Summary Report of Visit to LIGO, Caltech: **June 7th – July 30th 2004**

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This document summarises the work completed during a recent visit to Caltech. The purpose of this visit was to assist with the continued collaborative design work being undertaken by the Advanced LIGO Suspension Team. The work displayed in this document is both work that I did on my own with some interaction from others, and work done by my LIGO Colleagues in which I was involved.

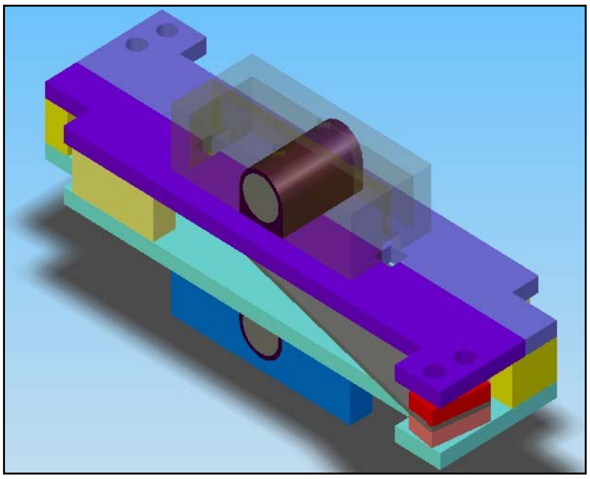
The aims of the visit were:

- To continue the development of the Upper Mass designs (both Top and Upper-Intermediate Mass for the main and reaction chain) for the ETM Controls Prototype, in line with the target completion of a 'Quad for Christmas';
- Assist on the development of interfacing designs (blades, tablecloths, structure, etc); and,
- To help finalise the set up of the Caltech PDMWorks vault for use by both suspensions and seismic teams.

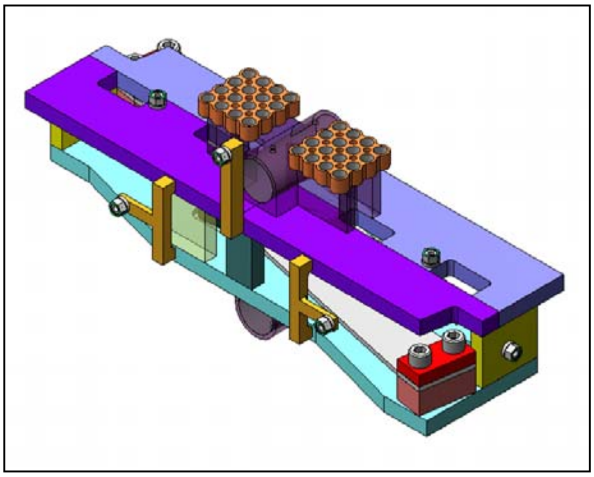
Additional to these tasks I was able to continue learning the LIGO working practices used during the design process, e.g. the drawing guidelines, DCN and RFQ processes.

During the visit, I worked closely with Calum Torrie and Janeen Romie and much of the good progress during my visit is credit to their being on hand to answer my questions. I must also thank Mike Pedraza, Larry Jones, Helena Armandula, Mark Barton, and Ric Paniagua who helped me out on a number of occasions during my stay.

Top Mass Detailed Design

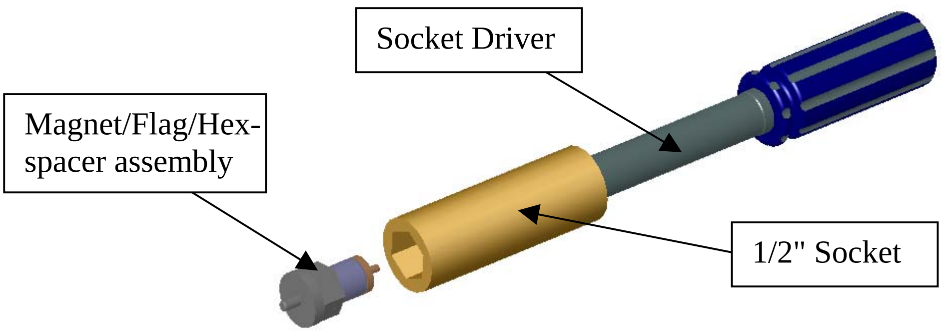


Top Mass Design - June 2004



Top Mass Design - August 2004

The design of the top mass moved forward considerably during my visit. A major aspect of the top mass assembly that I worked upon was ensuring that all components fit together without interference. This required interaction with Calum for his detailed knowledge of past upper masses, with Norna Robertson to confirm that all changes were within the tolerance levels set by the MATLAB suspension model, and with Ian Wilmut who was in charge of the blade and blade clamp design. After solving the interference issues, I then concentrated on the design with respect to assembly and installation. An example of this is an idea for the design of the magnet-flag-spacer that has since been manufactured for bench testing.



