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Lockheed Martin F-22 Raptor

The **Lockheed Martin F-22 Raptor** is an American single-seat, twin-engine, all-weather stealth tactical fighter aircraft developed for the United States Air Force (USAF). As the result of the USAF's Advanced Tactical Fighter (ATF) program, the aircraft was designed as an air superiority fighter, but also has ground attack, electronic warfare, and signals intelligence capabilities. The prime contractor, Lockheed Martin, built most of the F-22's airframe and weapons systems and conducted final assembly, while Boeing provided the wings, aft fuselage, avionics integration, and training systems.

The aircraft was variously designated **F-22** and **F/A-22** before it formally entered service in December 2005 as the **F-22A**. Despite its protracted development and operational difficulties, USAF considers the F-22 a critical component of its tactical airpower. The fighter's combination of stealth, aerodynamic performance, and mission systems enable unprecedented air combat capabilities.[2][3]

The USAF had originally planned to buy a total of 750 ATFs. In 2009, the program was cut to 187 operational aircraft due to high costs, a lack of clear air-to-air missions during production, a ban on exports, and development of the more versatile F-35,[N 1] with the last F-22 delivered in 2012.

F-22 Raptor

An F-22 Raptor flies over Kadena Air Base, Japan on a routine training mission in 2009.

Role	Air superiority fighter
National origin	United States
Manufacturer	Lockheed Martin Aeronautics Boeing Defense, Space & Security
First flight	7 September 1997
Introduction	15 December 2005
Status	In service
Primary user	United States Air Force
Produced	1996–2011
Number built	195 (8 test and 187 operational aircraft)[1]
Developed from	Lockheed YF-22
Developed into	Lockheed Martin X-44 MANTA Lockheed Martin FB-22

Contents

Development

Origins

In 1981, the U.S. Air Force identified a requirement for an Advanced Tactical Fighter (ATF) to replace the F-15 Eagle and F-16 Fighting Falcon. Code-named "*Senior Sky*", this air-superiority fighter program was influenced by emerging worldwide threats, including new developments in Soviet air defense systems and the proliferation of the Sukhoi Su-27 "Flanker"- and Mikoyan MiG-29 "Fulcrum"-class of fighter aircraft.[5] It would take advantage of the new technologies in fighter design on the horizon, including composite materials, lightweight alloys, advanced flight control systems, more powerful propulsion systems, and most importantly, stealth technology. In 1983, the ATF concept development team became the System Program Office (SPO) and managed the program at Wright-Patterson Air Force Base. The demonstration and validation (Dem/Val) request for proposals (RFP) was issued in September 1985, with requirements placing a strong emphasis on stealth and supercruise. Of the seven bidding companies, Lockheed and Northrop were selected on 31 October 1986. Lockheed then teamed with Boeing and General Dynamics while Northrop teamed with McDonnell Douglas, and the two contractor teams undertook a 50-month Dem/Val phase, culminating in the flight test of two technology demonstrator prototypes, the YF-22 and the YF-23, respectively. Concurrently, Pratt & Whitney and General Electric were awarded contracts to develop the YF119 and YF120 engines respectively for the ATF engine competition.[6][7]

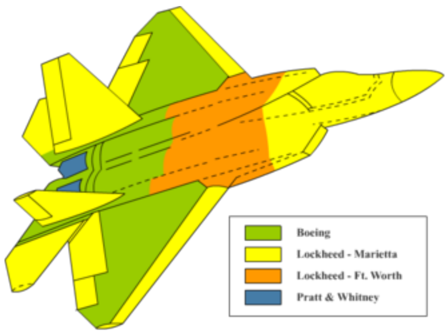
ATF SPO Patch, 1990

Dem/Val was focused on system engineering, technology development plans, and risk reduction over point aircraft designs; in fact, after the down-select, the Lockheed team completely changed the airframe configuration in the summer of 1987 due to weight analysis during detailed design, with notable changes including the wing planform from swept trapezoidal to diamond-like and a reduction in forebody planform area.[8] Contractors made extensive use of analytical and empirical methods, including computational fluid dynamics, wind-tunnel testing, and radar cross-section (RCS) calculations and pole testing; the Lockheed team would conduct nearly 18,000 hours of wind-tunnel testing. Avionics development was marked by extensive testing and prototyping and supported by ground and flying laboratories.[9] During Dem/Val, the SPO used the results of performance and cost trade studies conducted by contractor teams to adjust ATF requirements and delete ones that were significant weight and cost drivers while having marginal value. The short takeoff and landing (STOL) requirement was relaxed to delete thrust-reversers, saving substantial weight. As avionics was a major cost driver, side-looking radars were deleted, and the dedicated infra-red search and track (IRST) system was downgraded from multi-color to single color and then deleted as well. However, space and cooling provisions were retained to allow for the future addition of these components. The ejection seat requirement was downgraded from a fresh design to the existing McDonnell Douglas ACES II. Despite efforts by the contractor teams to rein in weight, the takeoff gross weight estimate was increased from 50,000 lb (22,700 kg) to 60,000 lb (27,200 kg), resulting in engine thrust requirement increasing from 30,000 lbf (133 kN) to 35,000 lbf (156 kN) class.[10]

Each team produced two prototype air vehicles for Dem/Val, one for each of the two engine options. The YF-22 had its maiden flight on 29 September 1990 and in-flight tests achieved up to Mach 1.58 in supercruise. After the Dem/Val flight test of the prototypes, on 23 April 1991, Secretary of the USAF Donald Rice announced the Lockheed team and Pratt & Whitney as the winners of the ATF and engine competitions.[11] The YF-23 design was considered stealthier and faster, while the YF-22, with its thrust vectoring nozzles, was more maneuverable as well as less expensive and risky.[12] The aviation press speculated that the Lockheed team's design was also more adaptable to the U.S. Navy's Navalized Advanced Tactical Fighter (NATF),[N 2] but by fiscal year (FY) 1992, the Navy had abandoned NATF.[13]

Production and procurement

As the program moved to full-scale development, or Engineering & Manufacturing Development (EMD), the production version had notable differences from the YF-22, despite having a similar configuration. The wing's leading edge sweep angle was decreased from 48° to 42°, while the vertical stabilizers were shifted rearward and decreased in area by 20%.[14] To improve pilot visibility, the canopy was moved forward 7 inches (18 cm) and the engine intakes moved rearward 14 inches (36 cm). The shapes of the wing and stabilator trailing edges were refined to improve aerodynamics, strength, and stealth characteristics. The production airframe was designed with a service life of 8,000 hours.[15][16] Increasing weight during development caused slight reductions in range and maneuver performance.[17]



