LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Rehang of the Quad NP with glass masses but metal wires (January 12-23 2009)

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1 Introduction

1.1 Purpose and Scope

This document describes the procedure used in going from the all-metal build of the quad noise prototype at LASTI to the build with glass masses but wires. It is written in the style of an instruction manual for ease of recycling the text into future procedure documents but except where noted is actually historical.

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™

1.3 Version history

1/18/09: First pre-v1 draft covering activities as far as having swapped out the masses in the reaction chain.

1/28/09: Second pre-v1 draft covering getting the system back in the tank.

2/12/09: Third pre-v1 draft with feedback from Brett on main and ESD procedures. Added Doug Cook as author. Changed installation tooling terminology to match Ken Mailand's ("rails" to "conveyor" etc). Got doc number: T0900055.

3/13/09: Corrected dates to 09 in version history. Cited E070292-00 for First Contact. Added timing and tools data.

2 Main procedure

Step	What	Where	Time	People	Tools
1	Lock all masses. Stops need only be done up gently – touching plus 1/8 turn. Putting divots in the metal is unnecessary. (The "2+1" in the "People" column refers to the the fact that all in-tank operations need at least one support person outside.)	in BSC	10 min	2+1	hex keys
2	Disconnect electrical wiring to lower structure and masses and tuck ends safely out of the way.	in BSC	5 min	2+1	
3	Lock top stage, lock top mass blades.	in BSC	5 min	2+1	hex keys
4	Raise stops under UIM to touch and overload UIM blade tip by 3mm.	in BSC	5 min	2+1	hex keys
5	Raise UIM until top to UIM wires are slack.	in BSC	5 min	2+1	hex keys
6	Remove UIM pitch mass (to allow access to screws in next step).	in BSC	5 min	2+1	hex keys
7	Disconnect wires from top mass to UIM at UIM.	in BSC	5 min	2+1	hex keys
8	Remove face earthquake stops.	in BSC	5 min	2+1	hex keys
9	Remove X braces and sleeve first, then ¼-20 bolts and spacers at the bottom of the sleeve, then 3/8-16 bolts up top. Loosen all the ¼-20 bolts at the bottom of the sleeve before removing them so that removing the spacers behind them is easier with less risk of dropping them on the optics.	in BSC	30 min	3+1	hex keys
10	Install conveyor, five-axis table and elevator (this was done first in reality which made it not quite impossible but very difficult to get the sleeve off). [Rich: conveyor through-holes to the door flange should be opened up so not so tight.] Make sure elevator is installed on 5 axis table such that you have +- 180^{o} of rotation. Wrap electrical cabling for elevator in UHV foil.	in, near BSC	1 day	4	5AT, conveyor

Step	What	Where	Time	People	Tools
11	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
12	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 five-axis table. To make this easier, start with some half-inch spacers at the bottom of the elevator to lift the LSAT above the pusher pins. These spacers will allow the LSAT to be pushed together before lowering it onto the pusher pins.	in BSC	5 min	2+1	½" spacers
13	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		LSAT side plates
14	Reinstall side plates on five-axis table, 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	5AT side plates, bolts
15	Raise LSAT on pushers until it almost engages with the structure.	in BSC	5 min	2+1	
16	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	
17	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	
18	Replace face stops on both chains.	in BSC	10 min	2+1	hex keys, face stops
19	Unbolt implementation ring from upper structure and remove bolts from upper to lower structure.	in BSC	10 min	2+1	hex keys
20	Retract pushers fully, lowering lower structure.	in BSC	5 min	2+1	

Step	What	Where	Time	People	Tools
21	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
22	Unbolt implementation ring from lower structure (because otherwise it won't get through the door).	in BSC	10 min	2+1	hex keys
23	Move lower structure to door of tank on conveyor.	in BSC	5 min	2+1	
24	Remove side plate on five-axis table on the main chain side ("2").	near BSC	5 min	2	hex keys
25	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
26	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
27	Cover the LSAT on the cart with a door cloth and wheel to the assembly area.	in transit	5 min	4	door cloth
28	Manhandle Genie past solid stack to assembly area.	in transit	5 min	4	
29	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
30	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
31	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
32	Remove plates holding halves of LSAT together.	assembly area	5 min	2	hex keys

