LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Advanced LIGO Quad Suspension Metal-Build Assembly Procedure

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1 Introduction

1.1 Purpose and Scope

This document describes the assembly procedure for the production version of the quad suspension, from receiving of parts through to a balanced and aligned all-metal build in storage.

Mark Barton and Betsy Bland wrote most of the final version, flagrantly recycling from documents by Joe O'Dell, Brett Shapiro and Ian Wilmut.

1.2 References

T080108-00: Notes on Lower Quad Installation at LASTI.
T080165-00: Metal Quad Noise Prototype Balancing and Alignment Procedure.
T060040-v1: Noise prototype Assembly procedure.
G070359-00: LASTI Tooling (instructional DVD)
E070292-00, H. Armandula, Optics Cleaning Specification - First Contact™
E960022-v4: LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
T040108-03: Blade, wire and clamp process specification

Top level assembly:
D0901346-v2: Advanced LIGO Quadruple Suspension
E0900316: ALIGO QUAD DRAWING TREE
E0900167: Bill of Materials for the ETM / ITM Quad Suspension Assembly (Production)
T0900590: Quad production status

Subassembly drawings:
D060310: QUAD N-PTYPE TABLECLOTH, Tablecloth (Noise Prototype)
D060324: Quad N-Ptype Top Stage, BLADE CARTRIDGE
D060341: QUAD N-PTYPE, PENULTIMATE REACTION MASS, ETM CONFIGURATION
D060355: Quad N-Ptype, Dummy Test Mass Assembly Tooling
D0902075: Quad N-Ptype, DUMMY PENULTIMATE MASS
D060356: Quad N-Ptype, Dummy Test Reaction Mass Assembly Tooling
D060375: Quad N-Ptype, UI MASS
D0902233: QUAD UI MASS REACTION CHAIN
D060403: Quad N-Ptype Top Mass, TOP MASS - MAIN CHAIN
D0902031: Quad N-Ptype Top Mass - REACTION CHAIN
D060454: QUAD N-PTYPE LOWER STRUCTURE, INNER LOWER STRUCTURE, SUSPENSION STRUCTURE
D060492: Quad ETM/ITM, Upper Structure Weldment
D070056: Quad N-PType, Quad Dog Clamp
D070214: Quad N-PType Wiring Harness, Top Ring Wire Clamp
D070217: Quad N-PType Wiring Harness, Upper Structure Stay Wire Clamp
D070538: Quad ITM/ETM, Implementation Ring Test Chain
D070539: Quad ITM/ETM, Implementation Ring Reaction Chain
D070552: ITM/ETM Structure, ITM/ETM Sleeve
D080241: Earthquake Stop Assembly

D090433: THIS, TRANSPORT PADS, QUAD SUS
D090434: THIS, FRONT TRANSPORT PAD, QUAD SUS
D0901342: SLEEVE - LS - WEDGE 1
D0901343: SLEEVE - LS - WEDGE 2

D060516: Wire jig assembly drawing (with usage diagrams)
D0902643: Top Wire Clamp Wire Assembly
D0902644: Middle Clamp Wire Clamp Assembly
D0902645: Bottom/Final Clamp Wire Clamp Assembly

Holo-Krome Bolt Torque Data Sheet (http://www.holo-krome.com/pdf/techbk34-40.pdf): recommended bolt torque values from Holo-Krome.
T080230-v1: Quad Pendulum Structure Pushers
EXXXXXX - Inventory Control Manual
F0900XX – Inventory Control Import Template
E0900047: aLIGO Contamination Control Plan

1.3 Version history

1/14/10: First pre-v1 draft, adapting T060040-v1

1/18/10: Second pre-v1 draft adding stuff from Brett's T080165-00.

2/24/10: Third-pre-v1 draft with input from Betsy on ICS, receiving, cleaning/baking, making of clamp-wire-clamp assemblies, etc.

2/26/10: v1. Tidying up by Mark B. Still very much a work in progress but released for comment.

2 Template

Copy and paste this to get another instance of the nice tables. Be sure to select the blank line after the table or funny things may happen (tables merging, etc). After adding a table, check the numbering of the table you added and the one below it - the setting to restart the numbering at 1 may have been cleared for either or both. If this is not what you want, click in the first numbered cell, choose Format->Bullets and Numbering… and click the "Restart numbering" radio button.

Step	What	Where	Time	People	Tools
1					

3 Preparation

Advanced LIGO has implemented a new Inventory Control System (ICS) which is designed to record all aLIGO hardware as it moves through receiving, inspection, clean, bake, storage, shipment, and assembly processes. The ICS is meant to replace the shipping type paper traveler used in iLIGO. While the ICS is still in final development as of this writing, the hope is that the engineering teams will be able to utilize ICS to record many aspects of the lifetime of a part from its initial receipt through the clean and bake processes previously documented in the iLIGO traveler. The sites have dedicated staff to help with managing the data related to the processing of parts in ICS. Engineering staff should become familiar with the ICS such that they can utilize it for their own record keeping and data management. If the ICS fails to facilitate data that you need to record, process travelers (PT) can be placed on the DCC. In either case, make sure to record all serial numbers and data in the ICS or the DCC during the following steps.

