ARCHIVED REPORT

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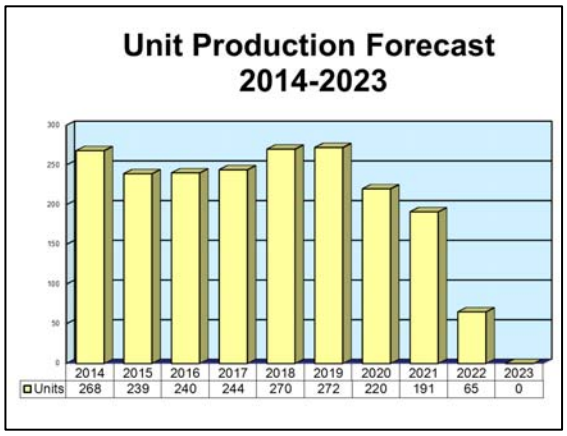
Williams International F107/F122/F415

Outlook

- Tight U.S. military budget may see reduced Tomahawk purchasing
- Standoff missile market favoring options other than Taurus



Orientation

Description. Two-shaft, axial-centrifugal-flow turbofan engines in the 600- to 900-lbst (2.7- to 4.0-kN) range.

Sponsor. The initial sponsor was the U.S. Department of Defense through the U.S. Air Force. Some cruise missile applications have been sponsored by the U.S. Navy and U.S. Army.

Power Class. F107: 600-700 lbst (2.67 to 3.11 kN). F122/F415: estimated at 750-900 lbst (3.33 to 4.0 kN).

Status. The F415 is in production for the Tactical Tomahawk. Future F122 production is expected for the KEPD 150.

Total Produced. As of August 2014, an estimated 699 F122 engines and 3,514 F415 engines had been built.

Application. Cruise missiles.

Price Range. F107-WR-402 estimated at $190,000. F122 estimated at $100,000-$140,000. F415 estimated at $135,000 (all estimates in 2013 U.S. dollars).

Competition. The F107/F122/F415 face competition chiefly from the Teledyne J402 in the 640- to 1,100-lbst (2.8- to 4.9-kN) range, as well as the Microturbo TRI 60 in the 750- to 1,000-lbst (3.3- to 4.4-kN) class.

Contractors

Prime

Williams International	http://www.williams-int.com, 2280 E West Maple Rd, PO Box 200, Walled Lake, MI 48390 United States, Tel: + 1 (248) 624-5200, Fax: + 1 (248) 669-0040, Prime

Subcontractor

Eastern Gear Corp	410 Straight St, Paterson, NJ 07501-2933 United States, Tel: + 1 (201) 278-3850 (Bevel Gear)
Metal-Fab Corp	PO Box 2611, Ormond Beach, FL 32175 United States, Tel: + 1 (904) 677-2140,

	Fax: + 1 (904) 672-2715 (Fuel System Accumulator)
Unison Industries	http://www.unisonindustries.com, 7575 Baymeadows Way, Jacksonville, FL 32256 United States, Tel: + 1 (904) 739-4000, Fax: + 1 (904) 739-4093 (Generator Kit & Igniter Plug)

Comprehensive information on Contractors can be found in Forecast International's "International Contractors" series. For a detailed description, go to www.forecastinternational.com (see Products & Samples/Governments & Industries) or call + 1 (203) 426-0800.

Contractors are invited to submit updated information to Editor, International Contractors, Forecast International, 22 Commerce Road, Newtown, CT 06470, USA; rich.pettibone@forecast1.com

Technical Data

Design Features. The Williams F107/F112 has the following design features (information does *not* apply to F122 or F415 variants):

Intake. Annular bellmouth air intake.

Fan. The fan consists of a two-stage unit, with each unit having integrally cast blades and discs of 17-4 PH stainless steel material. Fan rotation is 35,500 rpm.

Compressor. The LP compressor consists of a two-stage, axial-flow unit of near-net shape powdered-metal titanium. A single powder-metal-cast titanium centrifugal impeller provides high-pressure air to the combustor.

