BGM-109

Tomahawk

The Tomahawk is a long-range, subsonic cruise missile used for land attack warfare, launched from U.S. Navy surface ships and U.S. Navy and Royal Navy Submarines. Current Tomahawks are designed to fly at extremely low altitudes at high subsonic speeds and are piloted over an evasive route by several mission-tailored guidance systems.

The Tomahawk carries a nuclear or conventional payload. The conventional, land-attack, unitary variant carries a 1,000-pound-class warhead, whereas the submunitions dispenser variant carries 166 combined-effects bomblets.

Characteristics

Primary Function: Long-range subsonic cruise missile
Contractor: Raytheon
Power Plant: Block II/III TLAM-A, C & D – Williams International F107 cruise turbofan engine, ARC/CSD solid-fuel booster; Block IV TLAM-E – Williams International F415 cruise turbojet engine, ARC solid-fuel booster.
Length: 18 feet 3 inches
Weight: 2,900 pounds
Diameter: 20.4 inches
Range: Block II TLAM-A – 1350 nm; Block III TLAM-C – 900 nm; Block III TLAM-D – 700 nm; Block IV TLAM-E – 900 nm
Maximum Speed: 550 mph
Warheads: (Warhead) Block II TLAM-N – W80 nuclear warhead; Block III TLAM-C and Block IV TLAM-E – 1,000-pound-class unitary warhead; Block III TLAM-D – conventional submunitions dispenser with combined-effect bomblets.
Date Deployed: Block II TLAM-A IOC – 1984; Block III – 1994; Block IV – 2004
Inventory: 4,170 missiles

Highlights of Development Testing at AEDC

- **Analysis provided for the continued improvement of the Tomahawk Cruise Missile Program**

Current Tomahawk cruise missiles are designed to fly at extremely low altitudes at high subsonic speeds and are piloted over an evasive route by several mission-tailored guidance systems.

The first operational use of the Tomahawk was in Operation Desert Storm in 1991 with great success. The missile has since been used successfully in several other conflicts.

In 1995, the governments of the U. S. and the U. K. signed a Foreign Military Sales Agreement for the British acquisition of 65 missiles, marking the first sale of the Tomahawk to a foreign country. After a November 1998 launch and live warhead test, the U.K. declared operational capability.

Some 11 years prior to the operational use of the Tomahawk in Operation Desert Storm, AEDC was heavily involved in its development testing. In July 17, 1980, the center was conducting tests to ensure the accuracy of data taken by an instrumented rocket flying in the upper atmosphere at supersonic speeds. Conducted in one of the center's aerospace chambers, the tests provided data needed for proper calibration of a probe, which measures the ion charge in the upper atmosphere. Such data are needed for communications and environmental purposes. Since the shock waves around the rocket can alter atmospheric samples taken by the probe, engineers must know temperature and air density changes in the airflow around the instrumentation. Once these changes have been determined, the probe can be calibrated to take accurate measurements.

In August 1989, AEDC engineers performed testing and analysis for the Navy for the continued improvement of the Tomahawk missile. Thus the Tomahawk was tested in Propulsion Development Test Cell J-1 in support of the Navy Cruise Missile Program.

As it can be launched from standard submarine torpedo tubes, the Tomahawk family of cruise missiles sees a broad range of uses with the U.S. fleet on both surface ships and submarines. The Tomahawk features a terrain-contour-matching navigation systems (TERCOM) that periodically compares the missile's actual position to the planned flight path and updates the inertial navigation system. The then-current propulsion unit for the Tomahawk (circa 1989) was a Williams F107-WR-400 turbofan engine that had been evaluated in the J-1 test cell in a prior test program during 1985. Drawing from the experience gained at

A Tomahawk model is readied for testing at AEDC in 1985.

The Navy Tomahawk Cruise Missile used against Iraq during Operation Desert Storm was tested in 16T.

that time, AEDC supported the Tomahawk program with testing of a replacement turbofan engine, the Williams F107-WR-402, which enhanced performance of the existing F107-WR-400 engine.

