Summary Report of Visit to LIGO, Caltech: January 25th – February 25th 2004

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The following is a summary of the work completed during a recent visit to Caltech. The purpose of the visit was to continue the ongoing collaborative work between the University of Glasgow and California Institute of Technology. The key aims were firstly to assist with the set-up of a universal data management vault for use by the suspensions design team in California, Scotland and England, and secondly, to begin to establish a final design for the Caltech Quad Prototype. Supplementary to this much work was done in revising a number of documents in-line with the recent developments in the way that the collaborative design team will function.

I would like to thank Calum Torrie with whom I worked closely on the majority of the below tasks discussed below throughout this productive trip. I must also thank Janeen Romie, Irene Baldon and all others who assisted in the organisation of my visit and who ensured I had a very pleasant stay.

1. Caltech Quad Development

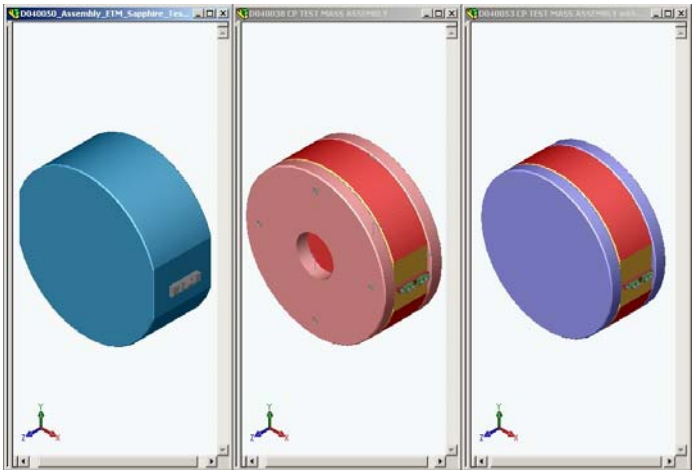
1.1. Suspension

To make inroads into achieving the target of a 'Quad for Christmas', one of the initial tasks worked upon was the development of the test mass for the Caltech Quad ETM prototype, for which a layout design was developed through the middle of last year. The test mass design was a good starting point as by designing & manufacturing this we would get a good feel as to the scale of the large masses we were to be designing at an early stage and hence allow for better informed decision-making during the design of the more complex top and upper-intermediate mass.

A multi-purpose test mass design was created that allowed for the attachment of either metal or glass faces. This meant that the design could be used in future Noise Prototype reaction pendulum designs (that have an electrostatic drive) as well as the current Caltech Quad Prototype. Engineering drawings of all parts for the test mass, wire clamps and the associated Wire Jigs were sent to the Caltech workshop for manufacture. It is hoped that the parts will be available for testing in mid-march when the prototype will be suspended as a single pendulum, then double pendulum, at Caltech.

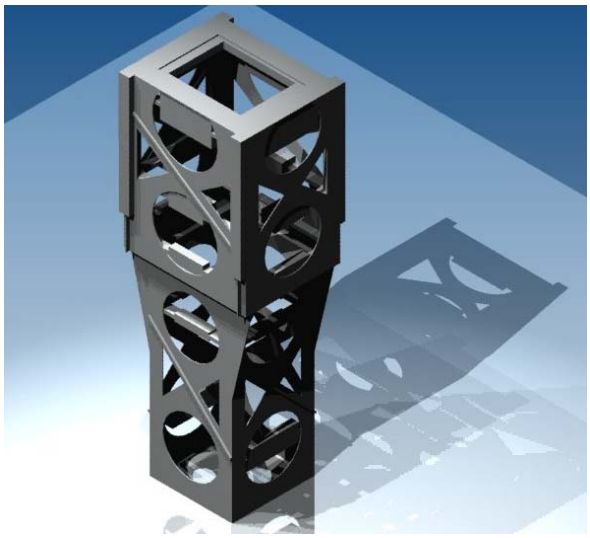
All mass and moment numbers for the test mass designs were sent to NAR for crosscheck[1]. The picture (right) shows the three different models, which, from left to right, are:

- Sapphire Mass with Silica Ears;
- Aluminium & Stainless Steel mass with Aluminium faces;
- Aluminium & Stainless Steel mass with Glass faces.



