LIGO Laboratory / LIGO Scientific Collaboration

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ALIGO NP-type: - Report on Ear Bonding at LASTI on 10th December – 14th December 2007

M. Van Veggel[1], H. Armandula[2], K. Haughian[1], D. Sellers[4], G. Moreno[5], R. Jones[1], J. Hough[1], S. Rowan[1], M. Barton[1], A. Cumming[1], J. O'Dell[3], K. Strain[1], I. Wilmut[3]

[1] Institute for Gravitational Research, University of Glasgow

[2] California Institute of Technology, LIGO Project

[3] Rutherford Appleton Laboratory

[4]Livingston

[5]Hanford

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California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Institute for Gravitational Research

University of Glasgow
Kelvin Building
Glasgow G12 8QQ
Phone: +44 (0)141 330 3340
Fax: +44 (0)141 330 6833
Web: www.physics.gla.ac.uk/igr/

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu

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Introduction

In the week of Monday 10th December until Wednesday 13th December the second stage of the delivery of the bonding of silica ears at LASTI, which consisted of bonding ears to the second penultimate mass, measuring the weights of the test mass, 1st and 2nd penultimate masses and the reaction mass, measuring the position of the ears and measuring the electrical resistance of the gold coating on the reaction mass as part of the ALIGO ETM/ITM noise prototype activity.

The experience gained in the first stage of the delivery from 27th August to 31st August 2007 during which ears were bonded to the first penultimate mass and the test mass, was used during this stage. A report on the first bonding exercise has reference LIGO-T070223-00-D.

This document is a report on the experiences during this second exercise based on the planning as has been described in LIGO-T070298-00-D.

1 Reference documents

Design documentation 'glass' essentials	
D050421-05-K	NP- type ETM Penultimate Mass
D040431-C-D	Quad ETM Silica Test Mass
D050420-06-D	NP-type ETM Reaction Test Mass
D060055-02-K	NP-type Refined Ear (Type A)
D060056-02-K	NP-type Refined Ear (Type B)
Design documentation of the alignment jigs	
D070391-05-D	NP-type ear bonding jig GA
Measurement reports on 'glass' essentials	
GNL-4025-R1	Penultimate mass 1 measurements
GNL-4027-R2	Penultimate mass 2 measurements
GNL-4020-R1	Reaction mass measurements
C070035-00	Test mass measurements
E070163-00-K	Test report on A ears for Advanced LIGO monolithic suspension[1] (update required)
E070164-00-K	Test report on B ears for Advanced LIGO monolithic suspension[2] (update required)
Back ground documents	
T-070298-00-D	ALIGO NP-type: - Preparations of Ear Bonding at LASTI on 10th December – 14th December 2007
E050228-00-D	(Specification) Silicate Bonding Procedure
T070138-00-K	Ribbon/Fibre Length Budget
T070156-01-K	Advanced Testing of the Noise Prototype Ear Bonding Jig
T070223-00-K	ALIGO NP-type: - Report on Ear Bonding at LASTI 27th August – 31st August
E970154-00-D	Large optics suspension balancing: component specification
E070070-00-D	LASTI Test Mass, Handling and Shipping Procedures
NOLIGO-1	Calibration document of scale VW-330-C

[1] Note there has been a renumbering of the ears characterized in E070163 – "A" replaced with "BB".

[2] Note there has been a renumbering of the ears characterized in E070164 – "B" replaced with "AA".

2 Preparations

2.1 Goals

The goals of the visit were to:

1) Weigh masses (1st and 2nd penultimate masses, test mass and reaction mass)
2) Measure the positions of the ears on the 1st penultimate mass and the test mass
3) Bond ears to the 2nd penultimate mass
4) Measure electrical conductivity of the gold electrostatic drive of the ERM

2.2 Resources

Helena Armandula was appointed as task leader when filling the safety forms with Rich Mittleman. Main safety hazard is the handling and lifting of the 40 kg masses. There are no chemical safety risks as the bonding solution is not hazardous.

Helena Armandula and Mariëlle van Veggel were responsible for the weighing of the masses, measuring the position of the ears, measuring the gold coating electrical resistance and bonding the ears.

Karen Haughian was responsible for photographing and filming all stages in the exercise.

Two observers were present for knowledge transfer to the LIGO sites: Danny Sellers (Livingston), and Gerardo Moreno (Hanford). They also played a significant role in assisting when lifting the masses and in preparing the laboratory.

2.3 Time schedule

Table 2.1 Time Actual progress

	Monday 10-12-2007	Tuesday 11-12-2007	Wednesday 12-12-2007	Thursday 13-12-2007	Friday 14-12-2007
Preparations					
Weigh test mass					
Measure position of the ears on test mass					
Weigh 2nd PM					
Bond ears to side 1 2nd PM					
Bond ears to side 2 2nd PM					
Weigh 1st PM					
Measure position of the ears on 1st PM					
Weigh + measure electrical conductivity of gold coating ERM					
Pack masses and clean					

In Table 2.1 the prospected time-schedule (green) and actual time schedule (red) are shown. It was decided to weigh all masses sequentially before bonding, such that the weighing scale could be removed from the laboratory before bonding, thus creating more working area during bonding.

2.4 Layout of the cleanroom

A floorplan of the cleanroom is shown in Figure 2.1. The room was filled with 2 tables, washing bath and ergo-arm, which means that the surface area available is the minimal required space for bonding the ears to the masses.

The table covered in aluminium foil was used to weigh the masses, measure the positions of the ears and to set the bonding template.

The other table had a black plastic surface that was used to put the mass on for bonding.

The bath sat on a movable trolley that was at the location indicated in Figure 2.1 during washing the mass, and that was moved to the right once the mass is lifted off the bath after washing. The mass is then put onto the table.

Ideally the room would be longer, such that the ergo-arm can be moved forward and backward more easily.