Manufacturers of the F-22

Prime contractor Lockheed Martin Aeronautics[N 3] manufactured the majority of the airframe and performed final assembly at Dobbins Air Reserve Base in Marietta, Georgia; program partner Boeing Defense, Space & Security provided additional airframe components as well as avionics integration and training systems.[18] The first F-22, an EMD aircraft with tail number 4001, was unveiled at Marietta, Georgia, on 9 April 1997 and first flew on 7 September 1997.[19][20] Production, with the first lot awarded in September 2000, supported over 1,000 subcontractors and suppliers from 46 states and up to 95,000 jobs, and spanned 15 years at a peak rate of roughly two airplanes per month.[21][22][23] In 2006, the F-22 development team won the Collier Trophy, American aviation's most prestigious award.[24] Due to the aircraft's advanced nature, contractors have been targeted by cyberattacks and technology theft.[25]

The USAF originally envisioned ordering 750 ATFs at a total program cost of $44.3 billion and procurement cost of $26.2 billion in FY 1985 dollars, with production beginning in 1994. The 1990 Major Aircraft Review led by Secretary of Defense Dick Cheney reduced this to 648 aircraft beginning in 1996. By 1997, funding instability had further cut the total to 339, which was again reduced to 277 by 2003.[26] In 2004, the Department of Defense (DoD) further reduced this to 183 operational aircraft, despite the USAF's preference for 381.[27][28] A multi-year procurement plan was implemented in 2006 to save $15 billion, with total program cost projected to be $62 billion for 183 F-22s distributed to seven combat squadrons.[29] In 2008, Congress passed a defense spending bill that raised the total orders for production aircraft to 187.[30][31]

The first two F-22s built were EMD aircraft in the Block 1.0[N 4] configuration for initial flight testing and envelope expansion, while the third was a Block 2.0 aircraft built to represent the internal structure of production airframes and enabled it to test full flight loads. Six more EMD aircraft were built in the Block 10 configuration for development and upgrade testing, with the last two considered essentially production quality jets. Production for operational squadrons consisted of 74 Block 10/20 training aircraft and 112 Block 30/35/40 combat aircraft; one of the Block 30 aircraft is dedicated to flight sciences at Edwards Air Force Base.[32][33][34] A number of newer Block 20 aircraft were upgraded to Block 30 standards, increasing the Block 30/35/40 fleet to 149 aircraft while 37 remain in the Block 20 configuration.[N 5][35][36]

The numerous new technologies in the F-22 resulted in substantial cost overruns and delays.[37] Many capabilities were deferred to post-service upgrades, reducing the initial cost but increasing total program cost.[38] As production wound down in 2011, the total program cost is estimated to be about $67.3 billion, with $32.4 billion spent on Research, Development, Test and Evaluation (RDT&E) and $34.9 billion on procurement and military construction (MILCON) in then year dollars. The incremental cost for an additional F-22 was estimated at $138 million in 2009.[39][40]

Ban on exports

Two F-22s during flight testing, the upper one being the first EMD F-22, Raptor 4001

The F-22 cannot be exported under US federal law to protect its stealth technology and classified features.[41][42] Customers for U.S. fighters are acquiring earlier designs such as the F-15 Eagle and F-16 Fighting Falcon or the newer F-35 Lightning II, which contains technology from the F-22 but was designed to be cheaper, more flexible, and available for export.[43] In September 2006, Congress upheld the ban on foreign F-22 sales.[44] Despite the ban, the 2010 defense authorization bill included provisions requiring the DoD to prepare a report on the costs and feasibility for an F-22 export variant, and another report on the effect of F-22 export sales on U.S. aerospace industry.[45][46]

Some Australian politicians and defense commentators proposed that Australia should attempt to purchase F-22s instead of the planned F-35s,[47][48] citing the F-22's known capabilities and F-35's delays and developmental uncertainties.[49] However, the Royal Australian Air Force (RAAF) determined that the F-22 was unable to perform the F-35's strike and close air support roles.[50] The Japanese government also showed interest in the F-22 for its Replacement-Fighter program. The Japan Air Self-Defense Force (JASDF) would reportedly require fewer fighters for its mission if it obtained the F-22, thus reducing engineering and staffing costs. However, in 2009 it was reported that acquiring the F-22 would require increases to the Japanese government's defense budget beyond the historical 1 percent of its GDP.[51][52] With the end of F-22 production, Japan chose the F-35 in December 2011.[53] Israel also expressed interest, but eventually chose the F-35 because of the F-22's price and unavailability.[54][55]

Production termination

Throughout the 2000s, the need for F-22s was debated due to rising costs, insufficient multirole versatility, and the lack of relevant adversaries for air combat missions. In 2006, Comptroller General of the United States David Walker found that "the DoD has not demonstrated the need" for more investment in the F-22,[56] and further opposition to the program was expressed by Secretary of Defense Donald Rumsfeld, Deputy Secretary of Defense Gordon R. England, and Chairman of U.S. Senate Committee on Armed Services Senators John Warner and John McCain.[57][58] The F-22 program lost influential supporters in 2008 after the forced resignations of Secretary of the Air Force Michael Wynne and the Chief of Staff of the Air Force General T. Michael Moseley.[59]

In November 2008, Secretary of Defense Robert Gates stated that the F-22 was not relevant in post-Cold War conflicts such as irregular warfare operations in Iraq and Afghanistan,[60] and in April 2009, under the new Obama Administration, he called for ending production in FY2011, leaving the USAF with 187 production aircraft.[61] In July, General James Cartwright, Vice Chairman of the Joint Chiefs of Staff, stated to the Senate Committee on Armed Services his reasons for supporting termination of F-22 production. They included shifting resources to the F-35 to allow proliferation of multirole fifth-generation fighters for three service branches and preserving the F/A-18 production line to maintain the military's electronic warfare (EW)


Two F-22As in close trail formation

capabilities in the Boeing EA-18G Growler.[62] Issues with the F-22's reliability and availability also raised concerns.[43][63] After President Obama threatened to veto further production, the Senate voted in July 2009 in favor of ending production and the House subsequently agreed to abide by the 187 production aircraft cap.[64][65] Gates stated that the decision was taken in light of the F-35's capabilities,[66] and in 2010, he set the F-22 requirement to 187 aircraft by lowering the number of major regional conflict preparations from two to one.[67]

In 2010, USAF initiated a study to determine the costs of retaining F-22 tooling for a future Service Life Extension Program (SLEP).[68] A RAND Corporation paper from this study estimated that restarting production and building an additional 75 F-22s would cost $17 billion, resulting in $227 million per aircraft, $54 million higher than the flyaway cost.[69] Lockheed Martin stated that restarting the production line itself would cost about $200 million.[70] Production tooling and associated documentation were subsequently stored at the Sierra Army Depot to support the fleet life cycle.[71] There were reports that attempts to retrieve this tooling found empty containers,[72] but a subsequent audit found that the tooling was stored as expected.[73]

