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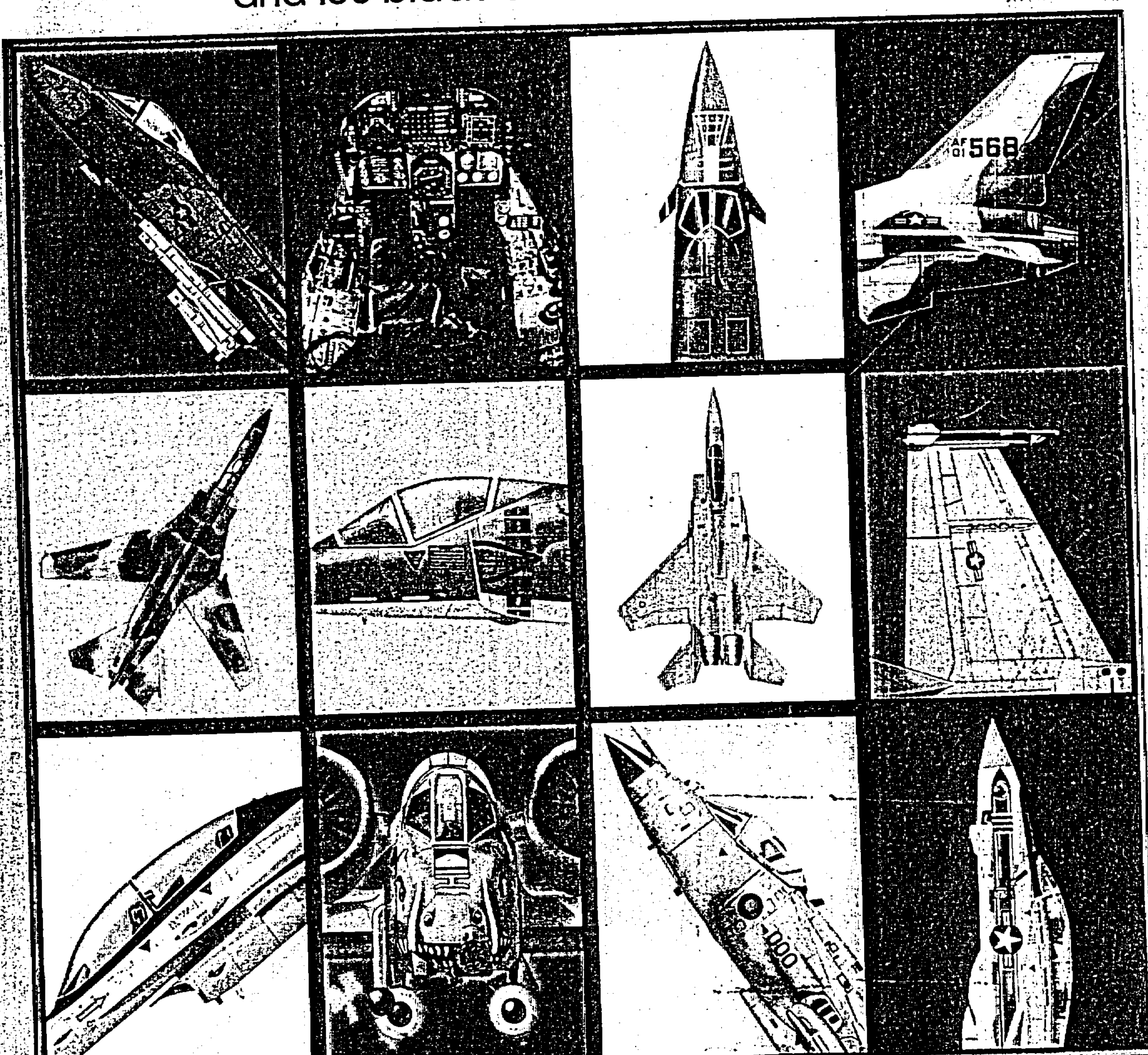

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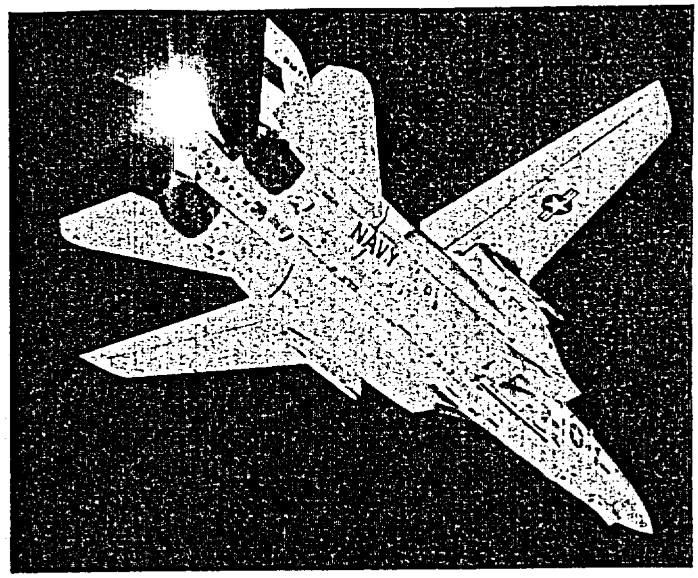

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Project Manager: Ray Bonds

Editors: Bernard Fitzsimons, Philip de Ste. Croix, Ray Bonds, Tony Hall

Designers: Grub Street Design, Tony Dominy, Rod Teasdale, David Allen, Barry Savage, Nick Buzzard, Lim & Lim, Mark Holt, Philip Gorton

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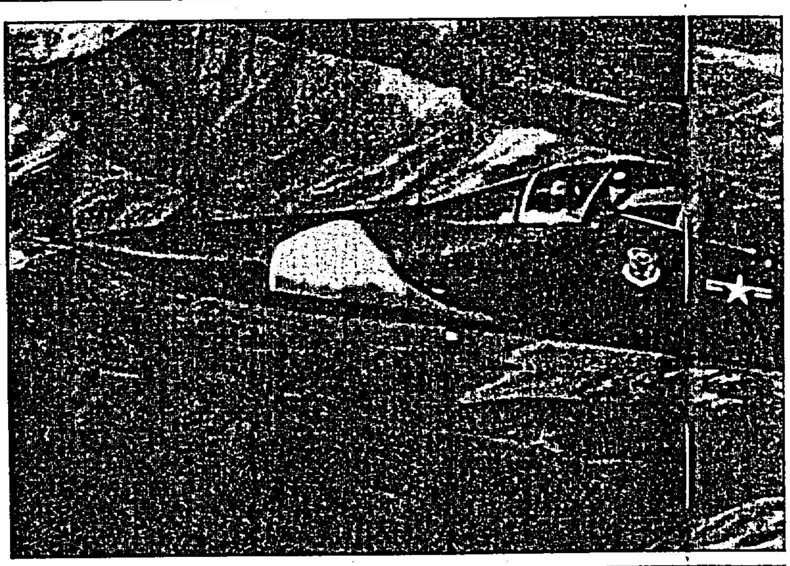

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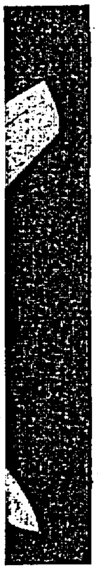