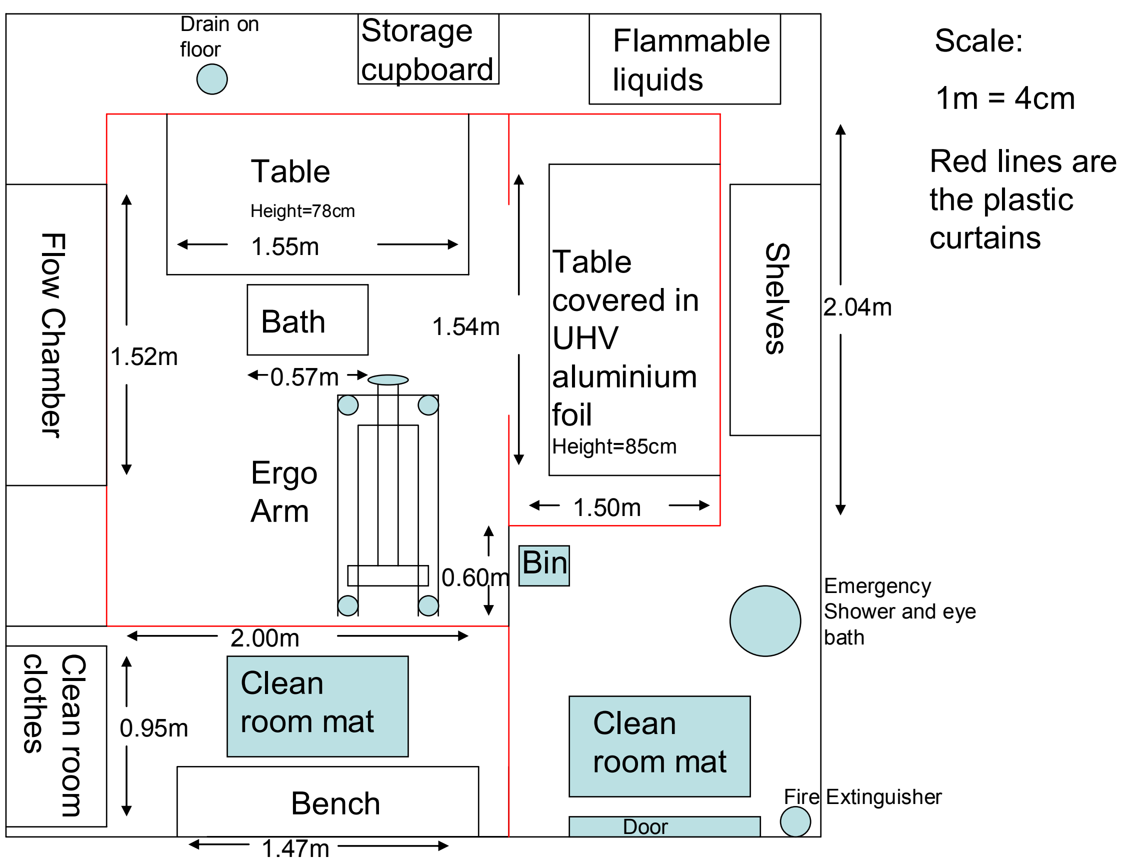


Figure 2.1 Floor plan of the bonding clean room

2.5 List of required items

Essentials

- Ears (2x D060055 + 2x D060056 for the 2nd penultimate mass, plus spares)
- Masses (2 penultimate masses, the test mass and reaction mass)

Bonding Jig

- 2 full bonding jigs are available for use (including templates, holders, t-pieces etc)
- Tools for setting up jig (Allen keys/wrench/tweezers)

Bonding equipment and consumables

- Flowing de-ionised water
- Methanol
- Deionising gun with pure, filtered nitrogen (low pressure)
- Centrifuge tubes (15 ml)
- Small centrifuge tubes (1.5 ml)
- Centrifuge
- Optical wipes
- Cerium oxide powder
- Sodium bicarbonate powder
- Petri dishes
- Sodium silicate solution (10% NaOH, 27 % SiO_2, Riedel-de Haën)
- 10 μl pipettes
- 10 μl pipette points

Large items

- Ergo arm and ring clamp
- Washing trolley (trolley with ultrasonic bath)
- V-blocks
- 2 tables (one for set-up and one for bonding)

Measuring devices

- Plastic ruler
- Digital calipers
- Height gauge
- Metric Feeler gauges
- Metric Slip gauges

Other items

- <u>Lighting</u>: Osram LED work light
- Magnifying glass
- <u>Clothing</u>: Clean room suits, overshoes, gloves, hairnets, face covers
- First Contact™ surface polymer
- Crash mat: used below ergo arm when manipulating the mass in free space
- Photo camera
- UHV aluminium foil

3 Weighing masses

Each mass was weighed. The mass of the TM, 1st PM, 2nd PM and RM was to be measured with an accuracy of +/- 30 g (see e-mail exchange between Ian Wilmut, Ken Strain, Mark Barton, Russell Jones, Helena Armandula and Marielle van Veggel on 8th November 2007).

For weighing the masses scale VW-330-C was used with a capacity of 50 kg and a readability of 0.002 kg (Figure 3.1).

Figure 3.1 VW-330-C counting scale (http://www.scalesolutionsllc.com/m8_view_item.html?m8:item=VW-330-C)

Steps:

- Set-up weighing scale VW-330-C such that it was level
- Calibrated it using two 20 kg (+/- 0.002 kg) masses (according to the procedure shown in 3.1)
- Lifted the mass onto the weighing scale
- Weighed the mass the 1st time
- Lifted the mass and put it back onto the weighing scale
- Weighed the mass the 2nd time
- Lifted the mass and put it back onto the weighing scale
- Weighed the mass the 3rd time

3.1 Calibration of the VW-330-C scale

The routine stated below was used to calibrate the scale.

- **Setting the resolution (count-by) and calibration weight**
  - ◊ Turn the VW330 OFF.
    - (1) *Note the power switch is located on the bottom of the scale in the front on the right side.*

◊ Press and hold the ‘ZERO/MENU’ key while turning the VW330 ON
◊ The display will prompt:
< d = 0.000x
Cal = XX
Where 0.000x is the resolution and XX is the calibration weight.
◊ The ‘bullet’ < on the display will be pointing to kg or lb indicating the selected unit of measure.
◊ Use the units switch to select the desired calibration unit as indicated by the bullet ‘<’ lb or kg.
(1) *Note the units switch is located on the bottom of the scale in the front on the left side.*
◊ Press the ‘TARE/CHG’ key to toggle through the available resolutions (d = 0.000x) until the desired resolution is displayed.
◊ Press the ‘ENT’ key to clear the calibration weight to 00.
◊ Use the numeric keys to enter the desired calibration weight.
◊ When the resolution and calibration weight are set power down the VW330.

