Cold War Lab Applies Strengths to New Missions

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The Charles Stark Draper Laboratory here is an engineering research and development organization that has evolved from its Cold War mission into an institution that gives modern interpretation to its traditional strengths.

The Massachusetts Institute of Technology's Instrumentation Laboratory was spun off as the independent Draper Lab in 1973. The work there for decades revolved around three areas—strategic guidance systems, primarily for the Navy's submarine-launched ICBMs, manned space guidance and control, and undersea systems.

However, the end of the Cold War brought large cutbacks. Employment dropped from about 2,000 in 1990 to about 1,080 now. Operating revenue has fluctuated between $229 million and $279 million since 1995, and it was $237.5 million in 2001, of which $140-150 million was spent directly at the lab, with the rest going to administered subcontracts.

The Draper Lab continues to innovate in technology and systems for guidance, navigation and control, but aimed more at tactical weapons and reconnaissance than strategic ICBMs. The laboratory's emphasis on autonomous vehicles grows out of its manned space projects and undersea vehicles. Devices to counter terrorism draw upon the lab's technical base and ability to build prototype systems.

"Our vision is complex dynamic systems," said President Vincent Vitto. "We like to work on first-of-a-kind, prototypes of next-generation systems. The stuff of new warfare is networking, autonomy and precision."

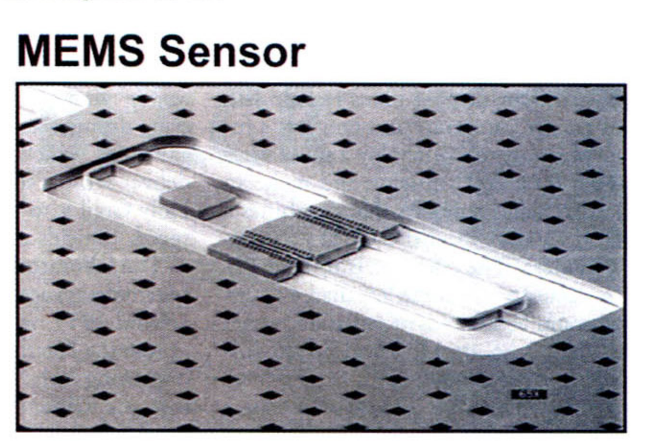
Vitto said Draper Lab goals include:

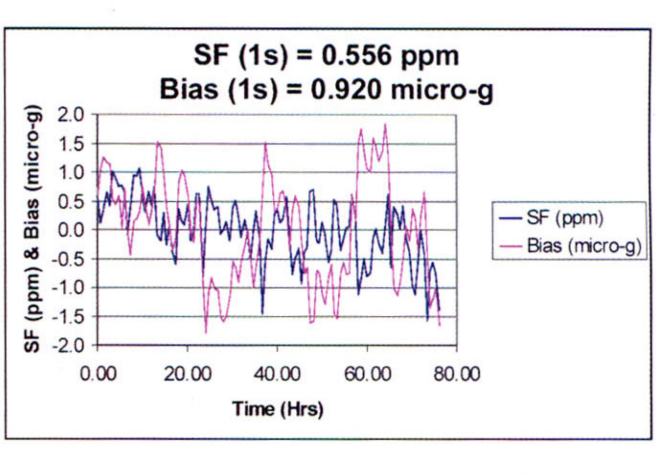
- Proving novel concepts through prototypes.
- Being an independent engineering resource for the nation.
- Maintaining stewardship of strategic guidance. The current Trident II D-5 SLBM is to serve until 2042.
- Providing a link between research and production by fostering technology transfer and startup companies.

As projects became smaller in the post-Cold-War cuts, they were not able to sustain their own independent staffs. The laboratory shifted to a matrix organization wherein technologies are supported by several programs, said James D. Shields, vice president for programs. Draper's core competencies include:

- High-accuracy strategic guidance sensors and systems.
- Radiation-hardened electronics.
- Integrated GPS/INS systems.
- Autonomous control systems.
- MEMS devices and systems.
- Custom electronics design and packaging.
- Fault tolerant systems design and evaluation.

The competent munitions advanced technology demonstrator was one of the gun projectiles that used a Draper Lab integrated GPS/INS guidance system. The GPS receiver was able to lock on to the signal in 15 sec.



