Update on development of Advanced LIGO quad noise prototype

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on behalf of Advanced LIGO Suspension Team / University of Glasgow /GEO600 Group

LSC Meeting, LHO, March 2006

LIGO-G060049-01-K

Advanced LIGO SUS team

- **LIGO Lab :**
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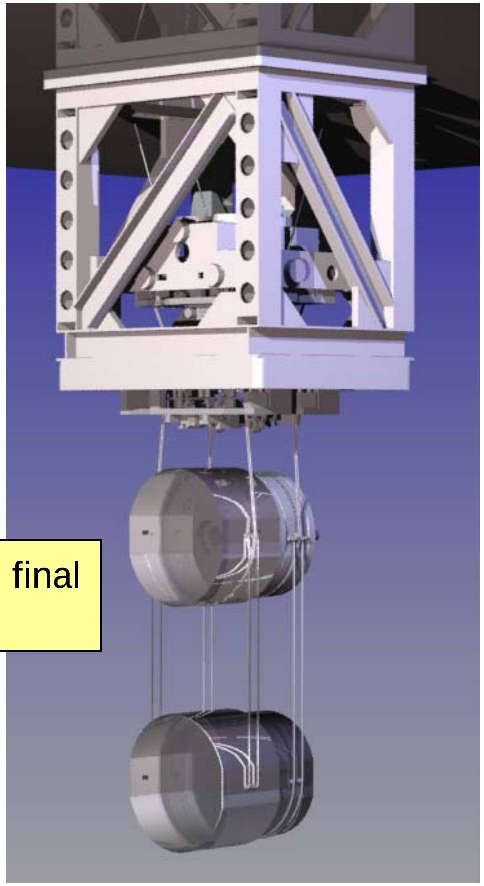
  MIT: P. Fritschel, K. Mason, R. Mittleman, L. Ruet, D. Shoemaker
  LHO: B. Bland, D. Cook
  LLO: J. Hanson, H. Overmier, J. Romie, G. Traylor
- **GEO600**:
  Glasgow: G. Cagnoli, C. Cantley, A. Cumming, D. Crooks, A. Grant, A. Heptonstall, J. Hough, R. Jones, I. Martin, M. Perreur-Lloyd, M. Plissi, D. Robertson, S. Rowan, K. Strain, H. Ward
  Universitat Hannover: H. Lueck
- **Stanford University.**: N. Robertson (also GEO/Glasgow)
- **Rutherford Appleton Laboratory (CCLRC)**: J. Greenhalgh, T. Hayler, J. O'Dell, I. Wilmut
- **University of Birmingham**: S. Aston, M. Cruise, A. Freise, D. Hoyland, D. Lodhia, C. Speake, A. Vecchio.
- **Strathclyde University**: N. Lockerbie

Quad noise prototype

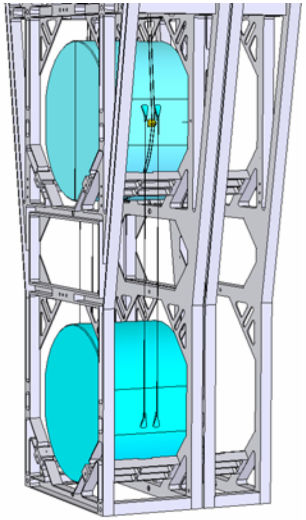
- UK project responsibility with US input
- Final stage is monolithic (based on technology first applied in GEO600)
  - silica test & penultimate mass
  - silica attachment ears
  - silica ribbons
- Assembly of monolithic stage
  - Lower structure acts as a mass catcher/assembly jig for 40 kg silica masses
  - CO_2 laser welding of laser pulled ribbons

monolithic final stage



Noise prototype (silica) ETM quad suspension and upper structure (lower structure not shown)

Lower structure (split design)