• **Calibration**
◊ Turn the VW330 OFF.
(1) *Note the power switch is located on the bottom of the scale in the front on the right side.*
◊ Press and hold the ‘ENT’ key while turning the VW330 ON. There may be a slight delay when powering up in the calibration mode.
◊ The display will prompt:
COUNT
CT330C
XXXXX where XXXXX is the internal raw weight value.
◊ With no weight on the scale wait for the internal weight value to stabilize. A small amount of motion is acceptable.
◊ Press the ‘ZERO/MENU’ key. The display will flash ‘SAVE’
◊ Apply the previously selected calibration weight (see above).
◊ Wait for the internal weight value to stabilize. A small amount of motion is acceptable.
◊ Press the ‘ZERO/MENU’ key. The display will flash ‘SAVE’
◊ Power down the VW330

◊ Turn the VW330 on in the normal weighing mode and check calibration.

3.2 Observations on weighing the masses

- The scale was calibrated using two masses of 20 kg (±0.002 kg). The set weight during calibration was 40.000 kg (Figure 3.2).
- Weight of the calibration masses after calibration was 40.018 kg. Expected was 40.000 kg. Therefore deviation is thought to be +/- 18 grams.
- The scale was not staying level because of low quality plastic feet. It was therefore re-levelled several times
- All masses were lifted using the ring clamp
- The built-in scale level was NOT level.

Figure 3.2 Weighing scale with calibration weights during calibration

- The measurements are shown in Table 3.1.
  - The test mass is lighter than estimated based on Solidworks modelling. The estimated mass without ears is 37 grams more than the measured mass with ears. (1 ear is about 2 grams, 4 ears is about 8 grams). Therefore the deviation from expected is about –45 gr. This is slightly out with the specification.
  - The 1st penultimate mass with ears has the exact same weight as the estimate without ears (1 ear is about 2 grams, 4 ears is about 8 grams). Therefore the mass is about 8 grams lighter than expected. That is within specification.
  - The Reaction mass is 24 grams heavier according to measurements than the estimate. It is therefore within specification.
  - The 2nd penultimate mass is 13 grams lighter according to measurements than the estimate. It is therefore within specification.

Table 3.1 Estimated and measured weights of the masses

Mass	**Estimate [kg]**	**Measurement 1**	**Measurement 2**	**Measurement 3**
Test mass	39.673 (no ears)	39.634 (with ears)	39.636 (with ears)	39.638 (with ears)
1st Penultimate mass	39.556 (no ears)	39.558 (with ears)	39.556 (with ears)	39.552 (with ears)
Reaction mass	42.203	42.224	42.226	42.224
2nd Penultimate mass	39.671 (no ears)	39.658 (no ears)	39.658 (no ears)	39.658 (no ears)

4 Observation of masses

4.1 Reaction mass

The reaction mass is packed in a cotton sheet. The mass is wedged into an aluminium crate, using cardboard sheets that have been cut to accommodate the mass.

A brief inspection of the mass did not reveal any flaws in the glass of the reaction mass. The gold coating looks flawless (Figure 4.1).

Figure 4.1 Reaction mass sitting in aluminium crate

Figure 4.2 Measuring electrical resistance of the coating tracks

4.1.1 Measure electrical resistance of gold tracks

To check the integrity of the gold tracks for the electrostatic drive on the reaction mass, the electrical resistance has been measured using a multimeter (Figure 4.2). The internal resistance of the multimeter was measured to be 0.007 Ω. The plus pole was connected to the start of each track and the minus pole was connected to the furthest end of the track. All measurements showed a resistance of 0.007 Ω, which means the resistance of the gold tracks is *negligible* and the tracks are intact.

4.2 Test mass

Inspection of the test mass revealed the following observations:

- AR coated side shows two flaws in the glass (maybe coating but unlikely) underneath the edge of the coating (Figure 4.3).
- During the previous bonding trip one ear did not bond as well as the other ears due to a dirt speck. Inspection of this "bad" ear still shows a dirt speck and a haze near the neck region (Figure 4.4). The ear is successfully bonded over ~2/3 of the surface.

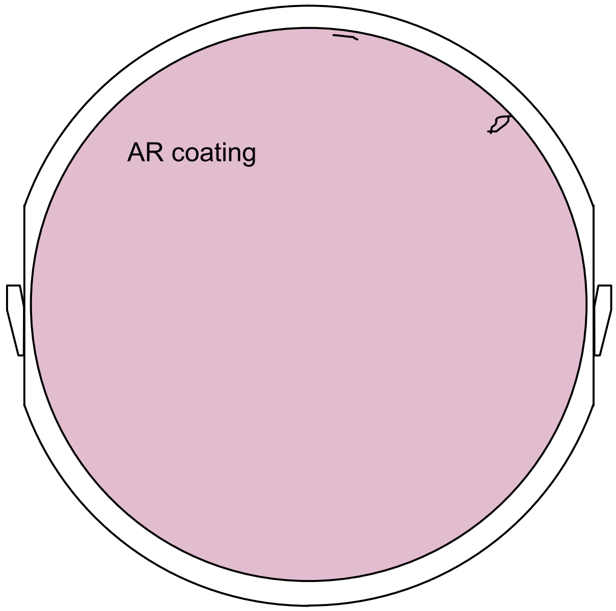
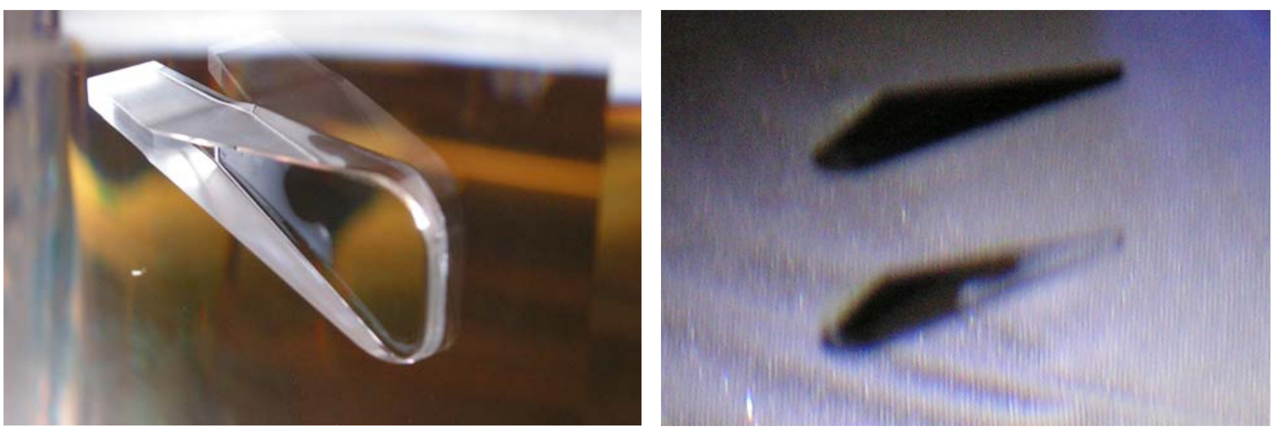


