LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T050010-00-K *Advanced LIGO* 28th January 2005

Monolithic suspension workshop (Glasgow January 2005): Minutes & Actions

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Distribution of this document:
LIGO Science Collaboration

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Monolithic Suspension Workshop

Agenda v.8

VENUE: IGR, University of Glasgow (Room 253)
DATE: Mon 24th to Fri 28th January 2005
ATTENDEES:

	24th	25th	26th	27th	28th
Armandula, Helena (CIT)	•	•	•	•	•
Aston, Stuart (BHAM)					•
Cantley, Caroline (IGR) (CHAIR)	•	•	•	•	•
Cagnoli, Geppo (IGR)	•	•	•	•	•
Crooks, David (IGR)	•	•	•		
Greenhalgh, Justin (RAL)	•	•	•	•	
Hayler, Tim (RAL)	• pm	•	•	•	
Heptonstall, Alastair (IGR)	•	•	•		
Hough, Jim (IGR)	•	•	•		
Jones, Russell (IGR)	•	•	•	•	•
Martin, Iain (IGR)	•	•	•		
Perreur-Lloyd, Mike (IGR)	•	•	•	•	•
Plissi, Mike	•	•	•	•	•
Robertson, Norna (SU)	•	•	•	•	•
Romie, Janeen (CIT)	•	•	•	•	•
Rowan, Sheila (IGR)	•	•	•		
Torrie, Calum (CIT)	•	•	•	•	• am
Strain, Ken (IGR)	•	•	•	•	•
Wilmut, Ian (RAL)		• pm	•		

Dennis Coyne and Mark Barton will participate by phone +44 141 330 2959
Eoin Elliffe also came along for one session.

Mon 24th Jan — **DESIGN STATUS UPDATE**

9:00 – 12:30 Overview of agenda & workshop objectives (CAC)
Review of GEO assembly & installation: lessons learned (GC)
Lessons learned from quad mock-up Caltech 04 (CT/ALL)
12:30 – 13:30 Lunch
13:30 – 16:00 Status of current installation jig/mass catcher design - functionality (RAJ)
Status of installation jig/mass catcher design: dynamic requirements (RAJ)
16:00 – 17:00 Weekly Design Meeting (ALL)

Tues 25th Jan — **REQUIREMENTS DISCUSSIONS + LAB (switchroom) SESSIONS**

9:00 – 12:30 Round-table discussions on requirements: design, assembly, installation & repair (ALL)
12:30 – 13:30 Lunch
13:30 – 17:00 CO_2 fibre pulling demo (DC)
Monolithic suspension assembly & installation: mock-up in lab (RAJ)
Interface with CO_2 pulling & welding machine (CAC/DC/RAJ)
17:00 – 18:00 Call Dennis at 5pm

Wed 26th Jan — **REVIEW OF ASSEMBLY & INSTALLATION PROCEDURES**

9:00 – 12:30 Short discussion sessions
Ear bonding procedure (HA/SR)
Ribbon welding procedure (GC/CAC/DC)
Detailed review of assembly & installation requirements (ALL)
12:30 – 13:30 Lunch
13:30– 17:00 Bonding. Alignment of ears. Blades.
17:00 - 18:00 DCC telecon (Justin)
18:00 – 19:00 Blade committee - acceptable stress levels (RAL)
Dinner – venue ICHIBAN (bottom of Byres Road – turn right)

Thurs 27th Jan — **MECHANICAL DESIGN SESSION**

9:00 – 11:00 Revision of notes
11:00 – 12:00 Authorship discussion (in common room or alternative venue) (ALL)
Discussion on attendance at March LSC Meeting (ALL)
12:00 – 13:00 Lunch
13:00 – 15;30 Review action list and assign names/dates (ALL)
15;30 – 17:00 Controls/Noise prototype status review (CIT/RAL)

Fri 28th Jan	**CONTINUED DISCUSSIONS – t.b.d.**
9:00 – 12:30	OSEMs update (SMA)
12:00 – 13:00	Lunch
13:00 – 17:00	tbd
17:00 – 18:00	Optics Telecon

Workshop Objectives

Round table discussion and lab sessions to cover Design, Assembly and Installation requirements for monolithic suspensions.
Overview of our current thinking and review to provide the optimised approach for design, assembly and installation – take on board repair requirements.
All of the points below should be covered but agenda should remain flexible

1. Design
    - A. Specifications / requirements
    - B. Optics / Penultimates
        - i. Flats
        - ii. Optic material
            - a. Silica now chosen – implications on design
            - b. Clocking requirements?
        - iii. Ears
            - a. Weld type - overlap or H-piece?
        - iv. Ribbons
        - v. Mass catcher/assembly jig
        - vi. Repair approaches
2. Assembly
    - A. Bonding of ears
    - B. Handling of optic & penultimate mass
        - i. Ergonomic arm
    - C. Interface with CO_2 machine for welding - functionality
3. Installation
    - A. Mass catcher/assembly jig
    - B. Interface with upper structure

Discussions / Lab Sessions

1. Lessons Learned
    - A. GEO 600
        - i. Good & bad points
        - ii. Additional challenges for Advanced LIGO
    - B. Quad initial mock-up in Caltech Dec 04
    - C. Quad assembly in Caltech Feb 05 (to be incorporated in future)
2. Review of current mass catcher/assembly jig design
    - A. Overview
    - B. Lab session
    - C. Discussion
3. Review of current CO_2 pulling & welding machine design
    - A. Overview
    - B. Lab demonstration
    - C. Discussion
4. Assembly procedure
5. Installation procedure

MONOLITHIC SUSPENSION WORKSHOP
GLASGOW January 2005

DAY 1 (Monday 24th January)

(1) Lessons learned from assembly at Caltech
(notes by Justin)

- Gazebo was not tall enough – is now being raised by 2 feet to be at the same height from he floor as the optics table in the BSC tank in the LVEA
- Large cutout in bottom of v-block essential to allow the wires to be aligned in the grooves in the PU mass.
- Also need something to hold the clamp-wire-clamp loop in place while the PU mass is fitted to the assembly
- To raise UI mass it's easier to pull from above than push from below (more space for the jack)
- For the controls prototype, no fibre stretching issue (but only if we use rather meaty wires – modulus difference is just 70 versus 200 Gpa).
- Subtle difference between controls and noise: For FIBRES: Nominal separation is 602, stretch is 8mm. So need to raise TM to 594 to weld fibres to allow for stretch. For WIRES: Nominal separation is 602, stretch is 2mm. So need to raise to 600 BUT need some slack in wires to fix them so in fact need to raise to ~595.
- This stretching could be done later in the assembly process by lowering the entire structure hence lowering both v-blocks – but this would leave the PU mass with a 8mm bigger gap to its v-block than the TM.
- LIGO is open to suggestions for modifications to LIGO-I style earthquake stops. e.g. use the smooth surfaces on the structure (the "v-blocks").
- The only job of the cams is to protect the welded fibres – not needed in CP and we have decided not to provide them on CP. Some sort of simple lockdown will need to be provided for the CP.
- At some stage we will have all the stages in place but with little or no tension in the wires/fibres. What next? (i.e. in what sequence so we introduce tension in the wires/fibres? And when do you take the protective cover off the optics?) Especially beware debris from adjustment screws falling onto optics. Russell and Mike have been thinking about this – it all links into the "implementation ring", and especially how much adjustment that allows. One of the lessons from GEO was that placing reliance on the idea of overloading the upper springs to pull the wires down and allow them to be attached, did not work out.
- Platform needed for any work above test masses
- LIGO-1 style tools in/out is needed!
- There will be a bracing structure to reinforce the quad structure in case the whole needs to be supported from below as seems almost certain during installation. The lower part of the structure as currently envisaged will not be strong enough.
- CHECK with Dennis – is there space around the footprint for the clamps? Is there space to add a ledge for clamping?

