



AdvLIGO Modecleaner Design and Testing Status

Mark Barton

LIGO LAB: CIT: H. Armandula, J. Heefner, J. Romie, C. Torrie, P. Willems. MIT: P. Fritschel, M. MacInnis, K. Mason, R. Mittleman, D. Ottaway, L. Ruet, D. Shoemaker. LHO: B. Bland, D. Cook. LLO: J. Hanson, J. Kern, H. Overmier, G. Traylor. Other: L. Williams
GEO600: GLASGOW: G. Cagnoli, C. Cantley, D. Crooks, E. Elliffe, A. Heptonstall, J. Hough, R. Jones, M. Perreur-Lloyd, M. Plissi, D. Robertson, K. Strain, P. Sneddon, H. Ward GLASGOW/STANFORD: N. Robertson, S. Rowan UNIVERSITAT HANNOVER: S. Gossler, H. Lueck

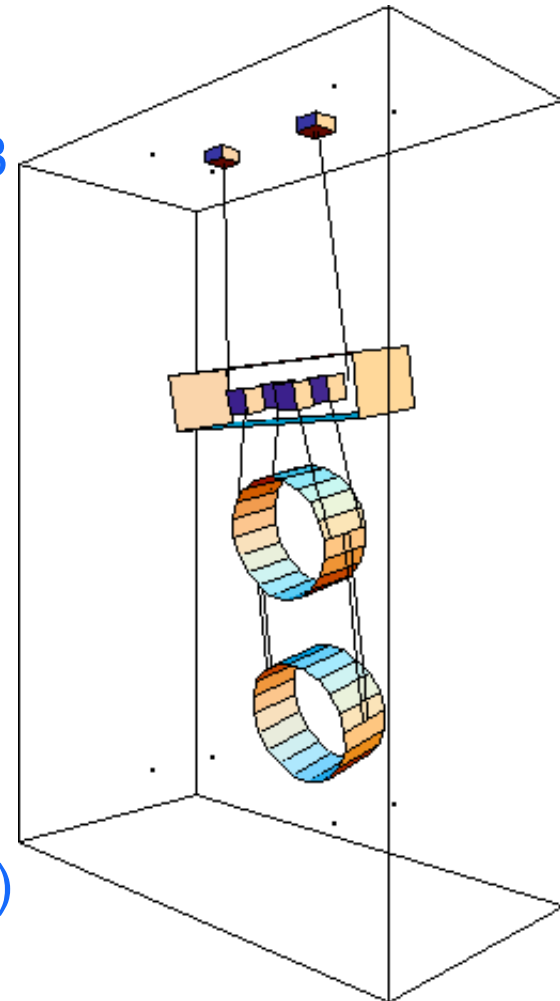
LSC Meeting, LHO, 8/19/04

Requirements

- Design requirements for seismic platform + suspension (from T010007-01):
 - Longitudinal noise (all sources): 3×10^{-17} m/ $\sqrt{\text{Hz}}$ at 10 Hz, falling to 3×10^{-19} m/ $\sqrt{\text{Hz}}$ at 100 Hz (based on coupling to frequency noise)
 - Pitch noise: 3×10^{-14} rad/ $\sqrt{\text{Hz}}$ at 10 Hz, falling to 3×10^{-16} rad/ $\sqrt{\text{Hz}}$ at 100 Hz (assumes ± 1 mm beam centering)
 - Yaw noise: 3×10^{-14} rad/ $\sqrt{\text{Hz}}$ at 10 Hz, falling to 3×10^{-16} rad/ $\sqrt{\text{Hz}}$ at 100 Hz (assumes ± 1 mm beam centering)
 - Vertical noise: 3×10^{-14} m/Hz at 10 Hz, falling to 3×10^{-15} m/Hz at 100 Hz (assumes 0.001 coupling to longitudinal)
 - Transverse noise: 3×10^{-14} m/Hz at 10 Hz, falling to 3×10^{-15} m/Hz at 100 Hz (assumes 0.001 coupling to longitudinal)

Conceptual Design

- Conceptual design given in T010103-03
- Based on GEO triple design
 - 2 maraging steel blade springs (on structure)
 - 2 wires
 - T-shaped upper mass (3 kg)
 - four maraging steel blade springs
 - four wires
 - fused silica intermediate mass
 - four fused silica fibres
 - fused silica optic (15 cm x 7.5 cm, 3 kg)



- Matlab model by (Torrie et al.)
 - » Quick to run
 - » Models springs indirectly by adding their compliance to that of the wires
 - » Does not allow for asymmetries
- Mathematica model (Barton)
 - » More general but slower
 - » Useful as a double-check and to investigate effects of asymmetries

Normal Modes

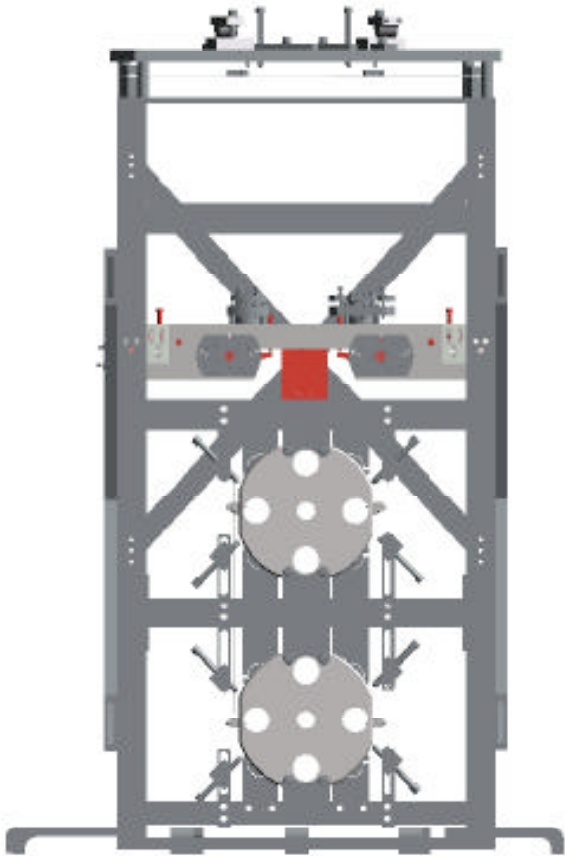
- 18 normal modes:
 - » all with anti-node at top mass for controllability
 - » all well below measurement band except for vertical and roll modes at 19.8 and 28.5 Hz