Figure 4.3 Flaws in the glass underneath the AR coating of the test mass



a) as seen from the side **b) As seen through the mass**
Figure 4.4 Haze and dirt speck in the 'bad' ear on the test mass

4.3 1st penultimate mass

During measurement of the position of the ears the weld horn was touched with the callipers, causing a small chip (Figure 4.5).

4.4 2nd penultimate mass

Observation of the 2nd penultimate mass revealed a large number of small flaws in the silica surface on the bonding flats and along the chamfer. We were unsuccessful at photographing the flaws because they are very small and difficult to focus on. By re-cleaning the surface with methanol and blow the surface dry with purified nitrogen gas we have confirmed that the flaws were not in fact dust particles. Figure 4.6 shows drawings of the approximate location of the flaws.

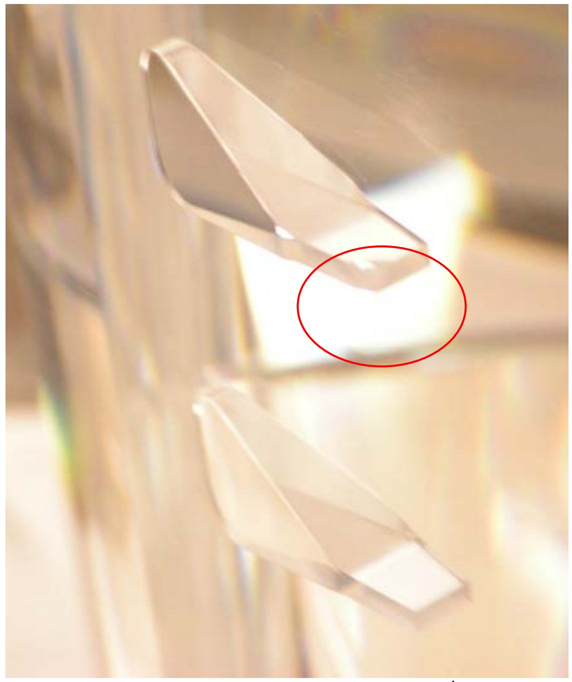
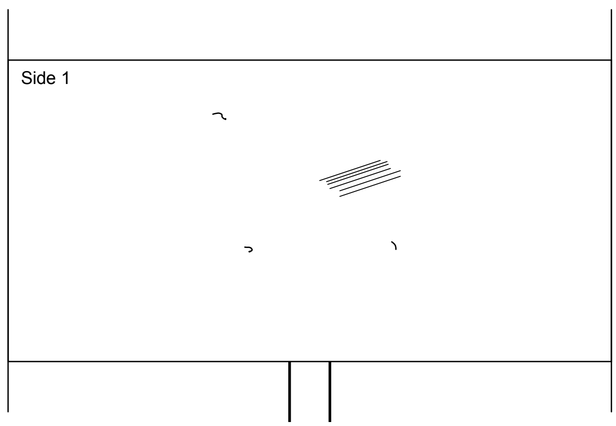


Figure 4.5 Chipped weld horn on 1 ear of the 1st penultimate mass



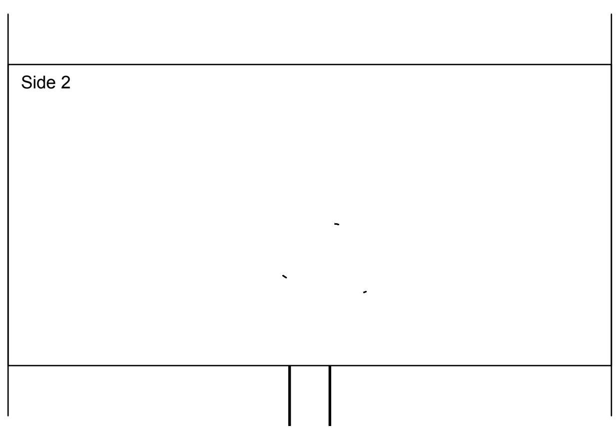


Figure 4.6 Flaws observed in the bonding flats of the 2nd penultimate mass

5 Measuring the ear positions on the test mass and 1st penultimate mass

The positions of the ears that were bonded during the first bonding visit at LASTI (T070223-00-D) were measured for two reasons:

1. To see if the ears were bonded as accurately to their positions as expected.
2. To see if a correction was needed on the position of the ears of the 2nd penultimate mass (in case of a misalignment of the ears on the test mass, as discussed in T070298-00-D).

5.1 Back track position of ears on the test mass

The bonding template was referenced to surface 1 "S1", with HR coating, which is the front face.

The average thickness of the TM according to measurements is:

$$t_{TM} = \frac{200.431 + 199.466}{2} = 199.95 \text{ mm}$$

The centerline distance d_{CL} from surface 1 to the centre of mass:

$$d_{CL} = \frac{t_{TM}}{2} = \frac{199.95}{2} = 99.98 \text{ mm}$$

The reference screws on the bonding template were set to d-screw1 = 0.5 mm (see Table 1, p. 15, T070223-00-K).

The width of the template to the centerline of the template is: 100.5 mm.

Therefore, the distance from the contact point to the centerline of the template was:

$$d_{template} = 100.5 - 0.5 = 100 \text{ mm.}$$

Provided the distances mentioned above, are correct the ears on the test mass have been aligned correctly.

5.1.1 Measure position of the ears on TM

Measure the distance of the outer part of the weld horn of the ear closest to surface 1 to surface 1 (d_{ear} in Figure 5.1).