(2) Lessons learned from GEO assembly.
(Notes by Justin)

- See also Geppo's three slides (covered by bullets below).
- Good points about silica fibres
  - Can be melted many times
  - Fibres are very strong
  - Ageing not a problem at 300 MPa (i.e. fibres may be stored a few days (up to two weeks, not kept in a particularly special environment) between manufacture and installation). The thing to avoid is dust, which might be attracted by static, so maybe better to store in dry N2. Helena envisages ionising bars. Beware UV from ionising bars causing flaws – OK with non-UV ionising bars. But BEST is to pull then install. See comments below about moisture.
  - Creep negligible (in terms of change in length)
  - Not sure what has happened about measuring noise from creep. (Norna: a new paper out under LSC review: things look OK.)
  - Welding works well and allows repositioning.
  - What could we use for a baffle that would not "give off" contaminants?
- Bad points about silica fibres
  - Untouchable – scratches, moisture (does this imply that fibres must be stored in a dry environment? – GEO experience is that this was not an issue).
    - No knowledge about the relationship between minor touches and effect on strength e.g. if I brush a piece of thread against the fibre will that reduce the strength by 20%? Nobody knows.
    - It is known that moisture and load together are a problem – the moisture attacks the cracks. Even moisture then load is not a problem unless there is water on the surface when you load it.
  - Repeatability of manufacturing was low. Better results using the Caltech lathe. Existing Caltech lathe-type fibres would not be suitable for GEO-type welding due to profile near ends – thought to be solvable.
  - Profile from GEO manufacturing technique was not ideal
    - We WILL (CAC) fix profile and repeatability with the laser machine.
  - Need to do annealing after welding to get full strength (plan to do this with the laser)
    - Needs a programme of tests to establish what annealing is needed/works.
  - Fibres (with pegs or H-pieces) should be ready annealed before you start to weld. This is a very important point. 1200C in a furnace. NB needs to be costed as part of ?UK project – scope issue. Estimated cost magnitude is a few $k – say $10k to allow for furnace plus special silica box. Maybe combine with blade furnaces.
    - Fibre annealing – essential. Post-weld annealing preferable.
    - Proposed sequence:
      1. Make fibre.
      2. Weld pegs.
      3. Anneal 1200C in argon (use silica box in furnace) for 2-3 days altogether including warm-up and cool down.

(Geppo can give details). Alistair has done this at Glasgow in a chamber nearly big enough for the fibres.
4. Each fibre tested for frequency under load.
5. Each fibre tested for "bending length" (i.e. flexure points will be found). (NOTE this will require a decision to be made on the extent to which the bending lengths need to be matched).
6. Currently damping e.g. by Teflon not envisaged
7. Can store (needs checked)
8. May handle pegs
9. Welding pegs to ears
10. Maybe, snap off handling piece
11. If possible (if known to be needed) post-weld anneal with laser e.g. 1200 for 5 minutes?
12. Note Russell has a process document for this Txxxxxx.

    - Both annealing steps needs research programme!

  - Contamination from "white smoke" – needs extract system.
  - Heat sink needed for gas welding. OK for laser welding but maybe not for annealing – need to check and if it's a problem solve it. This was done with a wet tissue on GEO; no apparent problems with ear bonds with this measure in place.
    - Helena has experience of bonds that have been to high temperature and seem OK.
    - Need to make tests of bonds with various degrees of heat sinking – especially during annealing.
  - Inaccurate positioning.
  - Procedure too "manual"
    - too much room for error.
    - too reliant on individuals; even with the same person and standard procedures there are still unpredictable features.
    - It would be essential to have reference marks on the flats – check this is in the specs for the optics.
- Related topics
  - Catcher –
    - the more room the better!
    - Must design weld so that the laser will not need to come at the ears "from behind" i.e. from test mass side. This is in the catcher spec. Other access issues, e.g. presence of nose, need to be borne in mind.
    - Footprint of lower structure is only 440mm compared with mass of 340mm wide – gives just 50mm each side (plus sagitta of flats less ears sticking out).
    - We now have the wire loops between the welds – the nose will limit access for the laser to the PU mass.
    - Needs micrometric movements to allow the TM to be put at the correct orientation. Maybe some of this functionality is provided by the ergo arm.
    - How do we define the requirement for the orientation of the mass WRT the catcher?
      - One flat must be vertical
      - There must also be correct location along two axes.

        - Maybe can rely on the horns of the ears to give us these dimensions.
        - No requirement to "clock" for crystal axes because we are using silica. (Need to preserve the POSSIBILITY of doing this should we switch back to sapphire).
  - Load test
    - The idea is to load the fibres after welding, without loading the UIM-PU wires. This would require EITHER lower the TM OR raise PU and UIM together.
  - Stress relief
    - Was done on GEO with the fibres under low tension, outside the tank. Then the fibres were put under full tension for a test. Then the tension was reduced for installation.
      - This step may not be needed for ALIGO because (a) lots of stretch gives more tolerance in length (b) hopefully our procedure will be more repeatable than GEOs.
      - Note on point (a): the greater stretch means that you have more tolerance for getting the same TENSION in all four fibres. But it does not help in the problem of getting the pitch right.
      - We discussed the issue of pitch errors in the monolithic suspension last year – what was the outcome?
      - A spec is needed to the requirement of matching the pitch of the TM to that of the PU – it is tied in to the maximum allowable pitch of the PU (for clearance) so is essentially an internal SUS problem.
      - In short – it looks likely that the stress relief step **will be** needed for ALIGO. The increase in length during this step needs to be quantified and allowed for.
    - If you load the fibres a little before doing the annealing, you kill two birds with one stone.
  - Transport – experience was that the fibres did not get damaged as the monolithic assembly was manoeuvred into place in the mass catcher. Implication is that with reasonably careful design and handling there should not be a problem with damaging the fibres during transportation. NB ALIGO fibres are longer and thinner than GEO.
  - MOST IMPORTANT – GEO was installed with too little testing.
    - Tests to include:
      - Bond strength testing at different temperatures and after different thermal cycling regimes
      - Check strength of fibres/ribbons, including welds
      - Check effect of weld annealing on bond strength
      - Check effect of fibre annealing on strength of fibre-to-peg weld
      - Check effect of weld annealing on weld strength. What is the best annealing regime? Is it repeatable?

- WHO is making the fibres for the mode cleaners? (Currently US but is this sensible?)

(3) Status of installation jig/mass catcher design: Dynamic Requirements (Notes by Caroline)

- Structure goals: (ref: Dennis' quad interface issues document T050005-01)
  - 1st concept (default) – upper structure attached directly to lower structure: ~100Hz for whole structure (including non-suspended mass) – difficult to model due to number of elements required
    - This is the default all the effort has to be put into this structure
    - Don't forget to add in effect of the ring heater (2 kg + mass of structure to hold ring heater and shield, say total of~ 3 kg? t.b.c.)
    - We require drawings of ring heaters to see what they look like.
  - 2nd concept – lower structure mounted off the support tubes: ~200Hz for upper structure and > 100Hz for lower structure mounted off support tubes (does this include the structure for attaching the lower structure to the support tubes? To be confirmed).
    - Have already achieved 200Hz for upper structure and > 100Hz on lower structure.
  - So we have achieved what we don't really need and have yet to achieve what we really need.
- FEA modelling problems for whole structure - error in file – running out of disk space – RAL checking this out
  - ANSYS research & ALGOR – not enough nodes in ANSYS – falls over in ALGOR
  - RAL problem ANSYS – falling over
  - To be resolved – trying to get trial period on commercial licence (with more nodes) – not possible.
  - We are in the process of simplifying the mesh
  - We will further investigate the problem with running the model
    - RAJ/CIT/TH to get together to remove lumps of material etc from the model to remove interface problems between solid areas and shells
  - We need to concentrate our efforts on Concept 1
  - Once fixed we need to pass the full model to Dennis to incorporate in his system model to get transfer functions
  - We need feedback from tests at Stanford on interaction betweens SEI and SUS structure and whether control system can cope with <100Hz first mode– need to supply Stanford with a full structure – use upper part as currently designed and provide a simplified lower structure.
- Have taken infinitely rigid clamping at top of lower structure and have tried to consecutively stiffen the structure to shift the frequency upwards. So far have achieved 140 Hz but this is with unrealistic boundary conditions. However the trend is in the correct direction.
- Caltech FE modal model validation tests – check upper structure, lower structure, combined structure on 80 ton milling machine. Use clamping arrangement representative of final installation. CAC to assist. April 05?
- Have already validated (up to a point) the dog-clamp boundary conditions using impact tests at Caltech
- It may be acceptable for low modal-mass resonance to be satisfactory (does not transfer up to platform).
- So far we haven't approached exotic materials and all the above analysis has been carried out using aluminium.