[1] T040013 – ETM Controls Prototype: Information Related To Design

1.2. Structure



Development of a revised SolidWorks model of the structure incorporating latest ETM suspension dimensions, as proposed in a recent document by NAR (T040028). The revised model was developed to replace the original model created by Dennis Coyne and incorporate a number of features that will allow future changes and additions to be easily made.

Following the creation of the new QUAD structure model (QuadX19), I assisted with the modal analysis of the structure in Ansys. Firstly our models was compared against the old model to confirm that results concurred and then a number of iterations were made such as adding larger number of elements to the mesh and comparing results.

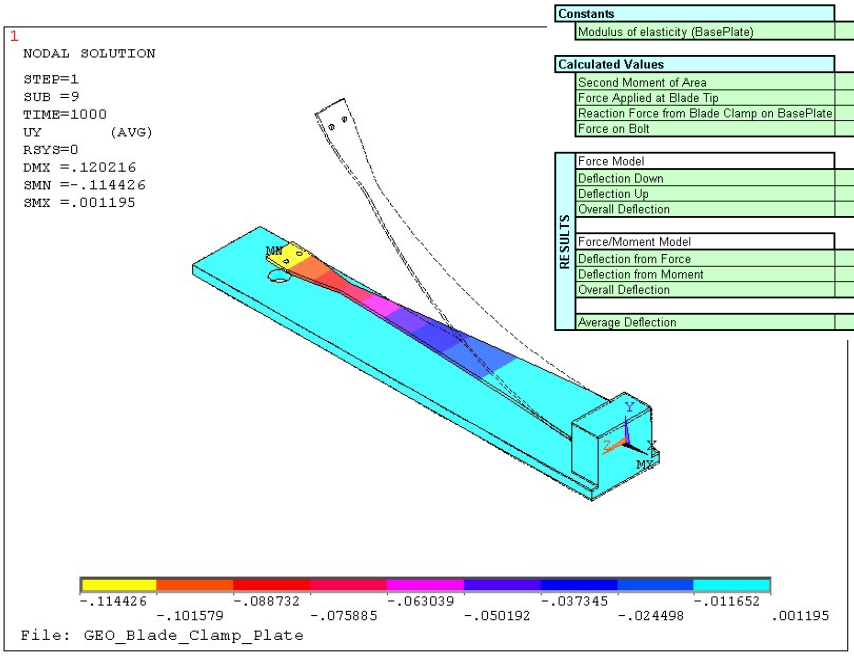
2. Blade-Clamp-Plate Analysis

A Blade-Clamp-Plate model, similar to that used by Dan Mason and John Veitch[2], was tested both in the laboratory, in FEA (ANSYS) and through a deflection calculator.

MPL UpperMass Deflection Calculator — March 8, 2004

Based upon Dan Mason's Work (LIGO SURF Student Summer 2002) — g = 9.81m/s²

	Description	Symbol	Input Dimension	Input Unit	Working Dimension	Working Units
Inputs	Clamping length (along Blade)	a	20	mm	0.02	m
	Upper Mass Width (x-dir)	b	38	mm	0.038	m
	Half Length of Upper Mass	L	300	mm	0.3	m
	Thickness of Upper Mass	h	4	mm	0.004	m
	Total Length of Blade (inc Clamping area)	C_l	240	mm	0.24	m
	Width of Blade	a1b	40	mm	0.04	m
	Thickness of Blade	h1b	2	mm	0.002	m
	Mass Suspended	m	7.837	kg	7.837	kg
Constants						
	Modulus of elasticity (BasePlate)	E	6.90E+10	N/m²	6.90E+10	N/m²
Calculated Values						
	Second Moment of Area	I	->		2.027E-10	m⁴
	Force Applied at Blade Tip	w	->		76.88097	N
	Reaction Force from Blade Clamp on BasePlate	Rf	->		1768.2623	N
	Force on Bolt	F	->		1691.3813	N
RESULTS	Force Model					
	Deflection Down	Ddown	1024.41	mm	1.024E+00	m
	Deflection Up	Dup	1034.15	mm	1.034E+00	m
	Overall Deflection	Do1	9.75	mm	9.748E-03	m
	Force/Moment Model					
	Deflection from Force	Df	-49.48	mm	-4.948E-02	m
	Deflection from Moment	Dm	59.38	mm	5.938E-02	m
	Overall Deflection	Do2	9.90	mm	9.896E-03	m
	Average Deflection	Dav	9.82	mm		



Entering the parameters for the above example initially revealed that there was a discrepancy between the theory in the report by Dan Mason and his calculator. Once the

[2] Caltech SURF students under the supervision of Calum Torrie, Summer 2002

theory was confirmed as being accurate, the parameters were entered into a revised calculator and the results obtained - through all three methods - were found to be similar. For your information, the experimental results gave a deflection of 9.9mm, the calculator gave 9.8mm and the simple ANSYS model gave 13.8mm[3].