Russian and Chinese fighter developments have fueled concern, and in 2009, General John Corley, head of Air Combat Command, stated that a fleet of 187 F-22s would be inadequate, but Secretary Gates dismissed General Corley's concern.[59] In 2011, Gates explained that Chinese fifth-generation fighter developments had been accounted for when the number of F-22s was set, and that the U.S. would have a considerable advantage in stealth aircraft in 2025, even with F-35 delays.[74] In December 2011, the 195th and final F-22 was completed out of 8 test EMD and 187 operational aircraft produced; the aircraft was delivered to the USAF on 2 May 2012.[75][76]

In April 2016, the House Armed Services Committee (HASC) Tactical Air and Land Forces Subcommittee proposed legislation that would direct the Air Force to conduct a cost study and assessment associated with resuming production of the F-22. Since the production halt directed in 2009 by then Defense Secretary Gates, lawmakers and the Pentagon noted that air warfare systems of Russia and China were catching up to those of the U.S.[77] Lockheed Martin has proposed upgrading some Block 20 training aircraft into combat-coded Block 30/35 versions as a way to increase numbers available for deployment.[35] On 9 June 2017, the Air Force submitted their report to Congress stating they had no plans to restart the F-22 production line due to economic and operational issues; it estimated it would cost approximately $50 billion to procure 194 additional F-22s at a cost of $206–$216 million per aircraft, including approximately $9.9 billion for non-recurring start-up costs and $40.4 billion for aircraft procurement costs.[78]

Upgrades

The F-22 modernization and upgrades consist of software and hardware modifications, or Tactical Mandates, captured under Increments as well as numbered software-only Operational Flight Program (OFP) Updates. The first aircraft with combat-capable Block 3.0 software flew in 2001.[79] Increment 2, the first upgrade program, was implemented in 2005 for Block 20 aircraft onward and enabled ground attack capability through the employment of Joint Direct Attack Munitions

(JDAM). The improved AN/APG-77(V)1 radar was certified in March 2007 and airframes from production Lot 5 onward were fitted with this radar, which incorporates air-to-ground modes.[80] Increment 3.1 and Updates 3 and 4 for Block 30 aircraft onward provided improved ground-attack capabilities through synthetic aperture radar mapping and radio emitter direction finding, electronic attack and Small Diameter Bomb (SDB) integration; testing began in 2009 and the first upgraded aircraft was delivered in 2011.[81][82] To address oxygen deprivation issues, F-22s were fitted with an automatic backup oxygen system (ABOS) and modified life support system starting in 2012.[83]

An F-22A of the 411th Flight Test Squadron test-fires an AIM-9X.

Increment 3.2 for Block 30/35/40 aircraft is a two-part upgrade process. 3.2A focuses on electronic warfare, communications and identification, while 3.2B includes geolocation improvements and a new stores management system that fully integrates the AIM-9X and AIM-120D; fleet releases began in 2013 and 2019, respectively. Concurrent with Increment 3.2, Update 5 in 2016 adds automatic ground collision avoidance system (GCAS), datalink updates, and more.[84][85] Update 6, deployed in tandem with 3.2B, incorporates cryptographic and avionics stability enhancements.[86] Alongside 3.2B, an open mission system (OMS) processor was added and an agile software development process was implemented to enable faster enhancements from additional vendors. The Multifunctional Information Distribution System-Joint (MIDS-J) radio for Link 16 traffic was installed starting in 2022, and the airplane can also use the Battlefield Airborne Communications Node (BACN) as a two-way communication gateway.[87] The planned Multifunction Advanced Data Link (MADL) integration was cut due to development delays and lack of proliferation among USAF platforms. Although the Thales Scorpion helmet-mounted cuing system (HMCS) was successfully tested on the aircraft in 2013, funding cuts prevented its deployment to the fleet.[88]

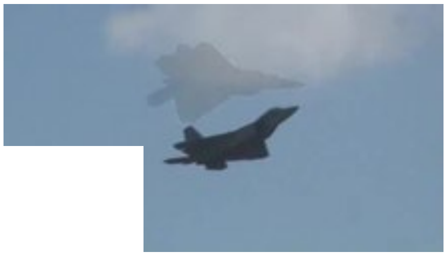
Additional modernization and enhancements are under development, with funding currently extending to 2031; expected upgrades include new sensors and antennas, a long range IRST, manned-unmanned teaming capability, cockpit improvements, and a helmet mounted display and cuing system.[89][90] Other enhancements being developed include IRST functionality for the AN/AAR-56 Missile Launch Detector (MLD) and more durable stealth coating based on the F-35's.[86][91][92]

Aside from capability upgrades, the F-22 fleet underwent a $350 million "structures retrofit program" to address improper titanium heat treatment in the parts of certain airframe batches.[93][94] By January 2021, all aircraft had gone through the Structural Repair Program to add another 8,000 flight hours to their usable lifetimes.[95][96] In the long term, the F-22 is expected to eventually be succeeded by a sixth-generation jet fighter from the Next Generation Air Dominance (NGAD) program's fighter component.[97][98]

Design

Overview

The F-22 Raptor is a fifth-generation air superiority fighter that is considered fourth generation in



F-22 flight demonstration video

stealth aircraft technology by the USAF.[99] It is the first operational aircraft to combine supercruise, supermaneuverability, stealth, and sensor fusion in a single weapons platform.[100] The F-22 has clipped diamond-like delta wings, four empennage surfaces, and leading edge root extensions running to the upper outboard corner of the caret inlets. Flight control surfaces include leading-edge flaps, flaperons, ailerons, rudders on the canted vertical stabilizers, and all-moving horizontal tails (stabilators); for speed brake function, the ailerons deflect up, flaperons down, and rudders outwards to increase drag. The aircraft has a refueling boom receptacle centered on its spine and retractable tricycle landing gear.[101]

The aircraft's dual Pratt & Whitney F119-PW-100 augmented turbofan engines are closely spaced and incorporate pitch-axis thrust vectoring nozzles with a range of ±20 degrees; each engine has maximum thrust in the 35,000 lbf (156 kN) class. The F-22's thrust-to-weight ratio at typical combat weight is nearly at unity in maximum military power and 1.25 in full afterburner. The caret inlets generate oblique shocks with the upper inboard corners to ensure good total pressure recovery and efficient supersonic flow compression.[102] Maximum speed without external stores is approximately Mach 1.8 at military power and greater than Mach 2 with afterburners.[103][N 6]

F-22 flying with its Pratt & Whitney F119-PW-100 engines on full afterburner during testing

The F-22's high cruise speed and operating altitude over prior fighters improve the effectiveness of its sensors and weapon systems, and increase survivability against ground defenses such as surface-to-air missiles.[105][106] The ability to supercruise, or sustain supersonic flight without using afterburners, allows it to intercept targets that afterburner-dependent aircraft would lack the fuel to reach. The use of internal weapons bays permits the aircraft to maintain comparatively higher performance over most other combat-configured fighters due to a lack of parasitic drag from external stores.[107] The F-22's thrust and aerodynamics enable regular combat speeds of Mach 1.5 at 50,000 feet (15,000 m), thus providing 50% greater employment range for air-to-air missiles and twice the effective range for JDAMs than with prior platforms.[N 7][109][110] The airplane's structure contains a significant amount of high-strength materials to withstand stress and heat of sustained supersonic flight. Respectively, titanium alloys and bismaleimide/epoxy composites comprise 42% and 24% of the structural weight.[111]