- Whole aluminium structure – has this been checked with respect to out-gassing requirements – particular grade of aluminium is important. 6061- T6 is the acceptable aluminium to use. The T6 is the work hardening state.
- Report on Stanford tests – use LIGO I structure as test bed – 50 kg mass. Caltech will send this to Stanford for initial testing.

4. Status of installation jig/mass catcher design: Functionality
(Notes by Caroline)
Ref: Russell's presentation slides.

- Current status of mass catcher/installation jig design
    - Two catchers back-to-back separated by 5 mm (attached to each other at discrete points).
    - Faceplate is machined from a solid sheet that forms the front of the structure (plus one at back).
    - Integrated gussets on plane of faceplate will be joined diagonally by removable cross-braces
    - Cross-members (6 off) will be welded in at selected positions to join front and rear faceplates.
    - Recessed plates (4 off) will be welded between the v-block angled struts (2 off) to enable a removable bearing pad to be slipped in between the mass and the support plates on the v-blocks.
    - Removable bearing surface can be slipped out and can be replaced with a shim that is stepped to act as earthquake stop.
    - Facing from the front, the rear of front faceplate in line with front surface of mirror.
    - Facing from the front, the rear of back faceplate in line with rear surface of mirror.
    - Ear is not symmetrical to the centre line of the catcher, from the side.
    - Gussets could be used to mount earthquake stops.
    - Penultimate mass: Teflon-like fingers to act as references for flats. Potential in controls prototype to use these as actuators to provide torque for initial "clocking" of mass prior to suspension. Reservations due to friction on Teflon bearing pads underneath. For noise prototype use ergonomic arm for "clocking" and fingers purely for reference.
    - Penultimate mass ergo plate will be smaller than face of mass to enable flats to be seen even when face covered.
    - Repeat for test mass.
    - Test mass protective cover plates will be smaller than face of mass to enable flats to be seen even when face covered.
    - Ergo arm should pick up test mass on (anti-reflection) rear side and penultimate mass will be handled in the same way.
    - Ergo arm should pick up reaction mass from non-gold coated side
    - Footprint of mass catcher/assembly jig:
        - Silica test mass thicker than sapphire (ETM sapphire 314 x 130 mm: ETM silica 340 x 200 mm)
        - Want to review mass budget to see if size can be increased bearing in mind new modal frequency
        - For welding access the worst case scenario is current design for sapphire with slim line mass catcher – we should continue to design CO_2 welding machine with this design – consider use of mirrors.

    - Ear bond area of 4.2cm^2 was calculated for sapphire/silica bond. We need to check whether the bond area can be increased significantly. With thicker silica mass we are further away from the coating so it will come down due to this (plus also will be same materials).
    - All calculations and associated documentation should be updated to reflect silica downselect. Requirements Review March 15th. SUS DRD; Universal DRD; IDC; Mechanical Drawing Guidelines; Generic Requirements Document. SUS notes Jan 18th gives details.
    - Some sort of removable toggled press is applied to the top of each of the test and penultimate masses to clamp them into place. Could be in-situ from the start.
    - Note that Upper-Intermediate mass is in place from the start (3 & 1 assembly)
    - Numbers of earthquake stops needs to be determined. Twelve were used for LIGO I for big optic. Lessons learned – refer to documents E021000-05 (LIGO I) & E040457-00 (AdvLIGO). Contact with chamfer is problematic.
        - In ideal world we would like of the order of twelve point stops per mass – or fewer line stops
        - Function is to stop mass swinging and to be used to cage the mass but not to raise and lower it (refer to docs above)
        - Speak to COC (Garilynn cc to Bill) to see if we can have stops on front face at top and bottom in area not occupied by flats – particularly crucial for the beamsplitter.
        - Need to avoid beam
        - 45-degree earthquake stops (fingers)?
        - Continuity testing to check that stops don't touch metal masses? Potentially conflicts with electrostatic build-up.
        - Clashes with ring-heater etc.?

DESIGN MEETING (24th January 2005)

- Item (1) – have covered this already during today's meeting (overall structure, ANSYS, ALGOR, alternatives).
- Item (2) - Upper structure, clamping at corners, will try both (1) and (2) - (1) lip round edge of top of structure or using I –beam (2) dog clamps.
    - Want to clamp as close to corners as you can – experience has shown this and this makes sense as this is where the vertical members are (controlling the lowest cantilever mode). The mid-span supports on the top ring are less effective at acting on these.
    - Top blades attach to the top ring that attaches to the top structure.
    - Upper structure – first resonance ~ 200 Hz. Clamping is critical in affecting this frequency.
    - Need to check that footprint at the top can be expanded to enable a lip to be used rather than slots in the upper ring.
    - Cold welding will be reduced using oversized threads
- Item (3) - Mike Gerfen, Larry Jones and Calum Torrie – study on galling and particles produced
    - Our concerns with respect to galling are the blade clamps and wire clamps
    - Silver plated & regular stainless steel screws okay (from one reliable supplier) – passed the test on the above

  - Where have need for removability and replacement use steel alloy (Nitronic 60) – passed the test on the above
  - Verify whether any further strength testing is required – oversized versus regular.
  - Reference document T040111-00 (nice pictures of dust particles produced).
  - Quality of threaded holes - trade fluid contamination for galling contamination?
  - For aluminium use water based taps
  - For wire clamps and blade clamps that are steel we need to find out if we can use rapid-tap?
  - Look for cleaner fluid than rapid-tap as a compromise?
  - Who will take this forward with the vacuum review board? First find out what rapid-tap is made of? It doesn't have silicon in it - a good start.
- Item (4) – visits to Caltech and link-in with delivery times
  - MPL coming on Sunday to build upper-intermediate mass
  - Upper structure will be ready by 21st Feb
  - Ian shouldn't come until the start of March (to coincide with tooling being ready)
  - Tim to arrive 14th March
  - Russell to follow MPL to aid with pre-assembly

List of questions for D. Coyne

1. Holes?
   Is the idea of multiple holes in the vertical members of the upper structure for cleaning access acceptable?
2. Footprint?
   Is it acceptable to add a lip outside our footprint where the upper structure meets the seismic table? This lip would be approx ¾ " wide and would allow clamping with dog clamps.
   What space has been allowed outside our footprint on the seismic table for our dog clamps? Comment – with the holes on a 2" pitch the dog clamps should be at least 4" long to work. Can we change pitch of holes on seismic table? Comment – if there is no space for 4" dog clamps can we make the hole pitch smaller?
3. Oven?
   We have a requirement for annealing of the ribbons with the end pins attached at 1200C in an argon environment. We will construct a silica box to provide the argon environment. Estimated cost of oven plus box $10k. One will be required at each site. Can this be covered by your funds for Larry's vacuum bake oven?
4. There was one other issue but we seem to be unable to identify what it was – if anything springs to your mind based on the above please let us know!

DAY 2 (Tuesday 25th January)

(1) Dennis email comments and responses from yesterday' session

> Caroline, et. al.,
>
> Comments:

1) I strongly suggest the use of threaded inserts of Armco Nitronic-60 (N60) material, an Austenitic Cr-Ni-Mn stainless designed to resist galling and particulate generation. See the report here (16MB): http://www.ligo.caltech.edu/~coyne/misc/T040111-00.pdf.
Reading further on in the report, I see that this is already endorsed for removable threaded fasteners -- good.
[OUR CONCLUSION – consider application when choosing]

2) Under "2, Fibers", the following question is raised: "What could we use for a baffle that would not "give off" contaminants?
Is this a temporary absorptive optical baffle for the CO2 laser irradiation (10 micron wavelength) during welding?
[OUR RESPONSE – yes understood correctly]

3) FEA modelling problems for whole structure - error in file – running out of disk space
Try using plate/shell and beam elements instead of solid elements.
Takes longer to develop but computationally more efficient.

