PROFILE

F-35

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The next generation of multi-role jet fighter

Lockheed-Martin F-35 Lightning II

by Nico Braas

Boeing's X-32; the second-best in the JSF competition! The picture shows the X-32B VSTOL version. (Photo: Boeing)

Lockheed-Martin X-35B VSTOL no. 301 flying over Edwards AFB with opened vertical lift fan. (Photo: Lockheed-Martin)

Introduction

With the current generation of U.S. fighters like the F-14, F-15 and F-16 now nearing the end of their operational life, these types will soon be succeeded by a next generation fighter.
One of these, known as the JSF or Joint Strike Fighter will replace over the next 5-10 years the older types. These types have been operational for a large period of time, more than 35 years. The new JSF will be used on a world-wide scale by various air forces over the next decades.....

It started as an X-plane:
The F-35 is the fifth generation of jet fighter since its introduction in the last years of the Second World War.
Here is an overview of the generations from the first one:

Examples		Main characteristics
First generation	Me 262, Meteor, P-80	Straight wings, subsonic
Second generation	F-86, Hunter, MiG-15	Swept wings, trans-sonic
Third generation	F-104, Mirage III, MiG-21	Mach 2
Fourth generation	F-16, MiG-29, Mirage 2000	Supersonic, very manoeuvrable
Fifth Generation	F-22, F-35, Sukhoi T50	Supersonic supercruise, stealth
Sixth generation	yet to come!	

The X-35A Joint Strike Fighter demonstrator. (Photo: Lockheed-Martin)

The F-35 is intended to replace aircraft types like the F-16.
The history of the F-35 goes back to the early seventies with the aim to develop a new and improved fighter type. Basic requirements were sustained supersonic cruise and a very low Radar Cross Section or RCS to make it difficult to track with ground and air-based military radar systems. The U.S.A.F. finally got its fifth generation fighter as the F-22 Raptor as a result of the ATF (Advanced Tactical Fighter) programme that started around 1980.
A second program was set up to develop a strike fighter that would suit the needs of all three U.S. armed forces (U.S.A.F., U.S. Navy and U.S. Marines). It became at that stage known as the Joint Strike Fighter or JSF project. Several companies submitted proposals, but finally Boeing and Lockheed-Martin were selected to build a prototype for evaluation. They received the X-designation for experimental aircraft types and purely served as flying concept planes. Boeing's experimental type received the type designation X-32; the Lockheed-Martin design received the type designation X-35. Boeing constructed two X-32s.
The X-32 made its first flight in September 2000. Since it was designed as a CTOL type (CTOL=conventional take-off and landing), it was designated as X-32A. The second prototype had an engine with a build-in vertical fan and an exhaust that could be swiveled downwards for vertical thrust. It could start and land 100% vertically in VTOL mode or in STOL mode (Short Take-Off and Landing) using its vectored thrust. In general, these start and landing characteristics were indicated with the abbreviation STOLV. Type designation of Boeing's second JSF was X-32B.
Lockheed-Martin constructed one X-35 prototype as X-35A for the CTOL version. Later during the testing program it was converted in STOLV mode as the X-35B for direct comparison with Boeing´s X-32B. First flight of the X¬¬-35 as CTOL version took place on 24 October 2000 by Lockheed-Martin test pilot Tom Morgenfeld. First flight of the modified X-35B STOLV version took place on 23 June 2001. A navalized third machine, designated as the X-35C had already made earlier its first flight on 16 December 2001.
After an extensive competition flying program with both X-32 and X-35 was completed, the X-35 was declared as the winner.

A difficult start of the JSF

After the X-35 was declared as the winner of the JSF competition the X-designation was soon changed

In-flight refuelling test mission of X-35 no. 301.
(Photo: Lockheed-Martin)

X-35B water taxiing test.
(Photo: Lockheed-Martin)

into F-35. This was out of sequence with the standard aircraft type numbering system of the U.S. Department of Defence, where it should have been the 'F-24'. However, the type designations X-35 and F-35 were in fact logical steps to 'show' it was the same design! As name 'Lightning II' was selected as a remembrance of a wartime Lockheed product: the P-38 Lightning fighter with its characteristic double tail.

Lockheed-Martin was awarded a contract for the construction of various F-35 evaluation models both with and without the possibility for vertical start and landing. Basically the new F-35 will replace existing types like the F-16, but also typical attack planes like the A-10 Thunderbolt and the AV-8 Harrier. Already at a very early stage the F-35 was offered for export to various countries to replace their ageing aircraft types in the near future. Large contracts for billion of dollars (or Euro's) were promised provided the governments in the export countries would contribute into the development costs.