Step	What	Where	Time	People	Tools
33	Remove remaining bolts holding halves of structure together.	assembly area	5 min	2	hex keys
34	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
35	Take weight of reaction chain with Genie and remove ¼" spacers under it. Withdraw straight back so as to cleanly disengage pins aligning two halves.	assembly area	5 min	4	Genie
36	Set reaction chain on a second foil-covered pallet (or piece of foil on the floor), remove spacers and pick up the reaction chain again closer to the centre of the forks.	assembly area	5 min	4	Genie, pallet #2, foil
37	Move the reaction chain to the turntable.	assembly area	5 min	4	breadboard on 10" blocks, turntable
38	Rotate reaction chain 180°, apply safety chocks under turntable to minimize rocking.	assembly area	5 min	4	chocks
39	Disconnect suspension wires between UIM and PM and between PM and (dummy) ERM.	assembly area	5 min	2	
40	Attach ergo-arm adapter plates to PM.	assembly area	10 min	2	adapter plates, bolts, hex-keys:
41	Bring in ergo-arm (see Section 3.2), move PM to work table (double-check weight etc).	assembly area	20 min	4	ergo-arm, vacuum pump, hose, reservoir
42	Remove dummy ERM with adapter plates and ergo-arm.	assembly area	30 min	4	adapter plates
43	Weigh CP and prepare replacement PRM with appropriate mass.	assembly area	30 min	2	CP
44	Install replacement PM using adapter plates and ergo-arm.	assembly area	30 min	4	adapter plates, ergo-arm
45	Install new wire assemblies incorporating UIM-PRM wires and wire loops for CP.	assembly area	10 min	2	pre-made wire assembly, hex-keys

Step	What	Where	Time	People	Tools
46	Set up the Brunson transit on opposite side from ergo-arm access direction.	assembly area	30 min	1	transit
47	Using the transit, clock the PRM until the clamps on either side are at the same height.	assembly area	10 min	2	transit
48	Prepare the CP, soldering on the tabs and electrical wires per Section 3.3. (This step could be done at any convenient time prior.)	clean room	1 day	1	tabs, coax, indium, Al buttons, soldering iron, nitrogen blower
49	Bring the CP into the assembly area and stand it up in a V-block with the non-ESD face accessible. (This was done manually, which is not ideal. On the other hand it's not clear that it could have been done with the ergo-arm because once the tabs and wiring are added, the CP can only be laid with the non-ESD face down, and one might worry that the tabs would prevent the suction plate from sealing on the ESD face – this needs to be tested.)	assembly area	10 min	2	V-block
50	Arrange a foil pouch (about 9"x9") near the bottom of the structure on the back (transit) side for receiving and keeping safe/clean the CP electrical wires.	assembly area	5 min	1	foil
51	Fit the silica-tips to upper earthquake stops but leave them fully retracted.	assembly area	10 min	2	silica [PTFE] tips
52	Put type "D" chocks under the lower pads.	assembly area	10 min	2	type "D" chocks
53	Bring the suction plate of the ergo-arm up to the non-ESD face of the CP with the T-piece between the valve and gauge at about 22.5° (so that in a later step it will fit into the corner of the octagon of struts defining the CP's position in the structure).	assembly area	5 min	4	ergo-arm
54	Pick up the CP with the ergo-arm, assigning a person to support the ESD wires throughout the next few steps.	assembly area	5 min	4	ergo-arm, vacuum pump, hose, reservoir

