**LIGO (Laser Interferometer Gravitational-Wave Observatory)**

**Customers:** CalTech, MIT (Massachusetts Institute of Technology)

**Responsibilities:** Systems engineering, design, analysis, fabrication and test.

**Technical Challenges:** Extreme vibration isolation and quietness, automated precision positioning of massive systems, passive damping, UHV compatibility.

The Laser Interferometer Gravitational-wave Observatory (LIGO) facility is dedicated to the detection of cosmic gravitational waves and the harnessing of these waves for scientific research. LIGO will be used for research into the nature of gravity, and it will open up an entirely new window onto the universe. HYTEC was responsible for the design, analysis, procurement, and testing of the support structures, passive isolation and micro-positioning systems.

The photograph on the left shows a prototype of the entire isolation system as assembled and tested in the HYTEC high-bay area in Los Alamos. The system includes high stiffness metallic structures, an automated six degree-of-freedom positioning system, a piezoelectric micro-positioning stage, and a four-stage in-vacuum isolation stack. A patented vacuum compatible internally damped spring was developed as part of the project.

HYTEC designed the LIGO isolation system to provide vibration attenuation that will permit measurements of a disturbance of less than one thousandth the diameter of a proton. The development of structural analysis methods and unique isolation concepts for this program has been very beneficial in the development of stable structure concepts for other HYTEC programs.
GLAST (Gamma-ray Large Area Space Telescope)

Customers: SLAC (Stanford Linear Accelerator), NRL (Naval Research Laboratory)
Responsibilities: Systems engineering, design, analysis, fabrication, and test.
Technical Challenges: Extreme dimensional stability, large opto-mechanical system.

GLAST is a next generation high-energy gamma-ray observatory designed for making observations of celestial gamma-ray sources in the energy band extending from 10 MeV to more than 100 GeV. GLAST follows in the footsteps of the CGRO-EGRET experiment, which was operational between 1991 and 1999.

HYTEC has played an important role in the design and analysis of the calorimeter, tracker and grid support structures to develop design concepts that solve the technical challenges of GLAST. Mechanical prototypes for the calorimeter and tracker subsystems were fabricated and tested in order to validate design choices. HYTEC continues to play a key role in the design, analysis and testing of the tracker subsystem mechanical structures to ensure the design concept is space-qualified. Efforts include development of an innovative, low mass, passively cooled silicon tracker that draws upon carbon-carbon composite materials to meet the unique challenges of the tracker physics criteria. A full-scale testing program will qualify the design to NASA specifications.
The Thirty Mirror Telescope (TMT) project is currently planning a thirty meter diameter ground based telescope. The telescope will be used for research in astronomy at near-ultraviolet, visible and near infra-red wavelengths.

At the heart of TMT is a 30-meter (98 ft) diameter, segmented primary mirror, three times larger and offering 9 times the light collection area of the largest telescopes currently in operation, including the 10-meter (33 ft) Keck telescopes on the summit of the Mauna Kea, Hawaii.

This segmented primary mirror will be comprised of 738 independent, ultra-low expansion glass segments, separated by 2 mm (.08") gaps. Each segment is hexagonal, cut from an aspherical meniscus, with a 1.2 meter (47") diameter, and a thickness of 40 mm (1.6").

These numerous pieces of glass must be operated in unison, as a single large mirror. The required surface accuracy of the combined primary is about 10 nanometers RMS, across the entire mirror (if the USA were this flat, the largest “hill” would rise a mere 1/32 of an inch!).

HYTEC has been charged with designing the support systems for the primary mirror segments. To achieve the required surface accuracy and stability, each segment will be supported by a multi-point, passive, near-kinematic system of levers and flexures, actively controlled in piston, tip and tilt by a set of three linear actuators, and figure-controlled by an automated warping harness with 18 independent actuators.