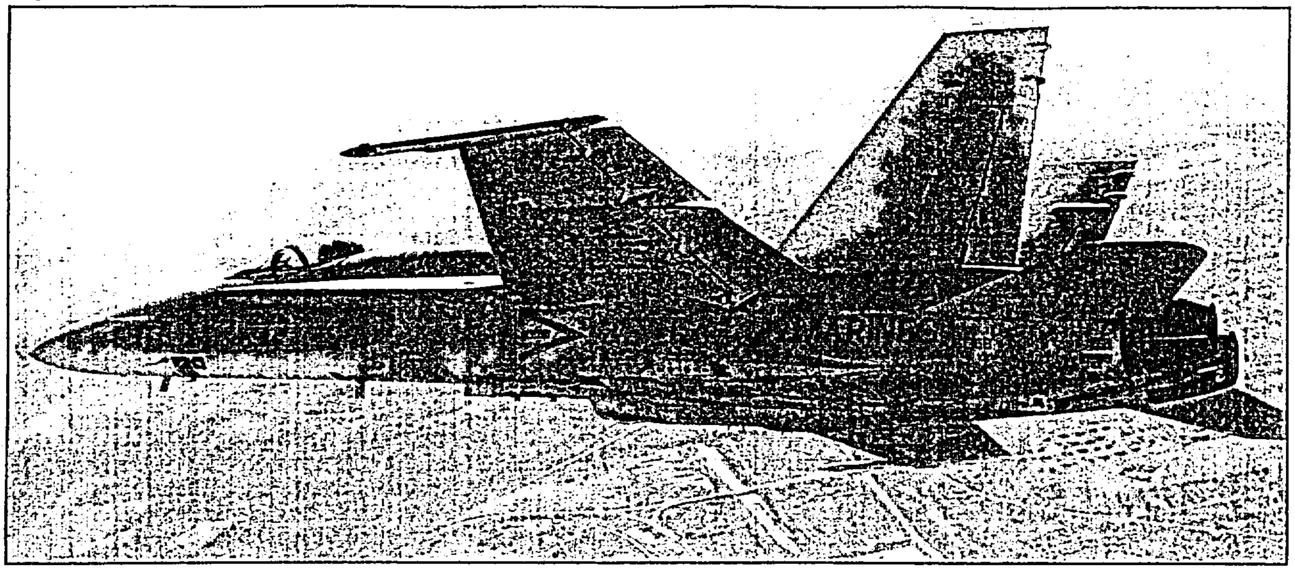

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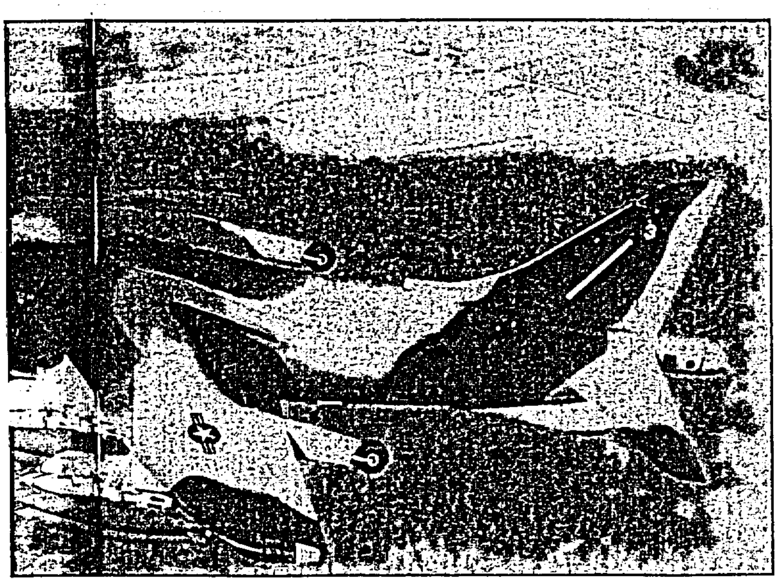

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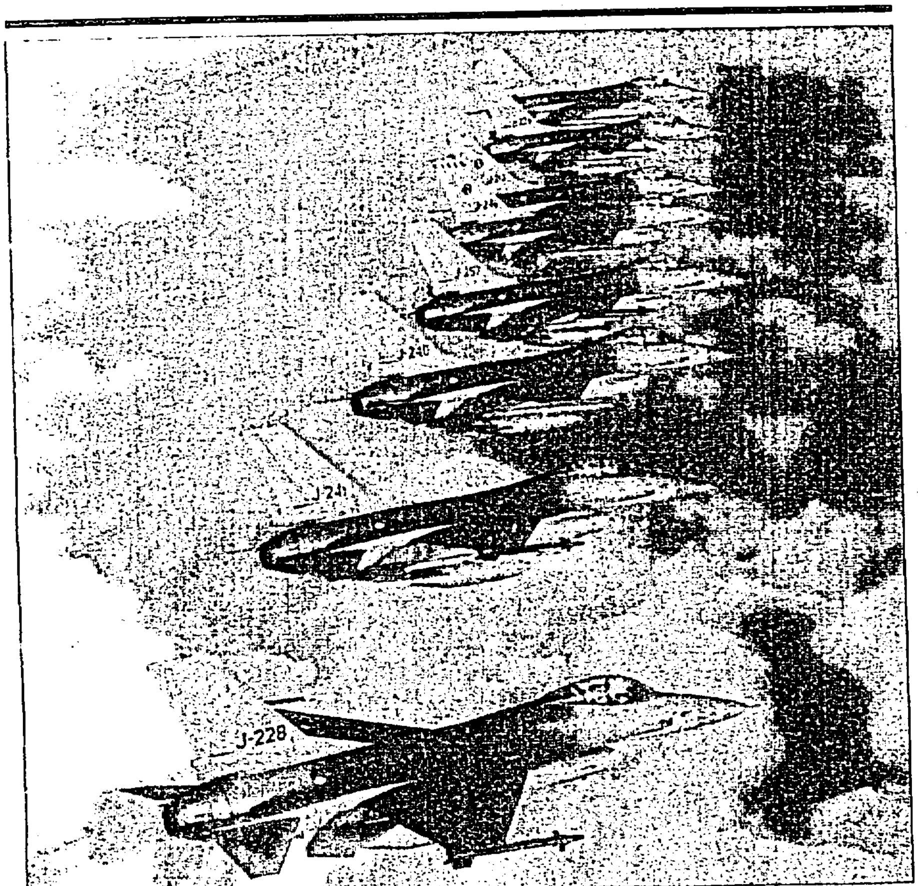
Chapter 3