The required/expected values of the parameters are:

$w_{ear\text{-}front} = w_{ear\text{-}back}$ = 100 – 14.75 = 85.25 mm

w_{ears} = 29.5 mm

The required/expected vertical position of the ears is:

d_{ear} = d-pin + d_{jig} – d-slider = 19.0 + 2.25– 18.7 = 2.55 mm

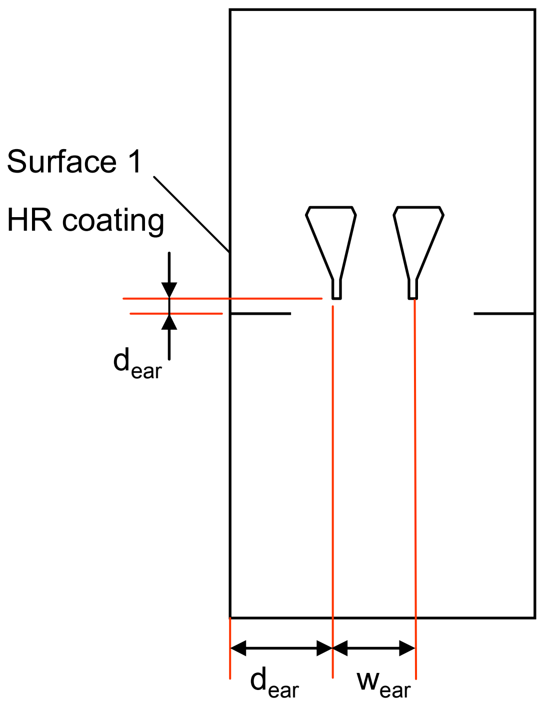
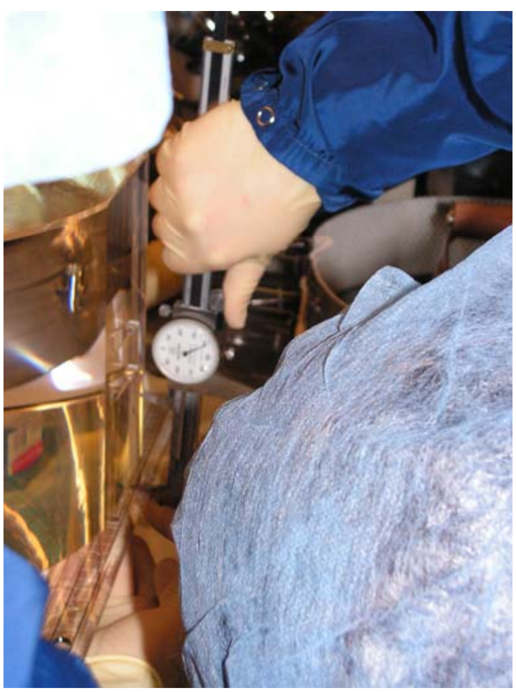


Figure 5.1 Parameters for the positions of the ears

The distances required were measured using a set of calipers (imperial) and a plastic ruler as shown in Figure 5.2 on each side of the mass.



a) Measuring $w_{ear\ front}$

b) Measuring d_{ear}

Figure 5.2 Measuring the positions of the ears

The results for the measurement on the test mass are shown in Table 5.1 and Table 5.2. The ears on the TM right side (bonding side 1) show an apparent offset of the ears of -0.2 mm. The uncertainty in the measurement is however also ±0.2 mm. After a short discussion with Mark Barton on 11th December 2007, it was decided NOT to adapt the alignment on the 2nd penultimate mass for this error.

The vertical alignment of the ears d_{ear} is 0.4 mm larger for bonding side 1 than for bonding side 2 and both are smaller than expected. The expected level of d_{ear} was 2.55 mm. They are both at the same height though.

Table 5.1 Fill in table for measurements of the position of the ears on the TM right side (bonding side 1)

Parameter	**Measured value [mm]**
$w_{ear\text{-}front}$	3.357 inches = 85.267 mm, 3.362 inches = 85.395 mm (85.3 mm)
w_{ears}	1.168 inches = 29.667 mm, 1.162 inches = 29.514 mm (29.6 mm)
$w_{ear\text{-}back}$	3.337 inches = 84.759 mm, 3.344 inches = 84.937 mm (84.8 mm)
$d_{ear\ 1}$	0.095 inches = 2.413 mm
$d_{ear\ 2}$	0.095 inches = 2.413 mm
	Error value [mm]
$w_{total\ smallest\ number}$	199.5 mm
$w_{total\ average}$	199.7 mm (actual width is 199.95)
$w_{total\ largest\ number}$	200.0 mm
$\varepsilon_h = 99.9 - (w_{ear\text{-}front} + w_{ears}/2)$	-0.2 mm (closer to back)

Table 5.2 Fill in table for measurements of the position of the ears on the TM left side (bonding side 2)

Parameter	**Measured value [mm]**
$w_{ear\text{-}front}$	3.358 inches = 85.293 mm, 3.364 inches = 85.445 mm (85.4 mm)
w_{ears}	1.168 inches = 29.667 mm, 1.162 inches = 29.514 mm (29.6 mm)
$w_{ear\text{-}back}$	3.357 inches = 85.267 mm, 3.358 inches = 85.293 mm (85.3 mm)
$d_{ear\ 1}$	0.08 inches = 2.032 mm
$d_{ear\ 2}$	0.08 inches = 2.032 mm
	Error value [mm]
$w_{total\ smallest\ number}$	200.1
$w_{total\ average}$	200.3
$w_{total\ largest\ number}$	200.4
$\varepsilon_h = 100.15 - (w_{ear\text{-}front} + w_{ears}/2)$	-0.1 mm (closer to the back/negligible)

5.1.2 Back track position of ears on the 1st penultimate mass

The bonding template was referenced to surface 1 "S1", with HR coating, which is the front face.

The measured thickness of the 1st PM according to measurements is:

$$t_{1stPM} = 200.5 \text{ mm}$$

The centerline distance d_{CL} from surface 1 to the centre of mass:

$$d_{CL} = \frac{t_{1stPM}}{2} = \frac{200.5}{2} = 100.25 \text{ mm}$$

The reference screws on the bonding template were set to d-screw1 = 0.5 mm (see Table 1, p. 15, T070223-00-K).