The F-22's aerodynamics, relaxed stability, and powerful thrust-vectoring engines give it excellent maneuverability and energy potential across its flight envelope. The airplane has excellent high alpha (angle of attack) characteristics, capable of flying at trimmed alpha of over 60° while maintaining roll control and performing maneuvers such as the Herbst maneuver (J-turn) and Pugachev's Cobra.[112] The flight control system and full-authority digital engine control (FADEC) make the aircraft highly departure resistant and controllable, thus giving the pilot carefree handling.[113][107]

Avionics

An F-22 releases a flare during a training flight

The aircraft has an integrated avionics system where through sensor fusion, data from the radar, other sensors, and external systems are filtered and combined into a common view, thus enhancing the pilot's situational awareness and reducing workload. Key mission systems include Sanders/General Electric AN/ALR-94 electronic warfare system, Martin Marietta AN/AAR-56 infrared and ultraviolet Missile Launch Detector (MLD), Westinghouse/Texas Instruments AN/APG-77 active electronically scanned array (AESA) radar, and TRW Communication/Navigation/Identification (CNI) suite. The MLD uses six sensors to provide full spherical infrared coverage.[114] Among the most technically complex equipment on the airplane is the ALR-94 system, a passive radar detector with more than 30 antennas blended into the wings and fuselage for all-round radar warning receiver (RWR) coverage. Its range (250+ nmi) exceeds the radar's and can cue radar emissions to be confined to a narrow beam (down to 2° by 2° in azimuth and elevation) to increase stealth. Depending on the detected threat, the defensive systems can prompt the pilot to release countermeasures such as flares or chaff. The ALR-94 can be used as a passive detection system capable of searching targets and providing enough information for a radar lock on. Tactical communication between F-22s is performed using the directional Inter/Intra-Flight Data Link (IFDL).[115][116]

The APG-77 radar has a low-observable, active-aperture, electronically scanned antenna with multiple target track-while-scan in all weather conditions; radar emissions can also be focused to overload enemy sensors as an electronic-attack capability. The radar changes frequencies more than 1,000 times per second to lower interception probability and has an estimated range of 125–150 mi (201–241 km) against a 11 sq ft (1 m^2) target and 250 mi (400 km) or more in narrow beams. F-22s from Lot 5 and on are equipped with the APG-77(V)1, which provides air-to-ground functionality through synthetic aperture radar mapping and various strike modes.[80][117] Radar and CNI information are processed by two Hughes Common Integrated Processor (CIP)s, each capable of processing up to 10.5 billion instructions per second.[118] The aircraft has also been upgraded to incorporate an automatic ground collision avoidance system (GCAS).[119]

The F-22's ability to operate close to the battlefield gives the aircraft threat detection and identification capability comparative with the RC-135 Rivet Joint, and the ability to function as a "mini-AWACS", though its radar is less powerful than those of dedicated platforms. This allows the F-22 to rapidly designate targets for allies and coordinate friendly aircraft.[117] Data can be transferred to other aircraft through a BACN or via Link 16 using the MIDS-J radio.[87] The IEEE 1394B bus developed for the F-22 was derived from the commercial IEEE 1394 "FireWire" bus system.[120] In 2007, the F-22's radar was tested as a wireless data transceiver, transmitting data at 548 megabits per second and receiving at gigabit speed, far faster than the Link 16 system.[121] The radio frequency receivers of the electronic support measures (ESM) system give the aircraft the ability to perform intelligence, surveillance, and reconnaissance (ISR) tasks.[122]

The F-22's software has some 1.7 million lines of code, the majority involving processing radar data.[123] Former Secretary of the USAF Michael Wynne blamed the use of the DoD's Ada for cost overruns and delays on many military projects, including the F-22. The integrated nature of avionics has also made upgrades challenging; an OMS processor was eventually added to facilitate future upgrades.[86][124]

Cockpit

Cockpit of the F-22, showing instruments, head-up display and throttle top (lower left)

The F-22 has a glass cockpit with all-digital flight instruments. The monochrome head-up display offers a wide field of view and serves as a primary flight instrument; information is also displayed upon six color liquid-crystal display (LCD) panels.[125] The primary flight controls are a force-sensitive side-stick controller and a pair of throttles. The USAF initially wanted to implement direct voice input (DVI) controls, but this was judged to be too technically risky and was abandoned.[126] The canopy's dimensions are approximately 140 inches long, 45 inches wide, and 27 inches tall (355 cm × 115 cm × 69 cm) and weighs 360 pounds.[127] The canopy was redesigned after the original design lasted an average of 331 hours instead of the required 800 hours.[63]

The F-22 has integrated radio functionality, the signal processing systems are virtualized rather than as a separate hardware module.[128] The integrated control panel (ICP) is a keypad system for entering communications, navigation, and autopilot data. Two 3 in × 4 in (7.6 cm × 10.2 cm) up-front displays located around the ICP are used to display integrated caution advisory/warning (ICAW) data, CNI data and also serve as the stand-by flight instrumentation group and fuel quantity indicator.[129] The stand-by flight group displays an artificial horizon, for basic instrument meteorological conditions. The 8 in × 8 in (20 cm × 20 cm) primary multi-function display (PMFD) is located under the ICP, and is used for navigation and situation assessment. Three 6.25 in × 6.25 in (15.9 cm × 15.9 cm) secondary multi-function displays are located around the PMFD for tactical information and stores management.[130]

The ejection seat is a version of the ACES II commonly used in USAF aircraft, with a center-mounted ejection control.[131] The F-22 has a complex life support system, which includes the onboard oxygen generation system (OBOGS), protective pilot garments, and a breathing regulator/anti-g (BRAG) valve controlling flow and pressure to the pilot's mask and garments. The pilot garments were developed under the Advanced Technology Anti-G Suit (ATAGS) project and protect against chemical/biological hazards and cold-water immersion, counter g-forces and low pressure at high altitudes, and provide thermal relief.[132] Following a series of hypoxia-related issues, the life support system was consequently revised to include an automatic backup oxygen system and a new flight vest valve.[83]

Armament

The F-22 has three internal weapons bays: a large main bay on the bottom of the fuselage, and two smaller bays on the sides of the fuselage, aft of the engine intakes; a small bay for countermeasures such as flares is located behind each side bay.[133] The main bay is split along the centerline and can accommodate six LAU-142/A launchers for beyond-visual-range missiles and each side bay has an LAU-141/A launcher for short-range missiles. The primary air-to-air missiles are the AIM-120 AMRAAM and the AIM-9 Sidewinder, with planned integration of the AIM-260 JATM.[134] Missile