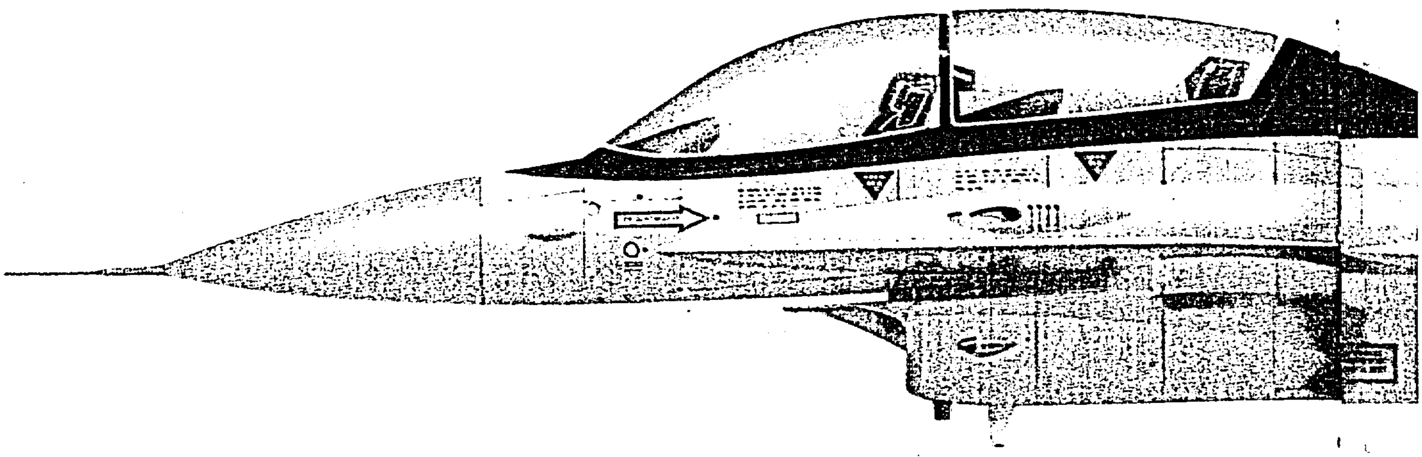
F-16

FIGHTING FALCON



Doug Richardson

F-16 Fighting Falcon



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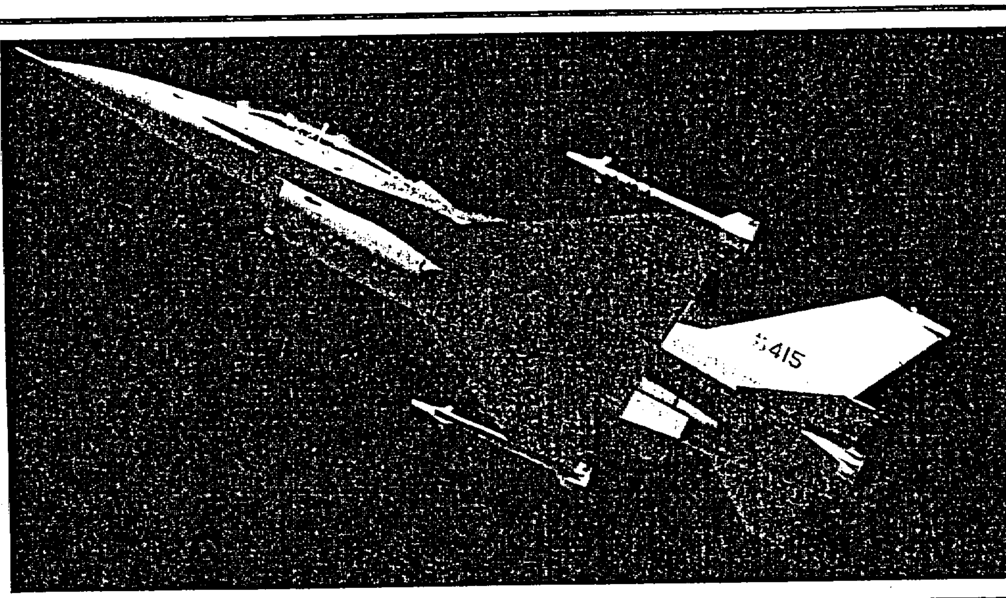

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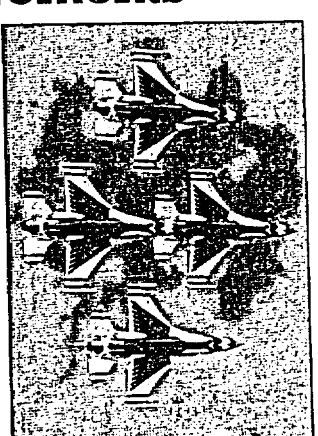


Author

Doug Richardson is a defence journalist specializing in the fields of aviation, guided missiles and electronics. Editor of *Defence Materiel*, the journal devoted to the British defence industry, he trained initially as an electronics engineer, starting his career as a technician with an R&D team working on avionics for the Buccaneer and the cancelled TSR-2 project.

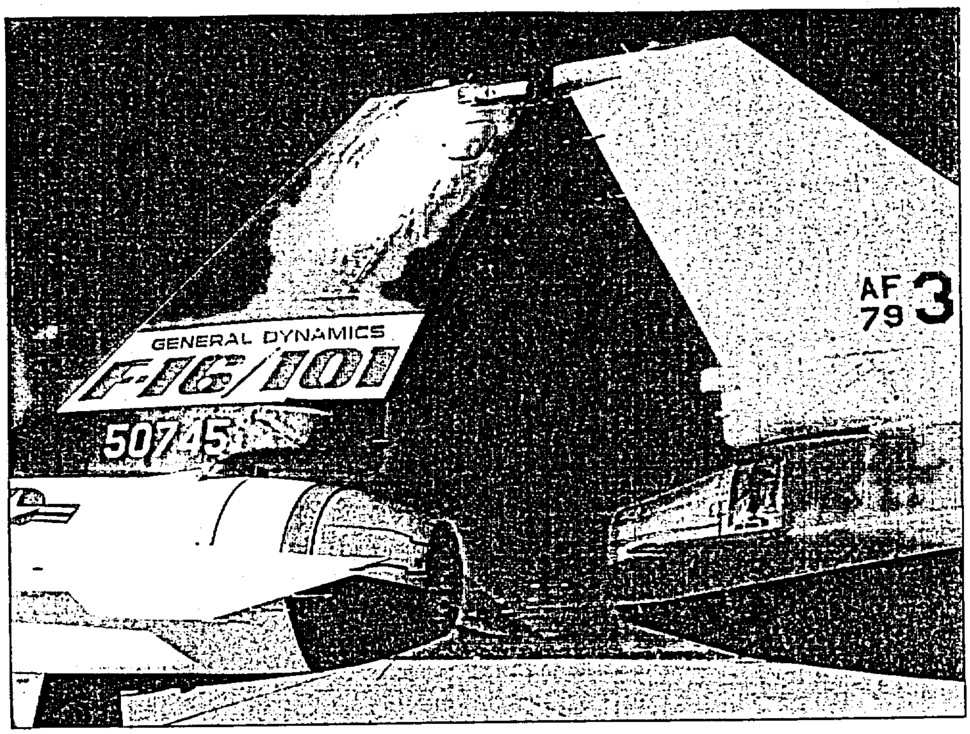
After an electronics R&D career encompassing such diverse areas as radar, electronic warfare, rocket engine control systems, computers, automatic test equipment and missile trials, he switched to technical journalism as a member of the staff of the internationally respected aerospace journal *Flight International*, serving as Defence Editor before moving on to become Editor of the international technical defence journal *Military Technology and Economics*.

His previous work for Salamander includes *The Illustrated Encyclopedia of Modern Warplanes* and contributions to *The Balance of Military Power*, and he has also written for such technical and defence journals as *International Defense Review*, *NATO's 15 Nations*, *Defence*, *Technologia Militar* and *Wehrtechnik*. In 1981 he edited *Defense Review*, a Chinese-language report on the British defence industry prepared for controlled circulation in the Chinese government, industry and armed forces.

plans to buy an additional 945, including 597 enhanced derivative versions.

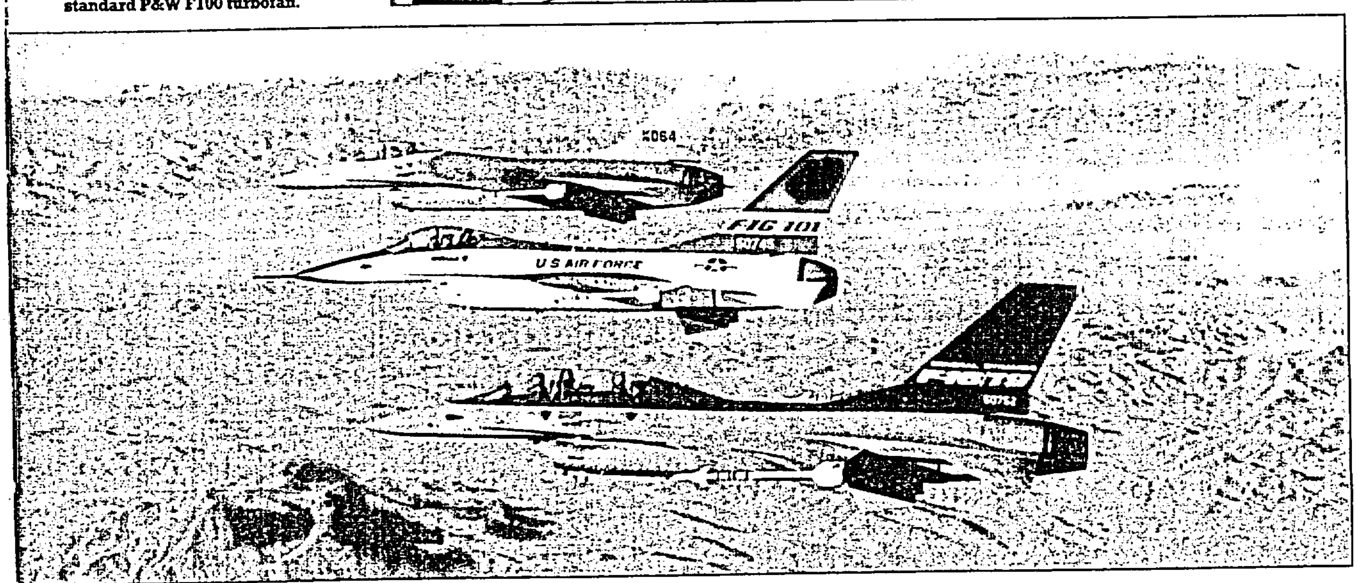
US military procurement is traditionally handled year-by-year, but the F-16 is one of the few aircraft being purchased under multi-year production plans. This results in real savings to the customer since the manufacturer has the confidence to negotiate with suppliers and subcontractors for larger quantities of components and materials, and to procure long lead-time items for aircraft to be built in the later stages of the contract. When this scheme was mooted in 1982, GD pointed out that 120 aircraft could be delivered per year under a multi-year contract for the level of funding which would pay for only 96 under annual procurement methods.