The width of the template to the centerline of the template is: 100.5 mm.

Therefore, the distance from the contact point to the centerline of the template was:

$$d_{template} = 100.5 - 0.5 = 100 \text{ mm.}$$

This means that the alignment of the ears is -0.25 mm with respect to the centre of mass.

5.1.3 Measure position of the ears on 1st PM

Measure the distance of the outer part of the weld horn of the ear closest to surface 1 to surface 1 (d_{ear} in Figure 5.3).

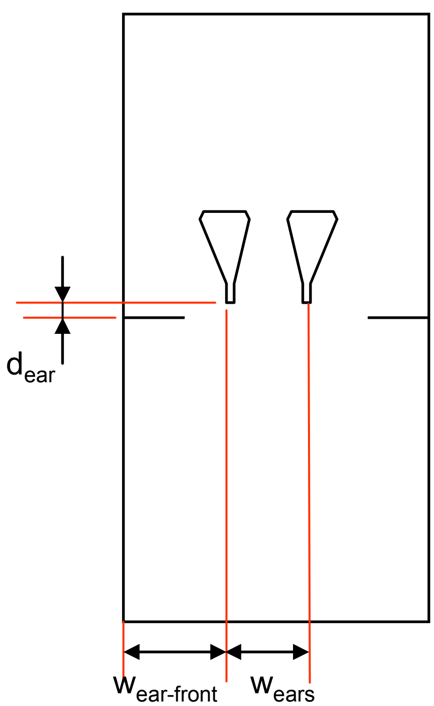


Figure 5.3 Measurement of position of ears

The required/expected values of the parameters are:

$w_{ear\text{-}front} = w_{ear\text{-}back} = 100.25 - 14.75 = 85.50$ mm

$w_{ears} = 29.5$ mm

The required/expected vertical position of the ears is:

$d_{ear} = d\text{-}pin + d_{jig} - d\text{-}slider = 19.0 + 2.25 - 18.6 = 2.65$ mm

The results for the measurement on the 1st penultimate mass are shown in Table 5.3 and

Table 5.4. The ears on both sides of the 1st penultimate mass show an offset of the ears of -0.25 mm as expected. The uncertainty in the measurement is also ±0.2 mm.

Table 5.3 Fill in table for measurements of the position of the ears on the 1st PM right side

Parameter	**Measured value [mm]**
$w_{ear\text{-}front}$	3.373 inches = 85.674 mm, 3.376 inches = 85.750 mm (85.7 mm)
w_{ears}	1.164 inches = 29.566 mm, 1.165 inches = 29.591 mm (29.6 mm)
$w_{ear\text{-}back}$	3.361 inches = 85.369 mm, 3.345 inches = 84.978 mm (85.2 mm)
$d_{ear\ 1}$	0.075 inches = 1.905 mm
$d_{ear\ 2}$	0.097 inches = 2.464 mm
	Error value [mm]
$w_{total\ smallest\ number}$	200.2 mm
$w_{total\ average}$	200.5 mm (should be 200.5 mm)
$w_{total\ largest\ number}$	200.7 mm
$\varepsilon_h = 100.25 - (w_{ear\text{-}front} + w_{ears}/2)$	-0.25 (more to front)

Table 5.4 Fill in table for measurements of the position of the ears on the 1st PM left side (bonding side 2)

Parameter	**Measured value [mm]**
$w_{ear\text{-}front}$	3.371 inches = 85.623 mm, 3.370 inches = 85.598 mm (85.6 mm)
w_{ears}	1.165 inches = 29.591 mm, 1.167 inches = 29.642 mm (29.6 mm)
$w_{ear\text{-}back}$	3.350 inches = 85.09 mm, 3.355 inches = 85.217 mm (85.1 mm)
$d_{ear\ 1}$	0.087 inches = 2.210 mm
$d_{ear\ 2}$	0.087 inches = 2.210 mm
	Error value [mm]
$w_{total\ smallest\ number}$	200.3 mm
$w_{total\ average}$	200.3 mm (should be 200.5)
$w_{total\ largest\ number}$	200.5 mm
$\varepsilon_h = 100.15 - (w_{ear\text{-}front} + w_{ears}/2)$	0.25 mm (more to front)

The vertical alignment of the ears d_{ear1} = 1.9 mm and d_{ear2} = 2.4 mm for bonding side 1 gives a 0.5 mm difference between the two ears, which means that fibres of different lengths would need to be welded to the ears to correct for this. d_{ear1} and d_{ear2} are smaller than the expected level of d_{ear} was 2.55 mm. The ears on bonding side 2 are both at the same height of 2.2 mm which is smaller than the expected level of 2.55 mm.

5.1.4 Recommendations

It is recommended to make a Teflon/plastic measurement jig with shims to measure the position of the ears. Teflon is less damaging for the silica than steel is and using the shims it is likely to be a more accurate and repeatable measurement.

6 Ear bonding to 2nd penultimate mass

6.1 Ear allocation

The ears that have been used for bonding to the 2nd penultimate mass are shown in Table 6.1. They have been inspected and did not show any flaws or chips.

Table 6.1 Ears to go on to the 2nd penultimate mass

	Side 1	**Side 2**
Left ear	Ear AA010[3]	Ear AA014[3]
Right ear	Ear BB005[4]	Ear BB012[4]

The remaining spare ears are: Ear AA001[3], Ear AA003[3], Ear BB016[4], EarBB001[4]

6.2 Bonding jig settings

A drawing of the bonding jig with ear holders and ears and critical reference dimensions is shown in Figure 6.1.

- The same bonding jig has been used, as was used for the test-mass. This is the template with a poorer quality surface finish than the template used for the 1st penultimate mass.
- D-slider for the 2nd penultimate mass was set as has been done for the 1st penultimate mass: D-slider = 18.6 mm[5] (confirmed by Ken Strain at Glasgow suspensions meeting 22nd November 2007)
- The average width of the 2nd penultimate mass is $W_{2nd\ PM}$ = 200.415 mm[6]
- The position of the ears on the second penultimate mass was based on the centre of mass

[3] D060055-02-K "NP-type Refined Ear (Type A)", E070163-00-K "Test report on A ears for Advanced LIGO monolithic suspension"

[4] D060056-02-K "NP-type Refined Ear (Type B)", E070164-00-K "Test report on B ears for Advanced LIGO monolithic suspension"

[5] T070223-00-D "ALIGO NP-type: - Report on Ear Bonding at LASTI 27th August – 31st August"

T070138-00-K "Ribbon/Fibre Length Budget"

[6] GNL-4027-R2 "2nd Penultimate mass measurements"

- The distances W_s and W_l of the jig sides from the centre line is $W_s = 100.5$ mm and $W_l = 107.96$ mm.