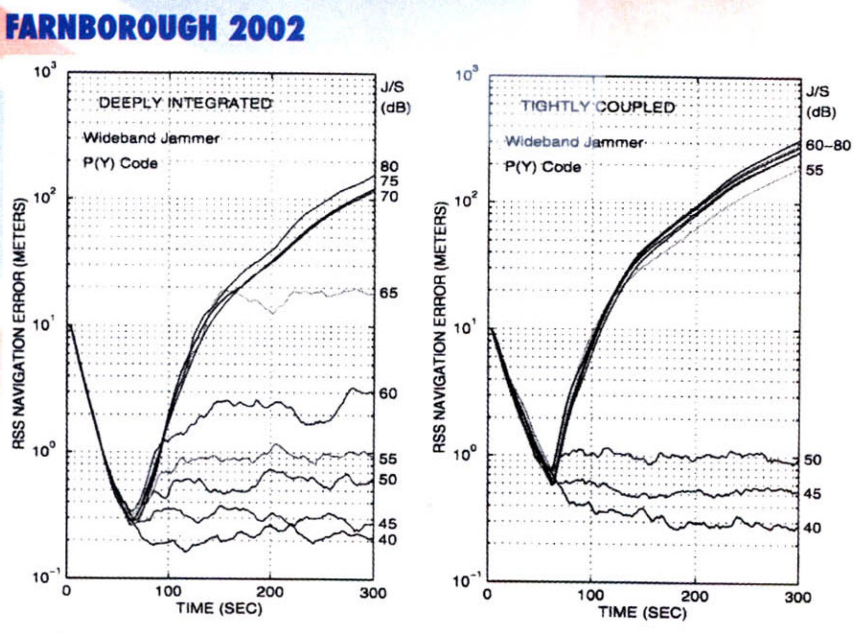


MEMS accelerometer has scale factor (SF) and bias errors near ICBM levels. The dual tuning fork layout is silicon-on-glass construction.

- Robotics design and prototyping.
- Information management and dissemination.
- Systems architecture design, testing and evaluation.

Draper's role in designing the avionics and guidance systems for the Apollo lunar program bolstered its skill in autonomous decision-making. The radio link to the Moon was sufficiently laggy and tenuous that landing guidance, navigation and control (GNC) had to be done on board without direct Earth support.

Apollo astronauts were doing the decision-making and some of the sensing, and now the effort is to automate this as well. Draper signed a memorandum of understanding with NASA's Jet Propulsion Laboratory on Jan. 10 to provide autonomy support on several projects. Most JPL missions to date have been run by remote control with the GNC on Earth, and events like the Mars landings were scripted, with no ability to detect and avoid obstacles. JPL's Deep Space 1 project started exploring autonomy, and the Draper collaboration is to push that along. One of the most difficult tasks will be robotically returning Mars surface samples to Earth, which requires autonomous rendezvous



A deeply-integrated GPS/INS system takes advantage of INS position knowledge to help GPS overcome jamming by adding processing gain. This Monte Carlo simulation assumes a flight vehicle making one-g maneuvers, and subjected to a 30 dB. jam/signal (J/S) ratio for the first 60 sec. Then jamming is increased to the level shown at the right of the graphs for the rest of the five-min. flight. The deeply-integrated system at left shows less navigation error overall.

of a Mars orbiter with a small spacecraft launched from Mars. "It's a complex quick event," Shields said.

Until then, Draper plans to help JPL put greater autonomy and range in a future planetary robot, develop a smart Mars lander for a 2009 mission and make an inertial/stellar compass that combines a MEMS 3-axis gyro with a CCD star-finding camera. The compass is to have 0.1 deg. accuracy, consume less than 4 watts, withstand 50 kilorads of radiation, weigh less than 2 kg. (4.4 lb.) and be self-initializing after a power failure. It's to be tested as a Hitchhiker payload on the space shuttle in 2005. Draper also teamed with JPL to propose using NASA's ST-7 experiment to test active control of aerocapture into a planet's orbit, but the bid was lost.

Draper is supplying its Autonomous Flight Manager to the Air Force Research Laboratory XSS-11 satellite inspection experiment, in which one micro-satellite approaches and inspects another. Lockheed Martin is the prime contractor, and the Draper component plans the trajectory, flight activities and rendezvous/inspection targeting.

The Autonomous Flight Manager is also to be used on the Defense Advanced Research Project Agency's $100 million Orbital Express demonstrator, recently won by Boeing. The scheme is to refuel satellites and upgrade their avionics. These items would be placed in a parking orbit with a cheap launcher, then transferred to the satellite by an autonomous tug and rendezvous vehicle (*AW&ST* Mar. 18, p. 36).