4) Whole aluminium structure – has this been checked with respect to out-gassing requirements – particular grade of aluminium is important. 6061- T6 is the acceptable aluminium to use. The T6 is the work hardening state.
Particular grade of aluminum is likely not important for outgassing IMO. 6061 was chosen because it is common in the aerospace industry and readily available, works well, welds OK. Alternatives are OK. The temper may be important for minimizing galling (if inserts are not used).

5) For wire clamps and blade clamps that are steel we need to find out if we can use rapid-tap?
Look for cleaner fluid than rapid-tap as a compromise?
Who will take this forward with the vacuum review board? First find out what rapid-tap is made of? It doesn't have silicon in it - a good start.

Relton's Rapid Tap:
http://www.relton.com/pdf/nrtmsds.pdf
includes mineral oil and so is not water soluble (only water miscible). So, this is not preferred. The reality is that we have undoubtedly cleaned parts machined with Rapid Tap (and similar) metal working fluids and managed to clean them to initial LIGO UHV standards. So if there are *strong* reasons to use it, it can be discussed further.
Alternative steel and stainless steel grinding and cutting fluids which are water soluble and free of sulphur, chlorine and silicones include a number of Cimtech fluids:

http://www.cimcool.com/cgi-bin/merchant2/merchant.mv?Screen=CTGY&Store_Code=M&Category_Code=CIMT
For example,
Cimtech 100 for Blanchard grinding
http://www.cimcool.com/cgi-bin/merchant2/pdf/ct100.pdf
Cimtech 190 for light to moderate machining and grinding of ferrous metals http://www.cimcool.com/cgi-bin/merchant2/pdf/ct190.pdf

Answers to questions:

1. Holes? Is the idea of multiple holes in the vertical members of the upper structure for cleaning access acceptable?

Yes. (see additional comments in separate email to Calum regarding the draft structure design assembly drawing.)

2) Footprint? is there space around the footprint for the clamps? Is there space to add a ledge for clamping?
Is it acceptable to add a lip outside our footprint where the upper structure meets the seismic table? This lip would be approx ¾ " wide and would allow clamping with dog clamps.

What space has been allowed outside our footprint on the seismic table for our dog clamps? Comment – with the holes on a 2" pitch the dog clamps should be at least 4" long to work. Can we change pitch of holes on seismic table? Comment – if there is no space for 4" dog clamps can we make the hole pitch smaller?

Well, by definition, I guess there has to be space allowed for the clamps ... that is, we do have to attach it to the optics table. But there does not appear to be sufficient room for the adjacent pick-off mirror structure (for which no design exists as yet). A 3/4" wide lip is "in the noise" with respect to the precision of the layout and dimensional information, so yes, this is OK. A 4" wide strip of real estate added around the entire periphery will not fit (in general). The hole pitch on the optic table can of course be increased with $. If we do it selectively then less $. I'd have to do some investigating to find out how much, but it isn't cheap to uniformly decrease the pitch from 2 to 1 inch, say.

Can you mount the clamps to the interior of the structure? Can you incorporate an adjustable breadboard plate which can mate to the optics table holes and provide a finer pitch of holes for attaching the SUS structure (or is this a 'crazy' duplication of the optics table function)?

3) WHO is making the fibres for the mode cleaners? (Currently US but is this sensible?)
Actually, I think the US is making the fibers for all suspensions. The UK is making & delivering the tooling & procedures to make the fibers for the quads. So I think a more appropriate question is "is it

sensible for the US to develop the tooling and procedures for the MC suspensions?" or " Is there sufficient time for the US to develop the procedures with the UK delivered tooling to make MC fibers after the UK has transferred the technology to the US?" The answer to the first question is "no" IMO. I don't know the answer to the 2nd question.

4) > 100Hz for lower structure mounted off support tubes (does this include the structure for attaching the lower structure to the support tubes? To be confirmed).
Confirmed: with the yet-to-be-defined, attaching structure. The lower structure by itself (with a simple support constraint at the attachment interface) should have a first resonance of > 100 Hz of course.

5) Oven? We have a requirement for annealing of the ribbons with the end pins attached at 1200C in an argon environment. We will construct a silica box to provide the argon environment. Estimated cost of oven plus box $10k. One will be required at each site. Can this be covered by your funds for Larry's vacuum bake oven?

No. There are no authorized funds for a new UHV bake oven. While the vacuum review board liked the design of the proposed large, higher and more uniform temperature oven, for vacuum baking parts, they felt that: 1) The requirements for hydrocarbon outgassing were set too conservatively and 2) the size of the chamber may not have been set at the optimum point. Given that we have other methods for the preparation of large in-vacuum components (air baking and FTIR testing) to use in the preparation of suspension and seismic system prototypes, the VRB recommends that the designers reconsider the requirements and that the project not invest in the proposed vacuum bake oven at this time.
"Larry's vacuum bake oven" has been cancelled.

Can other funds be allocated by the Lab? Perhaps. I will send this request along to be incorporated into a list that David Shoemaker is collecting for a discussion next week.

Dennis

(2) Repair Scenarios (Notes by Caroline)

- Ribbon breaks (or multiple)
    - Assess damage
    - Damage or removal of magnets?
    - GEO lesson learned – fibres snap in pairs at least
    - Disconnect upper intermediate from the top mass.
    - Do we remove both test and reaction chains or just test mass chain?
    - Implementation ring is in two halves
    - Can we repair weld in-situ?
    - Hand-held focussing device for manual laser weld repair?
        - Consider contamination from silica oxide?
        - Would need a 100 W laser for welding
        - What is power handling of fibre optic for CO2 radiation?

- Reverse the 3 & 1 assembly
    - Get tooling in – height adjustable tables
- Geppo's suggestion
    - Catchers are too narrow
    - Imagine using one structure 400 mm wide for two masses
    - Have bars to support the weight of the two masses
    - No vertical centre members – this provides much better access
- Russell's current pair of structures can have removable cross members on the sides

(3) Further discussions on mass catcher/assembly jig and its interface to CO2 welding machine (Notes by Caroline)

- Can take the existing design with separate test and reaction chains and remove sections of the vertical members in the region of the ears to improve welding access. Can provide additional external support whilst the welding takes place. The removable sections can then be replaced.
- Current design is for sapphire. Now that silica has been down-selected then the width of the whole structure will increase. Centre moves approximately 2cm outwards and the outer edge moves about 4cm outwards. So for silica the access will be greatly improved.
- When welding the ribbons to the horns on the penultimate mass the nose for break-offs of the wire loops will restrict the angle for welding on the inner surfaces.
- Should we modify the controls prototype lower structure? Plan - have a quick stab at changing the design (look at modal frequency and implementation of the new lower structure, mass increases etc) - review at this stage to see if we should use this for controls prototype.
- Various design options for earthquake stops being considered ranging from 12 to 16 points to 3 lines contacts to area contacts at top and bottom of mass. Using the flats for earthquake stops is also being considered. Note that the barrel of the optic may be several degrees out of parallel with the beam axis.
- Need to pay attention to OSEMs and magnets and flags especially for penultimate mass – ACTION: discuss with Stuart Aston on Friday a.m. meeting.

(4) CO2 laser demo (Notes by Caroline)

- Welding jig – head that moves – short beam paths desirable – beam dump required – extraction system required – consider very small system that works close into the ear. Factor of x (something big) more difficult to achieve. Two mirrors at 22 degrees. 2mm diameter pegs will be used for both fibres and ribbons. ACTION – CO2 team to investigate whether this is viable/feasible approach.

(5) Effect of silica downselect on allowable ear bond area (Notes by Caroline)

- Bigger mismatch between Young's Modulus silica/sapphire – less energy goes into bond/ears
- Bond has more significance for silica/silica – it is possible that allowable bond size is smaller with silica/silica
- Eoin's FE analysis results will be reviewed quite soon.
- The design levels for thermal noise in the mirrors needs to be reviewed and redefined. ACTION: Raise with Dennis in telecon tonight.