  Based on perfect alignment of the ears on the test mass, the settings of the screws can be calculated from:

  Bonding on flat 1 D-screw1 = $W_s - W_{2nd\ PM}/2 - c_h = 0.293$ mm

  Bonding on flat 2 D-screw2 = $W_l - W_{2nd\ PM}/2 - c_h = 7.753$ mm

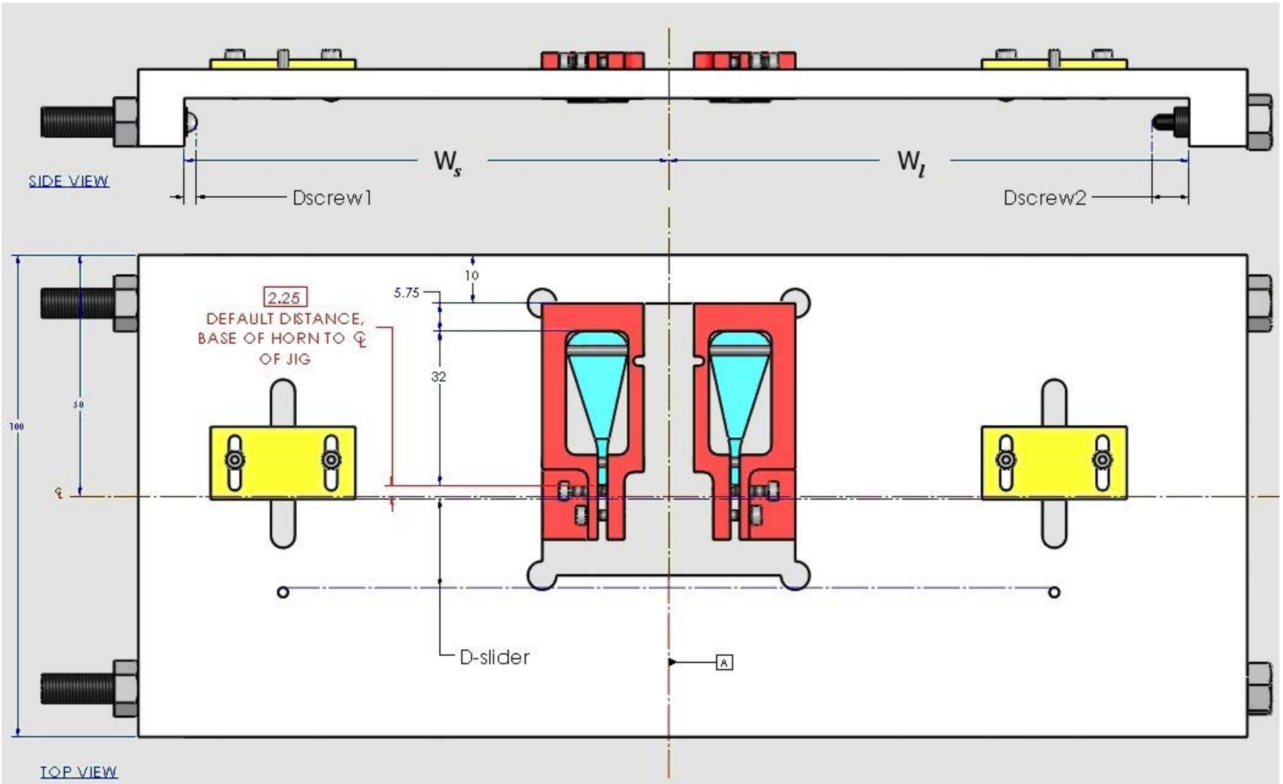


Figure 6.1 Bonding Jig: Critical Reference dimensions

- The distances D-slider1 and D-slider2 were set using a set of calipers and a screw driver (Figure 6.2 a).
- The distances D-screw1 for flat 1, and D-screw 2 for flat 2 were set using a combination of slip gauges and feeler gauges and Allen keys and a spanner (Figure 6.2 b).
- The front face of the penultimate mass was used as reference surface for both sides.
- The recommendations stated in the report on the first bonding exercise (T070223-00-D) still hold.

a) Setting D-slider **b) Setting D-screw1**
Figure 6.2 Setting the bonding jig

Table 6.2 Bonding jig setup for the 2nd penultimate mass

	2nd Penultimate Mass[7]	
	Flat 1[8]	**Flat 2**[9]
D-slider1 or D-slider 2	18.6 mm	18.6 mm
D-jig (new)[10]	2.65mm (above)	2.65 mm (above)
D-screw1	0.29 mm (±0.1)	(contact with sprung bolts)
D-screw2	(contact with sprung bolts)	7.75 mm (±0.1)

6.3 Ear bonding

6.3.1 Prepare the bonding solution

The bonding solution was made by mixing sodium silicate solution with water in a ratio of 1:6 in a 15 ml centrifuge tube and shaking it. The solution was then put into 1.5 ml centrifuge tubes and centrifuged. The solution was then filtered using a 0.2 µm medical filter to remove any larger particles.

Fresh bonding solution was made for each side of the mass.

6.3.2 Wash sides of the mass

The 2nd penultimate mass was washed in the same way as was done with the 1st penultimate mass in the first bonding exercise. The mass was moved onto a V-block on an ultrasonic bath on a movable trolley.

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[7] D050421-05-K_Serial number 002 (the second of the two penultimate masses).

[8] D050421-05-D_Surface "S2" in zone "D8". Template referenced to front face, surface "S3".

[9] D050421-05-D_Surface "S1" in zone "D8". Template referenced to front face, surface "S3".

[10] Distance from tip of the ear to the reference line on the flat (+/-0.25mm, the width of the reference line)

One side was washed on the 11th December using cerium oxide and de-ionized water first to make the bonding surface hydrophilic and then sodium bicarbonate to remove the remnant cerium oxide. This was followed by a rinse and a wipe with methanol.