Finite Element analysis of the bending in the top mass plate and its comparison with both mathematical and physical models was an important exercise to avoid the problems that occurred during the initial build of the MIT Quad. In FE analysis done earlier in the year, I had modelled a plate section, of similar geometry to that of a top mass, with both blade and blade clamp attached, however, the results attained at that time from ANSYS Workbench were somewhat inaccurate when compared to the other models. My conclusion was that the solid model I had been using was too detailed, thus for my analysis during this visit I simplified the model to a simple cantilever with a force and moment acting upon one end of it.

The results from this FE analysis, compared with the results from the mass deflection calculator, tied in a lot closer (see Appendix A). I went on to add further complexity to the model and was able to conclude with more confidence that these were matching the physical performance quite well. The real test of my theoretical results will come when a test plate, with blade and blade clamp attached, is bench tested in the coming month.

Upper-Intermediate Mass Detailed Design

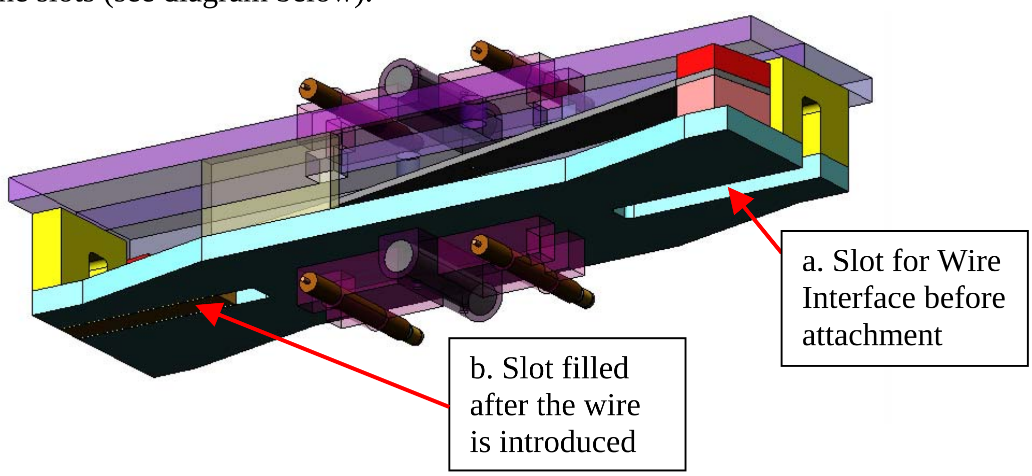
As per the Top Mass design, considerable progress was made with the U-I Mass design. The initial detailing focused on ensuring that all parts would fit together without interference. Discussions held during the design meetings were invaluable in helping solve the interference issues. For example, one interface issue involved designing a wire clamp component that was able to clamp the two wires coming from the Top Mass without any interference with the two crossed blades. The final solution involved changes to the clamp design, changes to the design of the blade tips and an alteration to a parameter from the MATLAB suspension model.

Concepts for moving and removing the magnet-flag-spacer assemblies in the Main chain U-I Mass and consequently concepts for the adjustment of the OSEMS coils on the reaction mass were drawn up. The cannon-style pitch adjuster for the OSEM coil has since been manufactured and will be bench tested in the coming weeks.

The alterations and changes to the Upper mass designs are all documented in the revised Top Mass and U-I Mass Design Specifications, document numbers T040073-02-R and T040096-02-R respectively, and are available on the DCC.