The Navy Cruise Missile Program Office authorized Williams to begin development of the F107-WR-402 engine and perform comparison testing with the F107-WR-400 at the Naval Air Propulsion Center. As a result of that testing both Williams, the engine contractor, and General Dynamics, the airframe contractor, recommended that full-scale testing of the Tomahawk be conducted with both engine types at AEDC. An extremely aggressive schedule was required to prepare for and complete the Tomahawk test in the J-1 test cell within the required time. AEDC personnel worked 40 hours a week for five consecutive weeks in support of this test program, with only three hours lost due to equipment delays.

The testing required flight simulation of the General Dynamics full-scale model of the Tomahawk missile at an altitude of 10,000 feet at Mach numbers ranging from 0.45 to 0.65. The desired flight conditions were simulated with the -20 degrees attained by injection of liquid air into the airstream.

Three major objectives of the J-1 testing were to (1) define the worst and best Tomahawk production inlets from a sampling of 18 inlets; (2) evaluate the effects of the worst and best inlets on the -400 and -402 engines; and (3) determine the effects of sideslip angle on the operation of the engine. The test procedure for these objectives required increasing the engine throttle every 30 seconds until a predetermined rate of engine surges was found.

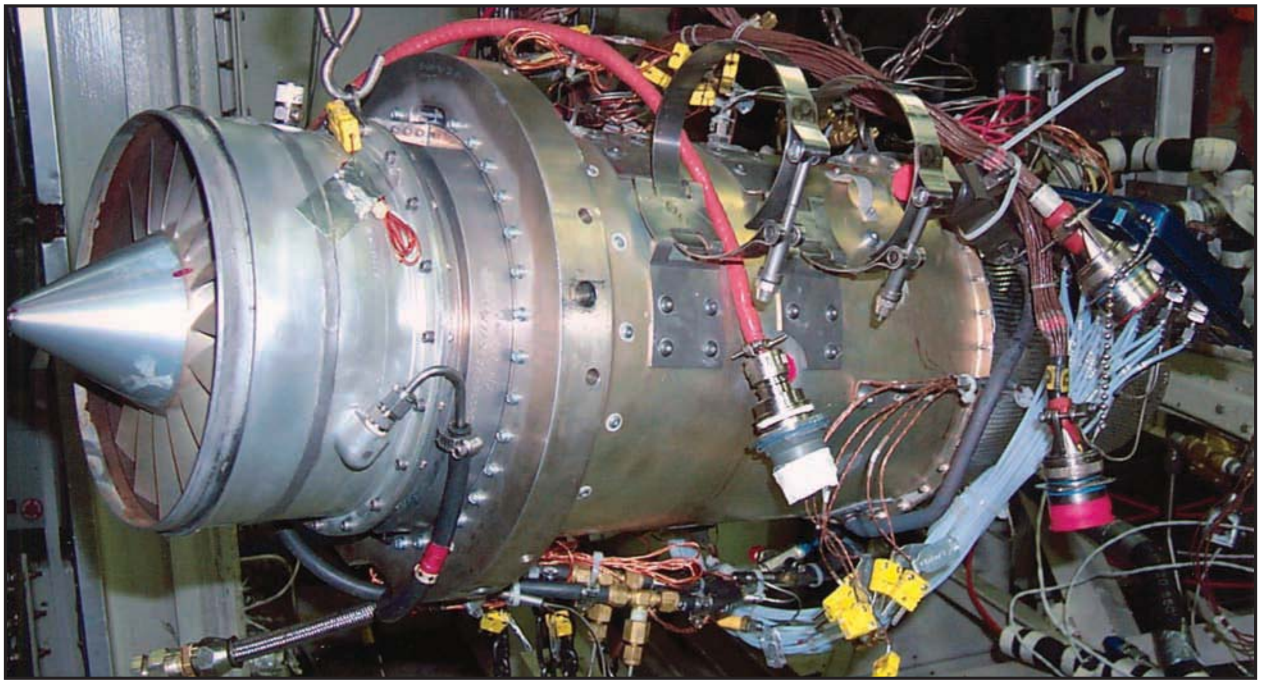
Engine surges were generally noticed as flashes from the engine tailpipe. (A surge is a momentary reversal of the flow within the engine.) The engine surges were monitored by the J-1 data acquisition system at a sampling rate of 100 samples per second.