The 1984 US defence budget allocates a total of $2,300 million to F-16 procurement in 1984, and $3,200 million in 1985, which will allow production to run at 120 aircraft per year. This may seem a long way from the original concept of a 'cheap' fighter, but if spent on F-15 Eagles the same money would buy only half that number.

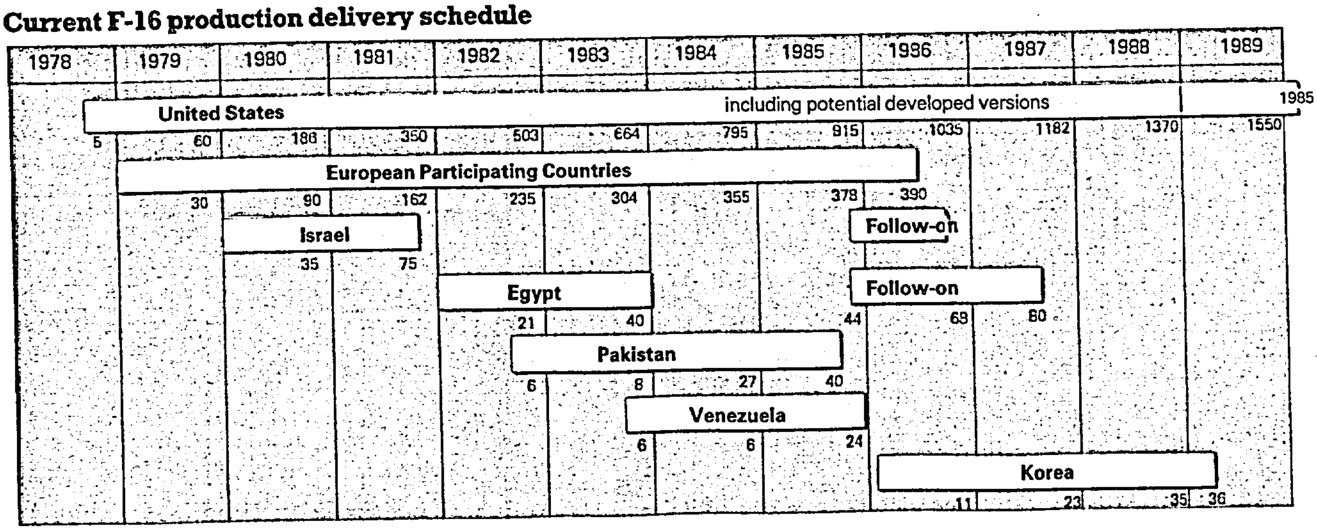


Right: Jet pipes of the F110-powered (left) and standard F100-powered (right) versions of the F-16.

Below: Fighting Falcon has now flown with the GE J79 turbojet, GE F110 (formerly F101 DFE) turbofan and the standard P&W F100 turbofan.



Current F-16 production delivery schedule



design promptly failed its final qualification tests.

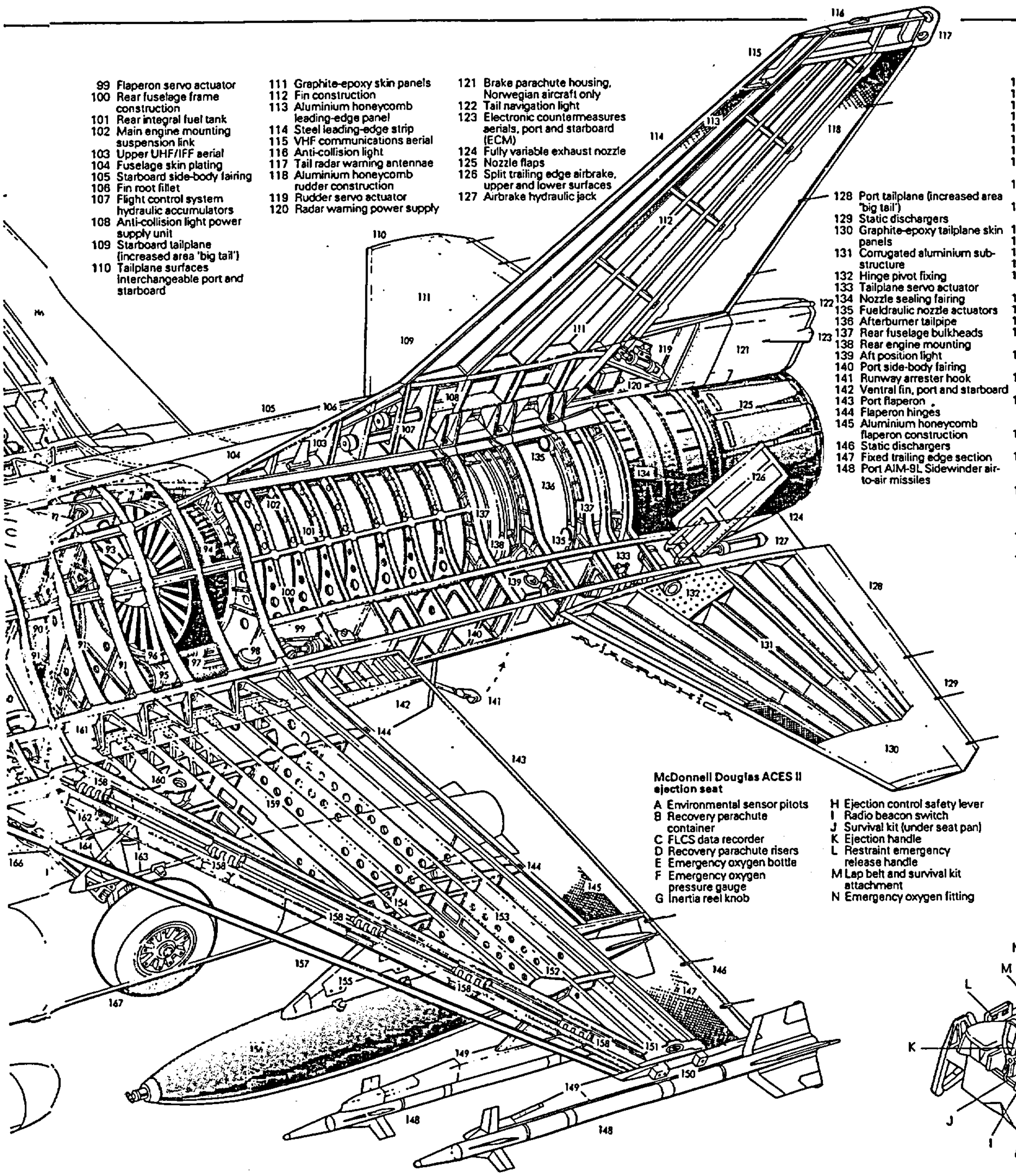
This failure triggered off a re-examination of the canopy design and test procedures, and studies of alternative canopy designs. A newer and heavier pattern of canopy was developed in order to ensure adequate resistance to bird strikes. The final design meets all USAF requirements, and offers a level of visibility which must leave MiG-21 and Mirage III pilots drooling with envy. Its high 'bubble' profile may result in some penalty in terms of supersonic drag, but the F100 engine has more than enough thrust to cope. Visibility from the cockpit covers a full 360deg in the horizontal plane, and from 15deg down over the nose through the zenith and back to directly behind – a total of 195 deg. Sideways visibility extends down to a depression angle of 40deg. The polycarbonate is 0.5in (1.3cm) thick, but its optical quality is high, and the curved surfaces offer minimal distortion of the outside view.