3.1 Receiving/inventory

3.1.1 Receiving/inventory of metal parts

Upon receipt of shipments of SUS parts, the following steps should be performed:

Basic inspection of shipment by receiver (crate damage, etc). Packing slips should be sent (hardcopy or emailed) to Jennie Murdock at LHO. Person performing this step should notify site subassembly lead of the shipment arrival.

Inventory Control and inspection performed by ICS person and site subsystem lead as parts are unpacked. Drawing numbers, serial numbers, and quantities will be imported into the ICS database via spreadsheet templates (F0900052). This is a good time for QA/QC and engineering inspections. The following processes can now be recorded in ICS by grouping the parts into Loads.

Parts get separated into cleaning loads based on their level of cleanliness, and moved to the appropriate cleaning station.

Parts get separated into clean and bake loads based on their material – see E960022. Sorting should be reflected in the Load records in ICS, where instructions to technicians can be added for any special handling or material considerations.

Parts will be processed as per E960022.

Parts will be stored in clean storage areas until assembly.

3.1.2 Receiving/inventory of glass parts

[?? Different from metal?]

3.2 Cleaning/Baking

Process all parts except for the Dummy Masses as Class A per E960022. Dummy Mass D0603XX is to be processed as Class B, as it will later be swapped out with Class A glass mass. All Parts should be processed as Class A or B prior to Helicoil installation.

3.3 Helicoils

Install all the helicoils in all the parts and make sure they are free running and not cross threaded, remove the tangs. Perform Helicoil inspections as per XXXXXXX.

4 Subassemblies

Assign each subassembly with a unique serial number based on the parent number which can be used for referencing data taken on that subassembly. For example, if 3 Top Mass Assemblies are assembled from drawing number D060421, the units should be assigned serial numbers like:

D060421-001

D060421-002

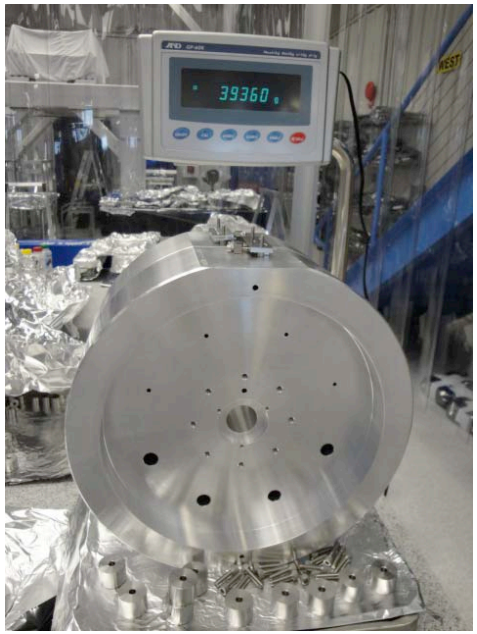
D060421-003, and so on. As individual parts are added to the subassembly, record their serial numbers as part of that subassembly. The overall subassembly number (i.e. D060421-001) can now be used in the ICS to track further operations performed on that subassembly. These subassemblies will eventually become associated with their parent QUAD which will have its own serial number, such as D0901648-001 (aka QUAD 001). Label the bag with the newly designated subassembly and serial number after wrapping and bagging.

When weighing subassemblies, use the high precision scale dedicated for the SUS assemblies.

4.1 Dummy test mass (D060355)

Steps for assembly are as follows:

Step	What	Where	Time	People	Tools
2	Prior to assembly, the half masses (D060358) can be processed as CLASS B, as it will be swapped with a glass mass.				
3	Assemble each mass with the addable masses such that each has the appropriate weight, as per the drawing. Masses should weigh as per specified to +/- 5 grams. Weight can be over or under, but should be as close as possible. Use washers with the fasteners if needed, to minimize the weight error. If the Dummy Test Mass is under weight a bit, make the Penultimate Dummy Mass over weight by the same amount. Symmetry of addable mass: Add masses to each face of the dummy mass such that the center-of-gravity s maintained, ie. When you add a 100g mass to the 3 o'clock position of the front face, add a 100g mass to the 3 o'clock position of the back face. The vector between the 2 added masses goes through the center of the dummy mass. If possible, leave the 1:30, 4:30, 7:30, and 10:30 o'clock holes available, as these will be needed when attaching the adaptor plate for the ergo arm.				
4	Record the weight of the assembly, along with the serial numbers of the half masses in ICS/PT.				



4.2 Dummy main chain penultimate mass (D0902075)

Step	What	Where	Time	People	Tools
5					

Prior to assembly, this mass (D060358) can be processed as CLASS B, as it will be swapped with a glass mass. Assemble all masses as per their assembly drawings. Assemble each mass with the addable masses such that each has the appropriate weight.

4.3 Dummy CP or ERM (D060356)

ERM stands for End Reaction Mass (chosen to avoid confusion with Recycling Mirror), which is also known as Re Test Mass. Note that due to abandonment of a plan to have an ERM of heavy glass, the production dummy ERMs are identical to the dummy CPs and lighter (approximately 22 kg) than the dummy ERM used in the all-metal build of the LASTI prototype (approximately 40 kg).

Prior to assembly, this mass (D060357) can be processed as CLASS B, as it will be swapped with a glass mass. Assemble all masses as per their assembly drawings. Assemble each mass with the addable masses such that each has the appropriate weight.