Changing requirements of what the new fighter had to do resulted in delays. Not only the changing specifications, but also a number of teething troubles encountered during the development phase would not only cause delays, but also rising costs!

However, with a production now (2015) underway, it is hoped that more numbers of F-35's ordered will result in a lower individual price tag!

A very realistic Lockheed-Martin F-35A mock-up displayed in 2006 during the KLu Open Days at Leeuwarden in the Netherlands. Tail marking is for Dutch 323 Squadron based at Leeuwarden.
(Photo: Nico Braas)

F-35 versions

Originally intended as a simple to maintain and simple to fly 'budged-priced' successor of various 4th generation fighters, the F-35 was soon updated with the most modern avionics.

Basically there are three versions:

-F-35A CTOL for use at the U.S.A.F. The F-35A is also the export model for various countries. It is powered by a Pratt & Whitney F135 engine. This was a new engine, based on the F119-PW100 engine as used by the F-22 Raptor. An alternative engine of the same class was developed jointly by General Electric and Rolls Royce as the F136. For budgetary reasons the development is this engine was cancelled in 2011.

-F-35B VSTOL for use at the U.S. Navy and Marines from small vessels or ground bases.

It featured after the cockpit a vertical fan and panels that can be opened at vertical start and landings. The fan is powered by a clutch-operated shaft drive from the jet engine. The jet engine further has an exhaust that can be swivelled in 90° downwards position. The F-35B is powered by a specially adapted Pratt & Whitney F135-PW-600 jet engine.

Another picture taken at Leeuwarden showing the Martin AGM-158 JASSM mock-up.
(Photo: Nico Braas)

Rear view of the F-35A mock/up in a light blue-grey KLu colour scheme.
(Photo: Nico Braas)

Visiting of the cockpit of the F-35A mock-up during the KLu Open Days was restricted to authorized persons!
(Photo: Nico Braas)

-F-35C CV or carrier variant (also sometimes known as CATOBAR or Catapult Assisted Take-Off But Arrested Recovery) for use from aircraft carriers. It has larger and foldable wings, a strengthened undercarriage for deck landings and an arrester hook. Also the F-35A has an arrester hook but this is only for emergency stops. The F-35C uses the same type of engine as the F-35A.

From the start of the F-35 program, a dual-seat training version was never considered. Basically it was regarded that the very advanced and realistic flight simulators of the F-35 would be sufficient. After the flight simulation phase is completed, student pilots make their first solo jet hours on adapted F-16s.

Together with the F-22 Raptor, the F-35 was from the early beginning designed to have a very low Radar Cross Section or RCS. The shapes of the F-35 were carefully designed for a minimal reflection of incoming radar signals. Much experience was already gained with earlier types like the F-117 and the B-2. Except for its shape, the F-35 also has a coat of special Radar Absorbing Material (RAM). However, since this RAM is still a highly classified product, export versions will have most likely a less sophisticated and somewhat less effective RAM coating! Details on this are still classified!

Early testing and teething troubles: When the X-35 was declared as a winner of the JSF competition Lockheed-Martin started to develop the purely experimental X-35 into an operational multi-role fighter as the F-35.

One of the main changes was a longer fuselage with an extended nose for the avionics.

With the F-35B VSTOL the biggest problem was to keep the weight within reasonable limits.

This was not an easy task since the vertical fan is nothing more than dead weight when not in use. Consequence that was unavoidable was a lower range when compared with the CTOL version since space occupied by the lifting fan cannot be used for other purposes like fuel storage. In spite of this, these disadvantages were taken for granted; otherwise there would be no real replacement for the ageing AV-8 Harriers!

Lockheed-Martin constructed the following F-35s for operational

evaluation:

F-35A CTOL version:

Registration no.	Date of first flight
AA-1	15 December 2006
AF-01	14 November 2009
AF-02	20 April 2010
AF-03	6 July 2010
AF-04	30 December 2010

The 6th test model AF-05 was cancelled and two additional F-35A aircraft (nos. AG-1 and AJ-1) were supplied in 2008 for static and fatigue testing. They were never flown.

F-35B STOLV version:

BF-01	11 June 2008
BF-02	25 February 2008
BF-03	2 February 2010
BF-04	7 April 2010
BF-05	27 January 2011

As for the A-version an additional two F-35Bs (BG-1 and BH-1) were used for static and fatigue testing and never flew.