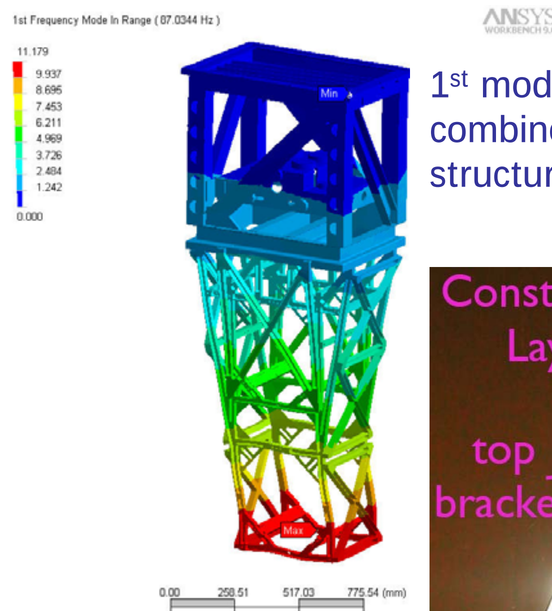
From controls to noise prototype

- In addition to the silica stage, the noise prototype has:
  - more eddy current damping on top mass
  - provision for ring heaters, and baffles
- Controls prototype designed with noise prototype and final article in mind
- Full consideration is being given to the monolithic stage assembly procedure, ensuring that the silica stage tooling can interface - welding, fibre proof loading etc
- Valuable assembly and adjustment experience has already been gained from controls prototype
- Results and further experiences from LASTI will feed back directly into noise design
- A few mechanical design surprises identified ....

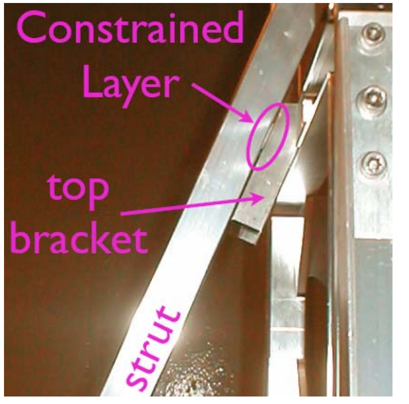
Quad noise prototype (all-metal mass version) within support structure

Support structure resonances

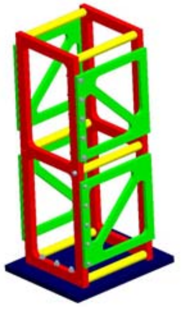
- Need to increase modes by ~ 20 Hz to meet SEI requirement (f_1 > 100 Hz)
- Structural performance does not match initial FEA
- Options under investigation:
  - Light-weighting: e.g. turning lower split structure into lower combined structure (77 & 86 Hz increases to 87 & 94 Hz)
  - Stanford (Lantz et al) investigating constrained layer damping strut (approx. x 20 amplitude reduction)
  - Outriggers to seismic table
- Vibration testing on simplified structure to further study stiffness of bolted joints