4.4 Penultimate Reaction Mass for CP or ERM (D060341)

This mass is also known as Pen Re. Just as all CPs and ERMs are now identical (see note in previous section), so are all the penultimate reaction masses. This mass needs to be cleaned to CLASS A because it is not a dummy and will be installed in vacuum.

4.5 Ring heater

ITM configuration only.

4.6 Wire assemblies

Follow the procedure in Section 4.10 for each assembly, taking account of the general notes immediately below, and the per-assembly-type notes in Sections 4.7 through 4.9.

Pay attention to the exploded views in the D060516 wire assy drawings – these show when to use what grooves in the jaws.

Take care to not over stress or bend the wires when releasing the wire sets from the jig. Also take care when storing. Wire sets should be stored in dry storage along with the spools of wire.

When setting up the wire in the jig, note that it should never bend around any fixture pieces except for at the clamp and the tuners. If the wire bends around any of the fixture, then recheck the fixture setup.

4.7 Top wires (D0902643)

There are 2 grooves in the D060334 jaws, but only one groove will be used for the Top Wire assembly. Use ~1” segments of wire inserted into the empty wire groove in each clamp.

Use the groove that is more centrally located in the wire clamp assembly to mount the wire. Use the outer groove for the “dummy” wire.

4.8 Middle wires (D0902644)

Note in the drawings which grooves to use in the clamps of this assembly. Some are used, some are not.

4.9 Bottom/Final wires (D0902645)

This is a compound assembly which includes the UIM-PM wires and the loop supporting the TM/CP/ERM.

4.10 General clamp-wire-clamp assembly procedure

Step	What	Where	Time	People	Tools
6	Class B the wire jig assembly. Helicoil the assembly.	VPW	2 days	1	
7	Using the Wire Jig assembly drawings as a guide, set up the jig fixture for the wire segment you will be assembling. There are 4 segments of wire assemblies to assemble for every QUAD. The jig can be reconfigured for each of these segment lengths. Note: Use gauge blocks of the thickness listed on the assembly drawings to set the jig fixture pieces the appropriate distance apart, and square relative to each other.	Lab	20 min.		
8	Cut a length of wire long enough to span the section of the jig you will be using.				
9	Clean the wire by wiping it thoroughly with acetone many times, followed by a thorough wipe with methanol. Take care to not bend or "kink" the wire during any of the subsequent handling steps. [?? Check]		5 min.	1	
10	Clamp the wire into the clamps held by the fixture, taking care to secure the free ends tightly in the outer fixture jaws and the guitar tuner.				
11	Snug up the "real" wire clamps such that the wire is free to slide through them, but does not chatter when the wire is strummed during the following tuning steps.		10 min	1	
12	Setup an oscilloscope (such as Tektronix TDS 2012B) to trigger on the peak of the frequency specified in the assembly drawings for the segment you are working on.		15 min	1	
13	Set cursors at +/-2Hz from the specified frequency.				
14	Hook the guitar pickup BNC to the scope.				
15	Place the guitar pickup on the jig just under the wire such that it will pickup the sound of a strum.				
16	Strum the wire like you would on a guitar, to see the frequency peak on the scope. Tension the wire by turning the guitar tuner until the peak is centered between the cursors on the scope.				

Step	What	Where	Time	People	Tools
17	Tighten the QUAD wire clamps and check that the frequency peak has not moved out of the cursor range. If it has, loosen the clamps slightly and retune by adjusting the tension. This might take a few iterations.		10 min	1	
18	Remove wire from jig by first loosening the guitar tuners, and the fixture jaws. Take care not to induce any stretching in the wire segment when removing it from the fixture.				
19	Repeat wire assembly steps above for each segment length necessary for the full QUAD assembly.				
20	Assign each wire assembly a unique serial number and record final resonance frequencies for each in the ICS/PT.				
21	Store as CLASS A in dry storage until ready for installation into a full QUAD Assy		10 min.	1	

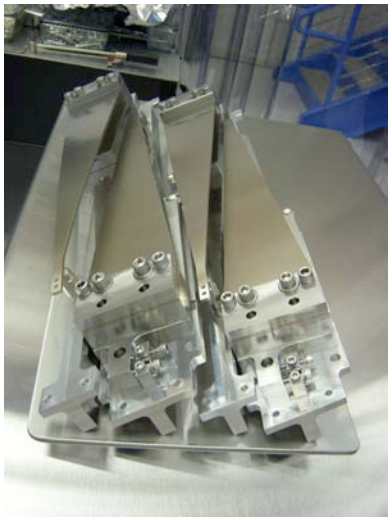
4.11 OSEMs

Assemble AOSEMs as per E090XXX. BOSEMs should be delivered by Birmingham, fully assembled and ready for Class A use.

4.12 Top Stage Blade Cartridges

Step	What	Where	Time	People	Tools
22	Assemble the Top Stage Blade Cartridge Tooling as per D060370. Clamp tooling to optical table.				
23	Choose blades which are a matched sets with the appropriate Blade Clamps D060326 and D060327. See T1000068 for sets of blades and clamps with corresponding serial numbers.				
24	Assemble 4 cartridges as per assy picture book D060370. Note that 3 of the cartridges will have a D060329 Backbone and 1 will have a D0901439 Backbones. It is important to align all holes in the clamps and blades the first time they are stacked together. Misalignments will mean that screws inserted later in the assy will not mate well.				

Step	What	Where	Time	People	Tools
25	Perform Creak bake on all Top Stage Blade cartridges at 120 deg C for 100 hours, as per T040108.				