F-35C CV (carrier version):

CF-01	6 June 2010
CF-02	29 April 2011
CF-03	21 May 2011

F-35C aircraft CG-1 and CJ-1 were exclusively used for static and fatigue testing.

All above aircraft were used for testing and evaluation during the SDD phase (System Development and Demonstration). The contract for System Development and Demonstration (SDD) was awarded on 26 October 2001. Tested were general flying, gun and weapon firing, flutter, aircraft and engine stress testing and determination of the total flight envelope. With the STOLV versions various short take off and landings as well as vertical starts and landings were tested under various conditions. Initially some 5000 tests were planned but by August 2011 this was increased to 7727. In March 2013 Lockheed-Martin announced it would need an additional budget of 6 billion US$ to complete the SDD phase in October 2017.

During the SDD phase a list of shortcomings and teething troubles was experienced.

With a combination of new engine and new airframe, this did not come totally unexpected, but it also meant more money had to be raised and spent to solve all problems encountered.

The list of points of concern encountered during the evaluation period was extensive and included items like:

-the helmet-mounted display system

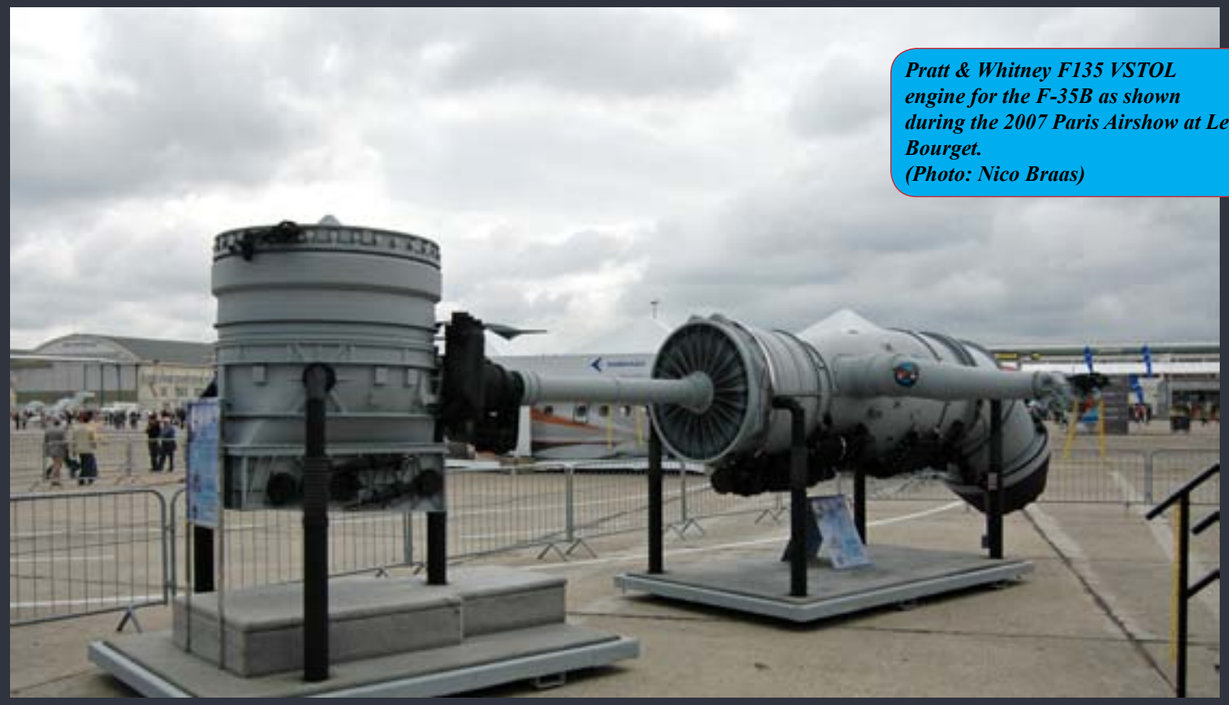
-the fuel dump sub-system

-the F-35C's arresting hook did not work properly (this was finally solved by replacing the U.S. built hook by an improved arrester hook built by the Dutch Fokker-Stork company)

-the software development is behind schedule. One of the nasty consequences is that the on-board cannon cannot fire!