Combustor. Annular folded type with a single igniter. Fuel is supplied by a centrifugal fuel spray nozzle via the HP compressor shaft.

Turbine. A single-stage, uncooled axial HP turbine drives the HP compressor and is cast of IN100. The HP nozzle has an integrally cast shroud brazed to the aft end of the combustor as a structural member. Compressor discharge air cools the shroud to improve turbine blade tip clearance control. Turbine inlet temperature (TIT) is approximately 1,750°F (954°C), but could exceed 2,000°F (1,093°C) with turbine blade cooling. A two-stage LP turbine is integrally cast of IN713LC. Stage 1-2 power turbine nozzles are integrally cast of Haynes 31 alloy. A total of 73 blades in F107-WR-100 Stage 1 HP turbine; 56 in F107-WR-103.

Accessories. The accessory drive gearbox is driven by the compressor shaft. Gearbox outputs drive the airframe and engine ignition generators, lube pump, and fuel control. Hydromechanical fuel control is provided to control engine speed and acceleration/deceleration, along with a positive fuel shutoff. The self-contained lube system contains 1.3 pints (0.61 liters) in a reservoir.

Applications. Current or proposed applications include the following:

Engine Variant	Thrust Rating	Application	Engines per Missile
F107-WR-100	600 lbst (2.67 kN)	Boeing Aerospace AGM-86A	1
F107-WR-101		Boeing Aerospace AGM-86B	1
F107-WR-102		General Dynamics/McDonnell Douglas AGM-109 ALCM(a)	1
F107-WR-103		Boeing Aerospace AGM-86C/D	1
F107-WR-400		General Dynamics/McDonnell Douglas BGM-109 SLCM/GLCM(a)	1
F107-WR-402	660 lbst (2.93 kN)(b)	General Dynamics/McDonnell Douglas AGM/BGM-109	1
F112-WR-100	750 lbst (3.33 kN)(c)	General Dynamics AGM-129 Advanced Cruise Missile	1
		Boeing X-50 Dragonfly	2
F121-WR-100	150 lbst (0.67 kN)	Northrop AGM-136 TACIT RAINBOW (air launch version, canceled)	1
F122	900 lbst (4.0 kN)(b)	DaimlerChrysler TAURUS KEPD series	1
F415	750 lbst (3.33 kN)(b)	Raytheon Tactical Tomahawk	1

(a) Early production model.
(b) Forecast International's estimated rating.
(c) Thrust rating could exceed 1,000 lbst with some engine rework.

Dimensions. The approximate dimensions and weight of the F107-WR-400 are as follows:

	Metric Units	U.S. Units
Length	937 mm	36.9 in
Diameter	304 mm	12 in
Weight, dry	65.3 kg	144 lb

See **Variants/Upgrades** for dimensions of the F121-WR-100.

Williams F415 turbofan

Source: USAF/AEDC

Variants/Upgrades

F107-WR-101/400/402. The F107-WR-101, -400, and -402 equip the Boeing AGM-86B Air-Launched Cruise Missile (ALCM) and the General Dynamics BGM-109 Tomahawk Ground-Launched Cruise Missile (GLCM) and Sea-Launched Cruise Missile (SLCM). These engine models are rated at 600 lbst (2.67 kN).

F107-WR-103. The F107-WR-103, formerly known as the F107-WR-14A6, is the production model designated for the remainder of the ALCM buy. It is rated at approximately 1,000 lbst (4.44 kN), and incorporates the use of new materials in the turbine section for a much higher turbine inlet temperature. It employs a new inlet to reduce parasitic losses due to high-angle-of-attack flying. Additionally, classified research and development methods were used to provide greatly improved compressor and turbine blade aerodynamics. F107-WR-103 powerplants use significant amounts of ceramic coatings and may, in addition, use ceramic material or composite metal / ceramic turbine rotors.

F107-WR-104. The F107-WR-104 is a possible development of the original WR19, with a substantial uprating to over 1,200 lbst (5.33 kN).

