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AEDC Space and Missile Ground Test Complex: 60 years of pioneering work defending the nation

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When V-2 rockets first rained down on England in 1944, the ballistic missile officially became the newest threat to the nations of the world. The V-2s, although initially not very accurate, provided a wakeup call to the U.S. and their allies.

After the end of World War II, American scientists made a disturbing discovery when they surveyed the Germany's sophisticated flight simulation test facilities, including where the V-2 rocket had been developed and tested.

General of the Air Force Henry "Hap" Arnold made it his mission to never let the U.S. fall behind in technology. Arnold Engineering Development Center (AEDC) was dedicated in memory of General Arnold to provide superior test capabilities. As the space race with the former Soviet Union began, AEDC began developing capabilities to ground test missiles, space vehicles and associated components. This led to the development of the facilities now known as the Space and Missile Ground Test Complex (SMTC) at AEDC.

SMTC is responsible for ground testing space and missile weapon systems over a wide range of operating conditions. The SMTC provides hypersonic, rocket propulsion and space environmental test and evaluation services and coordinates testing in more than 15 facilities that support the development of defensive ballistic and tactical missile interceptors as well as weapons systems such as theater defense, cruise missile, high-speed aircraft and launch vehicles.

Rocket motor test facilities

Over AEDC's 60 years, the upper-stage motors powering Peacekeeper, Minuteman, Trident and Titan were but a few of the motors tested in the center's facilities. From ballistic missiles to the lunar lander to rockets for positioning commercial satellites into orbit, AEDC has played a role in their development and ensuring they work as designed.

AEDC Outside Machinist J.R. Durham prepares a Minuteman Stage 3 motor before testing in J-6 in 2003. Operators fired the randomly selected motor at a simulated altitude of 100,000 feet to qualify the motor's production lot. (AEDC file photo)

James Brooks, program manager for the J-6 Rocket Test Facility, said AEDC has unique capabilities for testing high performance rocket propulsion systems, thrust vector control and those requiring altitude start and restart, stage separation and spin testing.

The earliest documented solid-fueled rocket motor testing took place in 1958 in AEDC's T-3 test cell in the Engine Test Facility (ETF). Before it was converted in 1989 to conduct small turbine engine testing, T-3 had been a rocket workhorse, conducting 2,423 firings.

During the 1960s, rocket motor testing also took place in turbine test cells J-2, T-1 and T-4.

In 1961, AEDC's first vertically-oriented Rocket Motor Test Facility J-3 came into service, fulfilling the need to provide the capability to test liquid-powered rocket motors.

AEDC's Rocket Development Test Cell J-4, also a vertical test cell designed for testing large rocket engines, came into service in 1964 to support the Apollo program.

The facility provided unmatched testing of liquid propellant rocket engines and solid-propellant rocket motors. J-4 was used to test a variety of engines over the years. The most recent were the test firings conducted on the RL-10B-2 between Sept. 8 and Oct. 3, 2001, in support of the Evolved Expendable Launch Vehicle (EELV). The EELV, in turn, led to the development of the Delta IV and Atlas V, the two primary launch systems for U.S. military satellites.

After it became operational in 1963, the Rocket Development Test Cell J-5 was used to test more than 500 motors for such systems as Minuteman, Surveyor, Poseidon, Trident and Peacekeeper before an explosion of a Peacekeeper third stage motor took the facility out of service in 1985. The blast occurred during the 502nd test firing in the cell; no one was hurt or injured. The facility was rebuilt in 1986 and used until 1994, with 90 tests conducted during that time.

AEDC's J-6 facility went into service in 1994 to provide expanded ground test capabilities for solid-propellant rocket motors at simulated altitudes up to 100,000 feet above sea level. These tests support development efforts by the DoD and commercial aerospace industry.

Currently, it is the only active rocket testing facility at AEDC.

According to Brooks, thrust, chamber pressure, temperature, strain and acceleration data are recorded during the firing.

"This facility is the largest of its kind in the world and provides the only altitude test capability for medium to large rocket propulsion systems in the United States," he said.