There were also flight problems with wing buffet being worse than expected. There were also concerns about the strength and integrity of the airframe with fears it would not last through its expected lifespan. Also its stealth characteristics were reported as being less than originally announced. Further, the F135 engine gave its share of problems and an early engine breakdown even resulted into the aircraft being grounded until all problems were adequately solved.

One of the totally new items of the F-35 was its Integrated Power Package (IPP) unit. This is a small Auxiliary Power Unit powered by a 200 hp capacity jet engine. It not only serves to supply electric power to start the engine, but it also controls cooling of the aircraft, the many on-board avionics, cockpit air pressure and oxygen supply and a number of other items. At jet fighters of an earlier generation all these items had their separate units. The IPP was never tried before and also had its share of teething troubles.



Pratt & Whitney F135 VSTOL engine for the F-35B as shown during the 2007 Paris Airshow at Le Bourget.
(Photo: Nico Braas)

For the F-35B VSTOL overweight was a constant factor and every unnecessary kilogram had to be removed!

Even today (early 2015) not all points of concern are fully solved and before the F-35 will be fully operational and for 100% fulfill all its intended tasks lots of work will have to be done!

Into production

In spite of all teething troubles and ever-increasing costs, all three versions are now in production for operational use. Also the export versions to countries like Canada, Australia and the Netherlands are now rolling from the production lines.

The first F-35A for the U.S.A.F. with serial no. 08-0747 was delivered in March 2014. Over 2014 some 16 more will be additionally delivered. Total number ordered until now is 144; total number planned is 1763.

The U.S. Marines will receive initially 340 F-35Bs and 80 F-35Cs. The F-35Cs will be assigned to U.S. Navy aircraft carriers while the F-35Bs will be shore-based.

The U.S. Navy has planned the delivery of 260 F-35Cs over the coming years.

Total delivery of the various F-35 versions to the U.S. forces planned is 2363.

Exports

When the Lockheed-Martin X-35 was declared as winner in the JSF competition, much effort was made to interest other countries in the F-35 as a successor for their existing fighter and attack aircraft. Already at the SDD phase compensation orders were promised when countries contributed in the development costs of the new fighter. The Netherlands, Canada, Australia and a number of other countries showed a great interest and were prepared to invest into the development costs.

Unfortunately cost increase was inherent on the project and in some parliaments (like The Netherlands and Canada) the choice of the F-35 as a successor for mainly the F-16 was firmly discussed.

In spite of this political uproar and in spite of cost increases and continuing teething troubles work on export F-35's continued.

Canada

As a direct neighbour Canada placed in 2010 an option for an order of 65 F-35As to replace their CF-18 Hornet fighters. The first machines were scheduled to be delivered in 2017. However, by end 2014 Canada was firmly hit in its economy by the low crude-oil price and as far as known the order for 65 machines is far from certain. Even if the world's economy will recover the final number of F-35As (or CF-35A as designated for this country) may be much lower than initially planed. In 2010 the Canadian option resulted in a full-scale wooden mock-up but until now (early 2015) no final orders have been placed yet. Now more and more F-35s are rolling out of the Lockheed-Martin plant its price is decreasing and that may be a decisive factor for the final decision.

Australia

Australia is since 2006 officially involved in the F-35 development. Planned number of F-35As to be purchased is 100. The first Australian machine, carrying the registration AU-2, has been arrived in December 2014 at Luke AFB for its initial test program. There are more to follow in the future.

Great Britain

Great Britain has placed an order for three F-35B STOLV test aircraft. Final number planned is 138 as a replacement for the retired Harriers and Sea Harriers. Both R.A.F. and Royal Navy will use them. The first British F-35B, with registration BK-1 made its first flight on 13 April 2012. It has been handed over to the U.K. with R.A.F. serial number ZM135. The second British F-35B, ZM136 made its first flight in October 2012. The third evaluation machine ZM137 made its first flight on April 1st 2013. The Royal Navy F-35B will provide vital 5th Generation carrier-strike capabilities to the Royal Navy's two new carriers – the HMS Queen Elizabeth and HMS Prince of Wales. These new Queen Elizabeth Class Carriers are designed specifically for integration with the F-35B aircraft, including a ski jump ramp for short takeoffs in place of the traditional catapult launch. HMS Queen Elizabeth was launched in July 2014 and will be fully commissioned in 2017.

