Building The F-35 – One Of The Most Advanced Machines Ever Made

Branded Content: From assembly to getting airborne for first flight, this is the story of F-35 stealth fighter production.

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Lockheed Martin factory floor

They say “everything is bigger in Texas.” It’s a phrase that’s highly relevant to first impressions on arriving at the Lockheed Martin production facility in Fort Worth. Walking the corridors of Air Force Plant 4, there’s visual reminders at every step that this is a highly significant place in aviation history and the current home of F-35 Lightning II production.

Stepping onto the production line, looking left and right, it takes a few moments to comprehend exactly what’s in front of your eyes. Two long nose-to-tail rows of bright green colored F-35s in their zinc chromate primer paint as far as the eye can see are lined up in either direction.

Lockheed Martin is building these fifth-generation stealth fighters at full-rate production to the tune of 156 aircraft a year. That's three complete jets rolling off the build lines every single week. The huge F-35 production operation to meet demand is underpinned by countless processes, a small army of skilled craftsmen and women, and technological advances that are designed to improve productivity, quality, and efficiency.

"We already have 19 different customers across the globe that have selected the F-35 and there are aircraft for 11 different customers that are being built and are flowing down this production line right now for delivery," comments Greg Day, F-35 international business development director as he talked to *The War Zone* on a platform overlooking the production line.

"This [production line] is the culmination of over 1,650 suppliers worldwide that are delivering components to keep this line moving smoothly," says Day. "It's really important to understand how the F-35 program never sleeps."

Building the F-35

Air Force Plant 4 began operations in west Fort Worth on April 18, 1942, with bomber aircraft being the initial focus of production, earning the facility the nickname of the "bomber plant." Some 2,743 B-24 Liberators were built here beginning in the early 1940s, and almost 400 B-36 Peacemakers were produced in Fort Worth in the late 1940s and early 1950s before work shifted to production of 116 B-58 Hustler supersonic bombers.

Development and eventual production of 564 F-111 Aardvarks commenced in the early 1960s and gave rise to a new nickname for the Fort Worth facility, which then became known as the "fighter factory." At that time around 30,000 employees worked at Plant 4, primarily supporting the F-111 program. Development of the F-16 Fighting Falcon began in the early 1970s, and this was to become the focus of operations at Fort Worth.

The F-35 production line in Fort Worth is located in the same building that manufactured the F-16. Nearly every square foot of the main factory floor was updated in the transition from the F-16 to F-35 production, a process which began in the late 1990s.

An F-35 in production in Fort Worth. *Lockheed Martin*

Lockheed Martin/Randy A. Crites

In some areas, the move from F-16 to the F-35 was as simple as unbolting F-16 tooling and jigs from the floor and installing new F-35 tooling in their place. In other cases, the concrete floors had to be demolished and replaced so that the more precise equipment that's required to produce the fifth-generation fighter could be installed.

Production of the very first F-35A (aircraft AA-1) began in Fort Worth in 2004, with final assembly commencing in May 2005. The aircraft rolled off the line on February 19, 2006, and was formally unveiled on July 7 that year, when the then USAF Chief of Staff Gen. Michael Moseley officially named it the Lightning II. This was the first of 13 instrumented production test aircraft built in the three F-35 variants, closely followed by batches of Low Rate Initial Production (LRIP) F-35s that were built for customers starting in April 2007.

The F-35 is designed to be stealthy, which means it required specialist tooling and processes to build it, with external coatings complementing the design configuration to give it a low observable radar signature. Plus, all three variants are crammed with sophisticated sensors and avionics, some of which are planned to be updated as the program evolves.

"From an engineering point of view, the F-35 has to do so many things. It has to fly, it has to compute, it has all sorts of sensors and systems on board, but also it has to be in the most compact and light form factor possible," explained Steve Howes, vice

president, F-35 Production Operations. “So from an engineering point of view, it’s incredibly complicated and incredibly impressive both in the design and in how we put it together.”

The approach to manufacturing the F-35 draws on Lockheed Martin’s experience with aircraft such as the F-16 Fighting Falcon, the F-117 Nighthawk, and the F-22 Raptor. The F-35 adds complexity in that a single production line produces the three different variants. They share approximately 20 percent parts commonality with the three having differing external dimensions, so the build stations are adaptable to enable each to be able to accommodate either an F-35A, B, or C.

“The stations themselves are built in such a way that all three variants [of the F-35] can be worked on at that one station, there’s certain features about each station that make them adjustable,” explains Howes. “If you have an F-35C variant, for example, the wings are larger, so there’s sliders that can adjust so that the variant will fit.”