This work is key to the future development of Top and Upper-Intermediate Mass designs that must be able to accommodate the high stresses associated with a suspension of this size. For now, the results through the calculator, FEA and experiment give confidence in the tools that we will use during the detailed analysis of these masses.

3. PDMWorks Development

A considerable amount of work was done understanding and developing the new PDMWorks[4] vault. In the very near future, it is hoped that this vault will become the sole file store for all future suspension design work including all documents, from parts and assemblies to engineering drawings and reports. As we found during our tests of the software, the great benefit of PDMWorks outwith its easy to use interface and all round good functionality in storing SolidWorks and other file types, is its ability to be used securely[5] by all parties involved in the Suspensions team[6].

Importantly the PDMWorks Vault will be able to handle Pro/Engineer based documents and hence solves, to some extent, the interaction difficulties of working with the fact that this is Rutherford Appleton Lab's primary CAD package. Initial progress was made between Ian Wilmut of RAL and me in finding the optimum universal file format and is to be finalised on my return to Glasgow.

It must be stressed however that the PDMWorks will not replace the LIGO Document Control Centre (DCC). The DCC will continue to be used as it is now as a storage point for finalised revisions of engineering drawings and documentation, whereas the PDMWorks vault providing a central source whilst designs and documents are being worked on by members of the suspension team.

To display the software's functionality and to describe its usage as a file storage facility, Calum Torrie and I presented a summary tutorial of the vault to Dennis Coyne, Janeen Romie and Larry Jones. It is hoped that the PDMWorks vault will be in place and available to use shortly after the forthcoming LSC – the condition for this being that Caltech are awaiting delivery of a backup server from the Livingston Site.

4. Documents

With the development of our migration toward the PDMWorks vault being used as the primary file store, and due to a number of alterations to the LIGO-customised SolidWorks tools over the past several months, a number of documents have become outdated. As these

[3] An explanation of the large discrepancy in the ANSYS FEA results are given in the attached Appendix.
[4] PDMWorks is a Data Management tool that can be used in conjunction with SolidWorks and many other file types to store files, log user data and track revisions on documents.
[5] Security and backup of the vault was approved by Larry Wallace and Mike Pedraza of IT support at Caltech
[6] The Caltech PDMWorks vault has been securely accessed from Caltech, MIT, Livingston and Glasgow

documents were originally collaborative efforts by Calum and me, it was sensible to update them during the visit.

Unless otherwise stated the authors of the documents listed are Michael Perreur-Lloyd and Calum Torrie. All documents are available on the DCC.

LIGO-D030382-04 – A summary of Drawing and data Templates, Macros, Bill of Materials and Customised Toolbox created for created SolidWorks & an introduction to the LIGO Caltech PDMWorks Vault (.pdf and .zip file)
LIGO-D030143-03 – Designing in SolidWorks: Customised Tools for Design and Documentation of LIGO Parts, Assemblies and Drawings
LIGO-D030383-04 – Customised Toolbox for SolidWorks (.pdf and .zip file)
LIGO-D030384-08 – Bill of Materials (.pdf and .xls file)

Other documents completed or worked upon during the visit were:
LIGO-D030118-01 – Revised version of the document entitled "Guide for Specification of Imperial Bolts, Threads and Hole Fits in Advanced LIGO Parts"
LIGO-D030734-02 – Completed version of "Concepts for addition/subtraction of +/- 500grams of Mass to/from Recycling Mirror Intermediate Mass", authors include Alastair Grant (IGR) and Norna Robertson (Stanford)
LIGO-D030716-02 – Ongoing work on document entitled "Concepts for Mode Cleaner Pitch Adjustment". Authors include Alastair Grant (IGR) and Betsy Bland (Hanford)

The final document in the above list has not yet been finalised due to further investigation of a mathematical model and calculator that aim to replicate, or at least find results in the region of, the results we are obtaining from the actual Mode Cleaner Upper Mass Pitch Adjuster. I have primarily been working on the compilation of this document whilst Calum and I together have spent time experimenting with the Mode cleaner to obtain the results. However, much of the credit for the development of the mathematical model and calculator for this document lies with Alastair Grant who has spent much time on both of these excellent resources. It is imagined that once finalised these can be easily developed for use in the design of pitch adjusters for the Caltech Quad and other future suspensions.