The Netherlands

The Netherlands was already involved in the F-35 development in 2000. Fokker-Stork helped with the development and production of essential parts from the beginning. On 12 January 2015 a contract for a follow-on order was signed for the production of wing parts. It is estimated this order is worth some Euro 30 Billion! The Netherlands has ordered two evaluation F-35As; first one with registration F-001 was flown on 6 August 2012. These two evaluation aircraft are now placed in storage in the US until orders will be final. There still is a lot of political discussion on the choice of the F-35A for the Koninklijke Luchtmacht or KLu and orders for in total 37 F-35As are not yet confirmed, although the planned purchase of the first eight seems to be in its final phase. Also here a lower final price for each F-35 aircraft may be a decisive factor! The F-35A will replace the KLu F-16 by 2019.

At the 2007 Paris Airshow, the JSF/ F-35 mock-up was also exhibited. (Photo: Nico Braas)

Norway

Norway joined the F-35 program during the SDD phase In November 2008, the Norwegian government chose the F-35 as the replacement for the F-16 fleet. In 2011, the government approved acquisition of four training aircraft with the first two F-35A conventional take-off and landing aircraft ordered and scheduled for delivery in 2015.

Denmark

Denmark joined the Joint Strike Fighter program in 2002 during the SDD phase and has helped influence technical elements of the F-35 Lightning II. In 2012, the Danish Parliament approved the acquisition of an additional 48 aircraft for a total of 52 F-35As.
However, in 2013 the Danish parliament decided to reconsider its earlier choice for the well known reason: the ever increasing costs. Also the F-18E/F Super Hornet and the SAAB Grippen NG were considered as an alternative. Final decision will be taken in mid-2015.

The instrument panel of the F-35A mock-up. (Photo: Lockheed-Martin)

Italy

Italy was one of the main global partners during the SDD phase. Italy has plans for the acquisition of 60 F-35A CTOL variants and 30 F-35B VSTOL variants.

Israel

Israel was the first non-NATO member showing an interest in the F-35 for the replacement of its ageing F-15 and F-16 fighters. In 2003, Israel signed a formal letter of agreement, worth almost $20 million, for the F-35A CTOL. Israel will buy 20 initial examples of the F-35A as the 'F-35I', with a total of 75 fighters desired. The Israeli F-35 is named the Avid ('the awesome').

South-Korea

South Korea has signed in September 2014 a deal for the acquisition of 40 F-35A CTOL fighters for delivery in 2018-2021.

Japan

The Japanese Ministry of Defense announced its selection of the Lockheed Martin F-35 Lightning II as the Japan Air Self Defense Force's (JASDF) next generation fighter aircraft on 19 December 19, 201. Japan selected the F-35A CTOL variant of the Lightning II. Japan's Ministry of Defense intends to order 6 F-35As in Fiscal Year 2015 and an additional 36 over the following years.

When all plans for the procurement of all F-35 versions are tallied, the total number of aircraft planned to be constructed is more than 3000. Up to now some 100 F-35s are delivered.

F-35A Lightning II mock-up in the colours of the Royal Canadian Air Force. It still is wishful thinking since final orders have not yet been placed!
(Photo: Lockheed-Martin)

The first F-35A evaluation aircraft AA-1 ready for its visit to the paintshop. (Photo: Lockheed-Martin)

F-35A AA-1 being towed to its inauguration ceremony on 7 July 2006. (Photo: Lockheed-Martin)

AA-1 in the spotlights during the official inauguration of 7 July 2006. (Photo: Lockheed-Martin)

At the AA-1 inauguration many people from various countries were invited! (Photo: Lockheed-Martin)

First taxi-trial of AA-1 on 7 December 2007.
(Photo: Lockheed-Martin)

Technical details:

	F-35A	F-35B	F-35C
Engine:	P&W F135-PW-100	P&W F135-PW-600	P&W F135-PW-100
Thrust:	128.1 kN	120.1 kN	128.1 kN
Dimensions:			
-length	15.70	15.40 m	15.70 m
-Wingspan	10.70 m	10.70 m	13.10 m
-Height	4.36 m	4.36 m	4.48 m
-wing area	42.7 m2	42.7 m2	62.1 m2
Weights:			
-empty	13,290 kg	14,651 kg	15,422 kg
-max. take-off	31,751 kg	27,216 kg	31,751 kg
Performances:			
-max. speed	1930 km/h (M 1.6)	1930 km/h (M 1.6)	1930 km/h (M 1.6)
-range*	2200 km	1667 km	2200 km
-service ceiling	n.s.	n.s.	n.s.
Armament	1x25mm GAU-22A	1x25mm GAU-22A	1x25mm GAU-22A

*on internal fuel

Engine run-up of AA-1 on 12 December 2007.
(Photo: Lockheed-Martin)

Systems and armament

The basic armament of all three F-35 versions is a belly mounted GAU-22A four-barrel rotary gun capable to fire rounds of 25mm calibre. It is manufactured by General Dynamics Ordnance and Tactical Systems. It is externally powered by a battery and has a weight of 104.3 kg. Rate of fire is up to 3300 shots per minute with a muzzle velocity ranging from 1036 to 1085 m/sec depending on the type of ammunition fired.