Above: A technician examines the forward undercarriage leg of a Belgian Air Force F-16. Note the inlet strut for increased rigidity

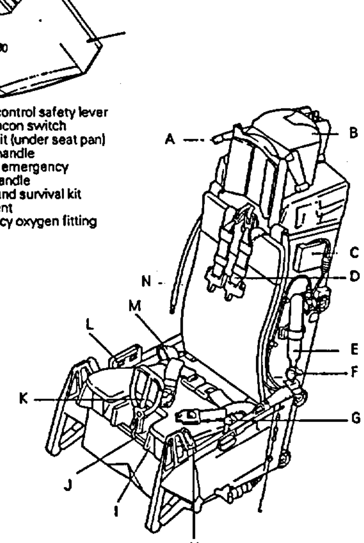
The ejection seat selected for production F-16s was the McDonnell Douglas ACES II (Advanced Concept Ejection Seat) used on the F-15 Eagle. This is a rocket-powered unit with a vectored-thrust STAPAC pitch-control system. Mounted beneath the seat, STAPAC consists of a small vernier rocket motor with a thrust of 235lb (107kg) and a 0.3sec burn time. As the seat leaves the cockpit, a gas generator spins up a pitch-rate gyro. This is uncaged and the vernier motor lit. The latter normally has its thrust axis aligned with the nominal centre of gravity of the seat and its occupant: should the seat pitch forwards or backwards due to aerodynamic forces or a low or high centre of gravity, the STAPAC vernier will be vectored to apply a corrective force.

ACES II offers zero-zero performance. From a stationary aircraft parked on the ground, it will lift to a height of more than 100ft (30m) and carry rearwards by at least 50ft (15m). Built-in survival equipment includes emergency oxygen, a URT-33C radio beacon, a liferaft and a rucksack.

The Multinational Staged Improvement Plan (MSIP) approved in February 1981 brought in a series of improvements developed under Engineering Change Proposal ECP350. This included modifications to the structure and wiring of the wings to allow the carriage of AMRAAM, the provision of hardpoints on the intake sides to carry

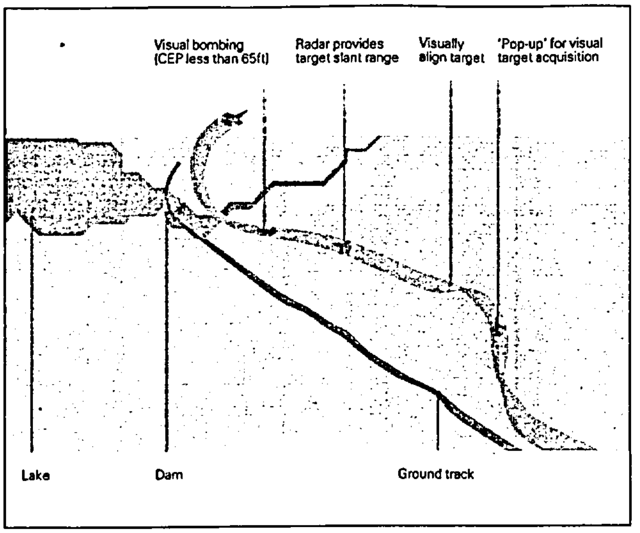


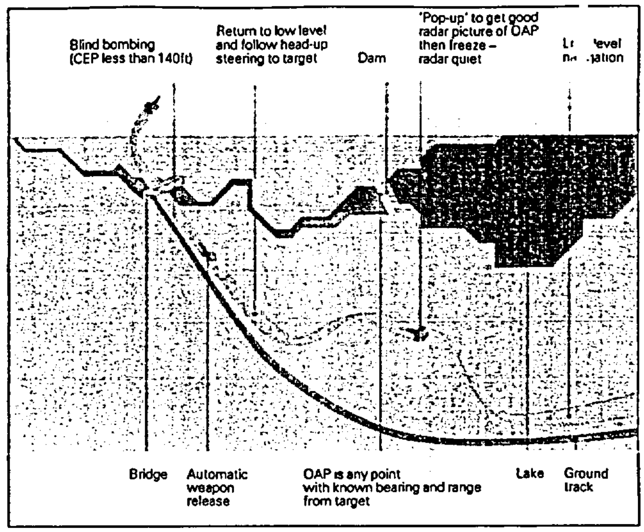
99 Flaperon servo actuator
100 Rear fuselage frame construction
101 Rear integral fuel tank
102 Main engine mounting suspension link
103 Upper UHF/IFF aerial
104 Fuselage skin plating
105 Starboard side-body fairing
106 Fin root fillet
107 Flight control system hydraulic accumulators
108 Anti-collision light power supply unit
109 Starboard tailplane (increased area 'big tail')
110 Tailplane surfaces interchangeable port and starboard
111 Graphite-epoxy skin panels
112 Fin construction
113 Aluminium honeycomb leading-edge panel
114 Steel leading-edge strip
115 VHF communications aerial
116 Anti-collision light
117 Tail radar warning antennae
118 Aluminium honeycomb rudder construction
119 Rudder servo actuator
120 Radar warning power supply
121 Brake parachute housing, Norwegian aircraft only
122 Tail navigation light
123 Electronic countermeasures aerials, port and starboard (ECM)
124 Fully variable exhaust nozzle
125 Nozzle flaps
126 Split trailing edge airbrake, upper and lower surfaces
127 Airbrake hydraulic jack
128 Port tailplane (increased area 'big tail')
129 Static dischargers
130 Graphite-epoxy tailplane skin panels
131 Corrugated aluminium sub-structure
132 Hinge pivot fixing
133 Tailplane servo actuator
134 Nozzle sealing fairing
135 Fueldraulic nozzle actuators
136 Afterburner tailpipe
137 Rear fuselage bulkheads
138 Rear engine mounting
139 Aft position light
140 Port side-body fairing
141 Runway arrester hook
142 Ventral fin, port and starboard
143 Port flaperon
144 Flaperon hinges
145 Aluminium honeycomb flaperon construction
146 Static dischargers
147 Fixed trailing edge section
148 Port AIM-9L Sidewinder air-to-air missiles
149 Missile launcher shoe
150 Wing tip launcher fixing
151 Port navigation light
152 Outboard pylon fixing rib
153 Multi-spar wing construction
154 Centre pylon attachment rib
155 Wing centre pylon
156 MK 84 2,000lb (908kg) low-drag bomb
157 Leading-edge manoeuvre flap
158 Leading-edge flap rotary actuators
159 Integral wing fuel tank
160 Inboard pylon fixing
161 Wing attachment fishplates
162 Landing/taxying lamp
163 Main undercarriage shock absorber strut
164 Mainwheel leg strut
165 Retraction strut
166 Mainwheel door
167 Forward retracting mainwheel
168 Port underwing fuel tank, 370US gal (1,700 litres)
169 Centre line external fuel tank, 300US gal (1,378 litres)
170 Electro-optical forward looking infra-red pod (EO-FLIR)
171 Laser target designator pod (LAST)
172 LAU-3/A rocket launcher, 19 × 2·75in (6,98cm) ground attack rockets
173 Westinghouse AN/ALQ119-1 electronic suppression system radar jamming pod (ESM)
174 Snakeye, 500lb (227kg) retarded bomb
175 GBU-10C/B 2,000lb (908kg) laser guided bomb



McDonnell Douglas ACES II ejection seat

A Environmental sensor pitots
B Recovery parachute container
C FLCS data recorder
D Recovery parachute risers
E Emergency oxygen bottle
F Emergency oxygen pressure gauge
G Inertia reel knob
H Ejection control safety lever
I Radio beacon switch
J Survival kit (under seat pan)
K Ejection handle
L Restraint emergency release handle
M Lap belt and survival kit attachment
N Emergency oxygen fitting





Above: During CCIP (continuously-computed impact point) attacks, the APG-66 radar is used to measure slant range to the target during the final run.

Above right: CCRP (continuously-computed release point) attacks use the the ground mapping radar modes. A radar map may be created and 'frozen' during a pop-up manoeuvre.

At high PRFs, the tube spends much more of its time transmitting, and has less time to cool down between pulses, involving a duty cycle of 50 per cent or more. As a result, the amount of power which can be extracted in each individual pulse is reduced.