Hypervelocity Ballistic Range

The work done in the Hypervelocity Ballistic Ranges can be described as "lethality and materials testing."

Range G, the workhorse of the facilities, propels a sub-scale model of projectiles down a 1,000-foot long track at speeds up to 23,000 feet per second. Testers are also able to recover model fragments after impact. Specialized photography using laser illumination provides still and video imagery of the projectile models in flight. The facility is the only range in the country capable of providing unequalled "soft launched" capability to minimize g-loading and launch high fidelity missile simulations at hypervelocity speeds.

G-loading refers to the acceleration forces acting upon an object, like a projectile.

The hyperballistic ranges also include Range I, and S-1 and S-3 facilities. Range S-1 is a two-stage lab gun with three bore sizes available for use; .3-inch, .5-inch, .625-inch and 0.75-inch. It is similar to, but smaller than Range G. Range I is also similar to, but smaller than, Range G.

Range S-3, a 7-inch, single stage gun, was originally used for bird-strike impact testing of aircraft canopies. Most recently, S-3 was used to conduct impact testing on space shuttle block foam in support of the Return to Flight mission following the Columbia disaster.

Larry Campbell, the operations lead for Range G, said when he first came to work at AEDC, testers at the facility were firing models of Intercontinental Ballistic Missile (ICBM) projectile materials down the range.

In 1977, a track was installed inside the larger gun.

"The track allowed you to guide the model through erosive fields, not just ablation," he said. "They were working on erosive environments, rain, dust and snow, for those same kinds of materials, basically ICBM nose tip materials."

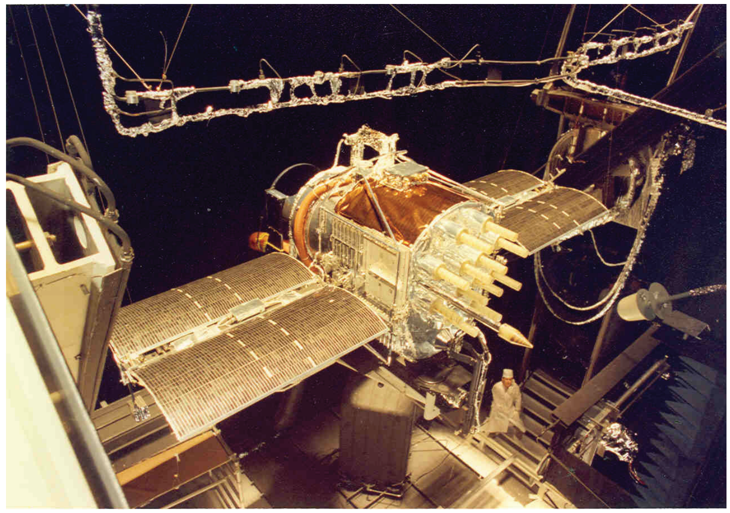
Testing in the range has included work done on the gun barrels and ammunition of the Air Force's A-10 Warthog and testing in support of NASA's Apollo capsule.

Campbell is particularly proud of his team's accomplishment in 2001, when a scale model of a conceptual missile powered by a scramjet was launched down the facility's two-stage light gas gun through its 130-foot long gun barrel.

This was the first-ever successful free flight demonstration at AEDC of a hypersonic projectile powered by a scramjet engine burning hydrocarbon fuel.

Space Chambers (7V, 10V, 12V and Mark 1)

Space test assets in this area include capabilities for evaluating infrared (IR) and visible sensor performance, mission simulation and other hardware-in-the-loop activities. This support includes testing and research for space systems in a thermal/vacuum environment from component level to full-scale, flight-qualified hardware. Addition¬ally, for component scale hardware, testing to simulate full spectrum space environments is available and includes contamination, solar, atomic oxygen, outgassing, radiation and other effects.