The mass was then moved back onto the bonding table using the ergo arm, while covering the bonding surface with an optical wipe. Just prior to applying the template the bonding surface was carefully wiped with methanol and purified nitrogen was blown over the surface with a de-ionizing gun. (This last step was not done during the first bonding exercise, because the pressure of the nitrogen flow was too high.) The surface was then inspected to look for dust particles. These inspections did not reveal dust, but they did reveal the flaws in the silica surface discussed in section 0.

The other side of the mass was washed on the 12th December just prior to bonding with the same procedure as discussed above.

The sides have not been washing simultaneously, to reduce the risk of dirt settling on the second bonding surface while the ears on the first bonding surface are settling.

6.3.3 Wash 2 ears and put them into the ear holders

Two ears were washed at the sink in the flow cabinet using the same procedure as for the mass, except that the have not been blown dry with nitrogen gas, just prior to bonding onto each surface.

The ears have been put in their ear holders and were wiped with methanol just prior to bonding.

6.3.4 Setting template on mass

The template was set onto each side of the mass prior to bonding.

6.3.5 Bond ears

- The pipette was set to 0.7 μl.
- The bonding solution was pipetted and checked to see if the amount is as expected.
- The bonding surface was inspected for dust
- The bonding solution was applied to the surface guided by reference lines on the template.
- The ear was inspected for dust and carefully turned over and then lowered onto the bonding surface of the mass.
- The bonds were then inspected and photographed.

6.3.6 Removing the ear holders and template

Approximately 5 minutes after bonding the ear holders and template were removed in order not to over-constrain them while curing.

7 Inspection of bonds

All bonds initially showed bubbles and colored fringes. Some bubbles disappeared within a few minutes and the fringes on all bonds disappeared over a number of hours, except for ear AA014 on side 2. It still had 2 fringes after 4 hours. All bonds still showed small bubbles when the mass was packed.

Pictures have been taken by filming the bonds. It is difficult to take sharp videos once the template has been removed. Therefore drawings have been made, showing features of the bond. All are shown in Figure 7.1.

It is unclear why 2 of 4 bonds show so many small bubbles. The procedure was exactly the same, except blowing the surface of the mass with nitrogen.

The temperature in the clean room seemed to be higher than during the first exercise in August. The temperature in the clean room on 12-12-2007 was significantly higher than on 11-12-2007. It was not measured.

a) Side 1 ear AA010

(11-12-2007, 15.57)

b) Side 1 ear AA010

(11-12-2007, 16.02)

c) Side 1 ear AA010

(12-12-2007, 9.48)

d) Side 1 ear BB005

(11-12-2007, 15.57)

e) Side 1 ear BB005

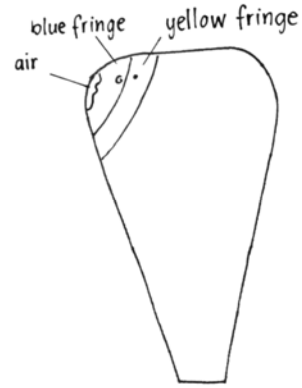
(11-12-2007, 15.59)

f) Side 1 ear BB005

(12-12-2007, 9.48)

g) Side 2 ear AA014

(12-12-2007, 10.56)



h) Side 2 ear AA014

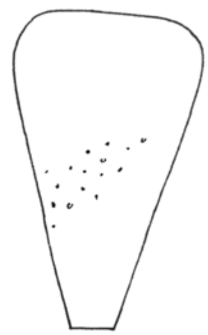
(12-12-2007, 16.00)

i) Side 2 ear BB012

(12-12-2007, 10.57)

j) Side 2 ear BB012

(12-12-2007, 10.57)



h) Side 2 ear BB012

(12-12-2007, 16.00)

Figure 7.1 Fringe pictures and drawings after bonding

10 minutes after bonding the observation was made that ear AA010 on side 1 had slid inside its holder, which has given the ear a vertical off-set of approximately 1 mm from the prospected off-set. It was decided not to de-bond the ear. This particular ear had been used to explain the alignment of the ear into its holder to the observers. The ear might have slided during the final methanol wipe.

The ears on the 2nd penultimate mass were covered using small plastic tubs and the mass was moved back into the container using the ergo-arm at 16.00 hours.

8 Remaining remarks, conclusions and recommendations

Some remaining remarks are:

- The air used in the room in which the bonding was performed is shared with the mechanical workshop next door. The air is filtered with HEPA filters in the clean room tent.

- The wheels of the ergo-arm were not replaced, because the new castor wheels did not want to roll at all.

In conclusion:

- All masses have been weighed. The masses of the reaction mass, and the penultimate masses were within ±30 gram deviation from the mass calculated using solidworks. The test mass is about 45 grams lighter than the mass calculated using solidworks.
- The position of the ears on the test mass was accurate to within 0.2 mm of the prospected in horizontal directed. The ears were 0.15 mm higher than prospected in vertical direction. They did not have an off-set with respect to each other.
- The horizontal position of the ears on the 1st penultimate mass was off-set by 0.25 mm to the back-side as expected. The vertical positions of the ears on side 2 were 0.44 mm higher than expected. They did not have an off-set with respect to each other. The vertical positions of the ears on side 1 were off-set by 0.5 mm. Also the ear with the smallest error was 0.2 mm higher than expected.
- During measurement of the ear position one weld horn on the 1st penultimate mass was chipped slightly.
- The electrical resistance of all gold electrostatic drive tracks on the reaction mass is negligible.
- Inspection of the masses revealed that:
  - The ‘bad’ ear on the test-mass has bonded over 2/3 of its surface area. The dirt speck that is the cause of a partially unsuccessful bond was still visible.
  - The test mass showed a few flaws in the glass underneath the edge of the AR coating.
  - The 2nd penultimate mass showed flaws in the glass on the bevel and bonding surfaces.
- All four ears were bonded successfully to the 2nd penultimate mass: all ears showed some but in surface area insignificant amount of bubbles.

Recommendations:

- A plastic measuring aid should be developed to measure the positions of the ears, such that the accuracy and risk of damaging the ears can be reduced.
- Change the air supply to the laboratory such that it is independent of a dirty room like the mechanical workshop.

A third stage of the bonding delivery to LASTI will be conducted in early 2008, in which prisms will be glued to the reaction mass and the penultimate masses.