1st mode 87Hz with combined lower structure concept



Constrained layer damping strut on lower structure at Stanford

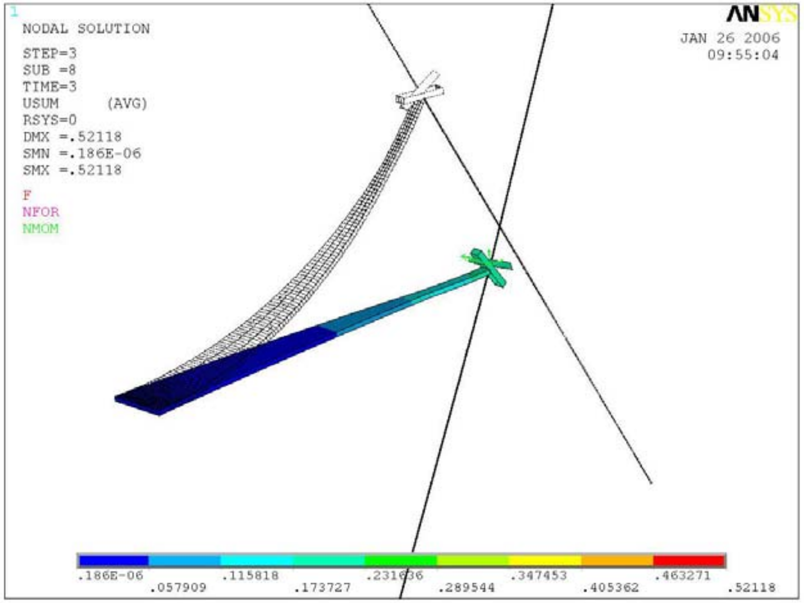


Test structure for bolt stiffness investigation

Talks by C. Torrie at SWG breakout and B. Lantz at SEI breakout

Cantilever blade springs

- Vertical stiffness corrections:
  - non-vertical loads: anti-spring affects resulting position of blade tip / wire flexure point
  - lateral compliance – leads to lower pitch modes
  - must also account for effective wire stiffness reduction due to diagonal loading
- FE & theoretical investigation
- Simple marionette built at RAL to:
  - corroborate models of blade behaviour under load
  - demonstrate accuracy of manufacture
  - determine required blade clamp adjusters
  - streamline assembly procedure



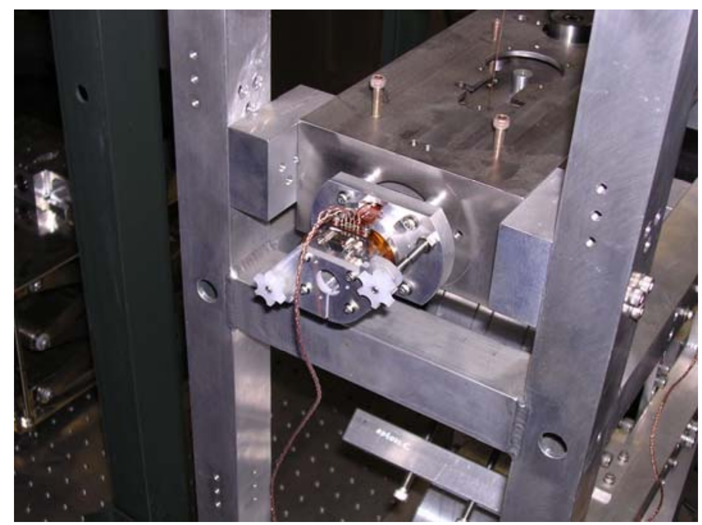
Blade loaded in ANSYS with non-vertical load - lateral force affects position of wire flexure point

Talks by M. Barton and J. Greenhalgh at SWG breakout

OSEM development for noise prototype

- Shadow sensor/electromagnetic actuators (OSEMS) & electronics for local control
- Hybrid OSEMs and eddy-current damping (ECD) has been selected for the quad suspensions over the interferometric sensor damping approach
- Hybrid OSEM performance:
  0.7 mm p-t-p range with sensitivity
  10^{-10} m/√Hz at 1 Hz
- Production of a few prototype units for the noise quad has already taken place
- Will enter production phase for Noise Prototype OSEMs within the next few weeks

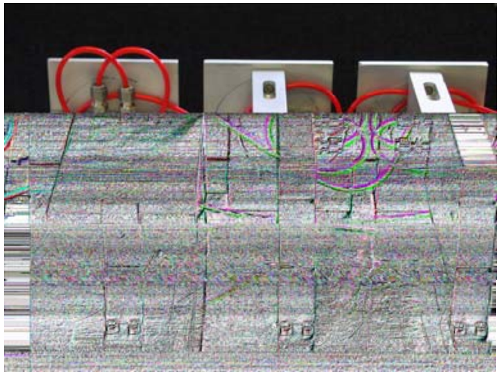
Prototype OSEM



OSEM Fit and function test at Caltech

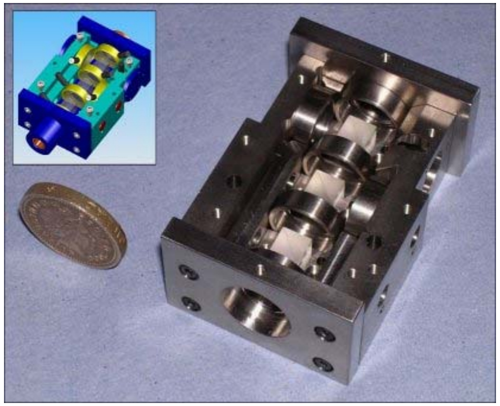
Electronics, ESD and interferometer development