5. Design Meeting and Task List

The two final invaluable exercises completed during the visit were the creation of a design meeting web page to log agenda items, actions and decisions, and the creation of task list for all items associated with the development of a 'Quad for Christmas'. The Monday design meetings and website have been well received and have been a good basis for team members to interact over technical aspects of suspension design.

Discussions on the design of the Quad and creation of a Task List led to the realisation that a 'Gazebo' structure to suspend the actual Caltech Quad within its structure would be required. The discussions also alerted us to the fact that a 0.5 degree wedge on the test mass would alter the position of the wire clamps as it altered the mass, centre of mass (CoM) and moments of inertia (MoI) accordingly. This wedge on the mass has since been reduced to 0.1˚ and therefore will not alter the mass, CoM and MoI as drastically but will still require consideration regards the accurate placement of Wire Clamps.

Subject: Re: Summary Report of Caltech Visit January/February 2004
From: Michael Perreur-Lloyd <m.perreur-lloyd@physics.gla.ac.uk>
Date: Mon, 15 Mar 2004 19:28:35 +0000
To: Dennis Coyne <coyne@ligo.caltech.edu>
CC: Michael Perreur-Lloyd <m.perreur-lloyd@physics.gla.ac.uk>, Caroline Cantley <c.cantley@physics.gla.ac.uk>, Jim Hough <j.hough@physics.gla.ac.uk>, Janeen <janeen@ligo.caltech.edu>, Calum <ctorrie@ligo.caltech.edu>, Norna <norna@fastloki.stanford.edu>, Justin GreenHaulgh <J.Greenhalgh@rl.ac.uk>, Ken Strain <k.strain@physics.gla.ac.uk>

Dennis,

Thanks for comments on my report. Prior to releasing my report, Calum and I had discussed whether or not to show the results seeing as they were not completely conclusive as far as the FEA was concerned. These additional comments should hopefully explain the reason for the slighty eroneous Ansys results.

The blade-clamp-plate tests were done primarily for me to fully understand the previous work done by Dan Mason and John Veitch. The Ansys analysis was tacked on in some respect as an exercise in finding how easily we could import a SolidWorks model into Ansys Workbench, apply two different materials (blade and clamp were steel; Plate was aluminium) and turn out a result that at least fell in the region of those from the experiment and calculator. As this work was done prior to the analysis of the QuadX19 structure and with this being one of my earlier trial uses of Ansys Workbench, the 'basic' mesh was most probably chosen.

So, in answer to your questions: This was a simple linear analysis; No, I did not study the effect of increasing the number of elements and look for a convergence in the results; and The contour plotted in the screenshot shows Total deformation. I realise now that I should have made this clearer in the report.

Incidently, you may have noticed, that the screenshot shown in my report was in fact one from Ansys Classic. This was a further test where we were checking the effect of opening up a file in the Classic environment that was originally created in Workbench. For your information the results after solving in Classic were almost identical to those from Workbench (within a tenth of a mm).

As I mentioned in the report the work will be continued as I develop the Top and Upper-Intermediate Mass designs. When I start that work in the coming weeks I intend to begin by remodelling the blade-clamp-plate with a more advanced mesh.

Regards,
Mike P-L

Dennis Coyne wrote:

> Mike,
> Thank you for all of your help during your visit. It was great to have you at Caltech working with Calum and Janeen.

I had a few comments/questions about your very nice trip report, related to the blade deflection analysis. I was surprised that the Ansys analysis of the blade deflection was so much larger than the experimental results. Was this a linear or nonlinear analysis? Did you confirm convergence by increasing the mesh size? What element was used? What is contour plotted in the Anysys results figure?

Dennis