F107-WR-105/401. The F107-WR-105/401 model offers an increase in thrust to 1,400 lbst (6.22 kN; 10:1 or better thrust-to-weight) by using all-ceramic turbines, combustors, stators, nozzles, and shrouds. It employs graphite polyamide composite casings, shafts, and compressor wheels for weight reduction. The engine could repower all operational Air-Launched, Sea-Launched, and Ground-Launched Cruise Missiles now employing the F107. Currently available for retrofitting or new production.

F112-WR-100. The F112-WR-100 is the USAF designation for the F107-WR-103 engine that has been identified as the propulsion engine for the General Dynamics Corp (Convair Division) AGM-129 Advanced Cruise Missile. While this engine variant's thrust rating is classified, we know that it is in the 750-lbst (3.3-kN) class. The F112 also powered the Douglas/NASA X-36 test drones.

F121-WR-100. The F121-WR-100 is the smallest Williams International engine. It was designated for the air-launched version of the TACIT RAINBOW. For this application, the engine was rated at 150 lbst (0.66 kN). Dimensions of the F121 are: length,

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26 inches (660mm); diameter, 8.3 inches (211mm); weight, 46 pounds (19.05 kg).

F122. Little information is available about this small engine other than that it powers the DaimlerChrysler TAURUS KEPD (Kinetic Energy Penetrating Destroyer) family of modular standoff weapons. The first weapon, the KEPD 150, has a range of approximately 150 kilometers.

F415. In 1999, a scaled-down version of the F122, USAF designation F415, was selected to power the Raytheon Tactical Tomahawk cruise missile after the Teledyne F402 turbojet was deselected.

The performance parameters of the F415 are apparently classified. The F415 was certificated in June 2002 after a year of testing.

Program Review

Background. F107 is the military designation of the Williams WR19 turbofan, itself a derivative of the earlier WR2 engine core. The first run of the WR19 occurred in 1967, and the engine found its first application in 1968 as power for the Bell Aerosystems Jet Flying Belt. The unit, weighing 64 pounds with accessories, saw tethered and manned flights that same year, but no production emerged from this program. However, Preliminary Flight Rating Tests (PFRTs) of the powerplant were completed in 1969, allowing use of the engine for military applications, which arose immediately. The USAF became interested in the engine, which it designated F107-WR-100, for the Subsonic Cruise Armed Decoy (SCAD) program, aimed at developing penetration aids for manned bomber strike missions. Williams emerged the winner in a competitive runoff in 1972 for the SCAD effort, and further development continued through mid-1973. At that time, the SCAD program was abruptly shelved. However, the F107 engine effort was reborn in 1974 with the development of the Air-Launched Cruise Missile (ALCM) system.

F107 Dual Sourcing. Teledyne CAE was designated the second source to Williams for production of the F107 cruise missile engine. However, due to the nullification proceedings regarding the Memorandum of Agreement that provided Williams with a guaranteed 80 percent share of all F107 production, F107 engines for the Tomahawk will now be procured competitively. However, it is unlikely that Williams will be adversely affected, as the company is well regarded and will probably continue to offer the more attractive pricing for this engine.

Teledyne CAE actually became involved in the program quite early, producing 48 engines in FY84, 48 in FY85, 90 in FY86, and 90 in FY87. The FY87 procurement for Teledyne CAE was 20 percent of the total of 447 engines; the FY88 procurement of 449 engines was again 20 percent (90 engines).

The engines built by Teledyne as the second source were provided to both General Dynamics and McDonnell Douglas as government-furnished equipment (GFE).

Applications

AGM-86A/B Air-Launched Cruise Missile. In 1975, Williams Research was awarded a $9 million contract to develop the F107 turbofan engine for the ALCM, a modified version of the canceled SCAD. Later that year, Williams delivered the first development engine to the U.S. Air Force for testing at the Arnold Engineering Test Center. This contract was followed by another in 1978, for $37 million, for tooling and other activities toward future production of the F107.

In 1980, Boeing was selected as prime ALCM contractor, with initial procurement calling for 3,400 missiles through the end of the 1980s. However, advances with the AGM-129 Advanced Cruise Missile, and the USAF's decision to deploy that missile quickly, led to the service's decision not to request ALCMs in FY84. Nevertheless, Congress decided to fund 240 missiles.

