**Summary of Research Results on the Initial LIGO Suspensions**
**R.Weiss, June 23, 2008**

The note describes the results of research done by Steve Penn, Gregg Harry, Nick Smith, Lucienne Merrill, David Kelley, Matt Evans and R. Weiss. The research was dedicated to understanding the losses in the violin modes of the steel wires of the Initial LIGO test mass suspensions. The research has established:

1. The variable and sometimes large losses in the violin modes of the wires have been a long known but unsolved problem starting with the experience on the 40meter suspensions.The experience in the suspension test rig with both the large variability in the Q and the occasionally very low Q values (<20K) is also observed in the measurements by Harry (time domain, large amplitude excitation) and by Malling (frequency domain, thermal excitation) in the Inital LIGO suspensions.
2. The dominant loss mechanism is a poorly defined boundary condition for the wire at the standoff on the bottom at the test mass. The position of the wire is constrained by the standoff but the slope of the wire is not and thereby motion is transmitted to a lossy and ill defined boundary on the barrel of the test mass.
3. A secondary loss mechanism is the inability of the fused silica standoff to withstand the normal force of the wire without crumbling. This causes fused silica dust to form between the wire and standoff which is lossy and causes hysterisis and up-conversion in the wire motion on the standoff. Both 2) and 3) lead to variability in the measured violin mode Q. After a lock loss or other impulsive acceleration to the test mass, it is very likely that the wire is repositioned in the cylindrical standoff and a different constellation of silica dust forms between the wire and the standoff. Furthermore,the wire may well reseat at the test mass tangent point with a new rubbing loss.
4. Several methods to reduce the wire losses at the test mass have been successfully tested. One consists of a equilateral sapphire prism with a laser cut notch in the middle of one edge followed by a second smaller aluminium prism between the test mass tangent point and the sapphire prism. The two prisms define a boundary condition for both the slope and the position of the wire. The abrasion of the sapphire prism edge is significantly smaller than that of the silica cylinder. The sapphire, when it breaks, cleaves in larger pieces which are not likely to get wedged between the wire and the prism edge. A second equivalently successful solution is a small hardened steel clamp grooved to guide the wire. Both techniques yield fundamental mode wire Q of 120K (330Hz) consistently.There is a reasonable probability that the Q is now not limited by the lower boundary but rather by other mechanisms (recoil, the upper clamp). The limit of the fundamental violin mode Q, if determined entirely by the wire's physical properties as measured by Steve Penn in a special purpose test rig, would be between 200K to 250K.
5. There is measurable up-conversion at the cylindrical stand-off. The up-conversion is easy to observe when the wire is driven at amplitudes much larger than the thermal excitation. Extrapolation to the amplitudes normally encountered during quiescent operation of the interferometer seems to indicate that the up-conversion is not a factor in the Initial Interferometer noise budget.

6. If the fluctuation - dissipation thermodynamic arguments are valid for the coupling of wire motion to the pendulum suspension, the expectation is that the enhanced LIGO performance below 130Hz will be compromised by suspension thermal noise.
7. The LIGO project currently has 11 laser cut sapphire prisms in house and 12 more are waiting to be laser cut at Resonetics in New Hampshire for delivery by the end of June. 24 small aluminium prisms are being fabricated in a machine shop and will be delivered by the end of June.

I have placed Lucienne Merrill's Bachelor's thesis on my website. The thesis describes most of the data leading to the summary above. The thesis is excellent and would be improved if there were no attempt at theoretical development. The thesis is in the directory:

http://emvogil-3.mit.edu/~weiss/suspension_research/