Suggestions for modifications to future (multi-stage) suspension designs

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1. Align the principal axes of rotation for each stage with the IFO coordinate global control system (no off-diagonal elements in the inertia matrix).
2. In order to keep all resonant frequencies low and/or clustered together, the distribution of mass between the stages should be optimized. More mass at top, less at bottom. See LIGO-T1300786.
3. To-date, for multi-stage suspensions, when designing mass, mass ratios, moments of inertia, and suspension points in the face of control via a dynamical model, only top-mass to top-mass, local control is considered. Remember to consider the behavior of the global control actuation (any stage drive to optic response) as well. (Experience has shown that reducing Qs at the top mass to top mass response doesn't necessarily reduce the Q of lower stage drive to optic response. See LIGO-G1401291)
4. Align the Longitudinal Actuation Plane with the Lower Zero Moment Plane of the suspension wires/fibers, especially on the top stage. This will help reduce length-drive to pitch-response.
5. Try to make the lever arm between the center of mass of each stage and **both** pitch and yaw actuators relatively large, especially on the top stage. This will help both with actuation range in pitch, and with angle-drive to length-response coupling.
6. Over-constrain longitudinal control of the top mass in a configuration similar to the previous point (e.g. 4 actuators). In aLIGO there are only 3, which makes length-to-angle decoupling more challenging since there is no 'pringle mode' to drive and zero out.
7. Consider adding of sensors and actuators on lower stage masses to control degrees of freedom / resonant modes not visible at the top stage. Stable, non-local, angle sensors at the optic stage are especially useful. Be mindful that the sensor and actuator noise of these control loops do not spoil the performance in the detection band of interest.
8. Utilization of better local sensors throughout the pendulum, and especially at the top stage. Non-local (but independent of the interferometer) sensors should also be considered (e.g. optical levers).
9. Align actuators / sensors with the degrees of freedom we want to control (pitch and yaw). That is use a plus pattern: one on top, one on bottom, one on left, one on right (not a cross pattern: upper left/lower left/upper right/lower right).
10. Do not consider the design of the cage last. Its design is important both for the performance of the seismic isolation to which the suspension is attached, as well as ease of assembly.

LIGO QUAD-specific:

11. Consider reducing the complexity and/or weight of the reaction chain (i.e. it does not need to be a copy-and-paste of the main chain).
12. Maybe we want to replace the ESD with a ‘photon calibrator’ like device.