N	f_ref (Hz)	type
1	0.670382	x
2	0.677404	y
3	0.849997	pitch
4	1.08049	yaw
5	1.11008	z
6	1.5153	y
7	1.51551	x
8	2.03232	yaw
9	2.09333	roll
10	2.27611	roll
11	2.64008	x
12	2.7755	yaw
13	3.55017	pitch
14	3.57592	roll
15	3.91252	z
16	4.0387	pitch
17	19.8397	z
18	28.5362	roll

Controls Prototype Purpose/Limitations

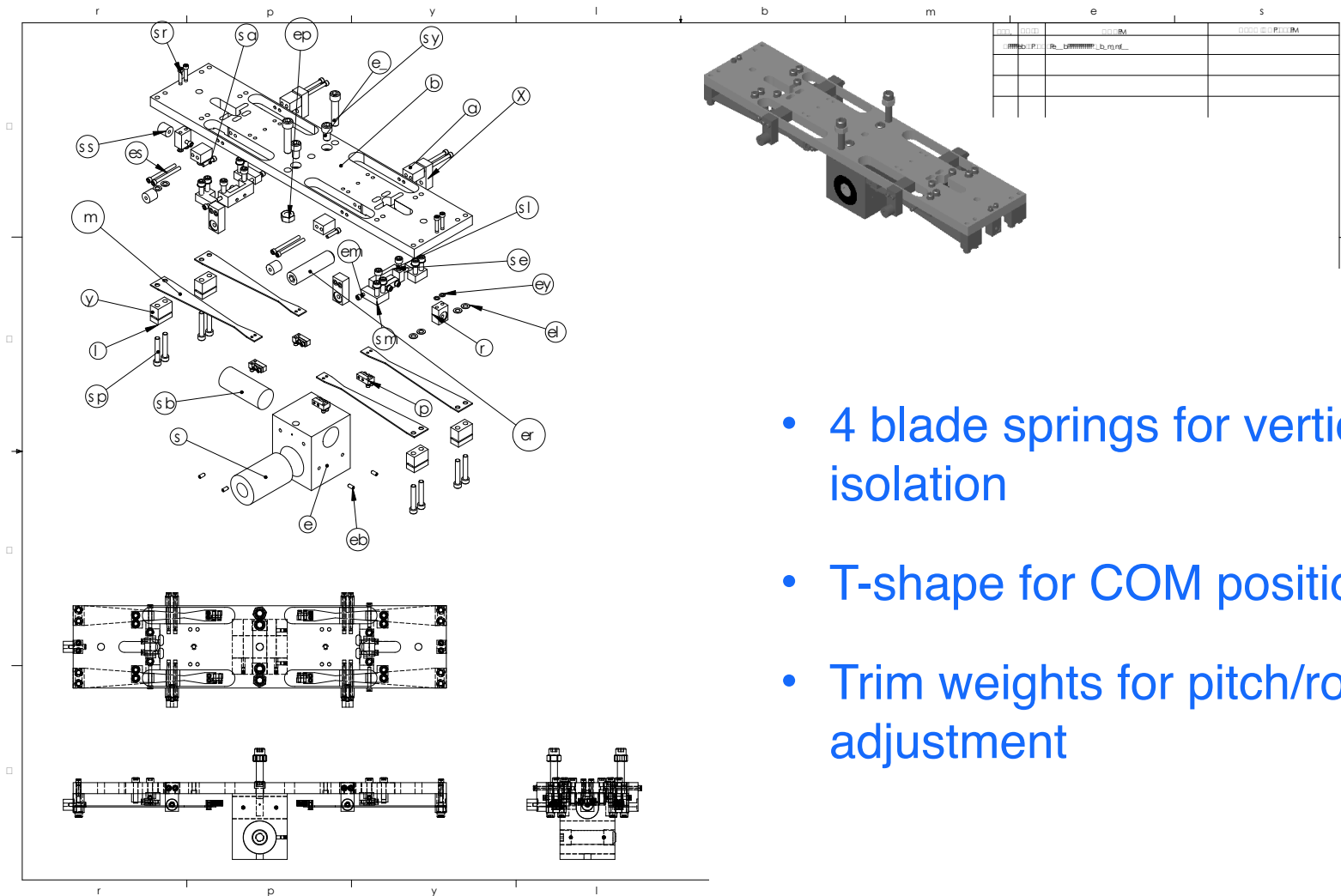
- For test of mechanical behaviour, assembly techniques, local control
 - » 6 “hybrid” OSEMs (LIGO-I sensor, larger magnet/coil) on upper mass for local control (analog electronics by GEO)
- Limitations
 - » Preliminary structure design (does not yet meet 150 Hz internal mode requirement)
 - » Dummy masses for I.M. and optic (same mass, MOI)
 - » Wires instead of fibres between I.M. and optic (no attempt to match elasticities -> frequencies of highest frequency vertical and roll modes are unrepresentative)
 - » 4 LIGO-I OSEMs on each of I.M. and optic for monitoring position/pitch/yaw, and as a stand-in for future low-noise actuators for global control