By the time that Westinghouse faced the problem of updating the APG-66, its great rival in the airborne radar business had developed a new type of TWT which made dual-mode operation much more efficient. Working in conjunction with Litton, Hughes had created a TWT able to cope with the high peak-power demands of low- and medium-PRF operation, while still operating efficiently at the high duty cycles required by high PRFs. Long-range detection performance at medium PRFs could now match that at high PRFs.

All-round improvements

The revised MSIP radar's high-PRF modes are expected to raise radar range by at least 30 per cent, and perhaps as much as 60 per cent. Track-while-scan facilities will match the set to the fire-and-forget multiple-target attacks made possible by the AMRAAM missile, while the extended range performance should allow maximum advantage to be taken of the weapon's long range. The higher resolution of the modified set also allows the provision of a Raid-Assessment mode in which individual aircraft within a tight formation may be detected and tracked.

Improved air-to-ground facilities include new operating modes for ground target detection and tracking, plus Doppler beam-sharpening facilities for high-resolution ground mapping. These modes will complement the performance of the LANTIRN sensors.

Under the initial contract, seven radars were built for software development, ground trials and flight testing. Flight testing of the updated radar began in 1982. Earlier trials had involved the use of an F-4 testbed, but the new version was mounted in a modified Rockwell International Sabreliner business jet. The nose section of the aircraft was modified to carry the distinctive drooping profile F-16 radome. Delivery of revised radars should begin in 1984.

A second application for the APG-66 is the F-4EJ version of the Phantom. As part of a retrofit programme intended to extend the service life of the Japan Air Self-Defense Force fleet of Mitsubishi-built Phantoms, the existing APQ-120 radar is to be replaced by the APG-66J derivative of the Fighting Falcon set. A total of 100 aircraft are to be reworked.

Hardware from the APG-66 is also being used in the new Offensive Radar System due to be fitted in the nose of the Rockwell International B-1B bomber. This equipment will be used for tasks including low-altitude terrain-following and avoidance, high-resolution ground mapping and target detection/tracking.

Development potential of the APG-66 is by no means exhausted. Westinghouse engineers are already predicting that future versions might be able to establish the identity of a target by analyzing the radar return, and that new air-to-ground modes might include terrain-following and high-resolution surveillance using synthetic-aperture techniques.

The LANTIRN programme

In the late 1980s, the APG-66 will be backed up by the Martin Marietta LANTIRN (low-Altitude Navigation and Targeting Infra-Red for Night) system. This equipment will allow the pilot of a single-seat aircraft to fly sorties by day or night and in adverse weather. It can provide terrain-following radar and FLIR (forward-looking infra-red) imagery for navigation; automatically acquire, identify and categorize tank targets, passing target information to the aircraft's fire-control system so that Maverick missiles may be launched against several targets in a single pass; and can acquire and track fixed ground targets using FLIR or visual techniques, then designate them for attack using a built-in laser.

The basic installation comprises two avionics pods containing the sensors for navigation and target acquisition/tracking respectively. Martin Marietta is prime contractor for both. On the F-16, the pods will be carried on hardpoints under the inlet. They can operate autonomously, so an aircraft could fly into action with only one should this meet the requirements of the mission. Although the programme was formally launched in 1980, it was suspended just over a year later, and reshaped to reduced the technical risks involved.

The navigation pod is 12in (30.5cm) in diameter, 78in (198cm) long and weighs about 430lb (195kg). Main subsystems are a Ku-band terrain-following radar, wide field-of-view FLIR, pod computer and the associated power supply. Sophisticated signal processing is used to give the radar a wide azimuth coverage, allowing high-rate turns at low level in order to avoid or confuse the defences. This should give greater survivability than earlier-generation equipments which simply issued pitch commands to the pilot. The latter may have allowed him to avoid the terrain ahead, but exposed the aircraft to ground fire during the 'pull up' manoeuvre.

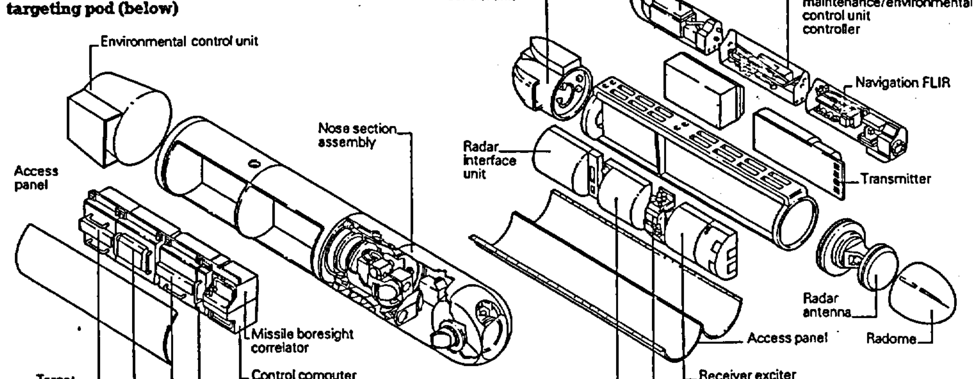
FLIR field of view is 28deg in azimuth and 21deg in elevation. The resulting wide-angle imagery may be superimposed on the outside scene by means of the HUD. In darkness or bad weather the HUD provides an image of TV-like quality and sufficient width to allow the pilot to look in the direction of his turn in order to 'preview' the terrain.

Targeting pod

The larger targeting pod has a movable nose section containing a FLIR sensor, laser transmitter/receiver and a stabilization system able to compensate for aircraft movements and vibration. A fixed centre section houses the tracker electronics and signal-processing systems and the boresight correlator used to pass target data to the aircraft's air-to-ground weapons. Environmental control of these systems and the nose-section sensors is handled by equipment in the aft section of the pod.

Flight testing using dummy fairings began in September 1982. The simulated pods have the same weight and mass distribution as the actual equipment and were instrumented to allow measurements of flutter, vibration and loads to be carried out. Test flying with functional equipment was scheduled to

LANTIRN navigation pod (right) and targeting pod (below)



begin in the summer of 1983 using two F-16B and two A-10A trials aircraft. By the winter of 1984, LANTIRN equipment is scheduled to have completed tests under adverse operating conditions during combined development test and evaluation/initial operational test and evaluation trials in Europe.

In a typical LANTIRN attack, the aircraft will perform a 'pop-up' manoeuvre at the initial point. Scanning to either side of the flight path, the sensors pass IR imagery to the target-recognition systems. Once targets have been assessed, they will be shown to the pilot on his head-down display, while the HUD marks the first to be engaged. Using a second cockpit CRT display to show IR imagery from the Maverick missiles, the pilot will assign the first round to its target. As one round is launched, the system will automatically set up for the next, allowing up to six targets to be engaged during a single pass. LANTIRN can also handle laser-guided munitions. In this case, the system would illuminate the pre-selected target as the aircraft pulled up and released its weapon.

The most technologically risky part of LANTIRN is the Automatic Target Recognizer (ATR) sub-system. The USAF no longer plans to incorporate this equipment into LANTIRN from the start, but to add it under a later retrofit programme. Competitive designs are being developed by Hughes and Martin Marietta for evaluation in mid-1984, and the result of this trial will determine whether either is to be committed to full-scale development.