From the outset each aircraft is allocated a build number, for example a British F-35B is prefixed as BK (a B-model for the UK), followed by the production number in sequence. So the first British F-35B was BK01.

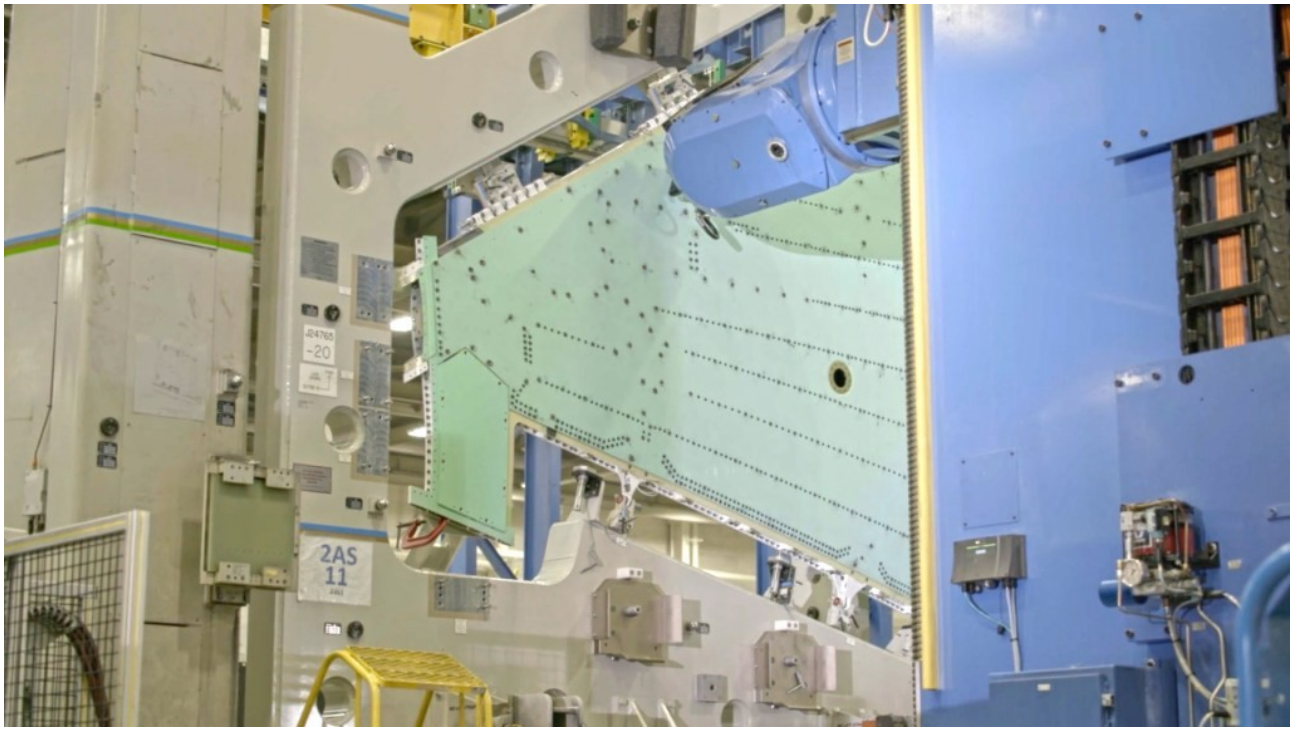
All F-35 forward fuselages, and more than 120 sets of wings per year, are produced in Fort Worth, which employs more than 3,000 touch laborers, as well as 2,000 production leaders, quality professionals, engineers, and more than 500 material handlers in what is a 24-hour, seven day-a-week operation.

All F-35 forward fuselages are manufactured in Fort Worth. *Lockheed Martin*

“The first challenge is getting the right parts to the right stations at the right time,” says Howes. “So there’s a team that works every day on optimizing the material movement. There’s another team that works on making sure we’re doing the right job in the right order, or assessing if we can switch these around to save time, that type of thing. We assess data on how we’re doing on different elements of the build process and always look at ways to do it better.”

“The way we move components around the line depends on the part we are talking about. In some areas, like the wing assembly line for example, the process flows from station to station every two-to-three days,” Howes explains. “In the first station you’re taking the big structural pieces and bolting them together. Then you move over to the next station, where the team will conduct hole drilling for example, then the next station installs brackets.”