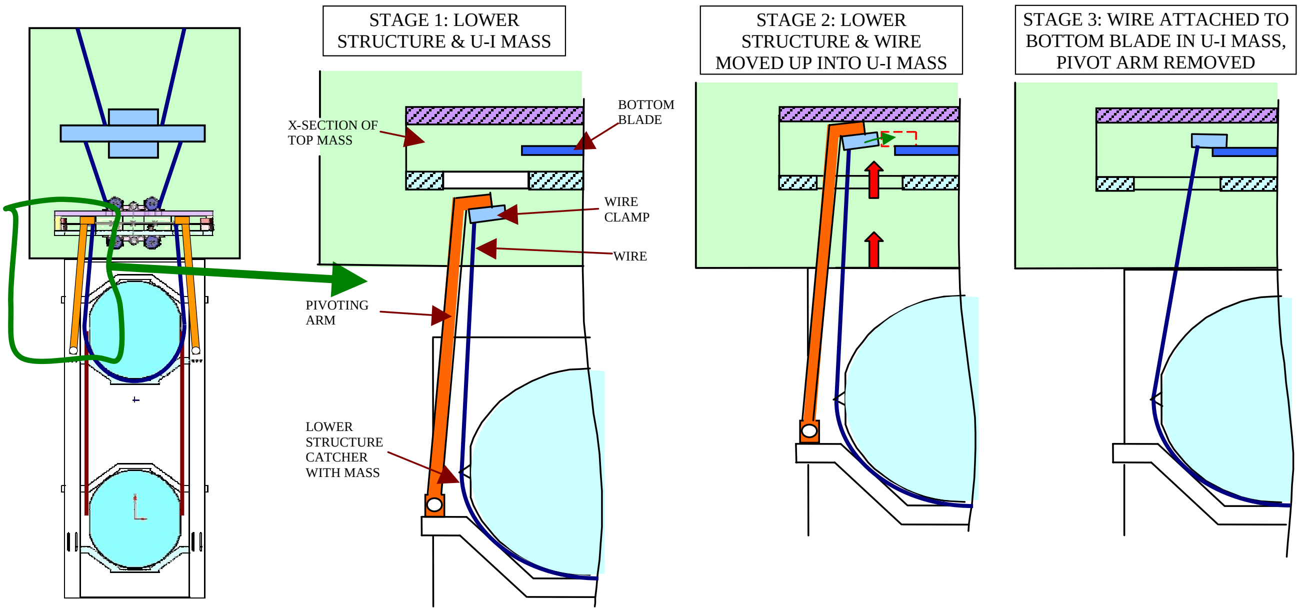
Design for the Noise Prototypes: Interface issues between the Lower Structure/Catcher and the U-I mass

Accommodation was made in the U-I Mass design to allow for some method of attaching the Penultimate wires to the bottom blades (the blades in the U-I Mass) – a problem made more complex when we come to the noise prototype due to the necessity of having the wire in a fixed position between the fibres prior to welding. By considering a prototype design used in Glasgow for a similar problem (but in a two stage suspension) we concluded that a simple workaround would be to add slots *(a.)* to the bottom plate on the U-I Mass. These slots would be later filled by metal spacers *(b.)* that would replace some of the strength lost by cutting the slots (see diagram below).

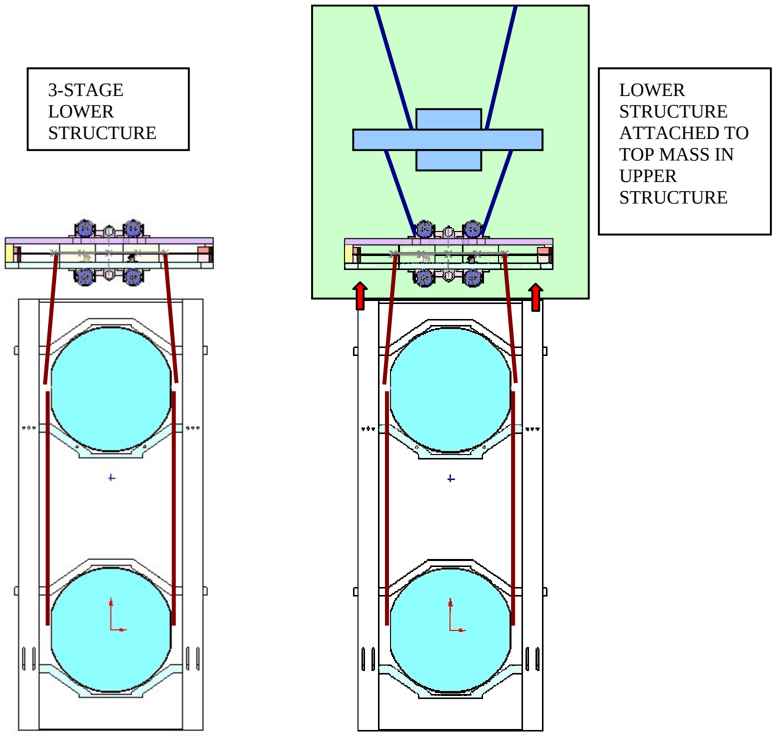


On further consideration, it was apparent that this might not be the ideal solution, as the large gap would considerably weaken the mass. In brainstorming sessions involving Russell Jones, Calum and Janeen three further ideas were put forward to solve the problem of which two of the ideas still remain.

