A View to a Kill

MILITARY strategists have dreamed for years of being able to stop an incoming missile in midair. Missile interception was the goal of the Strategic Defense Initiative of the 1980s and is a Department of Defense (DoD) goal today.

DoD has hired the Boeing Corporation as the lead system integrator for a weapons system to intercept an incoming ballistic missile. Boeing's interceptor for the Ground-Based Mid-Course Defense (GMD) program is currently being flight tested.

For the flight tests, a missile loaded with a "kill" vehicle is launched from Reagan Test Range at Kwajalein Atoll in the Pacific Ocean, to target the mock weapon-laden reentry vehicle of a missile launched from Vandenberg Air Force Base in California. Under contract to Boeing, a Livermore project has developed several sensors whose data help DoD determine whether the interceptor met the goal of killing the target missile.

Physicist Alex Pertica leads Livermore's Remote Optical Characterization Sensor Suite (ROCSS) project. Some of the ROCSS instrumentation has been developed by the Laboratory, and some is available commercially. Spectrometers examine the chemical makeup of the debris from the midair intercept while radiometers measure impact temperature and intensity. At the same time, high-speed cameras document the intercept event.

Livermore is one of several research organizations and companies responsible for monitoring the flight test program. "Our niche," says Pertica, "is the collection of spectral information as well as high-speed video to reveal the phenomenology of the intercept. Other organizations are tracking debris fragments and providing additional photo documentation of the intercept."