4.13 Top mass

In general, the more carefully each assembly and alignment step is done, the easier later steps will become. For example, the more accurately the blade springs were installed during assembly, the easier it will be to balance pitch.

Step	What	Where	Time	People	Tools
26	Insert helicoil repair in all D060430 top plates. (Not in picture book.)				Standard Class B Tool Kit
27	Choose Middle Blades (D060236) which have been characterized as a set of 4 (2 for test chain and 2 for reaction chain) designated in T1000068.				
28	Assemble one Top Mass as per the D060403 picture book, and one Reaction Top Mass as per the picture book D0902031 stopping at page 15.			2	Weight set for blade straightening

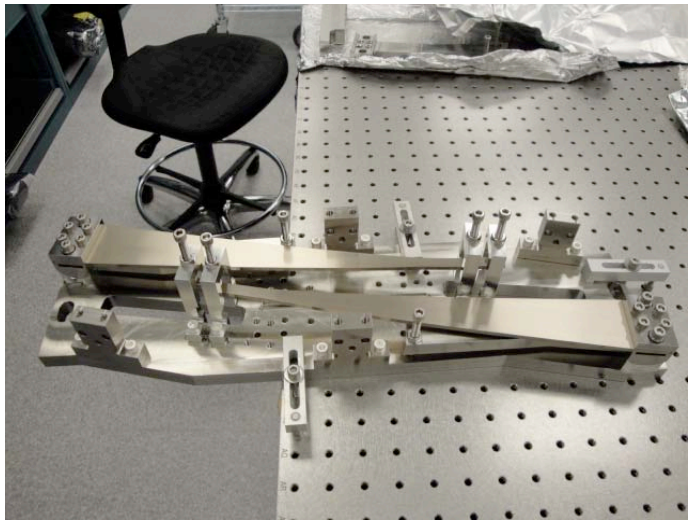
Step	What	Where	Time	People	Tools
29	Perform Creak Bake on Top Masses in air at 120 deg C for 100 hours as per T040108.				
30	Choose OSEMs which are matched to TBD.				
31	Complete assembly of the Top Mass and Reaction Top Mass as per the picture books. Notes: Take care when pressing the steel disks into the aluminum ECD and flag holders, as the aluminum can be easily bent. Handle magnets carefully as they are very strong and some are brittle. As well, be careful with tools in proximity to the magnets as many tools in the kits are magnetic. Torque all fasteners as per the assembly picture book.			2	Clean Press Standard Class B Tool Kit
32	Weigh the assembly. Add or remove Addable Mass symmetrically to the assembly until the unit weighs 22kg +/- 10g.				
33	Store the sub assemblies until you are ready to install them into a QUAD. Notes: 1) Magnets should be removed from assembly and stored with the unit separately.				

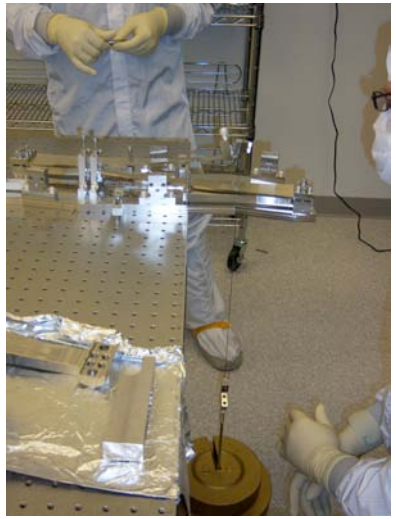
4.14 UI Mass

In general, the more carefully each assembly and alignment step is done, the easier later steps will become. For example, the more accurately the blade springs were installed during assembly, the easier it will be to balance pitch.

Step	What	Where	Time	People	Tools
34	Choose Bottom Blades (D060237) which have been characterized as a set of 4 (2 for test chain and 2 for reaction chain) designated in				

Step	What	Where	Time	People	Tools
	T1000068.				
35	Assemble one UIM and one Reaction UIM as per the picture book D060375 stopping at page 9.			2	Weight set for blade straightening
36	Perform Creak Bake on UIMs in air at 120 deg C for 100 hours as per T040108.				
37	Choose OSEMs which are matched to TBD.				
38	Complete assembly of the UIM and Reaction UIM as per the picture book. Notes: Take care when pressing the steel disks into the aluminum ECD and flag holders, as the aluminum can be easily bent. Handle magnets carefully as they are very strong and some are brittle. As well, be careful with tools in proximity to the magnets as many tools in the kits are magnetic. Torque all fasteners as per the assembly picture book.			2	Clean Press Standard Class B Tool Kit
39	Weigh the assembly. Add or remove Addable Mass symmetrically to the assembly until the unit weighs 22kg +/- 10g.				
40	Store the sub assemblies until you are ready to install them into a QUAD. Notes: 1) Magnets should be removed from assembly and stored with the unit separately.				





4.15 Lower structure

Step	What	Where	Time	People	Tools
41	Assemble all EQ stop Brackets. Note the callout on some of the drawings which specify that the PFA440 bushings need to be reamed out after assembly into the Aluminum bracket. A Class B reamer (such as McM-Carr 8851A23) will be needed for this step. The reamer will be used clean, and can be done by hand. Work in an area where the particulate can be removed easily and completely from the cleanroom.				