Each task performed on the aircraft by the touch labor force is done with a set of electronic work instructions that provides the details of how to perform the task along with the engineering specifications and technical drawings that are required. These are called operation cards. The electronic work instruction system records details on who performs each operation and the materials they use. To put this into perspective, it takes roughly 1,700 operation cards to build an F-35.



An F-35 wing in production at Fort Worth. *Lockheed Martin*

There are multiple small computer terminals at every single station, where the operators sign in and receive their work instructions. Those instructions will have an

identifying number and details of the task to be completed, and it can be on any of the F-35 variants. The instructions will also detail if there's any differences between this time and the last time the person performed the task.

If there's a significant change in the way a particular task needs to be performed it may require additional training, and there's a team of manufacturing engineers that decide on the specific jet and specific day when the change will be implemented.

"Manufacturing engineers understand the implications of how it might change our processes. Do we need new tools? Do we need new fixtures? Do we need new training for our mechanics? If there's tooling to be updated, that triggers another process within our digital production system," said Howes.

The wings, for example, are built on what is called a pulse line, which means they move around the various build stations. Moving large components from one workstation to the next uses a fixed, overhead rail system. The wings are built as one piece, and they stand up vertically, mounted on adjustable height jigs, for ease of access during construction.

Each F-35 includes four major components. The forward fuselage, which comprises the nose and cockpit, is built by Lockheed Martin. The center fuselage is built by Northrop Grumman, and the center wing (which includes the wing attach points and the engine mounts) are made at the Lockheed Martin facility in Marietta, Georgia. The outer wings are built by Lockheed Martin in Fort Worth and Leonardo in Italy. The aft fuselage is built in the U.K. by BAE Systems. The F135 engine is supplied by Pratt & Whitney, with the LiftFan for the F-35B coming from Rolls-Royce.

An F-35A is lifted by overhead crane to final assembly. *Lockheed Martin*

The four major airframe components are mated at one of three final assembly and checkout (FACO) facilities, the largest being in Fort Worth, Texas, with two smaller FACOs located in Cameri, Italy, and Nagoya, Japan. The annual production figure of 156 aircraft includes the overseas FACOs, although the vast majority are built in Fort Worth, with Cameri assembling approximately 15 jets per year and Nagoya under 10, according to Lockheed Martin.

“The Electronic Mate and Alignments Systems Stations, or EMASS, is where the four major structure pieces are put together,” Howes explains. “Essentially, we’ve got four main pieces and we’re trying to align them and attach them together using laser alignment.”

During the mate process, the major aircraft components are brought together three times using the laser-guided alignment fixtures. The first time the components are brought together and measured for gaps. Then they are separated again so that the shims (aluminum pieces used to fill tolerance gaps), once they’re fabricated, can be installed. Then the aircraft is brought together again for a match drilling operation through the shim and both pieces of mating structure. The components are separated one final time to debur the holes, followed by a third and final mate for permanent fastener install.

Following EMASS, the jet will be on its own wheels and it is lifted by an overhead crane to final assembly, where control surfaces will be added, along with final systems and engine installation.

Constantly evolving manufacturing processes

With 20 years having elapsed since work on the first F-35A began, much has changed in the way an F-35 is built. From the outset, advanced manufacturing processes were introduced, such as inspection of the carbon-fiber wing skins and other composite components with a laser ultrasonic technology (Laser UT) machine, which is designed to detect imperfections that would cause a part to be rejected. Laser UT inspects parts at a rate that is 10 times faster than previous water-coupled ultrasonic inspection machines.

“The requirements of a low-observable platform force extremely tight tolerances on all major mate interfaces and on every panel and skin on the outer mold line of the aircraft,” said Jon Olson, a member of Lockheed Martin’s advanced manufacturing technology team in Fort Worth. “We use laser technology to make measurements at the installation of each panel and skin. We also use robots for a multitude of operations. For example, we robotically drill over 20,000 holes on the aircraft, and we have robots that install low-observable coatings both out on the production line and in the aircraft final finishes facility.”

The long line of F-35s on the Fort Worth production line. *Lockheed Martin*

“It’s changed a lot, in terms of capacity too,” says Olson. “We identified the need for improved speed and quality, and opportunities for technology investment. Spending money to put automation in place to save time and improve quality. I could give you a dozen examples of technology improvements, but the auto drills are a good example. Their job is to take each of the wings, just the wing by itself, and drill between 2,000 and 3,000 holes in each.”