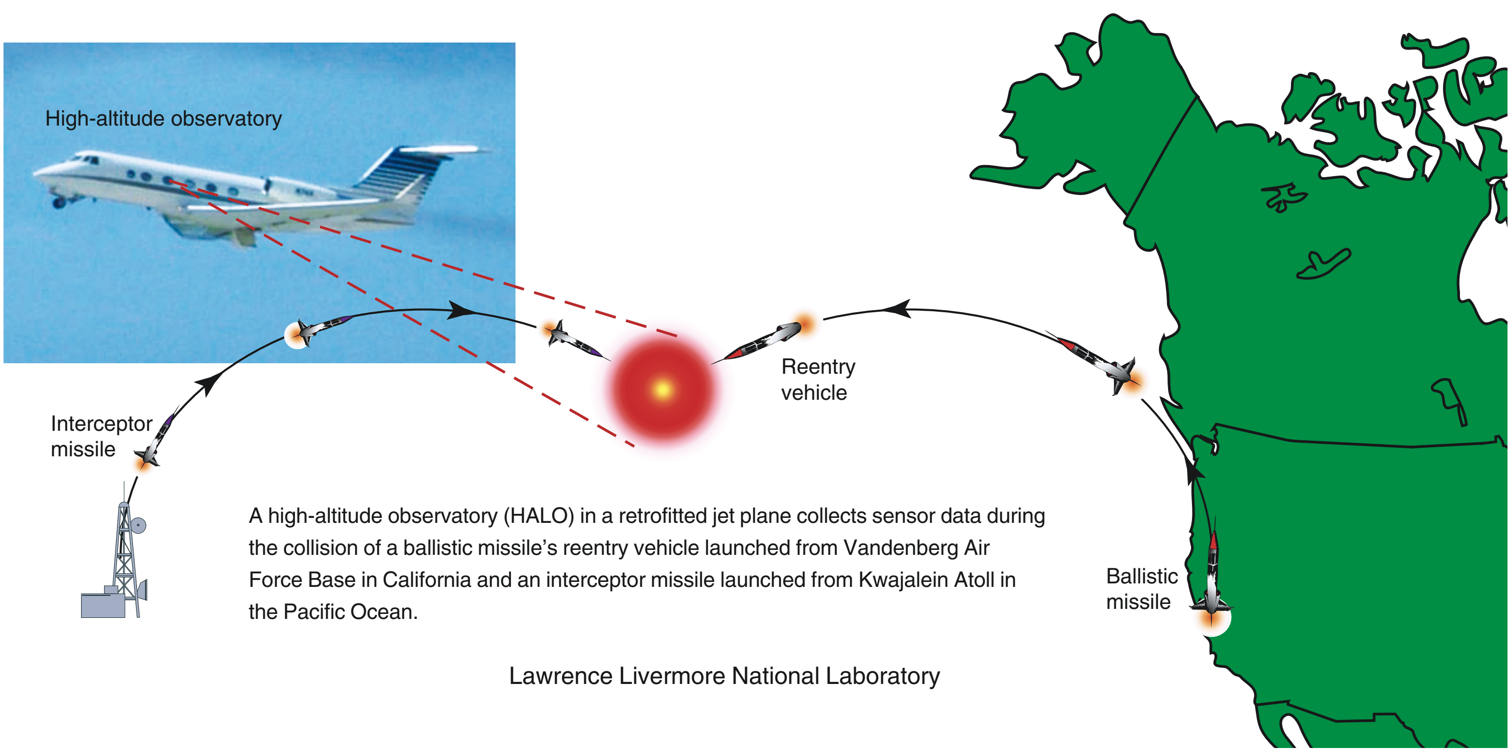
High-Flying Instruments

Livermore's sensors and cameras—as well as the instrumentation of other organizations—fly in a retrofitted business jet known as a high-altitude observatory (HALO). HALO flies at an altitude of about 14 kilometers, high above the weather. At least one Lawrence Livermore scientist is onboard each flight and must take Air Force high-altitude training before flying.

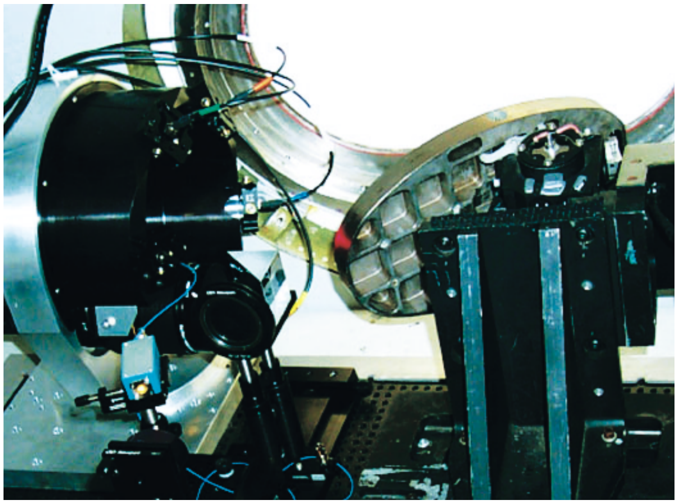
The HALO takes off from Reagan Test Range about 1 hour prior to the launch of the target missile from Vandenberg. Once in the air, HALO remains within 650 to 900 kilometers of the interceptor missile, also launched from Reagan Test Range, until the intercept occurs. A tracking mirror onboard the jet is guided by ground-based radar and tracks the trajectory of the interceptor missile.

The jet's high altitude not only keeps it above the weather but also provides for increased atmospheric transmission of infrared light. Many onboard sensors, including several of Livermore's, collect data in the infrared wavelengths. The ROCSS telescopes collect light through a window specially designed to transmit infrared light and channel it to the instruments via fiber-optic lines.

Five Livermore instruments fly onboard the HALO to collect data on the final boost of the interceptor rocket and then on the kill vehicle's collision with the reentry vehicle. A highly sensitive infrared echelle-grating spectrometer (EGS) detects the presence of gaseous chemical species in the effluent cloud. This instrument was developed at Livermore for another purpose entirely: to "sniff" the smokestacks of suspected chemical and nuclear facilities for tell-tale traces of weapon production.



A high-altitude observatory (HALO) in a retrofitted jet plane collects sensor data during the collision of a ballistic missile's reentry vehicle launched from Vandenberg Air Force Base in California and an interceptor missile launched from Kwajalein Atoll in the Pacific Ocean.