(6) Telecon with Dennis at 17:00hrs (Notes by Caroline)

- Structure infringement of footprint due to removable diagonal sections – we will try reversing these making some cut-outs for the OSEMs.
- Hole pitch – if we went by 2 x 2 to 1 x 1 cost goes up by $10k per chamber. This is a small percentage increase so if it is a reasonable solution to a difficult problem then it's a reasonable way forward.
- Alternative approach to dog clamps is to use a thick interfacing plate with breadboard to align to local holes.
- We require a new sensitivity curve for AdvLIGO given the silica downselect. We are not clear on what the baseline reference design now is. Which aspect of thermal noise is the top-level noise contribution to which we can only add 10% with subsystem noise. Dennis will liaise with Peter and Gregg and get back to us on this.
- Baffle for CO_2 laser – absorb radiation – material called "Martin Black" absorbs 10 microns. Clean and vacuum compatible. However may have particulate problems.
- 1200C oven for annealing the ribbon itself and the welded joint between ribbon and peg. Don't need vacuum furnace as we will use a silica box with argon environment. Given the length of the fibres might expect it to be a bit more expensive than $10k (including silica box).
- Storage of fibres, moisture free, clean environment – not a huge concern though it would be prudent to not store them too long and to make sure they are in a moisture free, clean environment.
- Earthquake stops intended to be adjustable and to be used for caging in the mass. The clamping arrangements will be used for transportation. LIGO I experiences have to be taken on board.
- It looks like we might be able to put earthquake stops at top and bottom (where flats would be if flats existed at top and bottom of mass). The coating is some distance back from the edge of the optic – we need to find out what the distance is to see if it would be acceptable to put earthquake stops here. Further discussions required on earthquake stops positions.
- We will spend a little time now looking at expanding the lower structure for silica for controls prototype. Then we will review this.

DAY 3 (Wednesday 26th January)

(1) Short discussion on Upper Structure (Notes by Caroline)

- ACTION: Mike Gerfen to suggest weld types on upper structure
- Stiffen the gussets and add plates to the U-sections
- Look at weakest points where gussets join to box section and consider stiffening box-section locally

(2) Tablecloth Update (Notes by Caroline)

- Alignment requirements for tablecloth – mirror angular tolerance needs to be defined – addressed during alignment review requirements in afternoon session on ears/welding – conclusion was that adjustment of the tablecloth in transverse (y) and vertical (z) is sufficient. The adjustment of the top blades would be used to match the chains to the tablecloth in longitudinal (x). The controls prototype OSEMs will cope with 3 degrees in tilt (Janeen to confirm) and so no tilt (pitch, roll or yaw) adjustment is required for the tablecloth. We need to speak to Stuart on Friday about OSEM alignment for noise prototype requirements. Where does the OSEM end and the tablecloth start? The adjuster for the OSEM is considered to be part of the OSEM (OSEM comprises adjuster plus head).

- Comprehensive adjustability of tablecloth – is this required?
- Maximum adjustability required for the controls prototype
- System level analysis required for noise prototype – can't put in unnecessary adjusters (over-design; mass budget considerations)
- The tablecloth can be adjusted transversely and vertically with respect to the masses. It is decided that longitudinal adjustment is not required.
- Tablecloth resonance frequencies - if tens of hertz then control system can notch any problems out. Wall thickness of plates about 6 mm.
  ACTION: Require to FE analyse natural frequencies of tablecloth.
- Eddy Current Damping – doesn't look easy to fit in the two 4 x 4 ECD arrays for each mass. We will investigate whether we can make these 3 x 3 ECD arrays instead. Initial plan was that controls prototype will use 4 x 4's. Use Controls Prototype to explore alternative arrays. Recommended damping 27 N/m/s which is half of what's in the design right now so if we want to half the number of magnet/rings that's okay. Also it's vertical not roll that has the largest requirements so we could position them differently if we wanted to. Ken happy to use combined ECD and active damping. Important that we use Controls Prototype to do test of ECD to validate models.
  Noise prototype has 3 options.
    - (1) ECD with active damping at times when you need it (ECD required in all d.o.f.)
    - (2) ECD combined with active damping all of the time (ECD required in all d.o.f.)
    - (3) ECD in only some dof (integrated mixture).

  We will always want OSEMs in all dof.
  Copper on the mass not magnets on the mass. Now have lightweight clover leaf design. Space might be a problem to fit ECDs for all dof.
  ECDs will help reduce robustness requirements for earthquake stops.
  Acquisition – the more ECD the easier to ensure noise from active damping doesn't move the mass more than the filtered seismic noise (since we want minimum velocity).
  Noise requirements in lock – active damping must be turned down a factor of approximately 1000 to reduce the noise unless we can fit some ECD in longitudinal.
  For acquisition longitudinal and vertical are the most important dof.
  Currently ECD optimised to work vertically. Space really tight on top of tablecloth.
  Note: the controller design philosophy has been changed from that used in GEO and therefore the requirements for lever arms have been relaxed in some cases.
  ACTION: For noise prototype design – have review of ECD requirements, optimisation and accommodation.
  NOTE: For noise prototype the philosophy will be (in absence of results from the controls prototype that override this):
    - vertical – ECD required 27 N/m/s
    - roll – likely to be required and likely to be taken care of by vertical
    - transverse – not required

    - longitudinal – see conclusions from OSEM review paper by KAS (T040110-01-K).
    - other dof – t.b.d.

  Note: the above philosophy applies to the quad. The modecleaner must also be considered.

(3) Structure Interfaces – Implementation Ring (Notes by Caroline)

- We want to determine the vertical range requirements for the implementation ring.
- Conceptually: Flange on upper structure; flange on lower structure; adjust their relative position; implementation ring (L-shaped) bolts into place.
- Need to sum up all the vertical adjustment contributions (to be checked)
    - '+' sign means lower part of structure needs to be lowered by this amount to enable suspension
    - Fibre stretch (+ 8 mm)
    - Clearance between the mass and its support (+ 5 mm)
    - Slack required for connection of wire clamps (+ 5 mm)
    - Residual errors in blade tip height, 3 blades in series (+ 3 x 2 mm)
    - Curve of blade tips from stop, 3 blades in series (zero because blade stops will be overcompensated
    - Stretch in steel wires, 3 in series [~ 44; ~ 30; ~ 34 cm lengths for stages] (+ 2 + 1 + 1 mm)
    - Provision for flexibility (droop) of structure
    - TOTAL ~ + 28 mm (conservative)
    - Make overall length of two structures 28 mm shorter then implementation ring increases the overall length
- Need to bear in mind possible requirement for this level of movement between main chain and reaction chain in repair scenario with respect to clearance of magnets attached to reaction mass.
- ACTION: the above numbers will be worked through the model as part of the design

(4) Bonding of ears (Notes by Caroline)

- Bonding procedure was drafted based on silica/sapphire bond
- Silica has now been downselected
- Need to conduct bond strength tests for silica/silica with 20 kg loading (one ear bond) – aim to do tests.
- Conduction of heat possible to bond area during welding
- Eoin's preliminary results
    - Previous work was carried out for silica ears on sapphire test mass – these gave a bond area limit of 4.2cm^2 per ear (two ears per mass)
    - This calculation needs to be repeated for a silica ear on the silica test mass. Work is underway and the model is currently being refined and validated.
    - 10% of top level sensitivity converted to motion of single mass (with two ears) – we have asked for clarification of top level noise for current assumptions
    - Difficulties have been encountered in bond FE models due to limited number of nodes on research licences
    - ACTION: look into options for upgrading FE software suites
    - ACTION: extend FE analysis to silica/silica

- ACTION: Silicate bonding procedure has been drafted – this needs to be reviewed and then will be placed on DCC.
- Ear design
  - MC noise prototype as per GEO ear
  - Quad penultimate and test mass preliminary ears have been designed. However these need to be reviewed in light of silica downselect and its effect on bond noise.
  - At the time of the downselect several fused silica noise curves were presented. It's not clear which one will become applicable. ACTION: should prepare a range of ear designs to match this range of sensitivities in advance.
- Ear positioning tolerance requirements need to be reviewed
- Cleaning requirements
  - Mechanical scrubbing of the surface is a good method
  - Stanford use UV light but this doesn't remove gross contamination
  - Helena's plan for flats – since manufacturer cleans mirrors then flats can be cleaned at same time – if we receive within short timescale then we can use UV light and this will achieve cleaning requirements.
  - Cleaning of bonding surfaces – dry i.e. UV and methanol wiping
  - In ITMs need to make sure we don't create colour centres with the UV light on the beam paths
  - ACTION: investigate absorption depth of UV in silica
  - Organic vapour cleaning? This implies use of tanks, chemicals, disposal….looks too messy. UV seems the best way forward.
  - The UV cleaning needs further investigation – reservations about damage to substrate and coatings. The fall back plan which worked well for GEO will be manual scrubbing.
  - Templates – Fiducials on the optic, use (improved) GEO approach. Perhaps a MachineVision system with camera using fiducials. Specifications for alignment are required.
  - Different mass designs will require their own unique templates.
  - How does position of wedge impinge on exact position of the ears?
  - ACTION: draft a document for how we will achieve the required alignment – templates, fiducials and procedure.