- OSEM & Electronics PDR held July 2005, completed March 2006
- Ongoing electronics design of coil drivers and satellite amplifiers
- Electrostatic actuator drive electronics design and fabrication conducted by ALUK collaborator N. Lockerbie (Strathclyde)
- Interferometric based OSEM development continued as a backup
  - Prototype device fabricated and characterised



ESD water-cooled heat sinks

Electrostatic drive gold coating shown for reaction mass of controls prototype

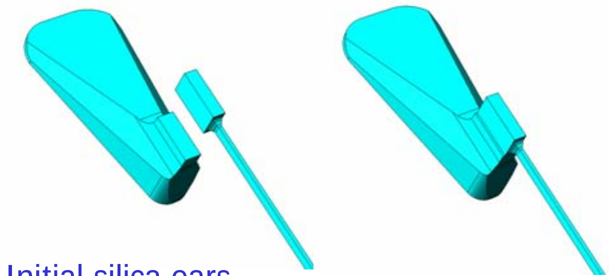


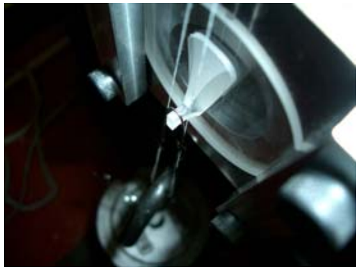
Interferometer Prototype

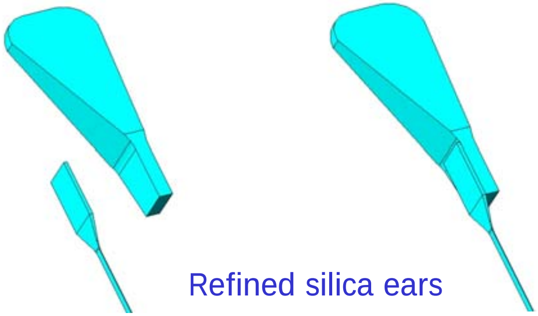
Talk by S. Aston at SWG breakout

Monolithic silica stage development - ears

- Initial ear has 90 degree horn
  - overlap weld for easy alignment
  - triangular bond face, reduces bond peeling effect
  - bonds so far tested up to 37 kg without failure
  - ear fails before bond
- Refined ear with parallel horn for lateral overlap weld
  - reduces stress at horn-ear interface (< 50 %)
  - easier manufacturing
  - accommodates original ribbon end tab removing need for transition piece
  - larger weld area
- Surface finish critical in maximising ear strength – polishing options