4.16 Sleeve

Ensure by trial fit that the upper and lower structure correctly interface to the sleeve. Matching of serial numbers between the sleeve and upper structure is unnecessary – the structures are interchangeable with each other.

5 Main assembly

Step	What	Where	Time	People	Tools

Step	What	Where	Time	People	Tools
1	Download the quad traveler template, F1000008 (a Microsoft Excel spreadsheet), start a new copy under a new DCC number and title as described in the instructions sheet of the template.				
2	Record the new traveler DCC number in the Related Documents field of E0900371 [?? and in the inventory control system in the record for the suspension being assembled].				
3	In the steps below, record the called-for data in the traveler spreadsheet. After each work session, resubmit the updated traveler to the DCC as a new version.				

5.1 Top stage and Upper Structure

Step	What	Where	Time	People	Tools
4	Install empty upper structure on the gazebo/Test Stand, attach with as many as possible. 16 dog clamps, 4 per side, with 2 per corner, are desirable. (Breadboard surface of Test Stand should be level to +/- XXX.)				
5	Install all four top stage blade units in place. Check the tips are central, and the location holes align.				
6	Ensure all blade tips are held well down with blade stops. Target is that the tips are 2mm below nominal (108mm from the optic table to the blade top).				

5.2 Tablecloth and top mass

Step	What	Where	Time	People	Tools
7	Lie two 36mm cross bars across the lower structure bottom ring and rest the two top masses approximately in place (the upper structure removable braces work well)				
8	Optional step which replaces step 11: [With plenty of slack, attach the wire clamps to the Top Stages and the Top Masses (note – the wire clamps can be attached to the Top Masses while still on the bench for				

Step	What	Where	Time	People	Tools
	ease).]				
9	Assemble the tablecloth side plates in place with no OSEMs/ECD assemblies. Install all the dowels to locate it nominally wrt to the structure. Adjust the plates until the dowel hole pins line up.				
10	With the stops raise the top masses into place. Position nominally in x and y using dowels and approximately 10mm too high in z (do this by inserting the stops too far).				
11	Connect the top two masses to the top stage, bolting the top wire clamps to the top blade tips and the top mass. The top plate of the top masses can be removed to make this easier.				
12	Lower top two masses to nominal position - note the top stage blade tips may need to be pushed down for this.				

5.3 Lower structure

5.3.1 LSAT

Step	What	Where	Time	People	Tools
13	Assemble both halves of the lower structure assembly tooling side by side on either the floor or a low table. Note when viewed from above they should look something like: ⊓ ⊔ ideally with the rear of the penultimate mass easily accessible.				
14	Install the respective halves of the lower structure into the tooling.				

5.3.2 Reaction chain

Note the test and reaction chains are subtly different approaches, either is acceptable, the only reason they are different is that they are more-representative of the glass procedure.

Step	What	Where	Time	People	Tools
15	Add the reaction UI mass into place onto stops which are retracted such that the tips are ~10mm above the UIM bracket. This will allow slack to				

Step	What	Where	Time	People	Tools
	clamp the wires on later. Note: OSEMS should be in place.				
16	Add the Penultimate reaction mass in to a position in its nominal position WRT lower structure (on fixed PFA440HP pads); set roll (approximately) Note: OSEMS should be present and in the approximately correct position.				
17	Add the reaction test mass; approximately set roll by eye.				
18	Add the UIM-PenRe-TestRe wire assemblies to both sides. Roll test mass and Pen mass as required.				
19	Lower test reaction mass to its nominal position.				
20	Raise the UI mass to its nominal position on the vertical stops taking care to keep it horizontal.				
21	Raise the UI mass further to lift the PenRe mass and remove the PFA440HP pads below the PenRe mass. Lower the UI mass to get the PenRe mass back into its original position.				
22	Remove the stops from below the test mass to ensure everything hangs stable and with no gross pitch.				
23	Lock all three masses in their nominal positions (leaving the wires all in tension).				

5.3.3 Main chain

Step	What	Where	Time	People	Tools
24	Add the test UIM into place on partially retracted vertical stops 10mm below nominal.				
25	Rough level the UIM with the vertical stops.				
26	Add the Penultimate test mass in its nominal position wrt lower structure, with magnets omitted, onto the fixed PFA440HP pads. Set roll by eye.				
27	Add the Test Mass into the LS. Set roll by eye.				
28	Attach the Bottom-Final wire assemblies to all 3 masses, note the UIM blade tips and masses may need to be worked down to make room for the				

Step	What	Where	Time	People	Tools
	wire clamp. The outer blade tip stop in the bridge will need to be retracted in order to bolt the wire clamp onto the tip. Replace the tip stop when clamp is attached.				
29	Lower TM stops such that mass is hanging. Check that it is about nominally positioned in LS.				
30	Raise the UI mass to its nominal position (line up the EQ stop holes on the D070548 plate with the UIM holes) on the vertical stops taking care to keep it horizontal.				
31	Relevel UIM on the vertical stops.				
32	Slightly raise the UIM mass allowing the Penultimate mass to raise and remove its PFA440HP pads (upper stops need to be retracted). Lower the UIM to its nominal along with penultimate mass suspending it.				
33	Check that the PM is hanging – if not, check wire lengths and positions of TM and UIM again. Care should be taken that no unexpected pitches occur although it is unlikely.				
34	Check and adjust if needed the 5mm lateral and 12mm height positions of the UIM blade tips wrt the bridge. If there is an error in the 12mm height, it is better to have the blade tips low than high.				
35	All masses can now be locked in place. The simplest thing to do is to lock them in their nominal positions. A more representative thing to do is to raise the test mass 8mm as it will be when there is glass. For now nominal positions is recommended.				