(5) Blade Committee Meeting (Notes by Caroline)

- Measurements Caltech & RAL have been making, how to interpret and what to do next
- Allowable stress, blade processing etc. – implications of Riccardo
- Riccardo's plans
  - Take plate material, grind it, roll it, 3 sets with combination of grinding and rolling (to change the thickness) – tasked with designing system for output mode-cleaner for LIGO – he will improve one of the test facilities at Caltech to do this (build ovens etc).
  - Is Riccardo's proposed work enough to tell us what we need or do we need to make additional plans?
  - There are limits/guidelines to the amount of grinding and rolling you can do on maraging steel.
  - Failure mode – radius not consistent along length (yielding).
  - Maraging steel is more difficult to get a hold of and 3 or 4 times more expensive than it was around 2001.

- ACTION: RAL need to determine whether they need to order maraging steel for the noise prototype now/soon.
- ACTION: assess how many blades are required for noise prototype? (2 noise prototypes – convertible one for LASTI and one for RAL to hang on to).
- Blade characterisation T040229_ETM C-PTYPE.xls
  - Match the blades in terms of elasticity/dimensions (deflection)
    - Take a fixed mass, load the blade and note its deflection from the horizontal
    - Measure internal mode and bounce frequency of each blade
  - Skim the clamps
- Ian set up a plan of how blades were to be measured and tested some – Helena & Bob Taylor continued with measurements.
- Reviewing the data for the first time –
  - ACTION: RAL need to analyse the data
  - There seems to be a problem with some of the data
  - What can be done to sort out this data?
    ACTION: One or two hours of video link RAL to Caltech to instruct Calum/Helena and perhaps Caltech technician on how to make measurements. Try to identify any defect in the apparatus or flaw in the procedure.
- Noted that the friction on the aluminium rail makes it very difficult to flatten the larger blades – design has been reviewed recently to improve this design problem.
- Tolerance of holes in facility with 0.5m blade means it rotates and can introduce error in measurement of position of tip
- Examine criteria for selection of matched blades
  - Deflection versus load
  - Gradient gives stiffness
  - Deflection at a given load doesn't give you the full story
  - Delta of unloaded deflection and loaded deflection should be matched
  - Procedure
    - Unloaded deflection $\delta 1$ – if way out reject
    - Loaded $\delta 2$ – if way out reject
    - Then review delta unloaded and loaded deflection to give Δ where $\Delta = \delta 1 - \delta 2$
    - Cross-check bounce frequencies
    - Quadratic relationship between bounce frequency and Δ
    - Fundamental matching is matching of Δ
    - Having matched then choose shims to give zero on $\delta 2$
    - Not part of procedure for matching – we will measure first internal mode of the blades to aid in model validation
  - ACTION: check clamps made with zero degree angle can be modified to other angles by skimming
  - We need to review Caltech support for aiding with gathering of blade data
  - ACTION: during blade characterisation always check unloaded shape at end of test and at beginning of test is the same.
- Maximum stress in blades and clamps – see note in T040108 on DCC
- ACTION: Caltech to supply blade quotes to RAL for impact of heat treatment times on cost

(6) Ear Positioning (Notes by Justin and Caroline)

- See also T040143 by Norna & Mark on cross-coupling in quad SUS.
- Adjustment:
  - First do initial alignment
  - Then use mechanical adjusters
  - Then use OSEMs (range governed by force capability as well as by detector range)
- Range and precision of mechanical adjusters.
  - Range sets requirement for initial alignment – the initial alignment must be good enough to get within the range of the mechanical adjustment.
  - Precision comes from the range within which we can do “live” adjustment with OSEMs
  - The ADJUSTMENT needs a better resolution than the precision above.
  - The measurement associated with the adjustment needs the precision above. This comes from the optical system we use for alignment.
  - The mechanical adjustment range will exceed the usable range of the OSEMs so they will need to be realigned after mechanical adjustment.
- Mechanical adjusters:
  - Top blades: yaw
  - Pitch adjusters on top mass: pitch
  - Change mass of top mass: vertical
  - Convention: longitudinal is x; transverse horizontal is y; vertical is z.
  - Six dof adjustment:
    - X (adjust structure to optical table)
    - Y (adjust structure to optical table)
    - Z by adding/removing mass (0.5kg increments to move ~1mm). Should not need to do in the chamber.
    - Pitch**.** Mechanical adjustment has been designed to get within OSEM range. Resolution of the pitch adjuster is about 1mRad (corresponds to 1mm movement), range is ~20mRad.
    - ACTION check what force the OSEMs need to exert to achieve 1mRad movement.
    - Roll. Roll adjuster at the IM. Range 2mRad resolution ~0.1mRad.
    - Yaw. Use the blade tip – can get ~0.1mm which gives 0.2mRad. (Can also adjust structure to optical table)
    - Seismic can also do some of each dof
  - The interferometer requirements are for pitch and yaw (of order 0.1 mRad), and more loosely for roll (through wedge angles), and x,y,z to between 1 mm and ~ 3mm.
  - Next problem: You adjust something at the top to get things right at the bottom, and something in the middle goes wrong.
  - Tough numbers:
    - Roll range is only +/-2mRad.
    - Pitch range is +/-20 mRad.
    - OSEM mechanical adjustment has about 1mm range in all three directions.
    - In the ROLL sense, the max OSEM separation at the top mass in y is the tranverse-acting one at about 300mm from centreline, so a 1mm movement gives 3 mRad at the top mass

which is about 2 mRad at the test mass. (note – this is approximately the same as the roll range).

- Geppo and 2 mRad. Welding is not critical because you match the starting lengths in the annealing. The welding and annealing will take out ear angular position errors. BUT if the fibres have different spring constants you have a problem. Can approach this by looking at the tolerances on violin modes and looking what effect such errors will have. Note that the tolerable errors in pitch are about 10 times those in roll; and the wire separation in roll is about 10 times that in pitch. (chalkboard calculation: 2 mRad corresponds to ~15% error in roll).
- ACTION to complete these sums and write them up.
- Longitudinal (x) errors in ear position – because the pegs sit in grooves you cannot compensate in welding. So need to calculate the error in longitudinal (x) location gives the relevant pitch error (which is that error correctable with the mechanical adjustment).
- ACTION to do the calculation above.
- Roll, z & pitch get taken out in welding.
- x and yaw mean that the ears must be right longitudinally (in x).
- How do you know that the masses are correctly aligned relative to each other before welding?
    - Horn co-ordinates
    - Centre-to-centre
    - Pitch
    - Yaw
    - Clocking relative to each other
    - Not forgetting ear longitudinal
- With the CO_2 laser you can shape the necks of the ribbon as desired and then snap off the ends beyond the neck to mount the pegs.