One AIM-120 AMRAAM (right) and four GBU-39 SDB (left) fitted in the main weapons bay of an F-22

launches require the bay doors to be open for less than a second, during which pneumatic or hydraulic arms push missiles clear of the aircraft; this is to reduce vulnerability to detection and to deploy missiles during high-speed flight.[135] An internally mounted M61A2 Vulcan 20 mm rotary cannon is embedded in the airplane's right wing root with the muzzle covered by a retractable door.[136] The radar projection of the cannon fire's path is displayed on the pilot's head-up display.[137]

Although designed for air-to-air missiles, the main bay can replace four launchers with two bomb racks that can each carry one 1,000 lb (450 kg) or four 250 lb (110 kg) bombs for a total of 2,000 pounds (910 kg) of air-to-surface ordnance.[138][100] While capable of carrying weapons with GPS guidance such as JDAMs and SDBs, the F-22 cannot self-designate laser-guided weapons.[139]

F-22 with external weapons pylons

While the F-22 typically carries weapons internally, the wings include four hardpoints, each rated to handle 5,000 lb (2,300 kg). Each hardpoint can accommodate a pylon that can carry a detachable 600-gallon (2,270 L) external fuel tank or a launcher holding two air-to-air missiles; the two inboard hardpoints are "plumbed" for external fuel tanks. The use of external stores degrades the aircraft's stealth and kinematic performance; after releasing stores the external attachments can be jettisoned to restore those characteristics.[140] A stealthy ordnance pod and pylon was being developed to carry additional weapons in the mid-2000s.[141]

Stealth

For stealth, the F-22 carries weapons in internal bays. The doors for the center and side bays are open; the six LAU-142/A AMRAAM Vertical Eject Launchers (AVEL) are visible.

The F-22 was designed to be highly difficult to detect and track by radar. Measures to reduce RCS include airframe shaping such as alignment of edges, fixed-geometry serpentine inlets and curved vanes that prevent line-of-sight of the engine faces and turbines from any exterior view, use of radar-absorbent material (RAM), and attention to detail such as hinges and pilot helmets that could provide a radar return. The F-22 was also designed to have decreased radio emissions, infrared signature and acoustic signature as well as reduced visibility to the naked eye.[142] The aircraft's flat thrust-vectoring nozzles reduce infrared emissions of the exhaust plume to mitigate the threat of infrared homing ("heat seeking") surface-to-air or air-to-air missiles.[143] Additional measures to reduce the infrared signature include special topcoat and active cooling of leading edges to manage the heat buildup from supersonic flight.[144]

Compared to previous stealth designs like the F-117, the F-22 is less reliant on RAM, which are maintenance-intensive and susceptible to adverse weather conditions. Unlike the B-2, which requires climate-controlled hangars, the F-22 can undergo repairs on the flight line or in a normal hangar. The F-22 has a *Signature Assessment System* which delivers warnings when the radar signature is degraded and necessitates repair.[117] While the F-22's exact RCS is classified, in 2009 Lockheed Martin released information indicating that from certain angles the airplane has an RCS of 0.0001 m^2 or −40 dBsm – equivalent to the radar reflection of a "steel marble"; the aircraft can mount a Luneburg lens reflector to mask its RCS.[145][146] Effectively maintaining the stealth features can decrease the F-22's mission capable rate to 62–70%.[N 8]


Front fuselage detail of an F-22

The effectiveness of the stealth characteristics is difficult to gauge. The RCS value is a restrictive measurement of the aircraft's frontal or side area from the perspective of a static radar. When an aircraft maneuvers it exposes a completely different set of angles and surface area, potentially increasing radar observability. Furthermore, the F-22's stealth contouring and radar-absorbent materials are chiefly effective against high-frequency radars, usually found on other aircraft. The effects of Rayleigh scattering and resonance mean that low-frequency radars such as weather radars and early-warning radars are more likely to detect the F-22 due to its physical size. However, such radars are also conspicuous, susceptible to clutter, and have low precision.[148] Additionally, while faint or fleeting radar contacts make defenders aware that a stealth aircraft is present, reliably vectoring interception to attack the aircraft is much more challenging.[149][150] According to the USAF an F-22 surprised an Iranian F-4 Phantom II that was attempting to intercept an American UAV, despite Iran's assertion of having military VHF radar coverage over the Persian Gulf.[151]

Operational history

Designation and testing


An F-22 refuels from a KC-135 during testing; the attachment on the back top is for a spin recovery chute

The YF-22 was originally given the unofficial name "Lightning II", after the World War II Lockheed P-38 Lightning fighter, which persisted until the mid-1990s, when the USAF officially named the aircraft "Raptor"; "Lightning II" was later given to the F-35. The aircraft was also briefly dubbed "SuperStar" and "Rapier".[152] In September 2002, USAF changed the Raptor's designation to F/A-22, mimicking the Navy's McDonnell Douglas F/A-18 Hornet and intended to highlight a planned ground-attack capability amid debate over the aircraft's role and relevance. The F-22 designation was reinstated in December 2005, when the aircraft entered service.[100][153]

Flight testing of the F-22 began in 1997 with Raptor 4001, the first EMD jet, and eight more EMD F-22s would participate in the flight test program as the Combined Test Force (CTF) at Edwards AFB. The first two aircraft tested flying qualities, air vehicle performance, propulsion, and stores separation. The third aircraft, the first to have production-level internal structure, tested flight loads, flutter, and JDAM separation, while two non-flying F-22s were built for testing static loads and fatigue. Subsequent EMD aircraft tested avionics, CNI, and observables, along with a Boeing 757 modified with F-22 mission systems to serve as the Flying Test Bed avionics laboratory.[32] Raptor 4001 was retired from flight testing in 2000 and subsequently sent to Wright-Patterson Air Force Base for survivability testing, including live fire testing and battle damage repair training.[154] Other EMD F-22s have been used for testing upgrades and as maintenance trainers.[155]

The first production F-22 was delivered to Nellis AFB, Nevada, in January 2003 for Initial Operational Test & Evaluation (IOT&E).[156] Delivery of operational aircraft for pilot training at Tyndall AFB, Florida began in September 2003, and the first combat ready F-22 of the 1st Fighter Wing arrived at Langley AFB, Virginia in January 2005.[154]

In August 2008, an unmodified F-22 of the 411th Flight Test Squadron performed the first ever air-to-air refueling of an aircraft using synthetic jet fuel as part of a wider USAF effort to qualify aircraft to use the fuel, a 50/50 mix of JP-8 and a Fischer–Tropsch process-produced, natural gas-based fuel.[157] In 2011, an F-22 flew supersonic on a 50% mixture of biofuel derived from camelina.[158]