Controls Prototype Structure



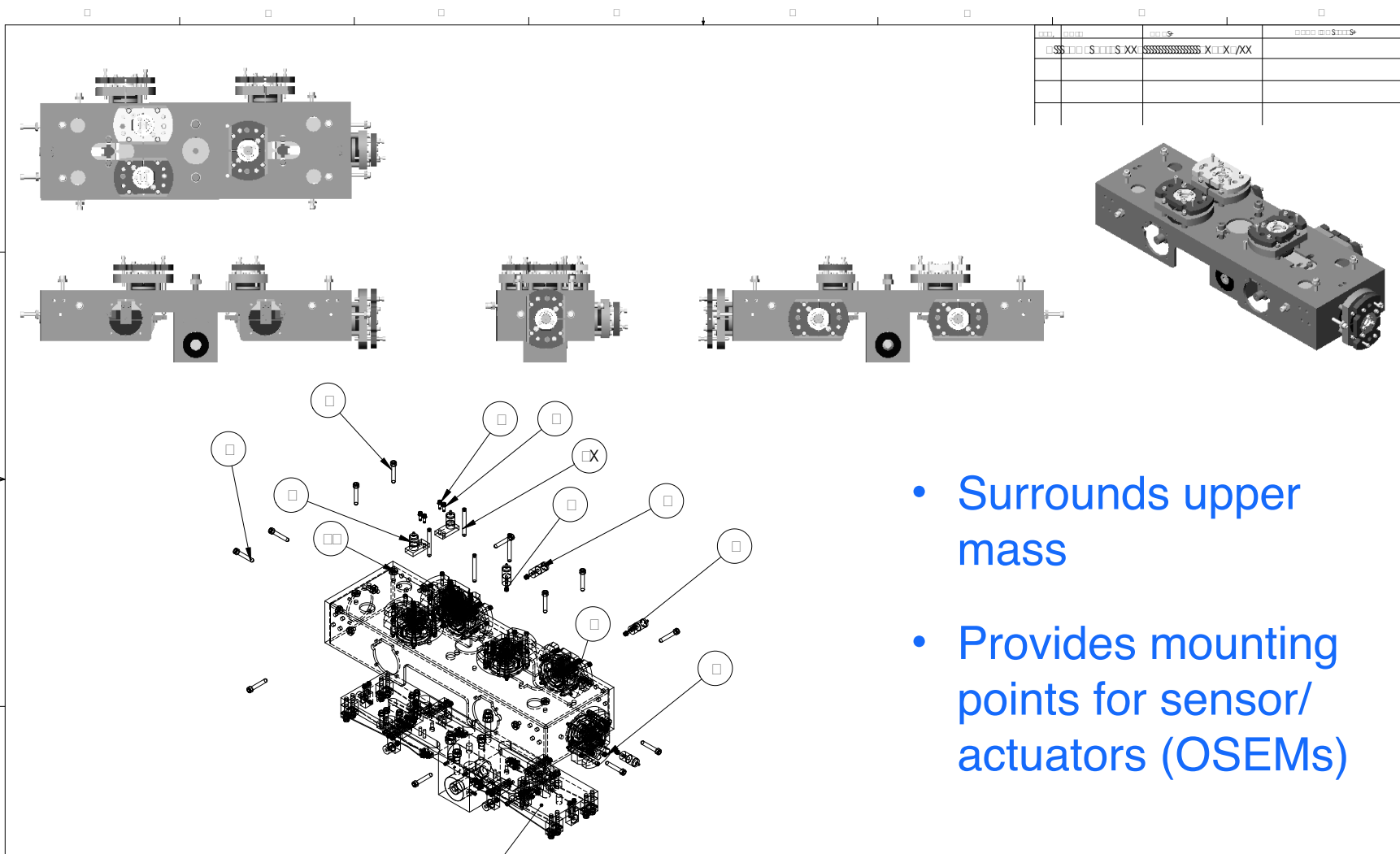
- Footprint:
 - » 220 mm x 400 mm x 890 mm
- Mass
 - » Suspended - 9 kg
 - » Non-suspended - 18 kg
 - » Bare structure - 11 kg
- Centre of gravity
 - » 365 mm from bottom

Upper Mass



- 4 blade springs for vertical isolation
- T-shape for COM positioning
- Trim weights for pitch/roll adjustment

“Tablecloth”



Hybrid OSEM

- Shadow sensor identical to that in LIGO-I OSEM
- Larger coil to accommodate larger magnet for greater force

REV.	DATE	DCN #	DRAWING TREE #
05	07/FEB/2003		SPRING PINS NOW USED RATHER THAN SPACERS
06	24/FEB/2003		ADDITION OF INSULATING SPACERS, SHOULDERS ETC.
07	01/MAY/2003		ADDITION OF COIL FORMER ONE PIECE & NOTE ON ISOLATION