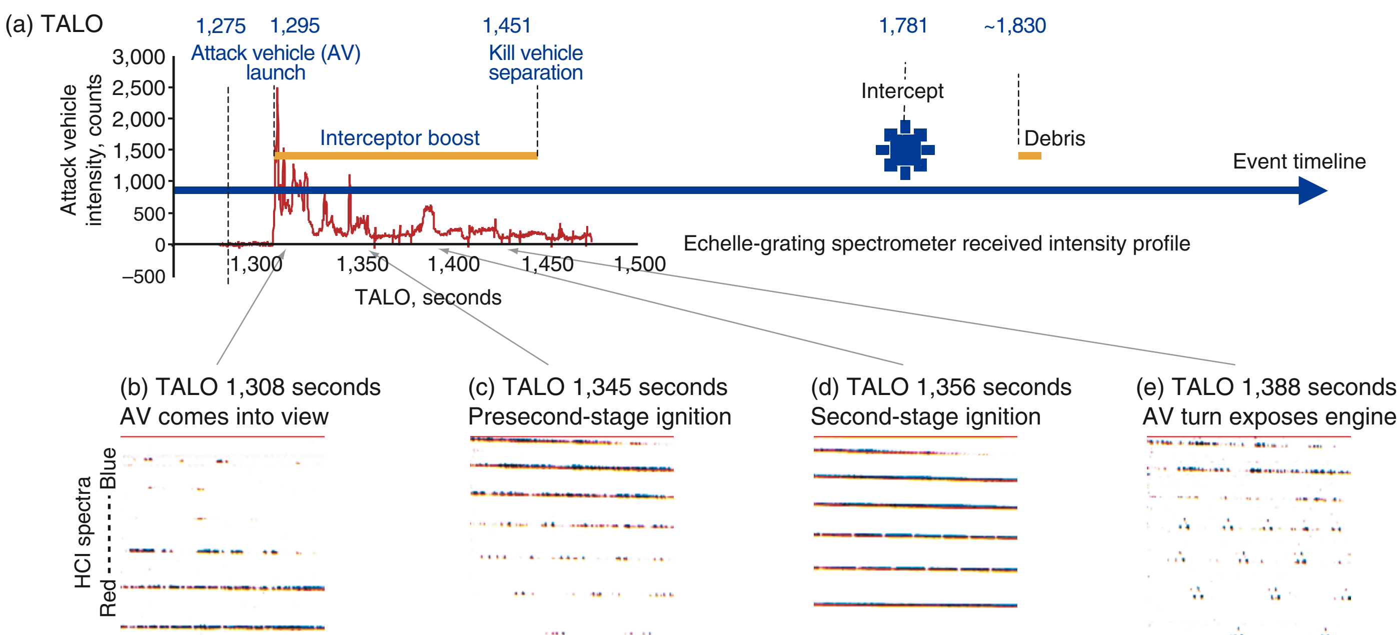
A tracking mirror (right) points out of a window of the high-altitude observatory (HALO) jet. The window is designed to admit infrared light for several of the onboard sensors. On the left is the front end of Livermore's instrumentation, whose fiber-optic lines carry data to individual sensors.

Another spectrometer operating in the visible wavelengths estimates temperatures and identifies materials produced by the interceptor's boost phase and by the collision of the interceptor with the target missile. It provides especially useful data about the first instant of the hit, just as the two vehicles are beginning to touch. A short-lived flash at that moment reveals the signatures of the metals that are crashing together.

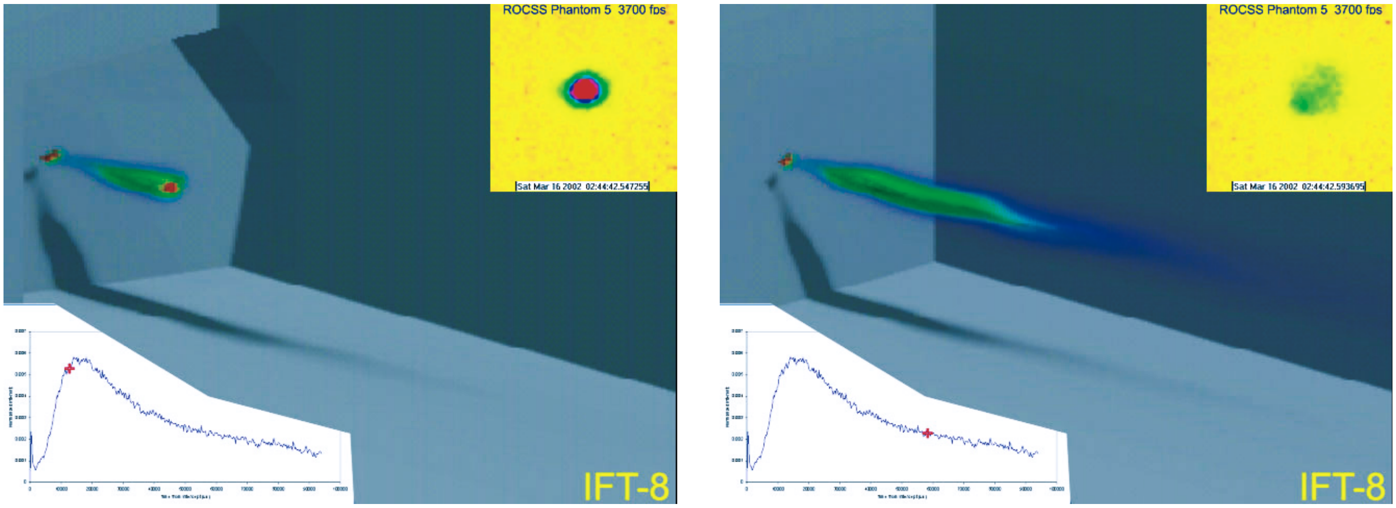
Radiometers operating in the visible, short-wavelength infrared, and mid-wavelength infrared spectral bands collect data on the temperature and intensity of the boost and the impact. A high-speed camera that captures 16,000 frames in 4 seconds records the evolution of the debris cloud created by the collision. A slower-speed videorecorder and another analog video system also record the collision.