Introduction into service

An F-22 fires an AIM-120 AMRAAM

In December 2005, the USAF announced that the F-22 had achieved Initial Operational Capability (IOC).[159] During Exercise Northern Edge in Alaska in June 2006, in simulated combat exercises 12 F-22s of the 94th FS downed 108 adversaries with no losses.[29] In the exercises, the F-22-led Blue Force amassed 241 kills against two losses in air-to-air combat, with neither "loss" being an F-22. During Exercise Red Flag 07–1 in February 2007, 14 F-22s of the 94th FS supported Blue Force strikes and undertook close air support sorties. Against superior numbers of Red Force Aggressor F-15s and F-16s, 6–8 F-22s maintained air dominance throughout and provided airborne electronic surveillance. No sorties were missed because of maintenance or other failures; a single F-22 was judged "lost" against the defeated opposing force.[160]

The F-22 achieved Full Operational Capability (FOC) in December 2007, when General John Corley of Air Combat Command (ACC) officially declared the F-22s of the integrated active duty 1st Fighter Wing and Virginia Air National Guard 192d Fighter Wing fully operational.[161] This was followed by an Operational Readiness Inspection (ORI) of the integrated wing in April 2008, in which it was rated "excellent" in all categories, with a simulated kill-ratio of 221–0.[162]

Maintenance and training

Each airplane requires a three-week packaged maintenance plan (PMP) every 300 flight hours.[163] The stealth coatings of the F-22 were designed to be more robust and weather-resistant than those used in earlier stealth aircraft.[117] However, early coatings still experienced issues with rain and moisture when F-22s were initially posted to Guam in 2009.[164] The stealth system account for almost one third of maintenance, with coatings being particularly demanding. More durable stealth coatings derived from the F-35's are being considered for future upgrades in order to reduce maintenance efforts.[165][86] F-22 depot maintenance is performed at Ogden Air Logistics Complex at Hill AFB, Utah.[166]

F-22s were available for missions 63% of the time on average in 2015, up from 40% when the aircraft was introduced in 2005. Maintenance hours per flight hour was also improved from 30 early on to 10.5 by 2009, lower than the requirement of 12; man-hours per flight hour was 43 in 2014. When introduced, the F-22 had a Mean Time Between Maintenance (MTBM) of 1.7 hours, short of the required 3.0; this rose to 3.2 hours in 2012.[63][94] By fiscal year 2015, the cost per flight hour was $59,116.[167]

To reduce operating costs and lengthen the F-22's service life, some pilot training sorties are performed using flight simulators, while the T-38 Talon is used for adversary training. Attrition reserve aircraft numbers are limited due to the small fleet size.[163]

Deployments

F-22 fighter units have been frequently deployed to Kadena Air Base in Okinawa, Japan.[168] In February 2007, on the aircraft's first overseas deployment to Kadena Air Base, six F-22s of 27th Fighter Squadron flying from Hickam AFB, Hawaii, experienced multiple software-related system failures while crossing the International Date Line (180th meridian of longitude). The aircraft returned to Hawaii by following tanker aircraft. Within 48 hours, the error was resolved and the journey resumed.[169][170] F-22s have also been involved in training exercises in South Korea and Malaysia.[171][172]

An F-22 from Elmendorf AFB, Alaska, intercepting a Russian Tupolev Tu-95 bomber near American airspace

In November 2007, F-22s of 90th Fighter Squadron at Elmendorf AFB, Alaska, performed their first NORAD interception of two Russian Tu-95MS bombers.[173] Since then, F-22s have also escorted probing Tu-160 bombers.[174]

Defense Secretary Gates initially refused to deploy F-22s to the Middle East in 2007;[175] the type made its first deployment in the region at Al Dhafra Air Base in the UAE in 2009. In April 2012, F-22s have been rotating into Al Dhafra, less than 200 miles from Iran;[176][177] the Iranian defense minister referred to the deployment as a security threat.[178] In March 2013, the USAF announced that an F-22 had intercepted an Iranian F-4 Phantom II that approached within 16 miles of an MQ-1 Predator flying off the Iranian coastline.[151]

On 22 September 2014, F-22s performed the type's first combat sorties by conducting some of the opening strikes of Operation Inherent Resolve, the American-led intervention in Syria; aircraft dropped 1,000-pound GPS-guided bombs on Islamic State targets near Tishrin Dam.[179][180] Between September 2014 and July 2015, F-22s flew 204 sorties over Syria, dropping 270 bombs at some 60 locations.[181] Throughout their deployment, F-22s conducted close air support (CAS) and also deterred Syrian, Iranian, and Russian aircraft from attacking U.S.-backed Kurdish forces and disrupting U.S. operations in the region.[182][183][184] F-22s also participated in the U.S. strikes on pro-government forces in eastern Syria on 7 February 2018.[185][186][187] These strikes

2005: An F-22 of the 43d Fighter Squadron flies alongside an F-15 of the 27th Fighter Squadron.

notwithstanding, the F-22's main role in the operation was gathering intelligence, surveillance and reconnaissance.[188]

An F-22 refueling prior to combat operations in Syria, September 2014

In late 2014, the USAF was testing a rapid deployment concept involving four F-22s and one C-17 for support, first proposed in 2008 by two F-22 pilots. The goal was for the type to be able to set up and engage in combat within 24 hours.[189][190] Four F-22s were deployed to Spangdahlem Air Base in Germany in August, and Lask Air Base in Poland and Amari Air Base in Estonia in September 2015, to train with NATO allies.[191]

In November 2017, F-22s operating alongside B-52s bombed opium production and storage facilities in Taliban-controlled regions of Afghanistan.[192] In 2019, the F-22 cost US$35,000 per flight hour to operate.[193]

Operational problems

During the initial years of service, F-22 pilots experienced symptoms as a result of oxygen system issues that include loss of consciousness, memory loss, emotional lability and neurological changes as well as lingering respiratory problems and a chronic cough; the issues resulted in a four-month grounding in 2011.[194][195] In August 2012, the DoD found that the BRAG valve, used to inflate the pilot's vest during high-*g* maneuvers, was defective and restricted breathing and the OBOGS (onboard oxygen generation system) unexpectedly reduced oxygen levels during high-*g* maneuvers.[196][197] The Raptor Aeromedical Working Group had recommended several changes in 2005 to deal with the oxygen supply issues that were initially unfunded but received further consideration in 2012.[198][199] The F-22 CTF and 412th Aerospace Medicine Squadron eventually determined that breathing restrictions were the root cause. The coughing symptoms were attributed to acceleration atelectasis[N 9] from high *g* exposure and the OBOGS delivering excessive oxygen concentration at low altitudes. The presence of toxins and particles in some ground crew was deemed to be unrelated.[200] Modifications to the life-support equipment and oxygen system allowed the distance and altitude flight restrictions to be lifted on 4 April 2013.[83][201][202]

Variants

- **YF-22A** – pre-production technology demonstrator for Advanced Tactical Fighter (ATF) demonstration/validation phase; two were built.
- **F-22A** – single-seat production version, was designated *F/A-22A* in early 2000s.
- **F-22B** – planned two-seat variant, cancelled in 1996 to save development costs with test aircraft orders converted to F-22A.[203]
- **Naval F-22 variant** – a planned carrier-borne variant of the F-22 with variable-sweep wings for the U.S. Navy's Navy Advanced Tactical Fighter (NATF) program to replace the F-14 Tomcat.