The F-35 has two internal weapon bays for the GBU-12 Paveway laser-guided 225 kg bomb.
With the LGBs fitted, there is further room for one air-to-air missile in each weapons bay.
On wing-mounted hard points a variety of other weapons can be carried, including the AIM-9X Sidewinder and AIM-132 ASRAAM short-range air-to-air missiles. Other weapons that can be carried are the AIM-120 AMRAAM BVR AAM, Storm Shadow cruise missile, AGM-158 Joint Air to Surface Stand-off Missile (JASSM) cruise missile, and guided bombs. Of course, the hard points can also be used for additional fuel tanks.
Disadvantage of external loads is that it has adverse effects on the stealth characteristics.
Although countries like The Netherlands insisted that the F-35 must 'not have nuclear bomb delivering capacity' this is of course always possible and later versions from the production line will be made suitable for carrying and dropping two B61 nuclear bombs.
The F-35 pilot carries a helmet showing all tactical information on his visor.
It is one of the many new systems fully integrated with the F-35 onboard computer and it gives the pilot a full 360° vision.

Comparative types

The F-35 is not any longer the only one of its kind of the 5th fighter generation. Russia has developed the Sukhoi T.50 and China the Chengdu J-20. The Chinese Chengdu J-20 must have been built using much information stolen by hacking of U.S. data. Both Sukhoi T.50 and Chengdu J.20 are as far as known only planned as CTOL version!

The Future

With the final production of all three versions now underway they will see actual service over the next years. Just as has been done for types like the F-16 the F-35 will be further improved with updated systems

There are at the moment no direct plans for more versions. but it is to be expected that these may be built in the future.

Possibilities are:

-TF-35A/B/C for more realistic combat training than can be given in the flight simulators

-ECM two-seat version in a similar way as has been done with the F-18 as the EA-18G

-Super-Stealth version for special attack missions

The story of the F-35 so far is still very incomplete; in fact it still has to start when the F-35 will be in full-scale production and operational at the U.S. and other forces. It still has a long way to go before it will have earned the same reputation as the General Dynamics F-16!!!

F-35A no. AA-1 at take off on 15 December 2006 for its 35 minutes maiden flight from Fort Worth by Lockheed-Martin test pilot John Beesley.
(Photo: Lockheed-Martin)

Critical moment: F-35 AA-1 leaves the ground for its first test flight,
(Photo: Lockheed-Martin)

References:
-Pieto van Buysen, Van JSF naar F-35 Lightning II, Lanasta, Emmen-the Netherlands (2014)*
-http://nl.wikipedia.org/wiki/F-35_Lightning_II
-http://www.lockheedmartin.com/us/products/f35.html

*although written in the Dutch language only, this recent book gives excellent information on the whole JSF/F-35 story from the beginning with some emphasis on the Dutch 'political situation'. At A4 size with more than 200 pages of text it more or less is obligatory reading for everyone having an interest in the F-35. It is illustrated with a few hundred photographs, most of them in color .
ISBN no. is 978-90-8616-135-5 and it can be directly ordered at www.lanasta.com

During the first flight of evaluation machine AA-1 the undercarriage was not retracted and airspeed was limited to 417 km/h. The first flight was completed without any major malfunctions.
(Photo: Lockheed-Martin)

GALLERY


F-35 LIGHTNING II
F-35
AA-1


F-35
AA-1
F-35 LIGHTNING II


F-35
AA-1


F-35
AA-1


F-35
F-35 LIGHTNING II


AFMC


F-35


RF-02


EG


STOVL
BF-01
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STOVL
BF-03
F-35


F-35
NAVY


F-35


NAVY


VFA-101
NAVY


STRIKE
PADDLES


5010
5009


F-001


Active Matrix Liquid Crystal Display image display
Sensor fusion
Binocular 40 degree by degree field-of-view
Integrated day and night camera
Ejection Safe to 600 knots equivalent air speed


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