ITEM NO	REQ.	SPARE TOT.	PART NUMBER	DESCRIPTION	MATERIAL
10	2	1	3	SST VENTED SOCKET HEAD CAP SCREW #4-40 UNC-3A X 0.625 LONG	A6 300 SSTL
9	4	2	6	FLAT WASHERS NAS 620-4L (OR EQUIV.)	300 SSTL
8	4	4	8	A6-SST SOCKET HEAD CAP SCREW #4-40 UNC-3A X 0.875 LONG	A6 300 SSTL
7	1	1	2	D030183 COIL FORMER CLAMP ONE PIECE	1801-TI-AL
6	2	1	3	D030123 SPACER FOR COIL FORMER BRACKET	TEFLON
ALT 1	1	1	2	D030124 KAPTON FILM 0.002" THICK (FOR COIL FORMER) 1.0" WIDE BY 4.7" LONG	KAPTON
4	1	0	1	D030105 ASSEMBLY COIL FORMER AND ASSOCIATED PARTS	
3	2	1	3	D030122 SHOULDER FOR COIL FORMER BRACKET	MACOR
2	4	2	6	A6-SST SOCKET HEAD CAP SCREW #4-40 UNC-3A X 1.1 LONG	A6 300 SSTL
1	1	0	1	D020282 COIL FORMER BRACKET	300 SSTL

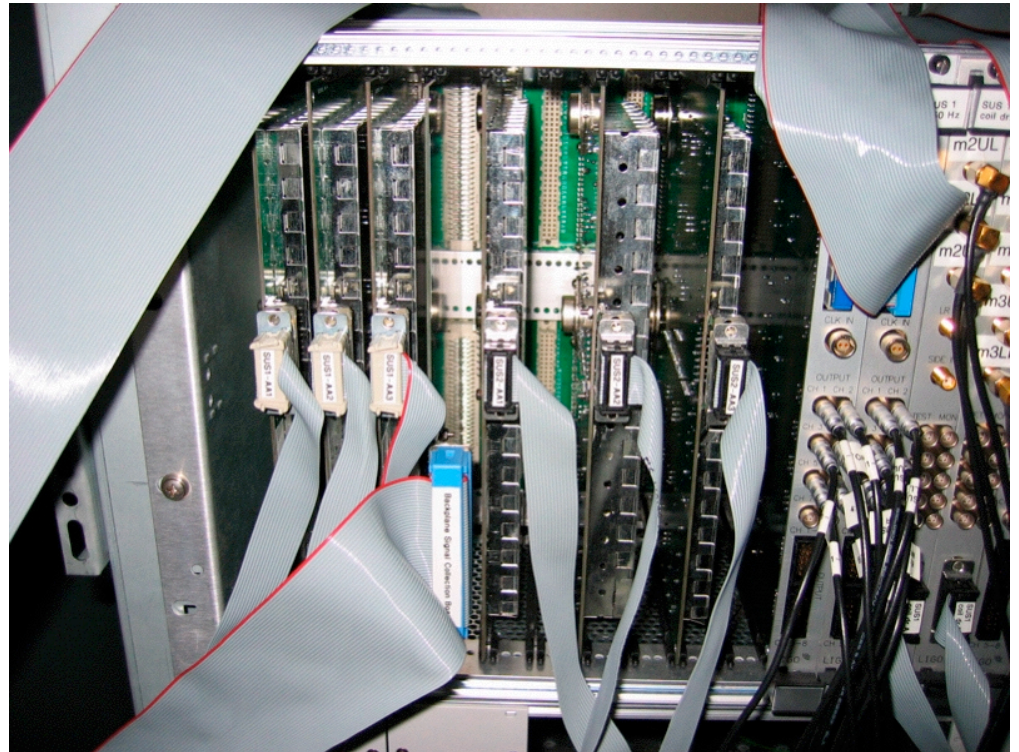
NOTES: (UNLESS OTHERWISE SPECIFIED)
 1. DIMENSIONS IN INCHES.
 2. REMOVE ALL SHARP EDGES, R.02 MIN.
 3. ALL MACHINING FLUIDS SHALL BE WATER SOLUBLE AND FREE OF SULFUR, CHLORINE AND SILICONE, SUCH AS CINCINNATI MILACRON'S CIMTECH 410 (STAINLESS STEEL).
 4. ASSEMBLE ACCORDING TO HYBRID OSEM ASSEMBLY SPECIFICATION, LIGO E03084-00-D.
 5. ADDITIONAL ISOLATION OF THE COIL HEAD ASSEMBLY, D030105, SUPPLIED BY A COMBINATION OF D030122, D030123, D030124 SHOULD BE USED AS REQUIRED.

PARTS LIST
 DRAWN: CIT DATE: 007/2003
 CHECKED: _____
 DIMENSIONS ARE IN INCHES TOLERANCES
 .XXX ±0.01
 .XX ±0.005
 ANGULAR ±0.5°

CALIFORNIA INSTITUTE OF TECHNOLOGY
 MASSACHUSETTS INSTITUTE OF TECHNOLOGY
ADVANCED LIGO
 SYSTEM: SUS
 SUB-SYSTEM: MC: COIL
 PART NAME: COIL ASSEMBLY
 REV (DWS): NO. 09
 B D020225
 SCALE: N/A PRODUCTION SHEET 01 OF 01

SolidWorks Educational License
 Instructional Use Only

- dSpace digital controller (<http://www.dspaceinc.com/>)
 - » PPC processor in expansion box, linked to Wintel PC by optical fibre
 - » control algorithm programmed in Simulink on PC
 - » user-interface programmed in dSpace ControlDesk on PC
- Drivers for 6 hybrid OSEMs on upper mass by GEO
- Drivers for 8 LIGO-I OSEMs on lower masses and other analog electronics by CDS



Control Algorithm

- Simple diagonalizing controller
 - » output from 6 hybrid OSEMs converted to x, y, z, yaw, pitch, roll
 - » standard GEO control law (velocity damping with rolloff above ≈ 10 Hz) in all DOFs
 - » de-diagonalization to individual OSEM drive signals

Controller UI (ControlDesk)

The screenshot displays the ControlDesk Developer Version interface for the LIGO experiment. The main workspace is divided into two sections for 'SUS 1' and 'SUS 2'. Each section contains a 'Servo Master Switch' and a 'Step Master Switch', both with 'On/Off' buttons. Below these are control panels for three motors (m1, m2, m3) for each system. Each motor panel includes gain controls (x, y, z) and step force/torque controls (pitch, yaw, roll) for both the motor and the offset. The interface features a hierarchical tree on the left, a toolbar at the top, and a status bar at the bottom with a log viewer and system information.