6 Glass prep

6.1 Test mass

6.1.1 Test mass ear bonding

[?? describe ear bonding]

6.2 Penultimate mass

6.2.1 PM ear bonding

[?? describe ear bonding]

6.3 PM prism gluing

[?? describe prism gluing]

6.4 CP

ITM configuration only.

6.4.1 CP prism gluing

[?? describe prism gluing]

6.4.2 CP electrical connections

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

Step	What	Where	Time	People	Tools
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 out to be too much given the narrow clearance between the CP and the structure – it should be more like 2-3 mm.)				tabs
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

6.5 ERM

6.5.1 ERM prism gluing

[?? describe prism gluing]

6.5.2 ERM electrical connections

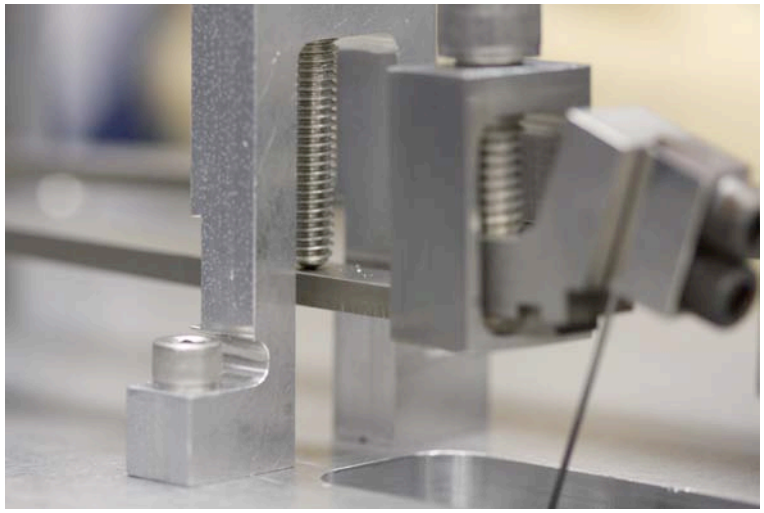
As for CP.

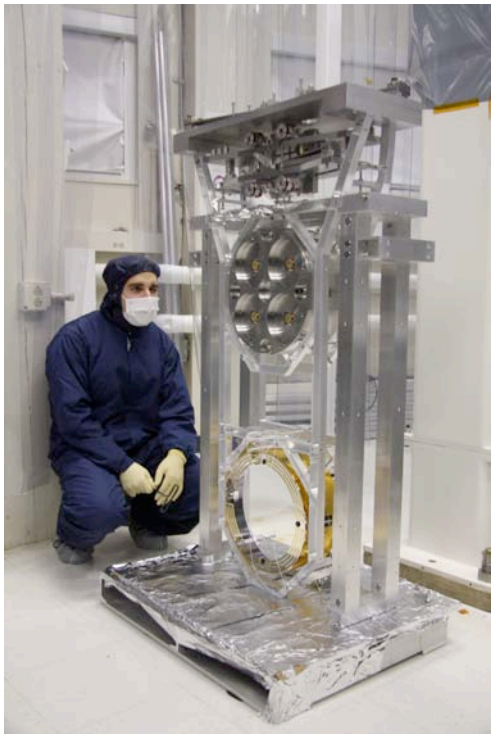
7

7.1 Using the triple-hang tooling

Step	What	Where	Time	People	Tools
36	Assemble the Triple Hang Tooling (D060321) as Class B. This involves making up 2 single wire lengths with Top wire d=1.1mm using the wire clamps provided with the tooling. The wire lengths need to be 160mm between clamps. Use a ruler to set these lengths. Use Spare Middle Blades for this tooling.				
37	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.				
38	Check UIM is level and if not, adjust earthquake stops till it is.		5 min	2	bubble level
39	Retract upper earthquake stops on bottom mass.		5 min	2	hex keys
40	Screw in lifting screws on lower earthquake stops a tiny amount to ease weight on pad spacers.		2 min	2	hex keys
41	Remove pad spacers.		1 min	2	
42	Retract lifting screws on lower earthquake stops until optic is suspended.		5 min	2	hex keys
43	Check that optic is level relative to structure by eye – debug if not.		1 min++	2	
44	Retract upper earthquake stops on PM.		5 min	2	hex keys

Step	What	Where	Time	People	Tools
45	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
46	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
47	Check that PM is level relative to structure by eye – debug if not.		1 min++	2	
48	On reaction chain, remove pitch adjuster, remove cable clamp, refit pitch adjuster.		10 min	2	hex keys
49	Fit wire assemblies from triple-hang tooling to UIM.		5 min	2	hex keys
50	Fit triple-hang tooling spacer blocks to top of lower structure.		5 min	2	hex keys
51	Fit triple-hang tooling top plate to spacer blocks.		5 min	2	hex keys
52	Connect wire assemblies to blades on triple hang tooling.		5 min	2	hex keys
53	Release overload screws on triple-hang tooling.		2 min	2	hex keys
54	Check that all three masses are level relative to structure by eye – debug if not.		1 min++	2	
55	Reapply overload screws on triple-hang tooling until tension is off wire assemblies.		5 min	2	hex keys
56	Disconnect wire assemblies at blades triple-hang tooling.		5 min	2	hex keys
57	Remove triple-hang tooling top plate and spacer blocks.		5 min	2	hex keys
58	Disconnect wire assemblies at UIM.		5 min	2	hex keys
59	On reaction chain, remove pitch adjuster, fit cable clamp, replace pitch adjuster.		10 min	2	hex keys
60	Repeat with other chain.				