The ALCM, designated AGM-86, can be carried by modified Boeing B-52 bombers. Shortly after B-52s were modified, the Rockwell B-1B was also designated an AGM-86 carrier, with initial deployment in 1986.

In 1980, Williams received $172 million, its largest contract ever from the U.S. government, to produce 559 F107 powerplants. In 1982, Williams received two contracts for a total of $143 million for additional powerplants. In FY83, 625 engines were procured for the AGM-86 and Tomahawk, and that year's budget may also have included funding for the purchase of the F112 engine for the ALCM. A total of 1,715 ALCMs were produced.

Power for the ALCM-B is provided by the F107-WR-101, with new ALCMs getting the uprated 1,000-lbst F107-WR-103 in 1985. And, while there have been no official statements, we believe that the USAF is retrofitting a few dozen F107-WR-101-powered AGM-86s with the F107-WR-103.

BGM-109 Tomahawk. The General Dynamics BGM-109 competed with the Boeing AGM-86 for the ALCM mission, but was ultimately chosen as a ship-, submarine-, and ground-launched cruise missile.

The Tomahawk was initially equipped with the F107-WR-400 engine, which is being replaced by the F107-WR-402 engine concurrently with incorporation of a Block III improvement package on BGM-109C/D models.

At one time, short-range versions of the Sea-Launched Cruise Missile were to have a Teledyne CAE J402-CA-400 turbojet rated at 2.97-kN (660-lb) static thrust at sea level. However, the Navy elected to use the Williams engine in all versions. Teledyne CAE has been selected and qualified as a second source on F107 engines.

The Tomahawk program has expanded into a number of specialized variants for specific missions. The associated acronyms have also multiplied, to the point that there is now some confusion when the various programs are discussed. To better understand this program, the following information about the various elements of the Tomahawk program has been supplied by Forecast International's *Missile Forecast.*

Designation	Type	Warhead
BGM-109A	TLAM-N	W80-0 nuclear
BGM-109B	TASM	454.55 kg high explosive
BGM-109C	TLAM-C	454.55 kg high explosive
BGM-109D	TLAM-D	CBU-87, BLU-97/B
BGM-109E	TASM	Reactive case high explosive
BGM-109F	TAAM	Submunition dispensing
BGM-109G(a)	GLCM	W84 nuclear
AGM-109C(a)	MRASM (USN version)	120 kg high explosive
AGM-109H(a)	MRASM (USAF version)	BLU-106/B BKEP
AGM-109I(a)	TASM	120 kg high explosive
AGM-109J(a)	MRASM (USN version)	Submunition dispensing
AGM-109L(a)	MRASM (USN version)	230 kg high explosive

(a) Model effort has been terminated.

Approximately 525 Ground-Launched Cruise Missiles (including 61 RDT&E units), 59 AGM-109 air-launched cruise missiles (all RDT&E or flight test units), and 5,755 Sea-Launched Cruise Missiles (of all types, including remanufactured plus over 120 RDT&E units) had been completed or were in production as of the end of 2003.

AGM-129 Advanced Cruise Missile. The General Dynamics Convair Division, San Diego, California, is producing the Advanced Cruise Missile, or ACM. The missile entered low-rate production in 1991. The program never left low-rate production, and was scheduled to end in December 1993 (though this could have stretched into 1994), with between 460 and 500 weapons produced. Prior to the arms reduction that followed the decrease in East-West tensions, some 1,500 to 2,000 weapons were expected to be produced. The missile is nuclear, with a 150- to 200-kiloton warhead. The AGM-129A flies at a speed of approximately Mach 0.9 to a distance of 1,290 nautical miles (2,750 km). The missile is of a low-observable design, optimized for minimal radar reflection directed from above and ahead; its shape is fairly radical, with a chiseled nose cone, forward-swept wings, two small straight leading-edge elevators on either side of the tapered tail, and a fully swept vertical stabilizer under the tail. Air intakes and exhaust are both flush with the body and masked. A conventionally armed version, the AGM-129B, was considered but was canceled by Congress. The ACM is carried aboard the Boeing B-52H, B-1B, and B-2.