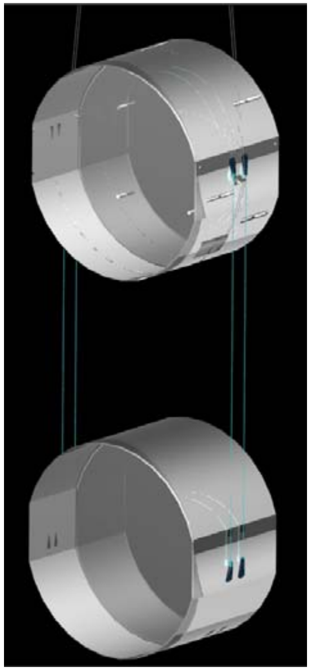

Initial silica ears


12 kg long term load test on bonded ear

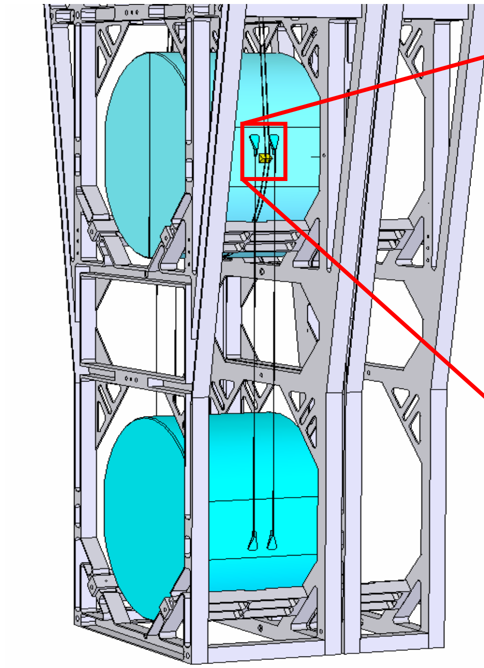

Refined silica ears

LIGO CLRC IGR GEO 600 CARDIFF UNIVERSITY UNIVERSITY OF BIRMINGHAM

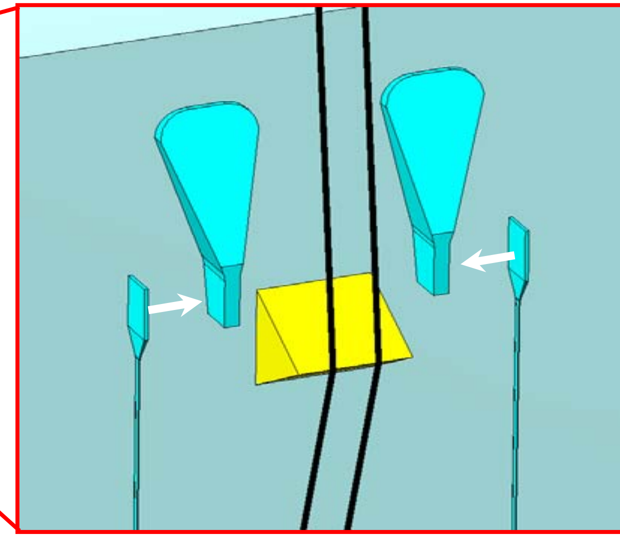
Monolithic silica stage development



Rendering of monolithic silica stage



Monolithic stage in lower structure / mass catcher assembly

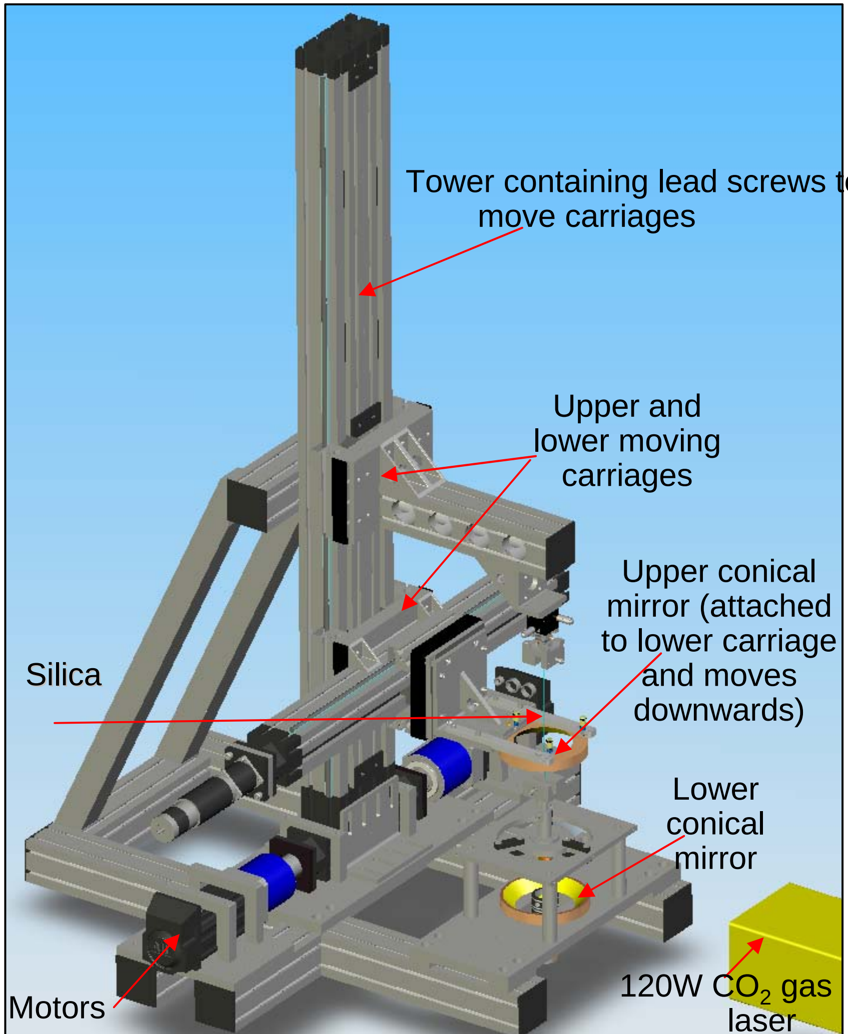


Lateral overlap welding configuration for ribbons (penultimate mass shown with wire standoff prism)

Bonding/ribbon/ears PDR conducted Oct 2005

Four mirror substrates delivered to Caltech Jan 06 – major UK project deliverable

CO_2 laser pulling & welding machine



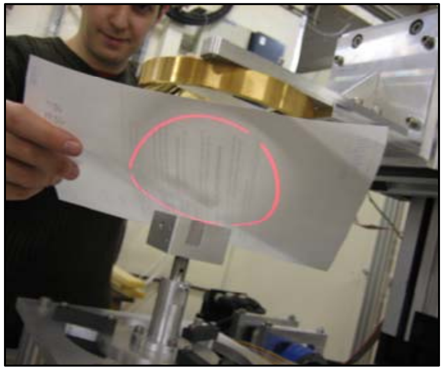
From concept, through development to prototype construction at Glasgow

(funded by EGO organisation and PPARC)

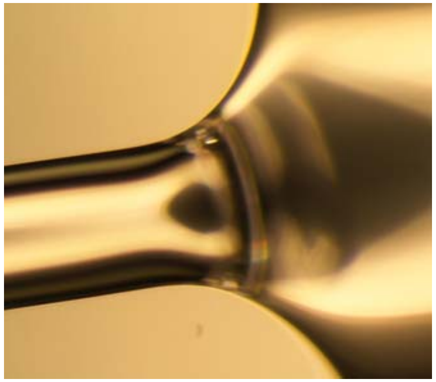
CO_2 laser pulling, welding & characterisation