7.1.1 Lower structure wrap-up

61 Ensure all 6 masses are in their nominal positions and are secured with stops that are wrench (not finger) tightened.

62 Use the genie to manipulate the two structures so that they are face to face. This may involve moving one or both of them.

63 Bolt two halves of the lower structure together, also bolt the two halves of the lower structure assembly tooling together with the connection plates (4 off)

64 Unlock test and penultimate masses in both chains and verify that the penultimate masses are parallel, and that the test reaction mass is hanging at the correct angle. Also verify that there is no differential yaw in each chain. Correct if required (locking the round masses, releasing the UIM masses and manipulating them is the recommended method).

7.2 3-in-1 assembly

Step	What	Where	Time	People	Tools
65	Lift lower structure and tooling on to the 5 axis table, ensure that is correctly centred, and that the table will go low enough that the lower structure will fit under the upper, bolt down with dog clamps (8 min).				
66	Wheel trolley and lower structure under upper structure on gazebo.				
67	Raise lower structure as far as it will go (~28mm above nominal), so that the legs of the lower structure pushes up against the upper structure, note the lower structure must be correctly orientated, (test mass on test chain side).				
68	Use the slack in the UI wires to connect to them to the top masses. Note that the top masses are in their nominal positions WRT the upper structure and the UI masses are in their nominal position WRT the lower structure. If necessary lower the blades on top mass using the stops in order to allow the wires to be connected.				
69	Let down the Lower structure into its nominal position, (28mm gap)				
70	Insert implementation shim and connect lower and upper structures, 8 bolts.				

7.3 Suspending

In general, the more carefully each assembly and alignment step is done, the easier later steps will become. For example, the more accurately the blade springs were installed during assembly, the easier it will be to balance pitch. The more precisely pitch is balanced on the first time through the alignment procedure, the fewer iterations will be needed to align all OSEMs, ECDs, and ESD.

While making adjustments on the quad make sure to watch out for touching stops and for interferences between the chains at every step. In particular the top masses have tight clearance around the blade spring clamp bolts. These bolts tend to get caught under the top plate of the opposing top mass if pitch and roll are not carefully aligned. There is nothing worse than spending an hour making adjustments only to discover that it was all for naught because a screw you did not see was touching one of the masses.

Remember that the blade springs magnify the tilts of the masses below them because their compliance allows for differential tilt between the masses.

Pitch is likely to cause a lot of trouble if the blade spring alignment within the rectangular masses is off. Pitch specifically is sensitive to errors in the blade assembly because any lateral misalignment of the blade tips away from the center of mass at each stage will generate a torque that will introduce a differential pitch between that stage and the one above it. If this problem is too extreme, it will be impossible to meet all the constraints of the OSEMs and test masses simultaneously, and the springs will need to be repositioned. Each blade tip should have exactly 5 mm of clearance on either side. Intolerable errors are on the order of a few tenths of a mm. More details on the spring positioning are in the procedure below.

Step	What	Where	Time	People	Tools
71	Ensure reaction top mass is horizontal and in its correct position.				
72	Release test reaction mass and then pen re mass, check the blade tips are still at the correct height in the UI reaction mass and then release the UI reaction mass.				
73	Release test mass and then pen test mass, check the blade tips are still at the correct height in the UI test mass and then release the UI test mass. There should now be two triples suspended side by side.				
74	Retract the blade stops in the top reaction mass and check the tip heights are correct.				
75	Retract the blade stops in the top test mass and check the tip heights are correct.				
76	Retract top stage blade stops.				
77	Carefully retract the stops on the top test mass, only retract them a little at a time and watch for pitch at all times. If the suspension appears stable and un-pitched then it is likely the blade tip stops are holding one of the blade tips down.				
78	Refer to Section [?? insert cross-reference] [?? there was no Appendix A in T060040-v1!] on fixing problems.				
79	As Step [?? insert cross-reference] but for the reaction mass.				

7.4 Final assembly

Step	What	Where	Time	People	Tools
80	Balance and align the quad to the point where both chains are at the correct height and are correctly pitched, and yawed. Note; alignment of the OSEMs will effect the pitch.				
81	Add the front and back plates to the tablecloth omitting the ECD and OSEM mounts.				
82	[?? Do we try putting on the sleeve? It probably has to come off again for storage.] Add sleeve.				

8 Storage

[?? work out how to get suspension into box and describe here]

9 Tools

Ian's list

Test stand:	Mechanical Test Stand mounted with Solid Stack Assembly
Manual fork truck:	Similar to Caltech Genie
Bench:	May be an optics bench but this is not mandatory
Tools:	All the appropriate hand tools and measuring devices
Masses:	These will be necessary to load blades flat.
Lower structure assembly tooling	
Wire jig	

Brett's list

$\frac{9}{32}$ inch nut driver or wrench for axial OSEM positioning.