In contrast with earlier segmented telescopes, the much larger size of the TMT mirror results in increased gravity-induced deflections of the primary mirror cell (the large steel structure that supports the mirror). This in turn requires larger actuator strokes and makes designing the flexure systems a challenge. The TMT segments are also thinner than in previous large telescopes, which makes control of gravity-induced deflections a more difficult problem. Finally, the raw number of assemblies required makes cost-effectiveness a key concern throughout the design process.
SNAP (SuperNova / Acceleration Probe)

**Customer:** LBNL (Lawrence Berkley National Laboratory)

**Responsibilities:** Systems engineering, design, analysis.

**Technical Challenges:** Extreme dimensional stability, large mirrors.

In 1999, researchers announced a startling discovery: the expansion of the universe is not slowing, as had been suspected until then, but accelerating. To better understand the mechanisms of this acceleration, the SNAP Project, now in its formulation phase, will scan the outer edges of the expanding universe, discovering and measuring an expected 2000 type 1a supernovae per year. The SNAP satellite will carry a two-meter aperture, three mirror telescope, and a number of instruments measuring wavelengths from infrared to near ultraviolet. With one billion pixels, SNAP will also carry the largest and most sensitive astronomical CCD imager ever constructed. HYTEC has been selected to provide thermo-mechanical engineering for the SNAP instrument.

The SNAP telescope is 2.5 meters in diameter by 4.5 meters in length. The large optical bench and metering structures that support the various mirrors and instruments are subject to extreme dimensional stability requirements (on the order of one micron over a wide temperature range). Extensive use of near-zero expansion graphite/cyanate ester composites is baselined to achieve dimensional stability goals.

HYTEC is charged with the requirements definition, design and analysis of the primary structures of the SNAP telescope. As the SNAP program progresses, it is expected that HYTEC’s role will increase to include prototyping and testing, as well as detailed design, procurement and qualification of the flight hardware.
STEREO (Solar TErrestrial RElations Observatory)

**Customer:** NRL (Naval Research Laboratory)

**Responsibilities:** Systems engineering, design, analysis, fabrication, integration, and test.

**Technical Challenges:** Extreme dimensional stability, precision optical systems.

Scheduled to Launch in 2005, the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) is the primary science instrument suite aboard the Solar Terrestrial Relations Observatory (STEREO) mission.

The primary goal of the SECCHI is to advance the understanding of the three-dimensional structure of the Sun's corona, especially regarding the origin of Coronal Mass Ejections (CMEs), their evolution in the interplanetary medium, and the dynamic coupling between CMEs and the Earth environment. This will be accomplished by an unprecedented combination of imaging instruments mounted on duplicate spacecraft flanking the Earth in its orbit around the sun.

HYTEC's responsibilities on the STEREO program include: development of requirements specifications, mechanical systems engineering, interface control documentation, design, analysis, integration, and environmental testing.

The HYTEC design makes use of high stiffness near zero expansion composite materials and an innovative kinematic mount and alignment system to provide a stable, yet ultra lightweight structure to support the suite of optical instruments. Key design features of the instrument structures are dimensional stability, stiffness, contamination control and cost. The design meets stringent mass budget and 30 arcsec instrument co-alignment requirements essential to mission success.
Projects

ATLAS Pixel Detector for LHC

Customer: LBNL (Lawrence Berkley National Laboratory)
Responsibilities: Systems engineering, design, analysis, fabrication and test.
Technical Challenges: Extreme dimensional stability, passive heat removal, high stiffness/mass ratio, advanced materials, forced cooling.

The ATLAS detector system will be used to study proton-proton interactions at the Large Hadron Collider (LHC) at the European Laboratory for Particle Physics (CERN). ATLAS-LHC is being designed to improve fundamental scientific understanding of matter and forces. HYTEC is designing, providing fabrication liaison, and testing the ATLAS pixel disk composite structures as well as the global support structures.

As shown in the pictures, a space-frame is used to support the pixel disks at the forward and aft ends of the detector. A dimensionally stable composite frame structure supports the central barrel region. The open space-frame structure was chosen for the forward and aft disk regions to provide ease of access and routing of services. The forward, central and aft sub-assemblies are assembled and aligned separately. Pins control the precise angular positions and provide alignment between the three sub-assemblies. All structural and thermo-structural elements are made from high conductivity and stiffness carbon-carbon materials.
**Vacuum-Qualified Vibration Isolation Mounts**

Vacuum Qualified (UHV) Damped Coil Spring for vibration isolation in high and ultra-high vacuum environments. Sets of 3 or more springs provide six degree-of-freedom isolation of systems weighing 300 lb and up, with suspension frequencies as low as 5 Hz, and loss factors in excess of 5%.