Program was cancelled in 1991.[203]

Derivatives

The FB-22 was a proposed medium-range supersonic stealth bomber for the USAF.[204] The design was projected to carry up to 30 Small Diameter Bombs to about twice the range of the F-22A.[205] However, the FB-22 proposal appears to have been cancelled with the 2006 Quadrennial Defense Review and subsequent developments, in lieu of a larger subsonic bomber with a much greater range.[206][207]

The X-44 MANTA, or *multi-axis, no-tail aircraft*, was a planned experimental aircraft based on the F-22 with enhanced thrust vectoring controls and no aerodynamic surface backup.[208] The aircraft was to be solely controlled by thrust vectoring, without featuring any rudders, ailerons, or elevators. Funding for this program was halted in 2000.[209]

In August 2018, Lockheed Martin proposed an F-22 derivative to the USAF and JASDF that would combine an improved F-22 airframe with the avionics and improved stealth coatings of the F-35.[210] The proposal was not considered by the USAF, while JASDF doubted its merits due to cost and existing export restrictions.[211][212]

Operators

The United States Air Force is the only operator of the F-22. As of June 2020, it has 186 aircraft in its inventory.[213]

F-22 from Tyndall Air Force Base, Florida, cruising over the Florida Panhandle

An F-22 landing at Holloman AFB, New Mexico

Frontline Squadrons

- 1st Fighter Wing at Langley Air Force Base, Virginia[214]
  - 27th Fighter Squadron[215]
  - 94th Fighter Squadron
- 3rd Wing at Joint Base Elmendorf–Richardson, Alaska[216]
  - 90th Fighter Squadron
  - 525th Fighter Squadron
- 15th Wing at Hickam Air Force Base, Hawaii
  - 19th Fighter Squadron (Pacific Air Forces associate unit)
- 154th Wing at Hickam Air Force Base, Hawaii
  - 199th Fighter Squadron (Air National Guard unit)
- 192nd Fighter Wing at Joint Base Langley–Eustis, Virginia[217]
  - 149th Fighter Squadron (Air National Guard associate unit)

- 325th Fighter Wing - Tyndall AFB, Florida
  - 43rd Fighter Squadron (Training Unit) at Eglin Air Force Base, Florida (Originally based at Tyndall Air Force Base, relocated after Hurricane Michael to Eglin, scheduled to move to Langley Air Force Base.)[218]
- 44th Fighter Group - Tyndall AFB, Florida
  - 301st Fighter Squadron (Air Force Reserve Command associate unit)[219]
- 477th Fighter Group - Elmendorf AFB, Alaska
  - 302d Fighter Squadron (Air Force Reserve Command associate unit)[220]

An F-22, based at Elmendorf AFB, Alaska, over mountain terrain

F-22 with drop tanks in transit to Kadena Air Base, Japan, from Langley AFB, Virginia

Test and Evaluation Squadrons

- 57th Wing at Nellis Air Force Base, Nevada[221]
  - 422nd Test and Evaluation Squadron[159]
  - 433rd Weapons Squadron[221]
- 412th Test Wing at Edwards Air Force Base, California
  - 411th Flight Test Squadron

Accidents

The first F-22 crash occurred during takeoff at Nellis AFB on 20 December 2004, in which the pilot ejected safely before impact.[222] The investigation revealed that a brief interruption in power during an engine shutdown prior to flight caused a flight-control system malfunction;[32][223] consequently the aircraft design was corrected to avoid the problem. Following a brief grounding, F-22 operations resumed after a review.[224]

On 25 March 2009, an EMD F-22 crashed 35 miles (56 km) northeast of Edwards AFB during a test flight, resulting in the death of Lockheed Martin test pilot David P. Cooley. An Air Force Materiel Command investigation found that Cooley momentarily lost consciousness during a high-G maneuver, then ejected when he found himself too low to recover. Cooley was killed during ejection by blunt-force trauma from windblast due to the aircraft's speed. The investigation found no design issues.[225][226]

On 16 November 2010, an F-22 from Elmendorf AFB crashed, killing the pilot, Captain Jeffrey Haney. F-22s were restricted to flying below 25,000 feet, then grounded during the investigation.[227] The crash was attributed to a bleed air system malfunction after an engine overheat condition was detected, shutting down the Environmental Control System (ECS) and OBOGS. The accident review board ruled Haney was to blame, as he did not react properly to engage the emergency oxygen system.[228] Haney's widow sued Lockheed Martin, claiming equipment defects, and later reached a settlement.[229][230][200] After the ruling, the emergency oxygen system engagement handle was redesigned;[231] the system was eventually replaced by an automatic backup oxygen system (ABOS).[232] On 11 February 2013, the DoD's Inspector General released a report stating that the USAF had erred in blaming Haney, and that facts did not sufficiently support conclusions; the USAF stated that it stood by the ruling.[233]

During a training mission, an F-22 crashed to the east of Tyndall AFB, on 15 November 2012. The pilot ejected safely and no injuries were reported on the ground.[234] The investigation determined that a "chafed" electrical wire ignited the fluid in a hydraulic line, causing a fire that damaged the flight controls.[235]

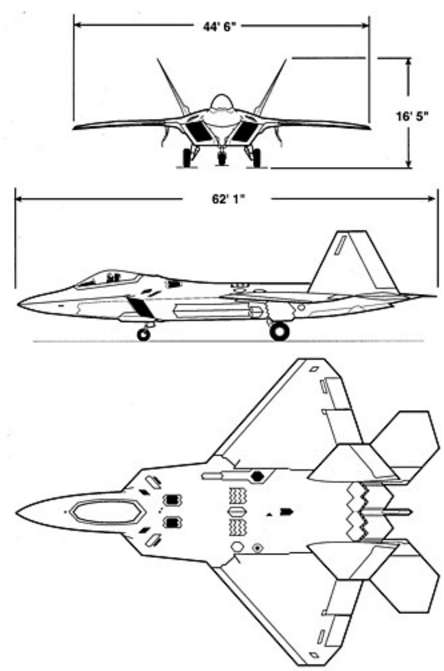
On 15 May 2020, an F-22 from Eglin Air Force Base crashed during a routine training mission shortly after takeoff; the pilot ejected safely. The cause of the crash was attributed to a maintenance error after an aircraft wash resulting in faulty air data sensor readings.[236]

Aircraft on display

EMD F-22A 91-4003 is on display at the National Museum of the United States Air Force.[237]