- Measured surface loss of laser pulled fibres ~8e-8
  - at least as good as flame pulled fibres
  - meets required noise performance
- Measured surface loss in flame pulled ribbons ~1e-7 (Heptonstall et al *Phys Lett A* (in press))
- Laser pulled ribbons at least comparable in strength to flame pulled
  - ~2.6 GPa
  - Adv LIGO design 0.7 GPa

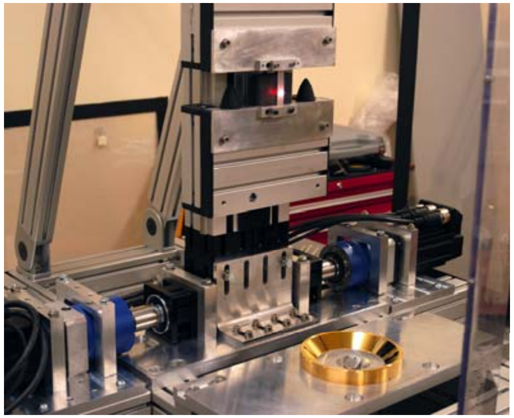
Talk by A. Heptonstall at SWG breakout



Rotating CO2 beam as shown by red tracker beam – fibre heated around 360 º during pull



CO2 laser weld



Dithered beam for ribbon pulling

Future work

- Controls prototype
  - complete installation in LASTI by Apr ’06
  - characterisation and testing completed by end of ‘06
- Noise prototype
  - complete design by mid ‘06 – with continued feed in from controls work
  - fabricate & initial assembly in UK (June to Dec ‘06)
  - assemble at LASTI (early ‘07)
  - LASTI tests (Spring ‘07 to Spring ‘08)