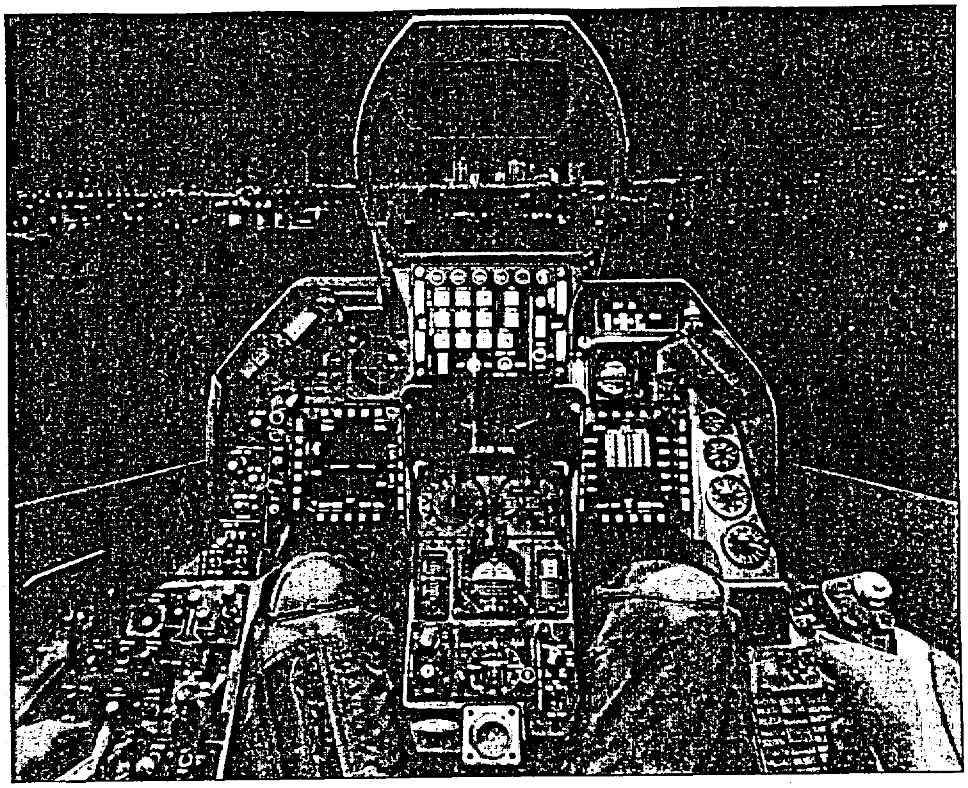
Central components of the LANTIRN cockpit display are the Marconi Avionics HUD, and two head-down multifunction CRT screens. The latter are able to display data from the radar and infra-red imagery from the LANTIRN sensors or the Maverick missile seeker head, plus the system-status displays required by the pilot.

LANTIRN funding

LANTIRN costs have been criticized by the US GAO, which ordered the USAF to re-evaluate its need for the equipment. In practice, says the USAF, the cost over-run has been less than 10 per cent – much of the alleged cost increase was due not to cost growth but to a change in accounting methods. The latter came about when LANTIRN was reclassified from being a retrofit programme of an existing weapon and upgraded to the status of being a programme in its own right. When this was done, the costs of development, testing and support became chargeable to the project and not to the F-16 programme. Further funding was added to allow for extra testing, and the programme has been stretched in timescale by about two years. To ease development, the USAF has dropped its requirement for LANTIRN to embody automatic laser correlation.

Flight trials of the LANTIRN HUD began in the summer of 1982, a year or so ahead of flight tests of the complete navigation and targeting pods. Congressional support for the project was waning, largely due to the high cost of the system, and the House Armed Services Committee reported that it had seriously considered 'recommending denial of all 1983 authorization of funding'.

Ford Aerospace has developed a FLIR pod for the US Navy, which will use it on the F/A-18 Hornet, and Congress has directed that this be tested in competition with LANTIRN before a production decision on the latter is taken in 1985. The USAF has in the meantime been prohibited from ordering LANTIRN into production until competitive flight tests have been carried out.



Above: A wide-angle HUD and two multipurpose CRT head-down displays are the main new features of the F-16C/D cockpit. The HUD was originally intended to be a holographic unit.

Cockpit displays

Data from the radar and Nav/attack systems of the Fighting Falcon are presented to the pilot on head-up and head-down displays. In the F-16A and B the head-down CRT display is manufactured by Kaiser, but for the HUD the USAF turned to the British company Marconi Avionics. A specialist in HUD technology, this Rochester-based company created the first HUD to enter service on a production aircraft – the Hawker Siddeley Buccaneer – back in 1960, and subsequently became an established supplier of HUDs to the USAF, building units for the A-7 Corsair II.

The original Buccaneer unit was primitive by modern standards, using analogue electronics and simple symbology. The A-7 HUD used digital electronics for computing and the positioning of the symbology, establishing the style of HUD now produced by many companies around the world. More than 2,000 units have been delivered for the Corsair II, and one of the company's HUDs was removed from the wreckage of an A-7 shot down in Vietnam, returned to the UK and found to be still in working order.

In addition to supplying the USAF, Marconi Avionics also provides equipment for other advanced military aircraft such as the Panavia Tornado, and had even developed the HUD for the Mirage F1.E contender for the NATO fighter order. For the Fighting Falcon programme, the UK company was involved from the beginning, having been awarded a contract to develop HUDs for the original two YF-16 prototypes. All subsequent patterns of HUD flown on or planned for the F-16 were designed by the same team.

In developing the F-16 HUD, the company placed great emphasis on the air-to-air gunnery role, aiming to create a system capable of giving a good first-burst hit probability. Radar ranging would normally be used, but a rotary switch on the HUD front panel provides for the more traditional stadiametric ranging, using the known wing span of the target as a reference from which to compute range.

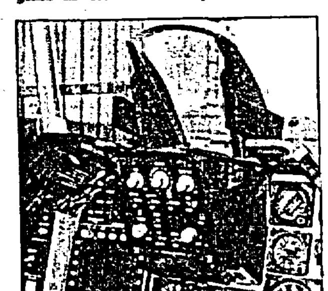
Since the entire canopy of the F-16 is a one-piece polycarbonate component, its loss in an accident or in preparation for ejection would expose the pilot to the full force of the slipstream. Design of the optical components of the HUD was contracted to the UK company Pilkington PPE, whose designers ensured that the combiner glass of the unit was strong enough to withstand the slipstream. With the canopy gone, the HUD can thus act as a temporary windshield.

Field of view of the F-16A/B HUD is 13·5deg in azimuth by 9deg in elevation. For the AFTI project a wider field of view was required, so the Rochester design team pushed conventional optical technology to its limits to produce an impressive 20 × 15deg field. For use with the LANTIRN pod, the USAF asked for a HUD with an even larger field – 30 × 20deg. This forced the design team to return to the first principles of optics and devise an entirely new type of display.

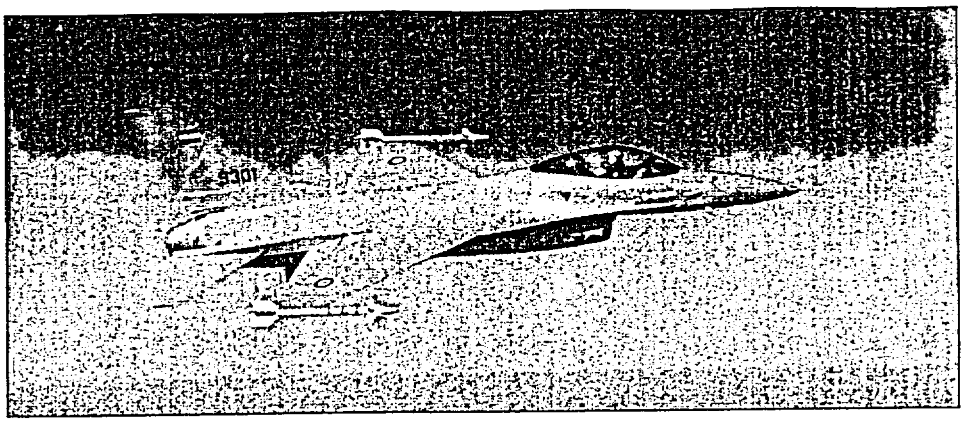
The constraints on the HUD designer include the need to interfere as little as possible with the pilot's field of view, to take up as little of the instrument panel as possible, and not to intrude beyond the confines set by the windscreen and the ejection line. The last boundary is set by the space needed by the pilot's legs and feet during ejection.

To maximize the field of view the designer could mount the combiner glass as close to the ejection line as

Above: Like the LANTIRN system itself, the Marconi Avionics holographic HUD is not certain to find a place in future F-16s. The USAF may modify the more conventional F-16C HUD to accept imagery from LANTIRN or other EO systems.



Above: Standard Marconi Avionics head-up display in an F-16A. The rectangular display seen below and to the left of the HUD control panel is not a radar display but forms part of the Fighting Falcon's sophisticated stores-management system.



Left: Deployment of the F-16 no doubt strained the logistic facilities of the Egyptian Air Force, but will dramatically improve Egypt's technological capability.

budget for low-level air defence missiles, but this might be used to purchase more F-16s.