GD Convair won over its arch rivals, Lockheed and Boeing, in the competition to produce the unique platform, incorporating the most advanced propulsion, airframe, coating, and electronics technologies available in the United States and other Western nations. The engine model used is the F112-WR-100.

The F112-WR-100, an F107 derivative, is the most advanced variant of F107 developed by Williams to date. It includes the use of advanced ceramic rotating components and coatings, high-temperature compressor materials, boron-slurry fuel for much greater specific thrust for added speed and range, and reduced infrared signature – all producing approximately 750 lbst.

The advanced F112 powerplant was funded from a host of sources, most of which remain classified; DARPA's Advanced Cruise Missile Technology (ACMT) program was known to be one source. The USAF says that over $200 million has been invested in the Williams F107 upgrade program.

TAURUS KEPD. DaimlerChrysler Aerospace (DASA) and Bofors are offering a new family of standoff

Williams International F107/F122/F415

weapons systems under the designation TAURUS. The TAURUS family provides both medium- and long-range missiles under the designation KEPD (Kinetic Energy Penetrating Destroyer).

The KEPD, a version of the Dispenser Weapon System (DWS), is outfitted with a flying gun warhead for deep penetration of hardened targets. The flying gun warhead is based on the Davis gun principle, in which the warhead has a penetrator that is fired from the front of the missile at a set distance from the target. This increases the impact speed of the warhead by one-third. The rest of the missile acts as a counterweight. On hitting the target, a shaped charge in the nose of the penetrator detonates to weaken the targeted structure, allowing a second charge to penetrate and explode within the target.

Three versions of the KEPD are known to exist: KEPD 150, KEPD 250, and KEPD 350. The numbers after the KEPD designation indicate the range (in kilometers) of the system. The Williams International F122 is used on these missiles.

Germany plans to procure the KEPD 350 TAURUS for use on its Tornado and Eurofighter Typhoon fighters. Two successful flight tests of the TAURUS, powered by an F122-15 engine, were conducted in mid-2002. Initial production units were expected to be in the field by early 2004. Germany could procure some 600 standoff missiles.

Sweden may delay its procurement of the KEPD 150. Meanwhile, a version of this system is being offered to Australia to meet its Project Air 5398 requirement.

Boeing Dragonfly. The "black projects" division of Boeing's Phantom Works is under contract from DARPA to design, build, and flight-test two canard rotary-wing Dragonfly unmanned aerial vehicles (UAVs) as part of a three-year, $24 million program that it is jointly funding with DARPA.

The helicopter-like UAV uses two F112 engines to vent exhaust gas through the rotor out to wingtip exhausts to spin the rotor for lift-off or hover. The exhaust is then gradually diverted to the engine's direct exhaust nozzles (exiting exhaust behind the UAV in the manner of a conventional jet) to build forward momentum.

The first Dragonfly was severely damaged after crashing during a test flight in March 2004, three months after flight testing began. A second vehicle that was built as part of the original contract with DARPA has taken the place of the first in testing. No forward-looking schedule is available.

The F112, like many other components, was selected as the least expensive off-the-shelf hardware in order to minimize costs in the experimental program.

Tactical Tomahawk. By 1997, the U.S. had considered meeting its cruise missile requirements with something less costly than the Tomahawk. The Raytheon Tactical Tomahawk proposal merged parts of the Block IV and Block V Tomahawk, and new unit production would continue for several years.

The weapon has a loiter capability in excess of two hours, allowing a number of Tactical Tomahawks to circle the battlefield until they are assigned target coordinates. The weapon also has the ability to carry several different advanced submunitions.

In 1998, Raytheon (then Hughes) was selected as the sole-source contractor for this program (a condition from the start) and was awarded a contract valued at $256 million. Raytheon had selected the Teledyne J402 turbojet to power the weapon, but the engine did not meet range performance requirements, as fuel consumption was higher than expected. Raytheon turned to Williams for a solution, which offered a smaller version of the F122 used on the DaimlerChrysler TAURUS KEPD, the F415.