Step	What	Where	Time	People	Tools
55	Bring the ergo-arm with the CP near the structure, and adjust the angle of the base and the height, lateral position, pitch and yaw of the head so that the CP is ready to pass through the structure neatly, with approximately equal clearance on all sides. Lock the castors of the ergo-arm.	assembly area	5 min	4	ergo-arm
56	Roll the CP so that the T-piece is at 12 o'clock. (This will put the prisms and ESD wiring tabs in line with corners of the octagon of struts.)	assembly area	1 min	4	ergo-arm
57	Pull the two loops of suspension wire gently out of the octagon at the far side of the structure and assign a person to hold them up out of the way for the next few steps.	assembly area	1 min	4	ergo-arm
58	Pass the ESD wiring carefully through the structure and place it in the foil pouch.	assembly area	1 min	4	foil pouch , ergo-arm
59	Move the CP carefully into the structure until the leading face, the ESD wiring tabs and the prisms have all fully entered the structure volume and are clear of the front-face struts.	assembly area	5 min	4	ergo-arm
60	Roll the head back to the original position with the prisms at 3 o'clock and 9 o'clock, and the T-piece at 22.5°.	assembly area	1 min	4	ergo-arm
61	Continue to move the CP into the structure either until it has reached its design position with the ESD face level with the far side of the structure or until the T-piece is about to foul on the near side of the structure.	assembly area	5 min	4	ergo-arm
62	Thread the pouch of ESD wiring up through the loops of suspension wire and lower the suspension wires against the far side of the structure.	assembly area	1 min	4	ergo-arm
63	Stretch the suspension wire loops around and under the mass, being especially careful not to snag them on the ESD wiring tabs. Route them between the pairs of upper earthquake stops on each side.	assembly area	1 min	4	ergo-arm
64	Lower the CP gradually until the wires are pulled straight but not taut. If the T-piece on the suction plate fouled against the structure earlier and	assembly area	1 min	4	ergo-arm

Step	What	Where	Time	People	Tools
	additional insertion is required, it will tend to become possible at this stage – alternate small downward and inward steps as appropriate.				
65	Nudge the wire loops into the grooves on the prisms and around the bottom of the CP. A mirror placed facing up on the turntable below the structure will make it easier to check that this has been done correctly.	assembly area	1 min	4	mirror, ergo-arm
66	Using the transit, adjust the CP in roll until the prisms are at the same height.	assembly area	10 min	4	transit
67	Continue to lower (and if necessary, further insert) the CP until the wires are taut and/or it rests on the bottom earthquake stops.	assembly area	1 min	4	ergo-arm
68	Screw in the upper earthquake stops to a 0.5 mm gap.	assembly area	5 min	4	
69	Position a person to restrain the CP in case it swings front to back. Have another person remove the vacuum hose, open the valve on the suction plate and withdraw the ergo-arm.	assembly area	5 min	4	ergo-arm
70	Back off the upper earthquake stops, insert Teflon pads and screw them back in to touch.	assembly area	5 min	2	Teflon pads
71	Install the face stops and screw them in to a 0.5 mm gap.	assembly area	5 min	2	face stops
72	Take out the chocks under the turntable and rotate the reaction chain by 180°.	assembly area	5 min	4	
73	Using the Genie, move the reaction chain off the turntable and place on pallet with approx ¼” spacers underneath. [In fact we used some of the plates for holding the halves of the LSAT together, which was a bad idea because we had to muck around later getting them out. Purpose-made would be better.]	assembly area	30 min	4	¼” spacers
74	Check reaction chain for balance per Section 3.4.	assembly area	45 min	2	triple-hang tooling, hex keys