- H pieces.
    - Current option implies separate pegs rather than H pieces.
    - Peg is around 2mm diameter welded to end of ribbon/fibre
    - Nose is so big to allow for clearance on masses with sapphire OR silica. We should review this for silica.
- Size of nose on penultimate ear is designed for both silica and sapphire (driven by silica)
- ACTION: complete review of ear design based on silica downselect
- H-pieces were devised because horn separation was only 15 mm and H-piece was good way of working in this tight space
- Now the horn separation is 30 mm so this is more relaxed – hence the move to the pegs or pins at top/bottom of the ribbons
- FE analysis is going to conducted to optimise (minimise the stresses) for a given bond area – this may require modifying the slopes on ears top & bottom
- Drum ended wires – may have to consider using these but if they can't be made long enough to loop round the penultimate mass then we would have to conduct a fairly major redesign of the penultimate mass/ear concept.
- ACTION: we have two options pegs or H-pieces. We need to generate a document to summarise the basis of the H-piece downselect to pegs/pins; the design basis of the proposed peg design; what would make us fall back to the H-pieces and should we do any more parallel work on H-pieces in the meantime.
- Pitch thermal noise needs to be looked at again in light of silica downselect + many other things as part of a review

- ACTION: organise a major design review of quad based on silica downselect
- One question is whether the procedure should include the two pegs being clamped relative to each other?
- The pegs will have a reference mark and from this we will know where the bending point is
- Repair scenarios
  - Flame manual method was to remove material by holding a piece of fibre in hand and attach to ears then once cooled heat it nearby then when glows pull a fibre from this. This removes material.
  - In Advanced LIGO deal with excess material by?
    - Fibre snaps, then cut off fibre. Peg still attached to the horn. It may be possible to melt the peg and flatten it in towards the mass with the new peg. This will have to be investigated experimentally before it can be adopted as a repair approach.
- Another test we have to do is to look at welding of the same grade of silica but from different batches and the effects this can have. It has been observed that there can be some kind of surface effect that can cause poor welding unless the two surfaces are rubbed together.
- We need to plan for a long period of training for site personnel for manufacture and installation of the ribbons and fibres.
- NOTE; a similar repair approaches must be considered for magnets on penultimate mass

(7) Additional Question from Justin (Notes by Caroline)

- Question:
  In light of silica downselect is the reaction chain going to remain as sized for sapphire?
  Answer:
  yes but depends on feasibility of electrostatic drive; commercial/economic issues surrounding purchase of SF4.
- Sapphire reaction chain was the easiest option in the first place from footprint considerations and it makes the masses up the top closer together
- But the penultimate mass in main chain will be resized and will be made of silica as a result of the silica downselect.

DAY 4 (Thursday 27th January)

(1) Update on FE analysis of overall structure (Notes by Caroline)
- ANSYS support in UK helped (Wilde & Partners)
- First resonance 99 Hz
- Start production soon?

(2) Authorship discussion for LIGO documentation for DCC (Notes by Caroline)
- Motive is that review boards require to see the level of output (scientific/technical/project management) from large scale projects.
- Supervisors will automatically be added
- Presentations (G) – rules exist already within the LSC
- All categories can be divided into two sets – one of which we have no decisions to make – the

- Inconsistencies – authors in DCC are not recorded even though on front page they are.
- DCN document change notification
- Technical notes; drawings, formal notes; management notes
- DRAWINGS
  DCN would have full author list (Note – this proposal has since been reviewed and is no longer held – author list would be "drawn by" person only)
  Drawing itself would only have drawn by, checked by, approved by
- TECHNICAL NOTES
  will have the full author list
  note should be added to drawing relating to technical note
- Important thing is to encapture in few words what we want
- Acknowledgements should be outside people (LSC)
- Someone inside LSC should be on author list
- Visit report – personal
- Authors should comment on content – so should be circulated to authors prior to release – no it's okay to place on DCC as place of deposit for authors to review before next draft?
- TECHNICAL DOCUMENTS/PM DOCUMENTS
  sub-group meeting and something substantive comes out in any way then attendees are the people who are on the technical paper
  Series of SUS discussions – DRD for example – then could argue that some entire group of people be included on that
  K documents – first author orientated
- This meeting notes – all people who attended plus by telephone
- Document as product of suspensions group as a whole – who are they?
- DRD is an extreme
- Small technical note example KAS with DH – subliminal input?
- SUS or smaller group? Somewhere between it will be grey and won't be worth bothering about. Each case should be considered individually – or should we just make it everyone.
- Identify set of core documents
    - Plenary documents LSC presentations
- The "big" group and the set of core documents that the "big" group should apply to - check with Dennis.
- Author of series of papers e.g. blade committee could have blade committee author list.
- TO TAKE THIS FORWARD
    - Announce our intention/desire we plan to be inclusive
    - We request that a group of top level documents have a big group authorship
- Can't force this on everyone on the big group list
- ALUK authors will think inclusively and others will be encouraged to do so. Also include complete lists of attendees at meetings etc.

(3) LSC attendance (Notes by Caroline)

- Caroline / Ken / Norna / Justin / Janeen* / Helena* / Calum* (subject to approval)
- Organise a SUS meeting within the LSC. A meeting room, not presentations.
- Monday morning - SUS breakout session – include statement that there is no requirement for SUS people to attend any other event at that time.

- TALKS
  - Caroline – SUS (Glasgow/UK) tech plenary + tech session CO2 update
  - Janeen - progress update/organisation of SUS work
  - Calum – technical session quad update & questions
  - Justin – SWG breakout maraging steel from SUS perspective
  - Stuart – technical session OSEM update
  - Tim (Dennis) – structure resonance analysis
- This list to be reviewed and approved by Dennis. Once approved can send on to Joe.

(4) Controls/Noise prototype status review (Notes by Caroline)

- What will RAL do next?
- Examine status of design of various sub-systems of suspensions
- ACTION Glasgow to conduct a full review of effect of silica downselect on monolithic suspension design.
- ACTION: Provide plan for Dennis where downselect has implications to see if we have missed any. Results of review will be passed to Norna to be incorporated into the models and the associated documentation leading to a revision of the relevant parts of the conceptual design (lengths of wires, blade lengths, angles of wires etc). This will lead to the start of an interactive process with RAL.
- ACTION :Assembly & installation document for monolithic suspension to be drafted (CAC/GC).

DAY 5 (Friday 28th January)

(1) "OSEM development update "show-and-tell" " by S Aston (Notes by Caroline)
(Refer to LIGO-G050060-00-K)

- There are two failure categories with respect to monolithic suspensions
  - Monolithic suspension itself breaks
  - Something else breaks (worse) e.g. penultimate magnet
- Based on this it has become clear that the clearance of OSEMs and stop positions must be accurate.
- Overview of OSEM talk
  - OSEM performance summary
  - Current OSEM design
  - Current OSEM status
  - OSEM next steps
- Refer to S. Aston talk G0500XX-00-K for full information - a few highlights are given below.
- Aiming for no worse than 0.7 mm working range p-t-p
- Required sensitivity 3 x 10^{-10} m/√Hz at 1 Hz
- OSEM performance summary
  - As of September last year sensor performance (N. Lockerbie (Strathclyde)) 0.6 mm p-t-p working range with 1 x 10^{-10} m/√Hz at 1 Hz – trade off between sensitivity and range – by 10 Hz it's improved by a factor of a few
  - Work has continued and the latest set-up has a lens and mask and additional lens and leaded receiver device (for commonality of design

– two leaded (2-legged) designs) – now have improved linearity with 0.95 mm p-t-p (sensitivity not yet evaluated)