SUS 1 Controls:

- Servo Master Switch: On/Off
- Step Master Switch: On/Off
- Motor m1: x gain (1.000), y gain (1.000), z gain (1.000); pitch gain (1.000), yaw gain (1.000), roll gain (1.000); m1 x step force (0.000), m1 y step force (0.000), m1 z step force (0.000); m1 x step torque (0.000), m1 y step torque (0.000), m1 z step torque (0.000); m1 x offset force (-100 to 100), m1 y offset force (-100 to 100), m1 z offset force (-100 to 100); m1 yaw torque force (-1 to 1), m1 pitch offset torque (-1 to 1), m1 roll offset torque (-1 to 1).

SUS 2 Controls:

- Servo Master Switch: On/Off
- Step Master Switch: On/Off
- Motor m1: x gain (1.000), y gain (1.000), z gain (1.000); pitch gain (0.000), yaw gain (1.000), roll gain (1.000); m1 x step force (0.000), m1 y step force (0.000), m1 z step force (0.000); m1 x step torque (0.000), m1 y step torque (0.000), m1 z step torque (0.000); m1 x offset force (-100 to 100), m1 y offset force (-100 to 100), m1 z offset force (-100 to 100); m1 yaw torque force (-1 to 1), m1 pitch offset torque (-1 to 1), m1 roll offset torque (-1 to 1).

Log Viewer:

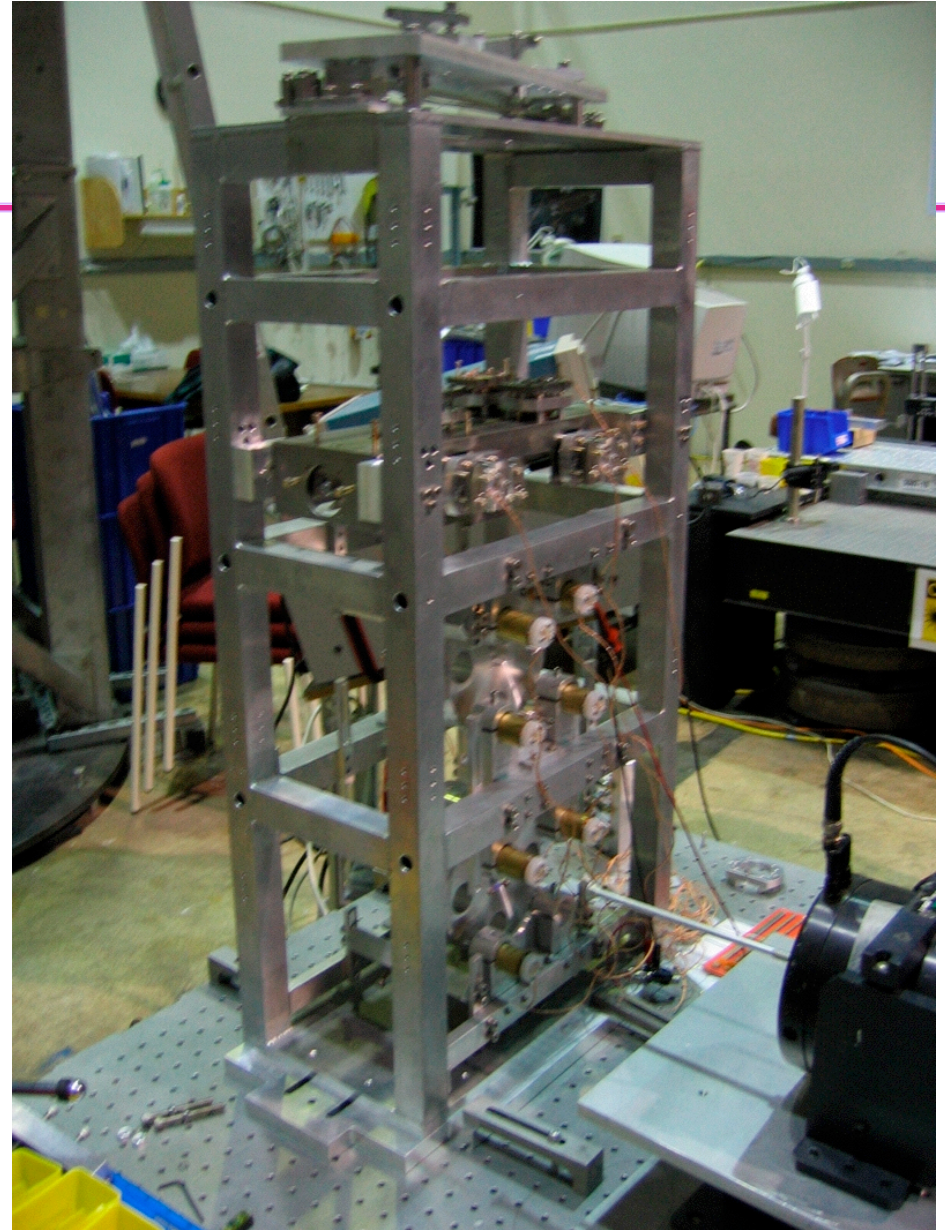
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Instrumentation: Loading file 'C:\Documents and Settings\control\My Documents\workspace\mchuldagivedual\capture.lay' ...
DataAcq: 10 connections read
Instrumentation: Loading file 'C:\Documents and Settings\control\My Documents\workspace\mchuldagivedual\judge.lay' ...
DataAcq: 116 connections read
Instrumentation: Loading file 'C:\Documents and Settings\control\My Documents\workspace\mchuldagivedual\control.lay' ...
DataAcq: 272 connections read
Instrumentation: ... finished
Variable Browser: ... finished
Experiment: ... finished
    