The first idea involves the wires being held by precision moveable arms that are attached to the lower structure/catcher and that hold the wires and their respective wire clamps under light tension. This idea assumes there being two masses (of each chain) in each half of the structure. The lower structure/structure and the protruding arms are moved up into the U-I mass and, once the lower and upper structures are fastened together, the clamp-wire-clamp assembly is rotated into place and attached at the tip of the blades (see below).



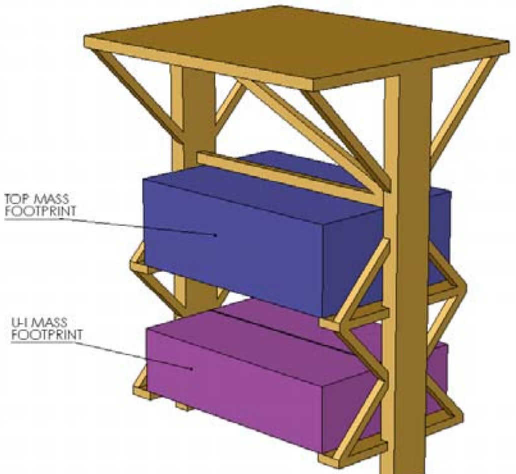
The second idea (see diagram, right) involves considering the lower half of the structure as a fixture/jig that holds the U-I mass as well as the penultimate and test masses, thus reducing the chance of a wire touching a fibre after the welding has been completed. This idea drives the overall suspension to be assembled as a 3+1 rather than the original 2+2 configuration, where the upper half of the structure holds only one mass.



This work is to be continued and as a result, the U-I mass will require further design work once a decision is made as to which idea will be adopted.

ETM Controls Prototype Upper Structure, Tablecloths and Earthquake stop for the Upper Masses.

Throughout the visit, discussions were held between Janeen, Calum and I, to bring forward the design for the Upper Structure. During these discussions, I assisted with laying down the requirements for the upper structure and I had input in the failure modes and installation fixtures documents for the overall structure. In parallel with Janeen writing up these documents, we also began throwing around some ideas as to how the structure could be designed primarily for the benefit of installation and assembly[1]. The concept structures considered will have to take in to account the changes that result from the decision on whether we adopt a 3+1 or 2+2 configuration, as mentioned in the previous section. The diagram, right, is an example of an upper structure for a 2+2 configuration.