$\frac{7}{16}$ inch nut driver or wrench for lateral OSEM positioning.

$\frac{9}{64}$, $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ inch allen wrenches.

A flat head screw driver for turning the top mass pitch adjusters.

Torque wrench for the blade clamp bolts capable of 400 in-lb (33 ft-lbs, 45 Nm).

Slip or block gauges for measuring 5 mm, 6.6 mm, and 12 mm gaps.

Dentist Mirror.

Flashlight or small lamp.

Structure pushers for rotating the structure on the optical table (see Figure 14).

5 axis table for safety while rotating the structure.

Lower structure tooling for use with the 5 axis table.

Safety goggles for working around the wires.

An optical alignment tool with 10 μ Rad accuracy, such as an autocollimator.

A small, light, reliable level to place on suspended masses (optional).

10 Useful procedures

10.1 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		30 min	2	

Step	What	Where	Time	People	Tools
	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.				
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	
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		1 min	1	

Step	What	Where	Time	People	Tools
	halfway between the initial and final positions.				
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	
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	

10.2 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	

END OF MAIN PROCEDURE

STUFF PAST HERE IS RAW MATERIAL FROM OTHER DOCUMENTS WHICH WILL GRADUALLY BE INTEGRATED ABOVE

11 Stuff from T080165-00 (Brett's balancing procedure) for plagiarizing

1 Related Documents

Numbers cited throughout this document refer to these documents.

1. Noise prototype Assembly procedure - T060040-05

URL:

http://www.eng-external.rl.ac.uk/advligo/Reviews/FRR/Documents/t060040-06.doc

Description:

This is the assembly procedure from RAL which should at this point be completed before balancing and alignment is to begin.

2. Quad Suspension Balancing and Alignment Procedure (UK Document)

URL:

http://www.eng-external.rl.ac.uk/advligo/Reviews/FRR/Documents/Quad suspension Balancing and Alignment procedure.doc

Description:

This document is the precursor to this updated procedure. It is a valuable reference since it contains additional details on how all the adjustments work and ideas on how to trouble shoot. This update should be considered a continuation, not a replacement.

3. Useful Data for Noise Prototype Quad Assembly (UK Document)

URL:

http://www.eng-external.rl.ac.uk/advligo/documents/Useful data for Noise Prototype Quad assembly.pdf

Description:

This document contains useful information about basic aspects of the quad such as weights, wire lengths and diameters, a description of how the blade tip positions are determined, and suspension stability.

4. Alignment Requirements for Quad - T080128-00-K

Description:

All the final alignment requirements for the quad are listed here.

5. AdvLIGO Quad Suspension Controls Prototype Suspension and Adjustment Method - T060039-00

Description:

This is the assembly and alignment procedure written for the quad controls prototype. Although the controls prototype clearly has some differences, many of the principles of aligning a quad are the same. As a result, this document is still a valuable reference of experience gained during the prototyping phases of the quad.

6. Holo-Krome Bolt Torque Data Sheet

URL:

http://www.holo-krome.com/pdf/techbk34-40.pdf

Description: This data sheet provides recommended bolt torque values from Holo-Krome.

7. Quad Pendulum Structure Pushers - T080230-00-0

Description:

This document provides additional detail on the use of the quad pendulum structure pushers used to align the quad structure on the seismic table.

12 Stuff from T0900055 (MB's LASTI rehang procedure) for plagiarizing

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	in, near BSC	1 day	4	5AT, conveyor

Step	What	Where	Time	People	Tools
	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.				
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

Step	What	Where	Time	People	Tools
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	
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

Step	What	Where	Time	People	Tools
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
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 10.2), 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

Step	What	Where	Time	People	Tools
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
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 **Error! Reference source not found.**. (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	assembly area	5 min	4	ergo-arm

Step	What	Where	Time	People	Tools
	later step it will fit into the corner of the octagon of struts defining the CP's position in the structure).				
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
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

Step	What	Where	Time	People	Tools
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 additional insertion is required, it will tend to become possible at this stage – alternate small downward and inward steps as appropriate.	assembly area	1 min	4	ergo-arm
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	assembly area	30 min	4	¼” spacers

Step	What	Where	Time	People	Tools
	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.]				
74	Check reaction chain for balance per Section 7.1.	assembly area	45 min	2	triple-hang tooling, hex keys
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	assembly area	20 min	2	ring heater, bolts, hex-keys

Step	What	Where	Time	People	Tools
	possible gap in the centre).				
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. Position wire loops around TM as it passes through. (Joe says: could try tilting to put prisms at 6 and 12 o'clock.)	assembly area	10 min	4	ergo-arm
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 7.1.	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

Step	What	Where	Time	People	Tools
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
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	near BSC	5 min	2+1	

Step	What	Where	Time	People	Tools
	table DOFs as necessary to achieve a good mate.				
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
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	in BSC	10 min	2+1	hex keys

Step	What	Where	Time	People	Tools
	the glass rod to a tighter radius!) and tighten that set screw.				
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
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 12.2.	in BSC	20 min	2+1	foil, lens tissue, methanol

12.1 Applying/removing First Contact

12.1.1 Applying

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

12.1.2 Removing

Step	What	Where	Time	People	Tools

Step	What	Where	Time	People	Tools
83	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
84	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
85	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	
86	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

12.2 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