“Robotics specifically can be tricky in aircraft applications compared to consumer products, for example, where you’ll build hundreds of thousands of the same part over and over again. It doesn’t always make sense to use a robot when the volume doesn’t justify the expenditure,” Olson explains. “But with the F-35 program, the technology has improved to the point where we’ve been able to have success with multiple robotic automation projects. If we think we could start using new technology for a process, we have to work up a business case analysis, and if it makes sense, we implement the technology.”

The use of additive manufacturing

Constant analysis of production standards is a key element of building the F-35. The aircraft’s internal weapons bay needs to accommodate a variety of different air-to-air missiles and air-to-ground weapons. Lockheed Martin must assess if all weapons configurations fit into each aircraft that’s built. For this purpose, engineers built a rather unusual fit check device to ensure each jet meets tolerance levels for all the F-35’s approved weapons.

“The design team made a CAD [Computer Aided Design] 3D model of every possible bomb or missile configuration as one giant chunk. It was a weird kind of knobbly, bumpy looking thing,” says Olson. “We 3D printed that in a series of six sections that represented the outer mold line of every possible missile or bomb configuration that could go in the weapons bay. We attach those sections together and physically put it all up into the bay. Close the bay doors and then check measurements to make sure everything is going to fit.”

“It was a great example of additive manufacturing and we still use this kind of manufacturing for some of our fit checks. But it was a pretty clunky way of doing that. So we moved to a 3D laser scanner that you place up into the bay. It scans the whole bay and provides an automatic report that compares the actual store with the design specifications. It tells us about any parts that might be sticking out slightly too far, things like that. We do that scan to check every jet.”

The F-35 team at Fort Worth has sought to make use of emerging technology where appropriate in the production program, with notable applications of automation geared towards quality control.

“We have also started using artificial intelligence [AI], which is very good at simple decision making. For example, there’s a quality check that we do on a certain part of each aircraft and based on data, it has to be exactly aligned to specifications. So it has to be reviewed by the quality team and they are now using AI for that. We’re also looking at AI for other inspections, maybe it uses imagery of the item and then uses AI to highlight something that it thinks isn’t supposed to be there? So, again a quality control solution.”

“We’ve also got areas where we use augmented reality. So the team can hold up a tablet computer or wear goggles and see overlaid information on the aircraft. That’s currently a training tool that we also use for new procedures. It works particularly well for training. Our training overall here is something that we’ve spent a good bit of time on over recent years. We have a whole classroom section in Fort Worth where we have actual aircraft parts and 3D mockups so our new trainees can do things like drilling in a safe environment before they hit the production floor.”

The team of employees that keep the F-35 production line moving are a critical resource in making each F-35 come to life. Recruiting the right people, with the right skill sets and the ability to embrace the bespoke F-35 training is vital.

“Ideally, we seek individuals with aerospace and defense experience and education,” said Howes. “The sheer volume of staff that we require also drives us to grow our own talent through the development and use of training material specific to the needs of the F-35 production system. Each employee, regardless of experience, goes through several weeks of initial training and assessment prior to deployment in the factory. That is then supplemented with annual training and specific skills training that allow us to continually develop the touch labor and support teams.”

Improving the F-35

As already mentioned, the F-35 program was conceived with a mindset of evolution and improvement over time. Lockheed Martin employs a principle called Continuous Capability Development and Delivery, or C2D2. Once a new requirement on the aircraft has been requested and agreed on by the customer and the contractor, the company initiates development engineering and tests the capability in both lab and operational environments.

As the development of the requirement matures into the final solution for the changes, an engineering change is released and lead time for production integration is incorporated.

Once the break-in is set, all of the incremental changes are made to each engineering drawing, process specification, or material specification. The engineering documents are then released, and the electronic work instruction teams provide updated instructions to the factory. As a result, the break-in tail number changes are implemented on the aircraft.

Flight test

Once completed and the stealth coatings are applied to the fuselage, each F-35 moves to one of the run stations at Fort Worth, ready for production acceptance flying. The run stations are a series of hangars that have been in use since before the F-111 and are set out adjacent to the factory as a continuous side-by-side row, and they allow access to the taxiways and runways at the adjacent Naval Air Station Fort Worth Joint Reserve Base.

“We know the state of the airplane, the build of the airplane. It’s a very mature process,” says Scott “Shark” McLaren, an F-35 test pilot at Lockheed Martin. “We know the state of the software, it’s already gone through testing at Edwards Air Force Base [California] and Naval Air Station Patuxent River [Maryland]. So when we get the new jet out here at flight test, it first goes through a series of ground runs.”