Getting to the First Test Flight

The EGS was first applied to ballistic missile defense in September 1998. On the ground at the White Sands Proving Ground in New Mexico, the EGS successfully detected the exhaust chemicals from an Army Theater High Altitude Area



(a) The timeline shows events for the interceptor missile fired from Kwajalein in seconds after launch of the target missile (TALO) from Vandenberg Air Force Base. (b) During the boost of the interceptor rocket, the spectra for hydrogen chloride (HCl) are visible as the rocket comes into view, although light in the blue wavelengths is attenuated by atmospheric absorption. (c) Thirty-seven seconds later, with less atmospheric attenuation, HCl begins to dominate the spectrum. (d) Eleven seconds later, the practiced eye can see atmospheric methane absorption and a dense cloud of alumina particles from the rocket's exhaust. (e) Finally, as the missile turns, HCl again dominates the spectrum.



The high-speed camera captures 16,000 frames in 4 seconds from the moment that the kill vehicle collides with the reentry vehicle. The development of the "worm" of debris from the collision is shown in these two frames.

Defense (THAAD) rocket. The chemicals it detected, primarily hydrogen chloride, almost exactly matched the model for the rocket's exhaust materials. "We were quite pleased with that first test," says Pertica.

Numerous other tests from 1999 to 2001 were equally successful. One took place in Livermore's High Explosives Application Facility with an explosion designed to simulate an intercept. In June 2001, Livermore's ROCSS instrumentation was integrated into the HALO jet. In the first flight of the ROCSS instrumentation, HALO followed a rocket launched from Vandenberg Air Force Base to detect chemical effluents in the rocket's exhaust. In a similar test, the jet trailed an Atlas 3B rocket launched from Kennedy Space Center in Florida.

The first actual intercept test for ROCSS was Intercept Flight Test 8 (IFT-8) at Kwajalein in March 2002. During an 80-second period, from 1,308 to 1,388 seconds after launch of the target missile, the EGS data reveal first hydrogen chloride in the rocket's emissions as the interceptor comes into view, then increased hydrogen chloride as atmospheric attenuation lessens, and later, hydrogen chloride mixed with atmospheric methane and a dense exhaust of alumina particles. (See the figure at the bottom of p. 20.) In the final spectrum, the hydrogen chloride is clear again as the interceptor turns to expose its engine.

This spectral information can also indicate temperatures of the exhaust using the line intensities from the two isotopes of hydrogen chloride: hydrogen chloride-35 and hydrogen chloride-37. If the intercept involves an enemy missile, chemical and temperature data can be used as a diagnostic tool to determine the type incoming rocket.

"Also," adds Pertica, "if a rocket isn't performing as expected, temperature information is especially useful for indicating possible problems."

Images from the high-speed camera during the intercept reveal the growth of what Pertica calls a worm of debris. The worm begins its growth at the first instant of the kill vehicle's collision with the ballistic missile's reentry vehicle and continues to develop until the debris cloud dissipates.

What Lies Ahead

With that first flight test, Livermore completed the development phase of this project. The next phase is deployment, which is planned to continue through 2008 and IFT-26. The next flight test, IFT-9, is scheduled for late in 2002.

The ROCSS team plans to upgrade the EGS to include the full mid-wavelength infrared range, almost doubling its spectral coverage. This spectrometer and other ROCSS instrumentation may begin supporting future development tests of the new GMD booster, in addition to the intercept flight tests.

Pertica hopes to develop a broader capability for monitoring intercepts with instrumentation mounted either on satellites or flying along on the kill vehicle's booster rocket, paving the way for eventual kill assessment of intercepts from real enemy missiles.

—Katie Walter

Key Words: ballistic missile interceptor, Ground-Based Mid-Course Defense (GMD), high-altitude observatory (HALO), high-speed camera, infrared spectrometry, Remote Optical Characterization Sensor Suite (ROCSS).

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