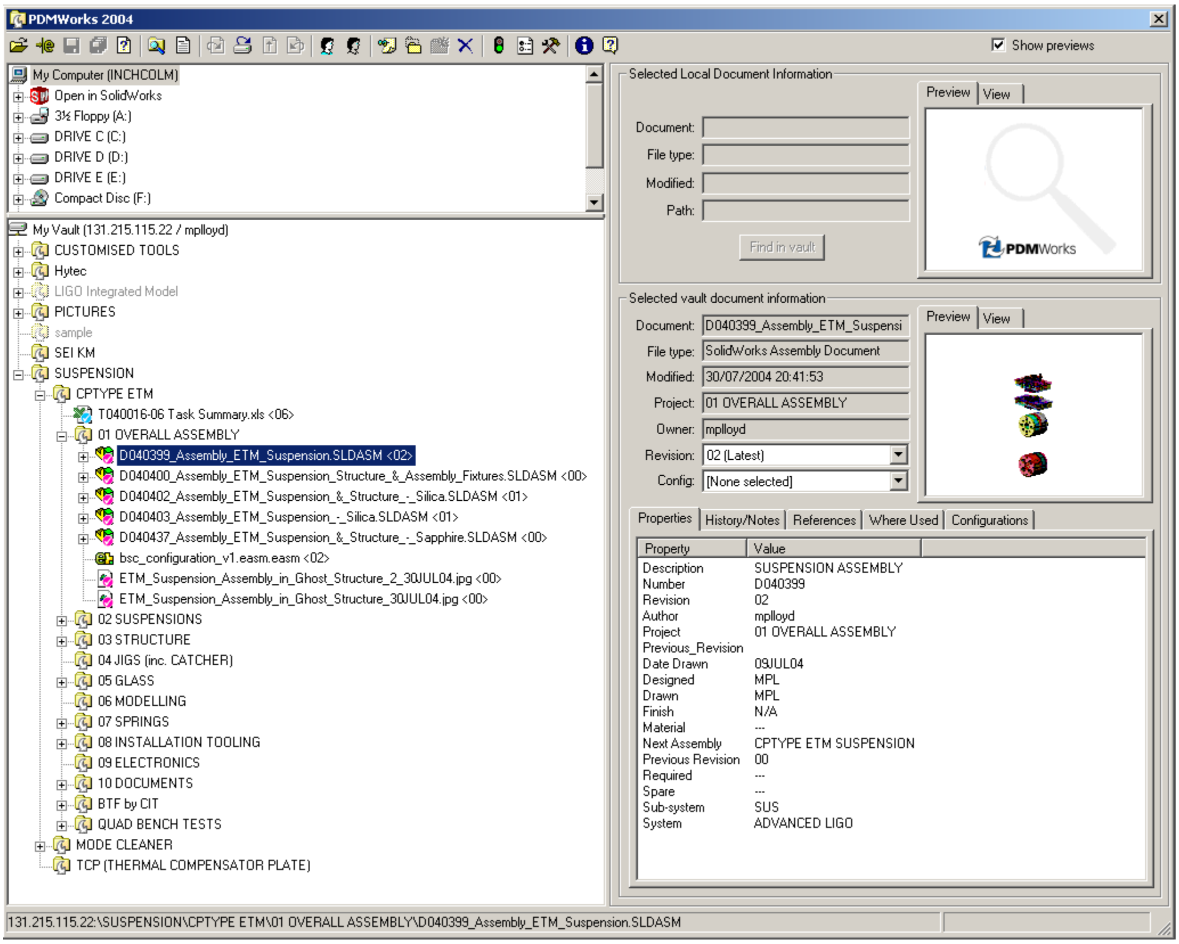
Example of Structure Concept – Designed for Assembly & Installation

[1] Since the structure concepts based around Dennis Coyne's thin skin concept were inconclusive in their results, i.e. did not match the requirement "that, once mounted on the seismic table, shall not produce a phase lag >90 deg between the non-collocated sensors in the SEI system", We therefore have a somewhat free licence to explore a wide range of structure concepts.
NOTE: the quote above is taken from document T040141, Upper Structure PDS, J. Romie, C. Torrie, M.Perreur-Lloyd

Issues related to the design of the tablecloth (top mass) and earthquake stops (U-I mass) became more apparent as I began to consider the assembly and installation of the Upper Masses, and subsequently their interface with the upper structure. Should I continue to develop my ideas on the tablecloth design, any interfacing will be much easier now that the PDMWorks vault is fully up and running, and from Glasgow I can gain unrestricted access to the latest structure concepts.

Setting up the Caltech PDMWorks vault

To encourage all members of the suspension team to move away from storing files on the Sirius/engmech vault it was important to transfer files from that location to the PDMWorks vault. The PDMWorks vault has been set up with a file structure on the vault that is based upon the order of the ETM Quad Task Summary[2]. All of the ETM CPtype files are fully up to date on the vault and additionally the files and drawings from the C-Ptype Modecleaner are available. I must stress that in the latter work mentioned I was purely an advisor the majority of the credit must go to Calum for creating and 'checking-in' the many modecleaner files.



Other Work

[2] T040016; ETM Controls Prototype Task Summary, C.Torrie + SUS Design Team

Highlights of other aspects of my visit were:

- RFQ and DCN Process: During the recent C-Ptype blade procurement I got a good idea of what was involved in preparing drawings for quote. This included seeing Calum set up and use the DCN document required when a change is made to a released drawing. Aspects of this work were included in the revisions to the LIGO Mechanical drawing guidelines, E030350.
- Lab Work
  - I saw for the first time the 1:1 scale Concept Quad Structure and was present whilst a number of other LIGO colleagues (Ken Mason [MIT], Ken Mailand [Caltech, SUS], Mike Smith [Caltech SEI]) were given a run down on the assembly & installation problems.
  - Disassembled and assembled the two stage all metal quad masses using the new lab jacks following the addition of grooves to the masses. The re-assembly with grooves solved the earlier pitch problems caused by the wire not being of a uniform separation as they looped under the mass.
  - Collected the complete data from the mode cleaner pitch adjuster. This will be compared against results from Alastair Grant's triple suspension pitch calculator and the MATLAB Suspension model shortly. Following the development of triple suspension calculator, Alastair Grant is already some way towards developing a pitch adjuster Calculator for the quad.
  - Bench-tested the Spark-plug style Hexagonal Magnet-Flag-Spacer.
  - Weighed several modecleaner and ETM components and checked them against SolidWorks predictions as a pre-cursor to the Stainless steel and Aluminium density tests. The tests using highly accurate blocks was later completed by Ian Wilmut and in future will form part of a collaborative document on Stainless Steel and aluminium testing.