Step	What	Where	Time	People	Tools
75	Route the ESD wiring up the chain. There need to be wire clamps at top and bottom of the back face of the PRM.	assembly area	30 min	2	ESD wire clamps
76	Using the Genie, put the main chain on the turntable with the outside of the LSAT towards the transit and the centre side toward the access side.	assembly area	20 min	4	Genie, turntable
77	Remove the UIM-PM and PM-TM wires.	assembly area	5 min	2	
78	Using the ergo-arm and adapter plates, remove the PM and TM and double-check weights etc.	assembly area	30 min	4	balance
79	Prepare new PM with appropriate mass.	assembly area	30 min	2	balance
80	Install the new PM with adapter plates and ergo-arm.	assembly area	30 min	2	adapter plates, ergo-arm
81	Install the wire assembly as for the reaction chain.	assembly area	10 min	2	pre-made wire assembly, hex-keys
82	Release overload on UIM blades until PM suspends and check for balance. Restore overload.	assembly area	10 min	2	hex-keys
83	Clock PM with transit.	assembly area	10 min	2	transit
84	Put silica tips on upper TM earthquake stops but leave well retracted. Install silica tipped face stops.	assembly area	5 min	2	hex-keys
85	Put type “A” adjustable pad spacers under lower earthquake pads.	assembly area	10 min	2	type “A” spacers
86	Install ring heater, leaving halves as far apart as possible (for the biggest possible gap in the centre).	assembly area	20 min	2	ring heater, bolts, hex-keys
87	Pick up TM with ergo-arm from AR side. (Angle of T-piece doesn’t much matter.)	assembly area	10 min	4	ergo-arm, pump, hose reservoir
88	Insert TM into structure, being *extremely* careful not to bump prisms on ring heater, stopping when ergo-arm side is level with face of structure.	assembly area	10 min	4	ergo-arm

Step	What	Where	Time	People	Tools
	Position wire loops around TM as it passes through. (Joe says: could try tilting to put prisms at 6 and 12 o'clock.)				
89	Lower TM until wires are straight but not taut.	assembly area	5 min	4	ergo-arm
90	Dress wire loops to pass through prism grooves and then neatly under TM. Again, a mirror is convenient.	assembly area	5 min	4	mirror
91	Lower TM onto pads, remove ergo-arm.	assembly area	5 min	4	
92	Put Teflon pads between upper earthquake stops and mass for both PM and TM and tighten stops.	assembly area	5 min	2	Teflon pads, hex keys
93	Pick up main chain with tips of Genie forks, using thin spacers (≈1/4") on tip side to counteract sag.	assembly area	10 min	4	Genie, ¼" spacers
94	Bring main chain over to pallet #2.	assembly area	5 min	4	Genie
95	Check main chain for balance per Section 3.4.	assembly area	45 min	2	triple-hang tooling
96	Remove First Contact from AR face of TM.	assembly area	5 min	2	razor blade
97	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
98	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
99	Attach plates holding LSAT together.	assembly area	5 min	2	hex-keys
100	Pick up whole LSAT with Genie, using thick spacers (≈1/2") to counteract sag.	assembly area	5 min	4	Genie, ½" spacers
101	Transfer LSAT to cart, clamp down, cover, and wheel to tank.	in transit	15 min	4	cart, hex keys, dogs

Step	What	Where	Time	People	Tools
102	Manhandle Genie past solid stack to tank area.	in transit	5 min	2	Genie
103	Pick up LSAT with tips of forks using ½" spacers	near BSC	5 min	4	Genie, ½" spacers
104	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
105	Remove one side-plate ("2") from elevator of five-axis table.	near BSC	5 min	2	wrench
106	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 directly above locating pins on pushers.	near BSC	10 min	4	5AT, elevator
107	Raise pushers to engage pins and support LSAT. Remove Genie.	near BSC	5 min	2	
108	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
109	Lower LSAT until it is almost sitting on floor of elevator (so that it will go through door).	near BSC	5 min	2	
110	Roll table into chamber on conveyor.	near BSC	5 min	2+1	
111	Attach implementation ring to lower structure.	in BSC	10 min	2+1	hex keys
112	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	
113	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
114	Remove remaining plates holding halves of LSAT together.	in BSC	5 min	2+1	hex keys