“When we start up the airplane, it does its own system checks and gives us feedback to tell us the state that it thinks it’s in. I know where it should be, so I put those [pieces of information] together and I can step up my risk level a bit and taxi out to the end of the runway. I go through the entire process, understanding the risk where I’m at and not moving forward until I have confidence to move on to the next step. That’s really our flight-test mentality, build-up to make sure we get through the entire profile, the entire checklist, to make sure the airplane is ready.”

An F-35C assigned to VX-9 Det Edwards for operational flight testing. *Jamie Hunter*

“For F-35A acceptance work it’s going to take approximately two flights. I can get through the entire checklist items in those two flights as long as everything is ready to go and I get on that normal timeline [with] the ground runs. We expand that for an F-35B to three flights because of all the different items that we need to check on an F-35B. The airplane can come into a hover and we open up a few more doors and that sort of thing. But I’m also going to use a little bit more fuel as I’m doing that. So I need to expand that into that third flight to make some room for that. For an F-35C, it’s very much like an F-35A. We’ll accomplish all those checks in about two flights.”

“That very first flight, I’m going to take someone with me, that’s my chase aircraft and ATAC [Airborne Tactical Advantage Company] Mirage F1s are supplying that for us right now. When we take off, that chase is going to be there right with me supplying backup for things like my communications if something fails. We have airliners flying in Dallas Fort Worth airspace, so we want to deconflict with them, and

the chase can help me out there. Those are just two small little pieces, but the chase is there for a lot of reasons."

An F-35 pilot signals to ground crew that he is ready to start the engine. *Jamie Hunter*

Alongside the production test work described here is development test, which is about evolving the new capabilities for the F-35. "A lot of the development, design, and laboratory work is done right here in Fort Worth, and I participate in a lot of that," says McLaren. "At the end of that development process, we update the [test] aircraft at Edwards and Pax River ready for flight-testing. They go through the flight-test rigor that needs to happen on new software and hardware combinations. We see all the reports and they send it back to us in a production version and now we can fly that on these airplanes. So really, we're not seeing any of that [development] process until its end state."

F-35 modernization: TR-3 deliveries begin

The culmination of SDD in 2018 ended development of the F-35's original baseline capabilities. The current follow-on modernization effort is known as Block 4, which is upgrading new-build F-35s to better equip them to tackle threats that have emerged since the original program requirements were set out in 2000. You can read more about Block 4 here. There is also a modernization effort centered around the F-35's Pratt & Whitney F135 engine to address power and cooling needs for post-Block 4 enhancements.

Technical Refresh 3 is a major hardware and software upgrade designed to provide the “computational horsepower” to underpin Block 4. More commonly referred to as TR-3, it includes a new integrated core processor with greater computing power, a panoramic cockpit display, and an enhanced memory unit. TR-3 entered flight-testing in January 2023, and production Lots 15-17 were the first F-35s to include the TR-3 updates.

The first TR-3 standard production jets began to be built in February 2023 and these airframes were expected to be completed before the end of July that year. However, delays associated with development and testing of the new processor and software, which are core elements of TR-3, meant that deliveries of TR-3 configured F-35s had to temporarily be put on hold. The team continued to produce the aircraft though and announced in July 2024 that, in coordination with the F-35 Joint Program Office (JPO), deliveries of F-35 TR-3 configured aircraft have begun.

The aircraft delivered in this initial phase include combat training capabilities, marking an important step as the team moves toward full TR-3 combat capabilities. Moving forward, Lockheed Martin expects continual software updates related to TR-3 insertions and Block 4 capabilities, with major milestone software drops along the way.

A pair of U.S. Air Force F-35As in action. *Jamie Hunter*

“Lockheed Martin is very focused on Tech Refresh 3,” Greg Day told *The War Zone*. “Right now, we are making sure that we are going to deliver a quality product that

has the full capability. It’s important to note that today over 95 percent of Tech Refresh 3 capability is in flight and is being tested and evaluated.”

The clearance for TR-3 aircraft to be delivered marks the next critical step towards Block 4 standard F-35s joining combat squadrons, albeit initially in a training configuration. This is a major advancement for the program, as the Block 4-standard aircraft marks a new era in the F-35 program in this overarching modernization effort.

Significantly, customer interest around the world in the F-35 continues unabated. “What we see is continued interest in the F-35 and we’ve seen repeated selections, most recently Greece selected to procure 20 aircraft,” commented Greg Day. “We’ve also seen the Republic of Korea step forward and increase their planned order to 60 aircraft in total, and right now we are supporting the U.S. government with the interest that is being shown by Romania in the F-35.”

Source