The Office of Naval Research awarded Draper an autonomous aircraft project to build a pair of helicopters that rendezvous and fly in formation by themselves. Searching for targets, they are to change routes on the fly to avoid threats, and steer around ground obstacles and other aircraft. The laboratory is also, along with MIT, looking at a system where a "mother ship" aircraft delivers autonomous hovering drones like Darpa's ducted-fan Organic Air Vehicle to search for targets or deliver sensors to a canopied area. "The Holy Grail is to fly in the woods at high speed," Shields said.

The laboratory became the guidance system design agent for the Navy's SLBMs around 1955, with the Mk. 1 guidance unit in the Polaris missile, and continued improving it through to the current Mk. 6 in the Trident II D-5. But the rapid progress is now replaced by maintenance. The Trident submarines are to remain in service another 40 years, and the design life of the guidance system is 25 years. "We used to continue to build new navigation systems, but since the 1990s we've just been maintaining the Mk. 6," Shields said. "We monitor the evolution of sensors, and want to get away from spinning devices due to wear."

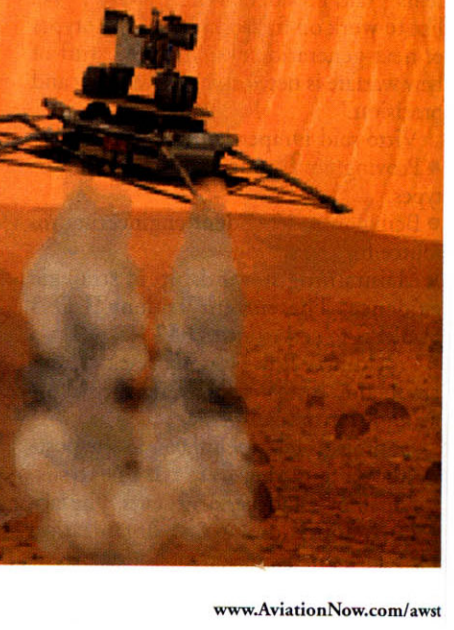
Draper has been working on MEMS inertial sensors since at least 1987, installing a 3,000-sq.-ft. Class 100 clean room as part of early Darpa inertial MEMS work (*AW&ST* Aug. 10, 1998, p. 68). Capability was increased when the first deep-reaction ion-etching machine was installed in 1995. A three-axis tuning fork gyro was successfully put on a single chip in 1999. One of the difficulties was handling the on-chip coupling between the gyros.

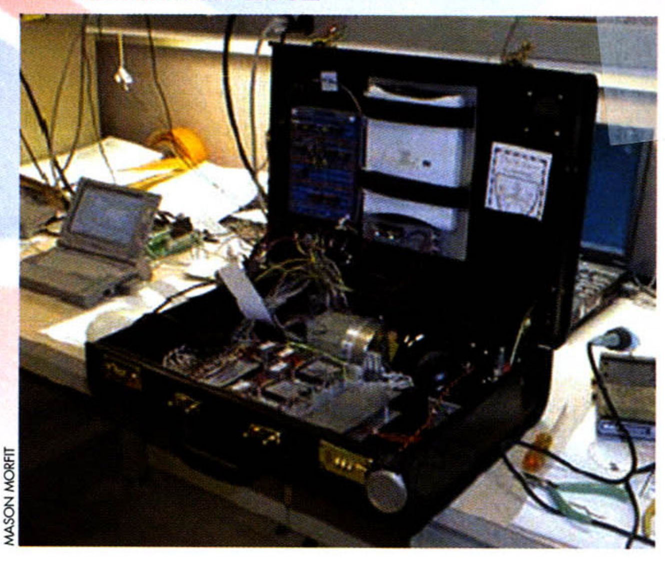
Now, a silicon oscillating accelerometer has been made with performance approaching ICBM accuracy, about three orders better than aircraft devices. It uses dual silicon-on-glass tuning forks. The one-sigma errors are 0.556 parts per million in scale factor and 0.92 micro-gs bias when thermally controlled to +/- 0.01C.

Tactical silicon sensors have been fired out of guns in several programs. A 5-in. shell was fitted with an 8-cu.-in. GPS/INS guidance system and small canards on a front despun section. The extended-range guided munition was qualified to 12,000 gs and fired at 6,500 gs (*AW&ST* Oct. 12, 1998, p. 48). It took 12-15 sec. for the GPS to lock on to the signal, but some shells fly for 7-8 min.

The Army has asked Draper to shrink the GPS/INS guidance system to 3 cu. in. and have 1 deg. per hr. drift, said Anthony Kourepenis, technical director of

Draper Lab is applying its background in autonomy to help JPL develop a smart lander with hazard avoidance and accurate navigation.





MASON MORFIT

Masint briefcase uses inertial navigation system and several sensors to map building corridors and caves with a walk-through.