Step	What	Where	Time	People	Tools
115	Remove upper two face stops on PM on both main and reaction chains.	in BSC	5 min	2+1	hex keys
116	Put two long spacers (1" thick) on floor of elevator.	in BSC	1 min	2+1	1" spacers
117	Lower pushers till LSAT comes to rest on spacers.	in BSC	2 min	2+1	
118	Using two people per side simultaneously, pull the halves of the LSAT out and remove.	in BSC	2 min	4+1	
119	Remove UIM upper pitch mass (both chains).	in BSC	10 min	2+1	hex keys
120	Connect wires from top mass to UIM (both chains).	in BSC	5 min	2+1	hex keys
121	Install UIM upper pitch mass (both chains).	in BSC	10 min	2+1	hex keys
122	Remove five-axis table and conveyor.	in BSC	1 hour	4	??
123	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	??
124	[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
125	Remove all face earthquake stops on the bottom two levels of both chains.	in BSC	10 min	2+1	hex keys
126	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

Step	What	Where	Time	People	Tools
127	Install X braces.	in BSC	10 min	2+1	hex keys
128	[This shouldn't be necessary!] Restore the upper half of the ring heater to its original condition.	in BSC	5 min	2+1	
129	Reinstall face stops and set at 0.5 mm.	in BSC	10 min	2+1	hex keys
130	Finish routing ESD and OSEM wiring.	in BSC	20 min	2+1	
131	Suspend per Section TBD.	in BSC	??	2+1	
132	Drag wipe per Section 3.6.	in BSC	20 min	2+1	foil, lens tissue, methanol

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

Step	What	Where	Time	People	Tools
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	
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		1 min	1	

Step	What	Where	Time	People	Tools
	identified earlier, rotating them in opposite directions, so as to tighten one as the other is loosened.				
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	
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 Using the ergo-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	

3.3 Preparing the CP

Step	What	Where	Time	People	Tools
1	Check the electrical continuity of the ESD cables. (The cables are *extremely* prone to failure at the end where the gold connectors have been crimped on.)		1 day for all steps		ohmmeter
2	Take the CP out of its case, remove the face-plate from the ESD side, and lay it with the ESD side up in a clean room. [It was very difficult to remove the face plates because they were quite tight and there were no vent grooves in them.]				
3	Carefully wipe the face and sides of the optic with lint-free wipes moistened with methanol [acetone?] to remove dust and dirt.				methanol [??acetone], wipes
4	Cut gold tabs to appropriate size: width about the same as the traces in the ESD mask, length sufficient to protrude about 5 mm off the edge of the optic. (This will be different for different traces.) [Brett: 5 mm turned				tabs

Step	What	Where	Time	People	Tools
	out to be too much given the narrow clearance between the CP and the structure – it should be more like 2-3 mm.)				
5	Crimp a furrow across the end of the gold tab which will be used to support the coax cable at a later step.				pliers
6	Set up a bottle of clean, dry nitrogen with a regulator and nozzles to direct a flow of nitrogen across the work area.				N2 bottle, regulator, nozzles
7	Repeat the next few steps for each tab to be soldered:				
8	Point the nozzles at the end of the ESD trace that the tab is to be attached to.				
9	Place a small bead of indium on the end of the trace, lay the flat end of the tab on top and cover with an aluminium button.				indium solder, Al button
10	Press a soldering iron heated to 600 degrees F onto the button and keep it there until 10 seconds after the indium melts. The button will visibly sag when the solder melts. Remove the button and inspect the joint. Too much heat can damage the pattern, so do not keep the iron there longer than necessary.				soldering iron, button
11	Remove a length of shield approximately 1.5” long from the end of the coax, exposing the (very delicate) central conductor and inner insulation.				wire stripper
12	Carefully strip the inner insulation exposing 2 to 3 mm of the central conductor.				wire stripper
13	Lay the end of the intact section of shield into the groove in the tab and roll the end of the tab over so that the shield is gripped.				pliers
14	Carefully bend the inner conductor around towards the body of the tab and solder it there, using the same procedure as for the tab. Maintain slight pressure on the tab at all times so that it does not move if it the solder behind it should melt.				soldering iron, solder, button
15	Test the electrical continuity from the pattern to the end of the cable.				ohmmeter

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	
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

Step	What	Where	Time	People	Tools
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

Step	What	Where	Time	People	Tools
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
1	Pour a little spectroscopic grade methanol into a small foil boat or dish.		5 min		foil, methanol
2	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
3	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