The first flight test of a Tactical Tomahawk was conducted in August 2002; the F415 engine reportedly performed flawlessly throughout the flight regime, including loiter and retargeting maneuvers. Full-rate began in August 2004.

Timetable

Month	Year	Major Development
Late	1960s	Development of F107 series begins
	1969	U.S. Army evaluates jet flying belt
Jun	1972	SLCM development begins
Feb	1974	ALCM DSARC I
Mar	1974	SLCM DSARC I
Oct	1974	ALCM DSARC II
Jan	1976	F107 Preliminary Flight Rating Test completed
Mar	1976	First flight of AGM-86A
Oct	1977	GLCM program initiated
Sep	1978	First ship-launched SLCM rolled out
Jan	1979	GLCM AFSARC held

Month	Year	Major Development
Mar	1980	Boeing selected as prime contractor for AGM-86
Oct	1982	First Teledyne-built F107 delivered
Dec	1982	ALCM Initial Operational Capability
Apr	1983	General Dynamics selected to develop ACM
Jul	1983	IOC of sub-launched anti-ship SLCM; IOC of sub-launched land-attack SLCM
Oct	1983	McDonnell Douglas opens Tomahawk facility
Dec	1983	IOC of GLCM
Oct	1986	AGM-86 production ends
	1987	Full-scale production of all Tomahawk variants begins; first production unit of TACIT RAINBOW becomes available
	1991	TACIT RAINBOW program canceled by U.S. Department of Defense
Dec	1993	Estimated end of production of Advanced Cruise Missile (AGM-129)
	1999	F415 (scaled-down F122) selected to power Tactical Tomahawk
Apr	2002	F122 completes successful test flight on TAURUS KEPD 350
Jun	2002	F415 certificated
Aug	2002	First flight of Tactical Tomahawk
	2004	Final series production of F107
Thru	2015	Continued production of F122/F415

Worldwide Distribution/Inventories

An estimated 14,786 F107/F112/F122/F415 engines have been built, the majority of which were installed in cruise missiles. Most are in the possession of the **U.S. military**, but some 50 to 75 are in **U.K. Royal Navy** service. Information regarding the inventory totals of the cruise missiles and their engines is classified.

Forecast Rationale

Williams produces the F122 for the KEPD 150 and the F415 for Raytheon's Tactical Tomahawk.

Tactical Tomahawk

Procurement of the Tomahawk cruise missile is holding steady, but the Pentagon is facing a shrinking budget. The need to reduce overall U.S. defense spending may result in reductions to Tomahawk procurement; as such, Raytheon is looking for additional export contracts. Potential clients exist in Asia, and there is great interest in that region for shipborne strike missiles. Britain's Royal Navy placed an order for the Tactical Tomahawk to replace the missiles used during the operation in Libya.

Taurus

Production of the KEPD 350 had ended, but it could restart should South Korea finalize its order in 2014 as planned. Production of the KEPD 350 version has ceased with the delivery of the final units to existing customers. MBDA and Saab Bofors Dynamics are working to find other customers for their TAURUS standoff attack missiles, but are facing competition from U.S.-made systems. Overall, the outlook for TAURUS is not good, as the market outside Europe seems to favor the SCALP-EG and Storm Shadow.

Our F122/F415 forecast data is based on current military procurement plans for the KEPD 150 and Tactical Tomahawk missile programs.

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Ten-Year Outlook

ESTIMATED CALENDAR YEAR UNIT PRODUCTION												
Designation or Program		**High Confidence**				**Good Confidence**			**Speculative**			
	Thru 2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Williams International												
F122 Military <> KEPD 150												
	0	0	0	23	46	49	48	25	0	0	0	191
F415 Military <> Tactical Tomahawk												
	3,514	268	239	217	198	221	224	195	191	65	0	1,818
Subtotal	3,514	268	239	240	244	270	272	220	191	65	0	2,009
Total	3,514	268	239	240	244	270	272	220	191	65	0	2,009