Documents

The following documents with my involvement were released during my visit:

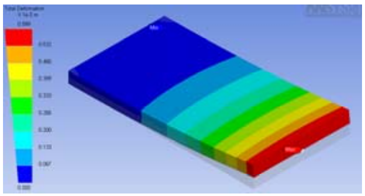
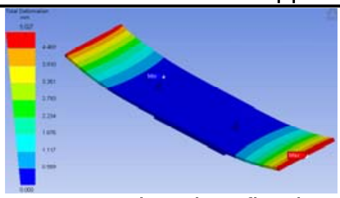
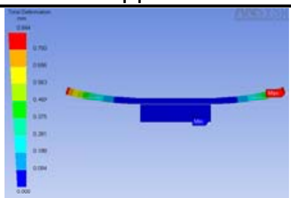
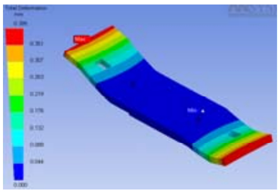
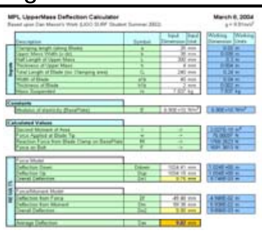
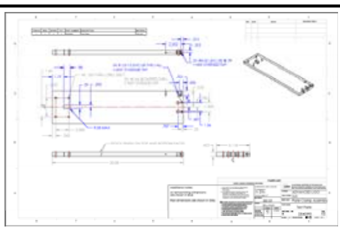
T040071-02-R: C-Ptype ETM Top Mass PDS; M.Perreur-Lloyd, C.Torrie, N.Robertson
T040096-02-R: C-Ptype ETM U-I Mass PDS; M.Perreur-Lloyd, C.Torrie, N.Robertson
T040072-01-R: Pendulum Parameters Descriptions & Naming Convention; M.Perreur-Lloyd, C.Torrie, N.Robertson

D030382-05-R: Introduction to the LIGO Caltech PDMWorks Vault and Summary of the Drawing and Data Templates, Macros, Bill of Materials and Customized Toolbox created for SolidWorks; C.Torrie, M.Perreur-Lloyd
D030384-04-R: Customised Toolbox for SolidWorks; C.Torrie, M.Perreur-Lloyd

T040141-02-D: ETM Upper Structure Product Design Specification; J.Romie C.Torrie, M.Perreur-Lloyd
E040329-03-D: Advanced LIGO Quadruple Pendulum Suspension Failure Modes and Subsequent Repair Approaches; J.Romie C.Torrie, M.Perreur-Lloyd
T040151-02-D: Installation & Alignment Fixtures Product Design Specification; J.Romie

Table of ANSYS Testing on Top Mass Plate Models

Force applied = 500N; Moment Applied = 225Nm [500Nx0.45m (Blade length)]
Element size = 4mm, Typical no. of elements for Plate with T-section = ~110,000

Model		Thickness					
		6mm	10mm	15mm	16mm	18mm	20mm
1	 1/2 length plate fixed at one end with moment & force applied	9.33mm	2.02mm	0.60mm	0.49mm	0.35mm	0.25mm
2	 Rectangular Plate fixed at breakoffs with moment & force applied	5.03mm	1.16mm	0.36mm	0.30mm	0.22mm	0.16mm
3	 As above but with addition of angled sections for blades	6.25mm	1.26mm	0.39mm	0.31mm	0.24mm	
4	 Angled Plate No T-Piece					0.47mm	
5	 Mass Deflection Calculator	9.75mm	2.10mm	0.62mm	0.51mm	0.36mm	0.26mm
6	 Test Plate	AWAITING RESULTS		AWAITING RESULTS		AWAITING RESULTS	