- Current OSEM design
    - Existing devices Honeywell surface mount emitter and receiver replaced with Optek leaded emitter and Centronics leaded receiver
    - Sensor development – slide 6 – section through sensor assembly – all aluminium unless stated otherwise.
    - No alignment to do – all of the components align themselves
    - Sensor components electrically isolated from rest of OSEM body
    - Orientation of mask must be aligned properly w.r.t. flag. – short dimension is the moving dimension
    - Birmingham responsible for specifying dimensions of flag, RAL responsible for building it
    - Slot can be rotated 360 degrees around cylindrical flag
    - ACTION: Submit to vacuum review board proof that their grade of aluminium, 6082, is comparable to 6061 and therefore acceptable (RJSG – two weeks)
    - Inter-connect development
    - OSEM mechanical adjustment – two point adjustment - make pilot hole and vent slots - avoid using vented screws. Want to use non-magnetic hex/Allen keys not thumb screws.
    - Pitch actuation magnet (PAM) retro-fit implementation – Slide 9
    - Coil-former development – Slide 10 – flag 3 mm diam. ~ 25 mm length, base ~ 10 mm
    - 3 mm flag into 5 mm aperture (tight) – so earthquake stops will need to be aligned very precisely. (LIGO I has 2 mm in one direction and 2.5 mm in another direction). Method of fixing flag onto magnet is still being investigated
    - ACTION check optimum position for magnet with respect to coil (SMA – six months)
    - Angular misalignment of flag/magnet assembly – 1 mm distance between the flag and the wall of the aperture. In LIGO I we could handle 3 degrees misalignment (relative to centre of rotation of mass) – clearly here it's much less due to long lever arm (larger masses) and tightness of fit.
    - The stop offset was 0.5 mm in initial LIGO – this was the basis for the OSEM clearance of 1 mm all the way round. (DC to confirm if this approach where we are now making the OSEM set a requirement for the stops is reasonable for Advanced LIGO)
      We haven't yet decided if we're going to instrument the sensors on the penultimate masses so we wouldn't need the flags hence the clearance will be large – initial LIGO magnet size.
    - Flexi-circuit part-procurement underway (slide 11)
    - Connector part procurement underway (slide 12). Identification of production issues (e.g. inking). Need to identify if there is any issue with vacuum compatibility as soon as possible. Test only male or female (whichever has the highest surface area)? To be considered.
    - Concerns & issues to resolve (slide 13)
        - Sensor alignment issues – we have no means of aligning sensor optical components but we have confidence that the emission pattern device to device is consistent. There is possible device-to-device variability in radiated intensity. Manufacturer is

unable to provide graded devices (~ 1000). Potential solution using drive electronics.

        - Plan to test and characterise performance of the prototype OSEMs e.g. by obtaining the "spread" of sensor transfer functions
        - Thermal issues – electrical isolation of sensor packages leads to a reduction in thermal link to the coil former via Macor sleeve – it's not clear if this has significant effect on the temperature stability of the device
        - Thermal effects will be further investigated. Characterise performance in vacuum in temperature-controlled environment Tests in Birmingham thermal vacuum chamber will take place some time in April 2005.
        - Other
            - Thread inserts (brass/steel) required to hold reliable threads in aluminium? No aluminium fine.
            - Coatings applied to any parts? No.
            - Current design omits any clearance holes in the coil-former clamp & bracket for access to earthquake stops. Intend to use MC controls prototype as a template.

- OSEM next steps
    - Prototype production – aim to have them for LSC
    - Further testing – conduct performance characterisation as required (including any thermal analysis/testing)
    - Part-procurement
        - Place orders for substantial quantities of components (sufficient to fulfil vacuum compatibility testing)
            - Flexi-circuit
            - Connectors (both OSEM and pigtail mating connector) – biggest risk
            - Sensor components (OP232 & BPX65)
            - Submit for vacuum compatibility testing
- Twenty- four connectors (one chambers worth) are sufficient for vacuum testing – numbers tbc - SMA will send to HA in April
- Dave Hoyland has been looking into the actual design of electronics. He has been liaising with Jay Heefner (integrator/user). The type of dewhitening is completely different from LIGO I.
- Need a requirement for viscous damping at the penultimate mass. ECD might be important there hence we might require a current source to drive the coil. Length of wiring important for electronic stability (GEO 5 m to 15 m of cable okay with compensation designed for 10 m without instability problems).
- Coil resistance ~ 17 ohms.

<END OF PROGRAMMED DISCUSSIONS>

Action list

(this will be followed up within weekly Monday/Tuesday meetings)

1. Discuss the magnets/flags of OSEMs with regard to earthquake stop with Stuart Aston on Friday a.m. meeting
   (ALL - tomorrow)

2. Small head for welding - CO2 team to investigate whether this is viable/feasible approach
   (CAC/GC/DC – next few months)

3. Design levels for thermal noise in mirrors - Raise with Dennis in telecon tonight.
   (DONE)

4. The design levels for thermal noise in the mirrors needs to be reviewed and redefined.
   (Raise with Dennis in telecon tonight.)

5. Mike Gerfen to suggest weld types on upper structure
   (TH – one week)

6. Require to FE analyse natural frequencies of tablecloth
   (JR – two weeks)

7. For noise prototype design – have review of ECD requirements, optimisation and accommodation
   (KAS with ALL – part 1 before controls prototype test and Part 2 within one month of tests)

8. Check the summing up of all the vertical adjustment contributions and work them through the model part of the design
   (RAJ/CIT – two weeks)

9. Look into options for upgrading FE software suites
   (MPL/CIT – two weeks)

10. Extend FE analysis to silica/silica
    (EE/CAC –one month)

11. Silicate bonding procedure has been drafted – this needs to be reviewed and then will be placed on DCC
    (HA/SR – two weeks)

12. Should prepare a range of ear designs to match this range of sensitivities in advance
    (EE/CAC – two months)

13. Investigate absorption depth of UV in silica
(HA – three weeks)

14. Draft a document for how we will achieve the required alignment – templates, fiducials and procedure
(HA/SR/JR – one month)

15. RAL need to determine whether they need to order maraging steel for the noise prototype now/soon.
(RJSG – one month)

16. Assess how many blades are required for noise prototype? (2 noise prototypes – convertible one for LASTI and one for RAL to hang on to)
(RAL need to analyse blade test data (IW – two weeks)

17. One or two hours of video link RAL to Caltech to instruct Calum/Helena and perhaps Caltech technician on how to make measurements. Try to identify any defect in the apparatus or flaw in the procedure.
(CIT – two weeks)

18. Determine availability of CIT staff for blade data taking
(HA – two weeks)

19. Check clamps made with zero degree angle can be modified to other angles by skimming
(IW – one week)

20. Caltech to supply blade quotes to RAL for impact of heat treatment times on cost
(CIT – one week)

21. Check what force the OSEMs need to exert to achieve 1mRad movement at the mirror
(SA/KAS – one week)

22. Geppo and 2 mRad. Welding is not critical because you match the starting lengths in the annealing. The welding and annealing will take out ear angular position errors. BUT if the fibres have different spring constants you have a problem. Can approach this by looking at the tolerances on violin modes and looking what effect such errors will have. Note that the tolerable errors in pitch are about 10 times those in roll; and the wire separation in roll is about 10 times that in pitch. (chalkboard calculation: 2 mRad corresponds to ~15% error in roll). Complete these sums and write them up.
(GC – two weeks)

23. Longitudinal (x) errors in ear position – because the pegs sit in grooves you cannot compensate in welding. So need to calculate the error in longitudinal (x) location gives the relevant pitch error (which is that error correctable with the mechanical adjustment). Do the calculation above.
(CAC – two weeks)

24. Complete review of ear design based on silica downselect
    (CAC – one month to NAR/complete three month)

25. We have two options pegs or H-pieces. Generate a document to summarise the basis of the H-piece downselect to pegs/pins; the design basis of the proposed peg design; what would make us fall back to the H-pieces and should we do any more parallel work on H-pieces in the meantime.
    (GC/CAC – one month)

26. Organise a design review of quad design parameters based on silica downselect. Results of review to be incorporated into the models (including 2D/3D layouts) and the associated documentation leading to a revision of the relevant parts of the conceptual design (lengths of wires, blade lengths, angles of wires etc).
    (NAR/RAL/ALL – revision of design three months – ongoing revision for noise prototype)

27. Glasgow to conduct a full review of effect of silica downselect on monolithic suspension detail design
    (GC/CAC – three months)

28. Provide plan for Dennis where downselect has implications to see if we have missed any.
    (KAS – ten minutes)

29. Assembly & installation document for monolithic suspension to be drafted
    (CAC/GC – one month).

30. Submit to vacuum review board proof that their grade of aluminium, 6082, is comparable to 6061 and therefore acceptable
    (RJSG – two weeks)

31. Check optimum position for magnet with respect to coil
    (SMA – six months)

32. The stop offset was 0.5 mm in initial LIGO – this was the basis for the OSEM clearance of 1 mm all the way round
    (DC to confirm if this approach where we are now making the OSEM set a requirement for the stops is reasonable for Advanced LIGO)

33. Twenty- four connectors (one chambers worth) to be sent to Caltech (Helena) for vacuum testing. Numbers to be confirmed
    (SMA – April 2005)