MEMS technology. The prior accuracy was 5-7 deg. per hr. This is supposed to be achieved in 2003. The Army is seeking low cost and wants to have two chip foundries qualified to make the system. Tactical users can accept about 1 deg. per hr. drift and milli-gs of accelerometer error, Vitto said.

"A small and uniform device has less thermal gradient and is easier to compensate," Kourepenis said. "Fabrication accuracy controls precision, and each MEMS device has its own signature. It's calibrated on a gyro table over a temperature range. We get 100-fold improvement with compensation, for example, going from 100 deg. per hr. to 1 deg. per hr." In one stringent test, a tactical MEMS gyro underwent 8,000-g shock and 10 thermal cycles of -18C to +47C over 35 days. The 3-sigma shift in bias was 25 deg. per hr., "which is about 10 times better than required," he said.

The deep-reaction ion etching machine, also known as the Bosch process, can cut lines in silicon that are more than 100 times deeper than they are wide, with walls that are within 0.1 deg. of perpendicular, but "it takes a lot of work for that," said Jeffrey T. Borenstein, MEMS sensor group leader and bio-engineering program manager. High depth gives larger proof mass for more accuracy, and some designs have the cuts go through the full 0.4-0.8-mm. thickness of a wafer.

Clever integration of the GPS and INS improves the jamming resistance of the GPS. The INS can tell the GPS where it is, which adds processing gain to receive the weak signal, said vice president of engineering Eliezer G. Gai. GPS can usually operate with a jam-to-signal ratio of 54 dB., but integrated GPS/INS has demonstrated a 70-dB. J/S ratio, a 16-dB. improvement. But a 30-40-dB. improvement is really desired, Vitto said.

With improved GPS satellite ephemeris and clocks, absolute accuracy should improve to about two meters and a guidance system error of 1-2 meters, Vitto said. A 250-lb. bomb needs a 2-3 meter circular error probable to be effective, he said. But "the big problem is determining target location." The best location accuracy is the same 1-2 meters, but this needs static targets and long processing time. "The unsolved problems are jamming and target location accuracy."

This leads to the perpetual argument of whether to use a smart seeker with target recognition, or a dumb seeker going to a location provided by offboard targeting, Vitto said. "We believe that offboard targeting and cheap GPS/INS is the way to go. That is our expertise."

Draper's fault tolerant processor lab has built systems for the first fly-by-wire submarine, the Seawolf, and NASA Dryden Flight Research Center's F-8, the first digital fly-by-wire airplane. A recent project is devising a network arrangement that gives redundancy to standard processors, in this case for the flight controls of NASA's X-38 lifting body testbed. The five-channel system uses nine ruggedized 333-MHz. PowerPC processors, and they communicate on a network at a one megabyte/sec. rate. While each runs at its own rate, the 50 Hz. frame rate for the X-38 is kept in synchrony by the network. A computer that is declared faulty by the network reboots itself, and can be back on line in about 10 sec. by receiving current state data over the network.

After Sept. 11, the laboratory looked at how its capability could counter terrorism. One device is a remote ground sensor to report activity at caves, camps, defense perimeters, etc., that at 8 oz. is one-tenth the weight of current units. A microphone and signal processor classify noises and report the results via radio. Trucks can be sensed at 200 meters and people at 20-30 meters. Power is carefully budgeted so batteries last one month. One version also has a camera.

SMALL ROBOTS ARE BEING developed for intelligence collection, such as looking inside buildings. They are 6-10 in. in size, to be man-carried. The Darpa Distributed Robots program uses commercial technologies to operate them, such as cellphone modem communication and personal digital assistants as controllers.

A MEMS array of 64 microbalances acts as a "micro canary" to detect chemical or biological agents. Each microbalance is coated with an affinity material that reacts with a particular agent and changes weight. Low false positives are achieved through sensor redundancy. Another sensor is a MEMS high-field ion mobility spectrometer, which measures ion acceleration by the field to identify chemicals.

THE MASINT BRIEFCASE could have come from James Bond's Q Branch. Masint stands for measurement and signals intelligence collection and analysis. The purpose is to map building interiors or underground passages with a single, possibly covert, walk-through. Assuming GPS signals are blocked, it uses an INS system augmented by doppler speed measurement and algorithms that guess when the briefcase has stopped, and calibrate by passing the same point twice. Sensors include sonar to measure the size of corridors, video, acoustic, radio frequency and magnetic fields. The briefcase is a testbed; the ultimate scheme would be to wear it on the body, or put it on a robot.

Draper's work with Boston biotech firms includes trying to grow a blood vessel network on a micromachined pattern.