```

LIGO

Mode Identification

- Mode identification measurements done in air at Caltech
- Shaker in swept-sine mode was applied to strategic points on structure to excite preferentially in x, y, yaw etc



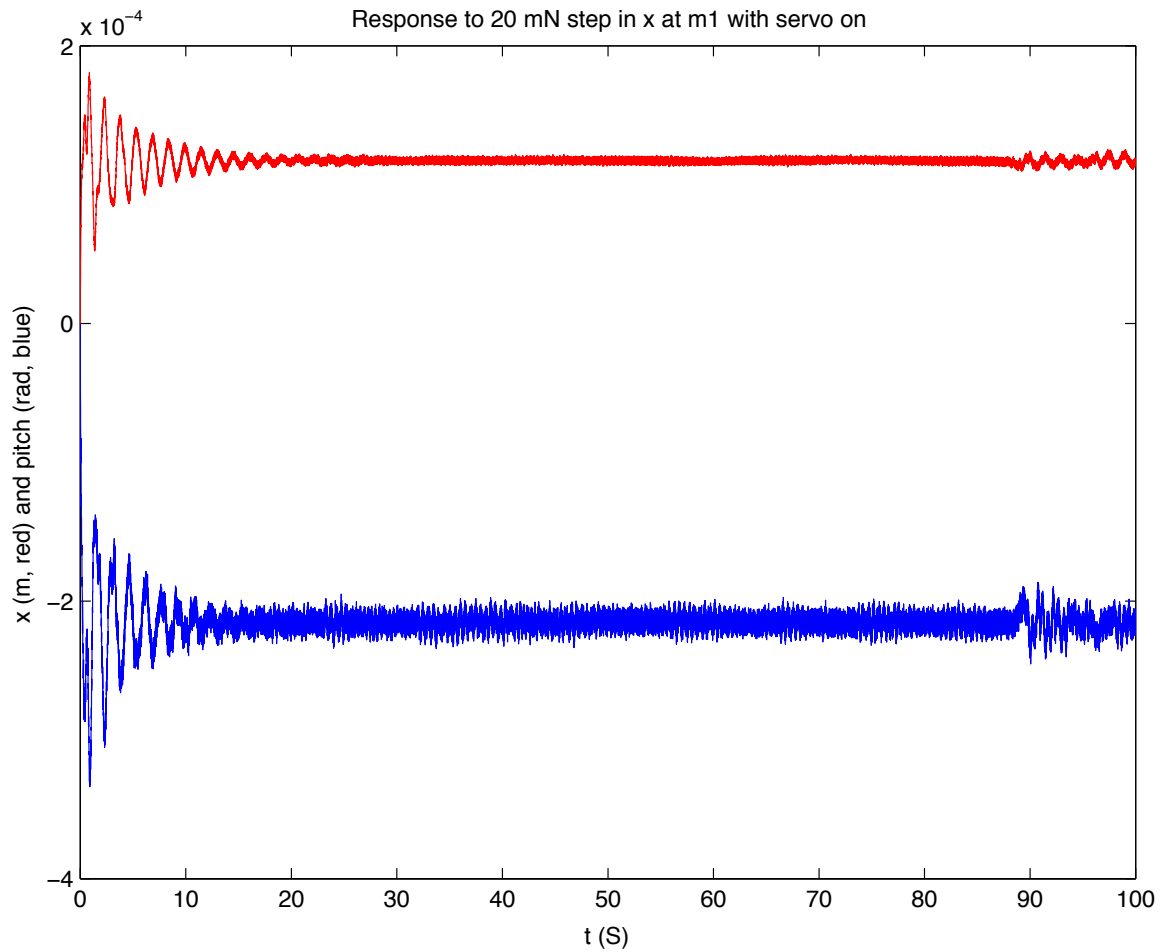
Mode Identification Results

- Theory:
 - » Mathematica model
 - » As-built parameters
 - » One fudge: set elasticity of “fibres” to reproduce highest vertical frequency
- Very good agreement (<10%) in other 17 frequencies

N	f (as-built)	f (meas)	type
1	0.667414	0.66	x
2	0.673777	0.671	y
3	1.05552	1.172	pitch
4	1.08668	1.094	yaw
5	1.1875	1.125	z
6	1.53096	1.516	y
7	1.53112	1.518	x
8	1.95707	1.742	yaw