**Applications:** Vibration and shock isolation in high and ultra-high vacuum environments. Existing applications: 3000+ springs isolating the test masses for the LIGO experiment (NSF), isolation of Atomic Displacement Metrology (ADM) experiment at NIST.

**Patents:** US Patent 6102379.

**More info:** Eric Ponslet, (505) 661-3000, ponslet@hytecinc.com (Los Alamos, NM)

**In-Vacuum Vibration Isolation**

Vibration-sensitive in-vacuum equipment must often be isolated from cultural noise inside the vacuum envelope (as opposed to isolating the vacuum vessel itself). This prevents acoustic inputs from shortcutting the isolation system and provides the utmost platform quietness.

Because of outgassing, few vibration isolation technologies can be used in high vacuum environments. To fill this need, HYTEC has integrated constrained layer visco-elastic damping inside a vacuum qualified metal coil spring.

![UHV isolation stacks support all 27 ultra-quiet optical platforms in the LIGO vacuum systems](image1)

HYTEC's in-vacuum isolation technology is a key element of the Laser Interferometer Gravity-wave Observatory (LIGO), a $300 million NSF project designed to detect gravity waves emanating from violent events in the distant universe. LIGO's interferometers are sensitive to motions as small as 10^{-18} meter, one hundred million times smaller than the diameter of a hydrogen atom! All 27 LIGO detector platforms are isolated by multi-layer stacks of HYTEC springs. More than 3000 springs were delivered to that project. A similar platform was built for the Atomic Displacement Metrology (ADM) project at the National Institute of Standards and Technology (NIST).

**Damped Metal Springs**

Used in sets of three or more, the springs provide near-isotropic, damped, high-performance passive isolation in six degrees of freedom for sensitive in-vacuum equipment.

![Spring with Fluorel Rubber Seats, and cross-section through internal damping structure](image2)

The springs are tubular compression coils, with internal constrained layer damping. They are sealed at the ends with electron-beam-welded plugs. Seats are molded from custom-formulated low-outgassing Fluorel rubber; they provide an extremely simple interface to flat surfaces as well as additional isolation in the acoustic range.

**Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposed Materials</strong></td>
<td>seats coil custom formulated Fluorel C510 Phosphorous bronze</td>
</tr>
<tr>
<td><strong>Outgassing Rate</strong></td>
<td>@21°C &lt;5x10^{-11} torr.l/sec</td>
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<tr>
<td><strong>Approximate Stiffness</strong></td>
<td>@5 Hz</td>
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<tr>
<td>Axial</td>
<td>246 lb/in (43 kN/m)</td>
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<tr>
<td>Shear</td>
<td>312 lb/in (55 kN/m)</td>
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<tr>
<td><strong>Approximate Loss Factor</strong> @5 Hz</td>
<td></td>
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<tr>
<td>Axial</td>
<td>4.0%</td>
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<tr>
<td>Shear</td>
<td>9.2%</td>
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<tr>
<td><strong>Load Capacity</strong></td>
<td>100 lb (448 N)</td>
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<tr>
<td><strong>Minimum Suspension Frequency</strong></td>
<td></td>
</tr>
<tr>
<td>Axial</td>
<td>4.9 Hz</td>
</tr>
<tr>
<td>Shear</td>
<td>5.5 Hz</td>
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<tr>
<td><strong>Temperature limits for specified performance</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70±9°F (21±5°C)</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>(Ø x height)</td>
</tr>
<tr>
<td>Unloaded</td>
<td>2.8”x3.0” (71x76 mm)</td>
</tr>
<tr>
<td>Loaded</td>
<td>2.8”x2.5” (71x64 mm)</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>0.646 lb (0.293 kg)</td>
</tr>
</tbody>
</table>

HYTEC, Inc. 110 Eastgate Drive, Los Alamos, NM 87544, USA (505) 661-3000 www.hytecinc.com

Version 06/17/2005
Monolithic, machined titanium flexures with stiff load-bearing directions and high compliance elastic decoupling. The mounts are used in sets of three to produce near-kinematic supports for high precision instruments.

Applications: kinematic support, precision alignment, and thermal isolation of high precision instruments. Mechanical and thermal decoupling in aerospace applications.

Patents: pending.

