the fibre. If the section of stock at the bottom is longer (and thus easier to hold away from the neck, as is the case with the current settings), grasp it with a second gloved hand and turn the fibre upside down. Be *extremely* careful not to touch the thin section or either of the necks.		1 min		
21	Click on reset button in software.				
22	If the fibre is free of obvious defects, glue either fuse-ends or cardboard to the ends depending on whether it is to be proof tested before use (non-destructively), or strength tested (destructively).				

Step	What	Where	Time	People	Tools
23	Test the fibre according to Section 4.1 or 4.2.				

4 Testing procedures

4.1 Proof testing a fibre

The proof tester requires fuse-ends on the fibre. Ideally these should be put on before pulling but at LASTI in August 2009, they were put on afterwards for the fibres to be proofed and used. Throughout this procedure, wear gloves and avoid letting anything touch the fibre in the thin section or near either neck.

Step	What	Where	Time	People	Tools
1	Fuse ends should be glued using low outgas epoxy (if available), and left to cure for the appropriate length of time.		??	1	Epoxy?
2	Make sure proof mass is on hydraulic lifter and at a suitable height, so that when the top fuse end is held beside the connection at the top of the cabinet, the bottom fuse ends dangles a tiny bit (1/8”) below the connection on the mass.		1 min	1	
3	Put the top fuse end into the top connection and insert the cotter pin.		1 min	1	
4	Put the bottom fuse end into the bottom connection and insert the cotter pin.		1 min	1	
5	Close the cabinet door.		1 min	1	
6	Open the valve on the hydraulic lifter to lower the mass until it suspends (or the fibre breaks). Leave suspended for at least 1 minute.		2 min		
7	If the fibre survives, pump the handle on the hydraulic lifter to raise the mass until the fibre is slack.		1 min		
8	Open the cabinet.		1 min		
9	Remove the bottom cotter pin.		1 min		
10	Hold the fibre by the top fuse-end, remove the top cotter pin and remove the fibre.		1 min		

4.2 Strength testing a fibre

Until such time as the LASTI strength tester is provided with fixtures to accommodate fuse ends, strength testing can only be done with bare-ended fibres. Throughout this procedure, wear gloves and avoid letting anything touch the fibre in the thin section or near either neck.

Step	What	Where	Time	People	Tools
1	Cut four pieces of cardboard approximately 1½"x1½".		1 min	1	cardboard, scissors
2	Crush cardboard and fold along the middle then coat surfaces with superglue. Place one piece on either side of the stock material and press tightly, hold for 30s to 1 minute.Repeat for opposite end, making sure to put the second piece of cardboard coplanar with the first.		2 min	1	SuperGlue
3	Leave SuperGlue to dry for 10 minutes or until the smell subsides, whichever is longer.		10 min		
4	Push up the grippers in the top jaw of the strength tester and insert one cardboard sandwich. Check that the protruding fibre is pointed straight down and press the grippers back down to grip the cardboard.		1 min		
5	Raise or lower the carriage of the strength tester to put the lower jaw level with the bottom cardboard, raise the grippers, insert the cardboard, check alignment and lower the grippers.		1 min		
6	Close the cabinet door.				
7	Press PEAK, then RESET, then PEAK again on the load cell readout (the display should flash).				
8	Set the carriage moving down slowly.		1 min		
9	Wait till fibre breaks and note reading on load cell readout.		3 min		