The successful completion of this testing provided the Navy with the information needed to support the planned flight testing and to assist in the production decision on the new Tomahawk propulsion system.

In 1997, AEDC again conducted performance verification testing on the F107-WR-402 engine, which was the then-current Tomahawk missile engine. By the time it was replaced, Williams International would have delivered more than 7,000 of these second-generation F107 cruise missile engines for Navy Tomahawk and Air Force Air-Launched Cruise Missiles.

During the summer of 2000, AEDC signed a contract with the Raytheon Company on behalf of the U.S. Navy for engine tests for a new Tactical Tomahawk (TACTOM) program to be performed in Propulsion Development Test Cell T-11. The testing, performed in 2002, confirmed that the TACTOM, the next generation of the Navy's Tomahawk long-range cruise missile system, was capable of completing its assigned mission on time and on target. The engine that would power the new Raytheon-built TACTOM missile was the Williams International F415-WR-402, a smaller version of the Taurus missile engine, which AEDC had tested in 2000. Testing and certification of the F415-WR-402 engine lasted for a year.

During 110 hours of testing in test cell T-11, the test team simulated hot- and cold-day conditions to evaluate the operability and performance of the F415 engine in different atmospheric climates. They evaluated smoke and exhaust emissions to establish how efficiently the engine burned fuel during a mission, and they conducted endurance studies to determine how far the missile could fly under the various conditions.



The Williams International F415 engine, installed for testing in test cell T-11, powers the Navy's next generation Tomahawk cruise missile system, the Tactical Tomahawk.

Mission endurance is critical to a long-range cruise missile system's success. The data obtained in the test cell T-11 gave the customer a clear understanding of how their engine would perform under different flight and mission conditions and confirmed that the engine (1) more than met its thrust and efficiency goals, and (2) the missile system could successfully reach its target. The Tactical Tomahawk test program also successfully demonstrated a new realm of cruise missile test capabilities in T-11.

For the tests, AEDC employees modified T-11, a former Navy test cell, to provide better data and more efficient operations. To support future cruise missile testing, they also added new test capabilities. T-11 employees installed universal engine installation interface panels for engine instrumentation, as well as support systems that allow quick installation of a wide range of small engines in the test cell. These cell modifications provided improved real-time mission simulations and data acquisition. The installation interface makes first-time installations faster and allows the customer to mate up to standard interface points, thus reducing their test costs. In most cases, an engine test entry can now be completed in less than one week.

The T-11 team also installed a new fuel temperature control capability that increased the fuel temperature range by 25 percent and resulted in a very stable system that can automatically maintain temperatures from -65 to 186 degrees Fahrenheit. An updated mission simulation control system ensured an accurate simulation of the entire cruise missile mission from start to finish. It automatically controlled the mission flight conditions and interfaced with the engine control system to create a seamless integration of the engine with the facility that resulted in a realistic simulation of the actual missile mission.

New cameras installed in the engine's inlet also provided valuable information on how the engine performed in cold atmospheric conditions, and cameras in the exhaust flow allowed the customer to see how hot the engine became during the simulated mission. Since ice ingestion was a concern, the inlet cameras allowed the customer to ensure that there was no significant buildup before or during engine tests. The exhaust cameras provided information that has never been seen before as well as a visual representation of the overall turbine temperature profile.

The AEDC Applied Technology Department conducted emissions and smoke number measurements during the tests to determine the fuel-burn efficiency. The analyzed gas samples provided data on fuel combustion at simulated altitude conditions, and a new optical smoke meter developed by the department provided real-time transient smoke numbers during the simulated mission.

A later variant, the Tactical Tomahawk Block IV missile is a long-range, highly accurate, guided missile with the capability to deliver a unitary payload to a preplanned location. The Block IV program expands responsiveness and capabilities of the Tomahawk Weapon System with lower-cost airframe and electronic technologies. This new generation TACTOM is designed not only with a new airframe, but with new avionics architecture, new mission control software, new rocket motor assembly, and a new cruise engine.