Specifications (F-22A)

Data from USAF,[100] manufacturers' data,[238][239][240] *Aviation Week*,[117][241] *AirForces Monthly*,[103] and *Journal of Electronic Defense*[116]



F-22 Raptor 3-view drawings

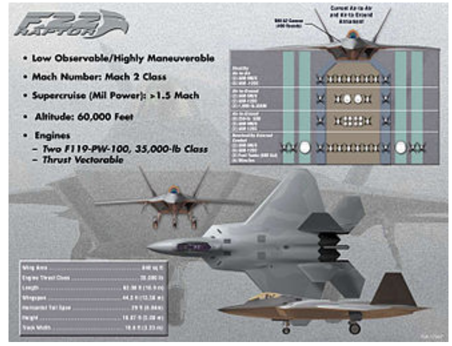
General characteristics

- **Crew:** 1
- **Length:** 62 ft 1 in (18.92 m)
- **Wingspan:** 44 ft 6 in (13.56 m)
- **Height:** 16 ft 8 in (5.08 m)
- **Wing area:** 840 sq ft (78.04 m^2)
- **Aspect ratio:** 2.36
- **Airfoil:** NACA 6 series airfoil
- **Empty weight:** 43,340 lb (19,700 kg)
- **Gross weight:** 64,840 lb (29,410 kg)
- **Max takeoff weight:** 83,500 lb (38,000 kg)
- **Fuel capacity:** 18,000 lb (8,200 kg) internally, or 26,000 lb (12,000 kg) with two 2× 600 US gal tanks
- **Powerplant:** 2 × Pratt & Whitney F119-PW-100 augmented turbofans, 26,000 lbf (116 kN) thrust each dry, 35,000 lbf (156 kN) with afterburner[N 10]

Performance

- **Maximum speed:** Mach 2.25 (1,500 mph, 2,414 km/h) at altitude
  - Mach 1.21, 800 knots (921 mph; 1,482 km/h) at sea level
  - Mach 1.82 (1,220 mph, 1,963 km/h) supercruise at altitude

- **Range:** 1,600 nmi (1,800 mi, 3,000 km) or more with 2 external fuel tanks
- **Combat range:** 460 nmi (530 mi, 850 km) clean with 100 nmi (115 mi, 185 km) in supercruise
    - 590 nmi (679 mi, 1,093 km) clean subsonic[N 11]
- **Ferry range:** 1,740 nmi (2,000 mi, 3,220 km)
- **Service ceiling:** 65,000 ft (20,000 m)
- **g limits:** +9.0/−3.0
- **Wing loading:** 77.2 lb/sq ft (377 kg/m^2)
- **Thrust/weight:** 1.08 (1.25 with loaded weight and 50% internal fuel)



USAF poster of key F-22 features and armament

Armament

- **Guns:** 1× 20 mm M61A2 Vulcan rotary cannon, 480 rounds
- **Hardpoint:** 4× under-wing pylon stations can be fitted to carry 600 U.S. gallon (2,270 L) drop tanks *or* weapons, each with a capacity of 5,000 lb (2,270 kg).[243]
- **Air-to-air mission loadout:**
    - 6× AIM-120 AMRAAM
    - 2× AIM-9 Sidewinder
- **Air-to-ground mission loadout:**
    - 2× 1,000 lb (450 kg) JDAM *or* 8× 250 lb (110 kg) GBU-39 Small Diameter Bombs
    - 2× AIM-120 AMRAAM
    - 2× AIM-9 Sidewinder

F-22's underside with main bay doors open

Avionics

- AN/APG-77 or AN/APG-77(V)1 radar: 125–150 miles (201–241 km) against 1 m^2 (11 sq ft) targets (estimated range), more than 250 miles (400 km) in narrow beams
- AN/AAR-56 Missile Launch Detector (MLD)
- AN/ALR-94 radar warning receiver (RWR): 250 nautical miles (460 km) or more detection range
- Integrated CNI Avionics
- MJU-39/40 flares for protection against IR missiles[244]

Notable appearances in media

See also

Related development

- Lockheed YF-22 – Prototype fighter aircraft for the US Air Force Advanced Tactical Fighter program
- Lockheed Martin FB-22 – Proposed bomber aircraft for the US Air Force derived from the F-22 Raptor
- Lockheed Martin X-44 MANTA – Conceptual aircraft design by Lockheed Martin

Aircraft of comparable role, configuration, and era

- Chengdu J-20 – Chinese stealth fighter aircraft
- Lockheed Martin F-35 Lightning II – Family of stealth combat aircraft
- Sukhoi Su-57 – Russian fighter aircraft

Related lists

- List of fighter aircraft
- List of Lockheed aircraft
- List of active United States military aircraft
- List of megaprojects, Aerospace

Notes

1. Referring to statements made by the Secretary of Defense Robert Gates: "The secretary once again highlighted his ambitious next-year request for the more-versatile F-35s."[4]
2. The naval F-22 design was to be carrier-borne and had variable-sweep wings and additional sensors.
3. Lockheed acquired General Dynamics fighter division at Fort Worth in 1993 and merged with Martin Marietta in 1995 to form Lockheed Martin.
4. Block number designates production variation groups.
5. The combat-coded fleet consist of 123 primary and 20 reserve airframes, while several Block 30 aircraft are devoted to operational testing and tactics development at Nellis AFB.
6. This capability was demonstrated in 2005 when General John P. Jumper exceeded Mach 1.7 in the F-22 without afterburners.[104]
7. In testing, an F-22 cruising at Mach 1.5 at 50,000 feet (15,000 m) struck a moving target 24 miles (39 km) away.[108]
8. "... noting that Raptors are ready for a mission around 62 percent of the time, if its low-observable requirements are met (DAILY, 20 November). Reliability goes up above 70 percent for missions with lower stealth demands."[147]
9. Atelectasis is the collapse or closure of a lung resulting in reduced or absent gas exchange.
10. Actual thrust is up to 37,000 lbf (165 kN).[242]
11. 750 nmi (with 100 nmi in supercruise), 860 nmi subsonic with 2× 600 US gal tanks. Figures include −6% routing factor, combat and 2× GBU-32 + 2× AIM-9 + 2× AIM-120.

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Further reading

- Holder, Bill, and Mike Wallace. *Lockheed-Martin F-22 Raptor: An Illustrated History* (Schiffer Military/Aviation History). Atglen, Pennsylvania: Schiffer Publishing, 1998. ISBN 978-0-76430-558-0.

External links

- Official website (http://www.f22-raptor.com)
- F-22 page (http://www.globalsecurity.org/military/systems/aircraft/f-22.htm) on GlobalSecurity.org
- F-22 Demo at 2007 Capital Airshow in Sacramento – with narrative by F-22 pilot Paul "Max" Moga (https://web.archive.org/web/20090329025521/http://www.kbvp.com/extreme-videos/f-22-raptor)