9	2.22731	2.141	roll
10	2.74927	2.672	roll
11	2.82618	2.813	x
12	3.53868	3.563	yaw
13	3.61966	3.75	pitch
14	3.76754	3.578	roll
15	4.33279	4.047	z
16	4.84859	4.813	pitch
17	34.5714	34.875	z
18	49.1598	49.875	roll

Damping Response

- Preliminary damping results in air at Caltech
- Good damping in all modes

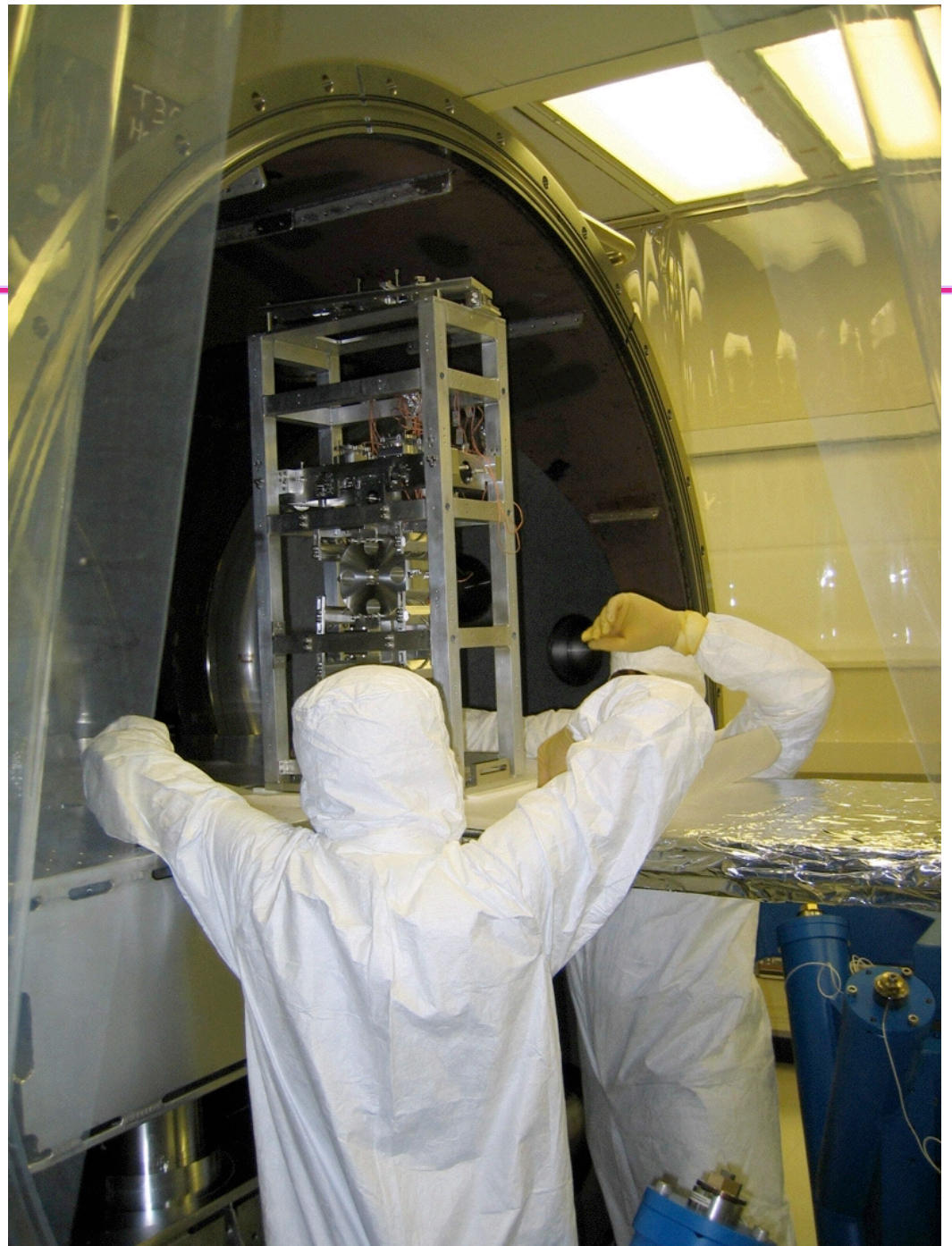




LIGO

Installation

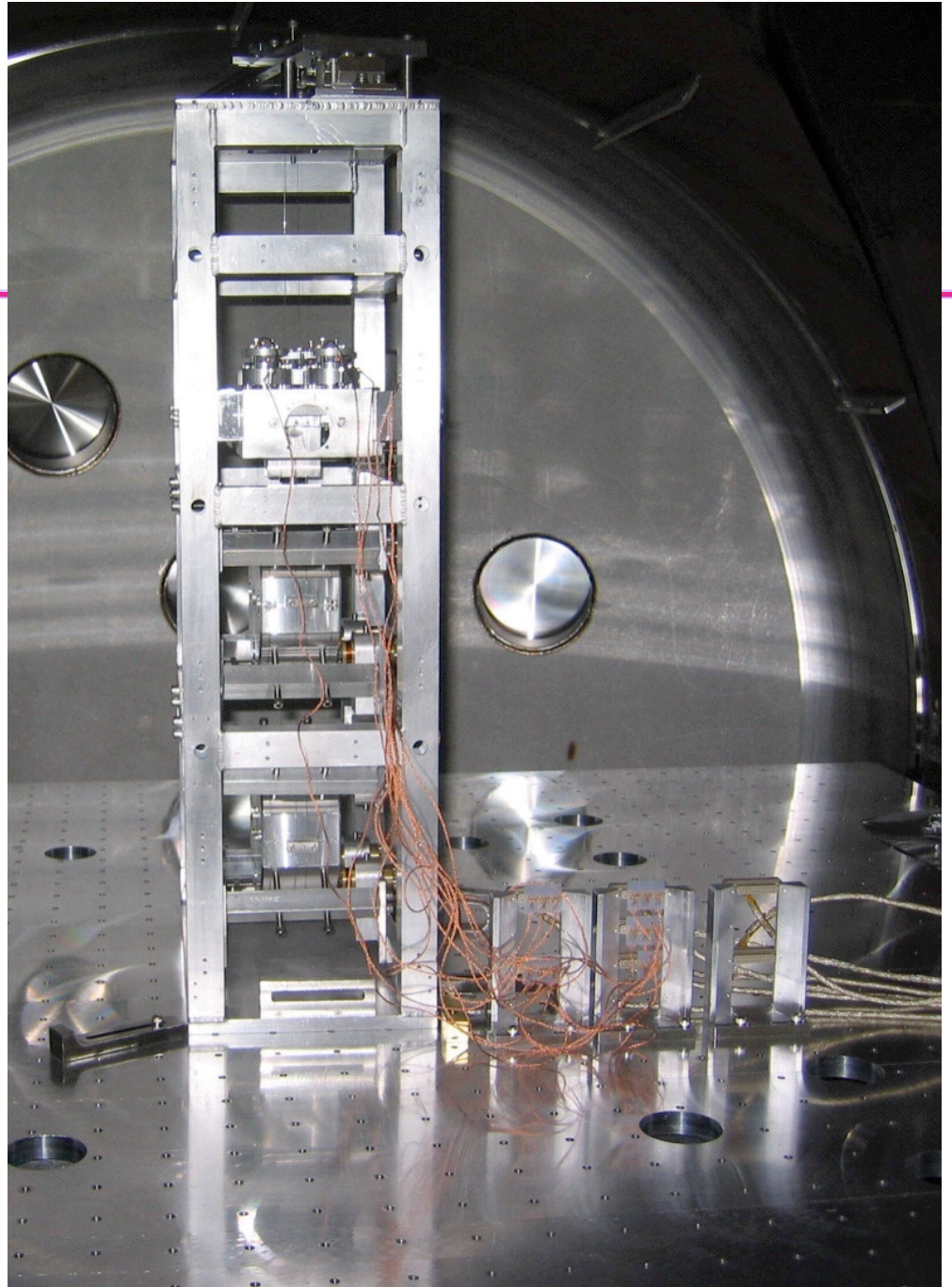
- Structure is manhandled onto bed of forklift and raised to level of HAM optical table
- “Teflon highway” is used to slide structure into position
- Structure was tipped onto one edge to allow removal of highway - need a safer procedure