A full-scale GPS was tested in the Mark I Space Simulation Chamber at AEDC in 1977. The tests checked reliability of the satellite's systems prior to its launch in 1978. (AEDC file photo)

Jim Burns, AEDC's Space Chambers lead, said the first space chamber went into operation in 1961 when 7V was accepted for service. The 7-foot diameter, 30-foot long space chamber has been reconfigured over its lifetime to support a variety of test programs, with support in recent years to Missile Defense Agency (MDA) and Air Force Space and Missile Systems Center.

Jere Matty, AEDC deputy director of the SMTC, said 7V is still the most advanced and capable facility available at Arnold for testing Unmanned Aerial Vehicle sensor pods.

Construction on AEDC's Mark 1 Test Facility was underway by February 1965.

This facility is a space environment simulation test chamber for full-scale space systems testing. At 42-foot-diameter by 82-foot-high, the facility exposes test articles to conditions that replicate the extreme vacuum and temperatures of space.

Mark 1 was essential for testing the Global Positioning Satellite in 1977 and the Block II GPS also spent four months of testing in the facility. In 2000, The GOES-M Weather Satellite underwent pre-launch qualification testing in the facility. It has also been used to conduct faring separation testing.

Burns, who came to AEDC 10 years ago, said he is impressed by the work accomplished by his predecessors.

"Those guys anticipated a lot of what we've got now [in the way of technological capabilities]," he said. "We have reports and correspondence from these old files where they were laying out the requirements for some of the chambers that we've wanted to do for years. And these are things that we're still just now trying to figure out how to do."

The one area that has Burns and his colleagues especially excited about is a new facility under construction, the Space Threat Assessment Testbed (STAT).

STAT is a ground-test capability that will evaluate full-scale space systems and subsystems against realistic threats in realistic environments while simulating various orbits.

It will provide the ability to evaluate space protection Key Performance Parameters for space hardware, ground control equipment and software prior to launch.

STAT will submit test articles to solar, proton, electron, atomic oxygen and hostile threats. STAT will also supply a means to "train like you fight" by interactively connecting with satellite operations centers to conduct realistic exercises and to develop tactics, techniques and procedures.

Arc Heaters

AEDC's High-Enthalpy Arc-Heated facilities provide aerothermal ground test simulations of hypersonic flight over a wide range of velocities and pressure altitudes in support of materials and structures development by the DoD and the commercial aerospace industry.

The facilities are the sole DoD arc facilities in operation and provide high-enthalpy test conditions that duplicate aeroheating environments at velocities from 5,000 to 20,000 feet per second.

The combination of high-enthalpy test gas and high plenum pressure makes possible heat flux simulations representative of flight at speeds in excess of Mach 20 at high dynamic pressures (i.e. low altitude flight simulation).

Dennis Horn, an AEDC Fellow and long-time consultant on the facilities, said aerothermal testing began shortly after a commercial 5-megawatt arc heater was purchased and installed in the Propulsion Wind Tunnel in 1964.

Originally intended to conduct survivability testing for nozzle throats of a wind tunnel, the arc heater's capabilities soon caught the attention of Air Force Systems Command (AFSC). They wanted to find a way to conduct testing on ICBM nose tip materials to ensure they would survive and with enough accuracy to hit targets.

Horn said the next step later in the 1960s was development of the Dust Erosion Tunnel (DET) incorporating an upgraded version of the 5-megawatt Huels arc heater.

"They (AFSC) were concerned that if the Soviets launched a nuclear strike, would our ICBMs be able to survive a launch through dust clouds created by the impact of incoming missiles," Horn said.

Today, AEDC's arc-heated test facilities include two high-pressure segmented arc heaters (H1 and H3) and one Huels arcs-heated tunnel (H2). The facilities utilize a high-voltage, direct current electric arc discharge to heat air to temperatures up to over 13,000 degrees Farenheit.

These facilities have been used to conduct aerothermal testing for the Army, Navy, Air Force, NASA and commercial customers.

"Arc heaters simulate the aeroheating (friction heating) on flight vehicles when they fly within the atmosphere at many times the speed of sound," explained Mark Smith, a senior ATA project engineer in the arc facilities. "We do a lot of re-entry work here, as well as testing for surface-to-air interceptor missiles, target vehicles and some tactical missile materials evaluations.