More info: Eric Ponslet, (505) 661-3000, ponslet@hytecinc.com (Los Alamos, NM)

Kinematic Support Systems

High precision instruments are often isolated from their supporting structures with kinematic (or near-kinematic) supports. Kinematic supports provide the minimum number of restraints to completely define the position of the object in space. Additional restraints are avoided, as they would induce deformations in the object in response to temperature changes or deformations of the support structures.

Kinematic supports typically consist of a set of three mounts, each providing one to three translational constraints.

Monolithic Flexure Mounts

HYTEC has developed an innovative mount design that relies entirely on elastic flexures to provide the required degrees of freedom. This eliminates locking, hysteresis, and lubrication problems common with classical mechanism-based mounts.

Our mounts provide two degrees of high stiffness constraint (2, 3) and four degrees of high compliance elastic decoupling (1, 4, 5, 6). They are machined from monolithic blocks of low thermal expansion, low conductivity Titanium alloy.

Used in sets of three, they provide reliable, mechanically and thermally decoupled support solutions for precision instruments. They also incorporate features for over-travel protection and precision line-of-sight adjustments.

<table>
<thead>
<tr>
<th>Specification</th>
<th>114-STO-04-2832</th>
<th>114-STO-04-2812</th>
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<tbody>
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<td>Max. Deflections (one at a time, no loads)</td>
<td>D1 = 0.098 in</td>
<td>D1 = 0.079 in</td>
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<tr>
<td>R1 = 23 mRad</td>
<td>R1 = 24 mRad</td>
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<tr>
<td>R2 = 121 mRad</td>
<td>R2 = 101 mRad</td>
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<tr>
<td>Max. Load (one at a time, no deflection)</td>
<td>F2 = 303 lb</td>
<td>F2 = 472 lb</td>
</tr>
<tr>
<td>F3 = 221 lb</td>
<td>F3 = 788 lb</td>
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<tr>
<td>Stiffnesses</td>
<td>K1 = 313 lb/in</td>
<td>K1 = 565 lb/in</td>
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<tr>
<td>K2 = 26,700 lb/in</td>
<td>K2 = 48,200 lb/in</td>
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<tr>
<td>K3 = 26,800 lb/in</td>
<td>K3 = 137,600 lb/in</td>
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<tr>
<td>K4 = 1260 lb.in/Rad</td>
<td>K4 = 2370 lb.in/Rad</td>
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<tr>
<td>K5 = 340 lb.in/Rad</td>
<td>K5 = 615 lb.in/Rad</td>
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<tr>
<td>K6 = 113 lb.in/Rad</td>
<td>K6 = 194 lb.in/Rad</td>
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<tr>
<td>Combined Design Point (simultaneous loads and deflections)</td>
<td>D1 = 0.032 in</td>
<td>D1 = 0.017 in</td>
</tr>
<tr>
<td>F2 = 0 lb</td>
<td>F2 = 231 lb</td>
<td></td>
</tr>
<tr>
<td>F3 = 162 lb</td>
<td>F3 = 199 lb</td>
<td></td>
</tr>
<tr>
<td>R1 = 6.5 mRad</td>
<td>R1 = 7.3 mRad</td>
<td></td>
</tr>
<tr>
<td>R2 = 7.1 mRad</td>
<td>R2 = 6.6 mRad</td>
<td></td>
</tr>
<tr>
<td>R3 = 4.9 mRad</td>
<td>R3 = 4.9 mRad</td>
<td></td>
</tr>
<tr>
<td>Thermal cond.</td>
<td>k3 &lt; 3 mW/ºF</td>
<td>k3 &lt; 4 mW/ºF</td>
</tr>
<tr>
<td>Material</td>
<td>6Al-4V Titanium</td>
<td>6Al-4V Titanium</td>
</tr>
<tr>
<td>Dim. (LxWxH)</td>
<td>2.5x1.625x1.725</td>
<td>2.174x1.4x1.75</td>
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<tr>
<td>Mass</td>
<td>0.251 lbm</td>
<td>0.332 lbm</td>
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</tbody>
</table>

Custom Solutions

Our engineers can quickly design and proof-test custom solutions to suit your requirements of load (to 5000+ lb) and deflection (to 0.5°) capacities. Please contact us to discuss your application.