LIGO

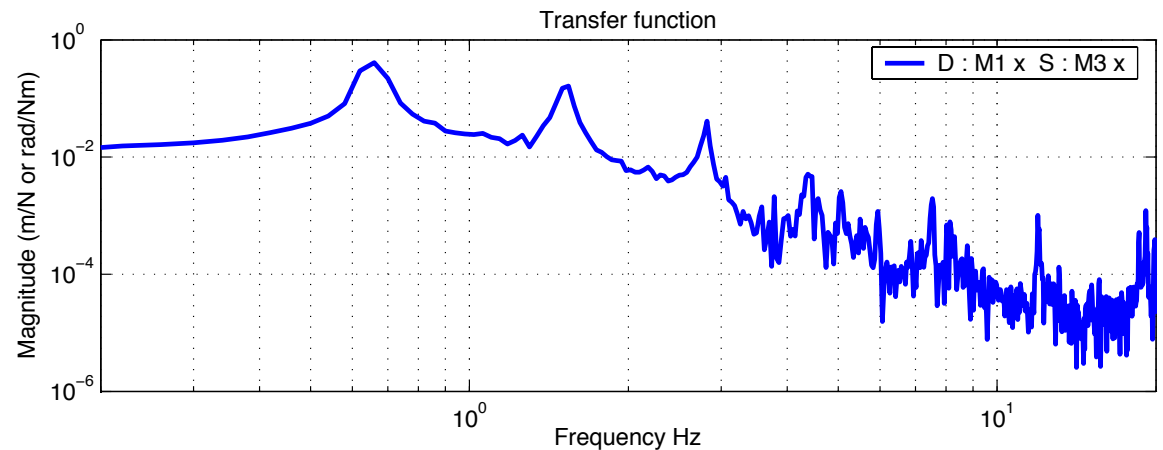
In Position

- After installation and alignment in LASTI

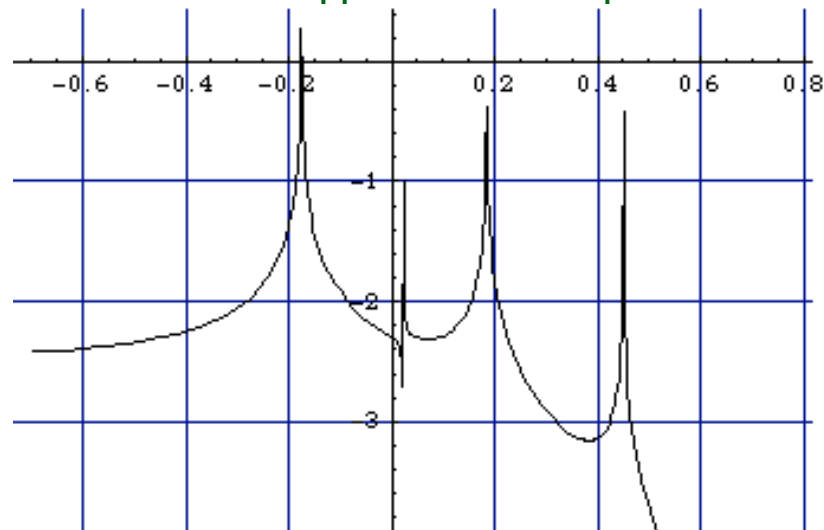


Transfer Function Results

- First transfer function results by Laurent Ruet at LASTI
- All combinations of OSEM actuator input to OSEM sensor output



Force in x at upper mass to displacement in x at optic



- Continued testing at LASTI
 - » Use HEPI as shake table to do true displacement transfer functions
- Design team focussed on quad
- Structure needs beefing up to meet (or more closely approach) 150 Hz structure resonance goal
- Noise prototype with fused silica masses, fibres