"Thermal protection materials technology is a key enabling technology for hypersonic vehicles. If you can't wring those materials out in ground testing you never really get to the point where you have an affordable and low risk flight test program.

"In addition, the DoD fields aging missile systems that will continue to operate for decades, for example the strategic systems for the Navy and the Air Force which have a mandate for another 20 to 30 years of operation. To validate performance of critical materials to do the job that they were designed to do, you have to periodically bring them back in and retest them.

"Similarly, replacement materials are needed on occasion to meet the specifications of the original materials, and those require qualification at the same aerothermal test conditions as the originals. The viability of aging systems such as our strategic systems is an important reason for the existence of these facilities.

"We've done [testing on materials for] NASA's Crew Exploration Vehicle and the Mars Science Lab. We also have performed leading-edge testing on candidate materials for hypersonic air-breathers like the X-43, with NASA's Hyper-X program, and Defense Advanced Research Agency's (DARPA)/Air Force Research Laboratory's Falcon. We've done several large test entries for NASA programs in H-2."

APTU

Originally built by the Navy for its Ordnance Aerophysics Laboratory in Dangerfield, Texas, the Air Force moved the Aerodynamic and Propulsion Test Unit (APTU) to AEDC in 1971.

APTU, brought on-line in 1973, tested several programs, including the Navy Integral Rocket Ramjet surface-to-surface missile, MIG-21 fuel tank lethality and Marquardt Advanced Strategic Air Launched Missile.

A blow down, free-jet test facility, APTU is now capable of duplicating flight speeds up to Mach 8 and altitudes of 110,000 feet. These conditions are needed to support the emerging high-speed/hypersonic air-breathing propulsion systems being developed. But that hasn't always been the case.

APTU originally used a system that heated ceramic pebbles and then pushed air through them to heat it and generate the required test conditions. The downside of this clean-air heating source was it limited testing to Mach 3.

In 1980, an erratic flow control valve caused excessive air flow through the heater and forced the ceramic pebbles to exit the heater violently. The ensuing damage put the facility out of commission for two years. By 1982, a newly designed Vitiated Air Heater (VAH) had been installed to replace the damaged heater, giving APTU a performance boost to Mach 4. The first run of the VAH was conducted in June of that year.

For the next 25 years, APTU supported numerous programs seeking to push the technology envelope, accelerate their development and reduce the risk of acquisition and fielding. Programs included the Navy Standard Missile, Advanced Strategic Air Launched Missile and Air Force Ducted Rocket.

Several major upgrades have been made to the facility since it first brought the VAH online. By September 2007, a new Combustion Air Heater (CAH) had replaced the VAH. The CAH increased APTU's capability to its current levels while providing greater facility reliability.

On June 24, 2009, engineers at APTU ran their first scramjet propulsion test. The test for the DARPA's Falcon Combined-cycle Engine Technology (FaCET) demonstrator used the recently acquired CAH, Mach 3, 4 and 6 nozzles and JP-7 fuel heater. FaCET was the first-ever test of a near-flight scale hypersonic engine at AEDC.

The CAH set the stage for the most ambitious upgrade project APTU had undergone to date. The Hypersonic Propulsion Test Capability (HPTC) upgrade is progressing through its design and will provide APTU with a real-time varying Mach capability. An OSD-funded multi-year project, HPTC will ultimately give research, development and acquisition programs across all three services the ability to "fly-the-mission" from ramjet light-off to scramjet cruise repeatedly on the ground.

Space and Missile Ground Test Complex: The future

Peter Montgomery, Deputy Branch Manager of Space and Missiles, says the future of ground testing in the space and missiles' facilities is promising.

"I say that because the need is clearly there – in terms of our warfighters," he said. "I think it's clear that we rely more and more today on our space assets. Being able to test those systems, make sure those systems are there and stay there, and that they're available is critical for those folks. It is important in the commercial world as well, you can see the growing interest in commercial space, significantly in the last few years. And yes, with all those different needs that are out there, all of our facilities line up very well with those and so I do see the future being bright."