Non-NATO customers

Given the capability of the F-16, further orders for the aircraft were inevitable. On May 7, 1975, both YF-16s were flown to Cecil Field, Jacksonville, Florida to carry out flight demonstrations for the Shah of Iran and King Hussein of Jordan. The programme watched by the monarchs included a mock dogfight between the GD aircraft and an F-4 Phantom.

Iran became the first third-party nation to adopt the F-16. A letter of intent signed by the Imperial Iranian Government on October 27, 1976, covered the procurement of 160 aircraft, and a follow-on buy of a further 140 was also discussed.

Following the Iranian revolution early in 1979, the new Iranian Government cancelled all the massive arms contracts signed by the former Shah, including the F-16 deal. Work on these aircraft had already started, but only minor components had been built. Discussing the cancellation with the author at the time of the announcement, a GD spokesman pointed out that hardware already built could be switched to other customers, and that the likely beneficiary was Israel.

In terms of cost, the loss of the Iranian order had a more marked effect. The likely cost increase for the USAF was estimated at $175,000 per aircraft, while the price rise of European-built examples was predicted to be $129,000 or more per aircraft.

Israel was virtually a captive market for the F-16. After the 1967 arms embargo on the Mirage 5 fleet, Israel was unlikely to place a major order for warplanes with France, and given the importance of the Arab world as a market, it is unlikely that Dassault-Breguet would want the undesirable publicity of another Israeli aircraft deal.

Price information was originally sought on a package of 250 aircraft, and the Tsvah Haganah le Israel – Heyl ha'Avir (Israel Defence Force – Air Force) was reported to have a long-term requirement for a further 150 to 200 examples. In August 1978 Israel announced plans to procure 75 aircraft under a contract valued at around $1·2 billion. This purchase was split between 67 F-16As and eight F-16Bs, and was expected to lead in the longer term to a total purchase of 225 aircraft by the end of the 1980s.

A total of 17 modifications to the Fighting Falcon were requested by the IDFAF: Israeli aircraft would carry weapons not used by other F-16 operators, while IDFAF training and mission-management techniques differed from USAF/NATO practice. Hardware and software had to be modified to meet these specific national requirements.

Deliveries to Israel started on July 2, 1980, at a rate of four per month under a schedule which should have seen the last handed over in November 1981. Flown by US personnel drawn from the 16th Tactical Training Squadron, the first four made the journey from Florida to Israel in 11 hours. An excellent demonstration of the type's long range, this delivery sortie required the use of full external tanks and three in-flight refuellings.

The near-paranoid Israeli rules concerning military security prevent individual IDFAF squadrons or pilots being identified. The identity of the squadron chosen to operate the first Fighting Falcons has never been released officially, but it is known to have a history of pioneering new types. The first Israeli squadron to fly jets, the unit in question equipped with Gloster Meteor F.8 fighters in August 1953, and in 1956 it was the first to receive the Mirage III.

The Osirak raid

Less than 14 months after entering IDFAF service, the Fighting Falcon went to war. On June 7, 1981, eight were used in a precision air strike against the Osirak nuclear reactor being built at Twartha near Baghdad. Due to become operational in the late summer or early autumn of 1981, this facility was seen as a threat to Israeli security. According to Israeli intelligence, if allowed to 'go critical', the 70MW Osirak reactor would have turned out sufficient plutonium to allow Iraq to construct up to five 20kT nuclear weapons by the mid-1980s.

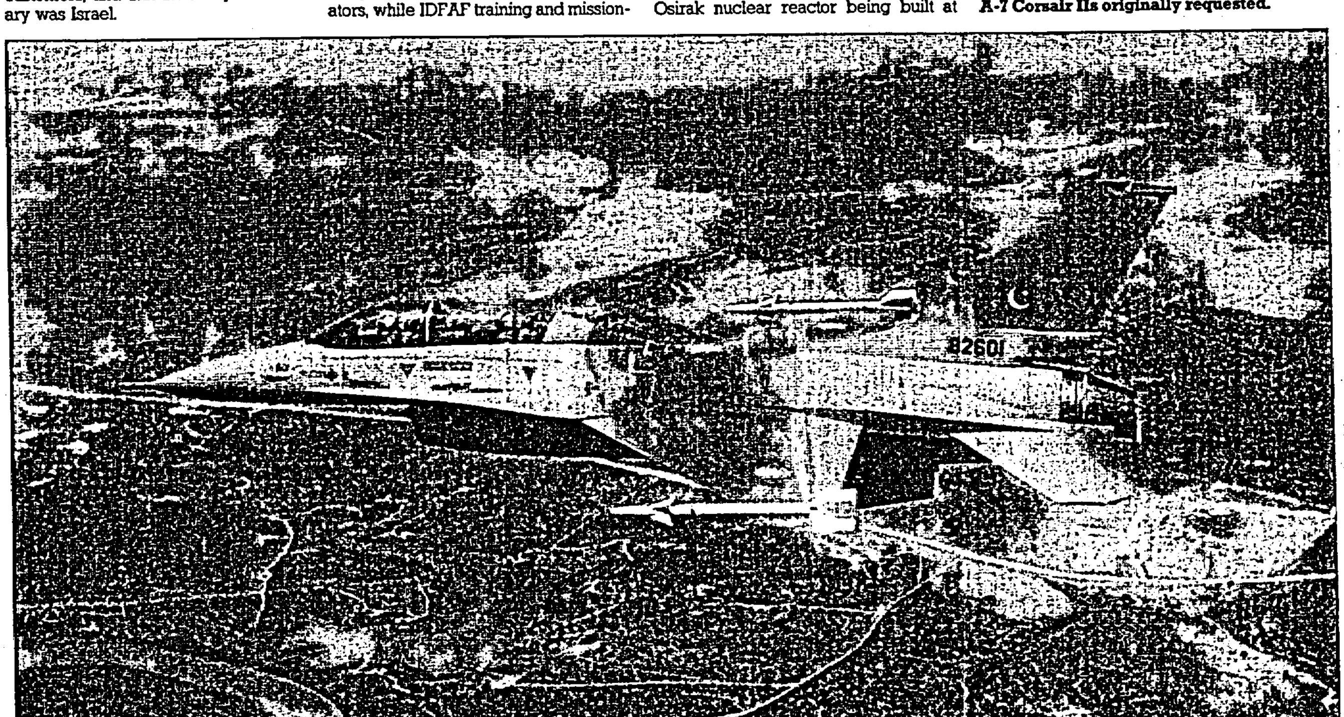
Timing of the raid was critical. The longer it was delayed, the more complete Osirak would be at the moment of its destruction, and thus the greater the losses in equipment suffered by Iraq. At the same time, it was essential that the raid be conducted before the reactor began operating, lest its destruction released a cloud of intensely radioactive material into the atmosphere.

Selection of the F-16 for the Osirak mission resulted from several factors, including the type's long range, the ground-mapping modes available on the APG-66 radar, and the accuracy of the navigation and attack systems. Eight aircraft formed the strike component of the mission, while six F-15 Eagles flew top cover in order to protect the Fighting Falcons using the longer-range APG-63 radar and AIM-7 Sparrow missiles.

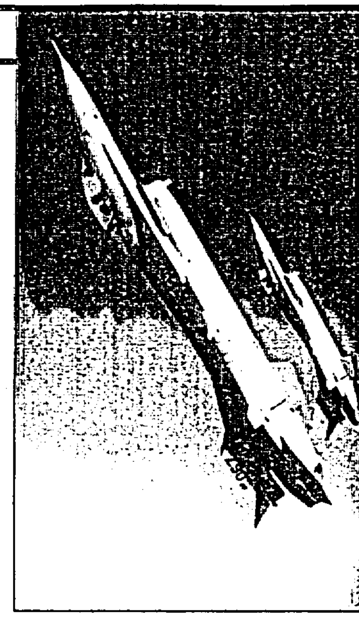
Exact details of the raid have never been published: Israeli accounts contain minimal information, often verging on hagiography rather than combat reporting. The eight aircraft, plus their escort of six F-15s, probably took off from Etzion air base, near Eilat in southern Israel. External tanks were carried and the formation may have begun by topping up from tanker aircraft.

First leg of the flight probably took the formation across southern Jordan and then into Saudi Arabian airspace.

Below: One result of the Soviet invasion of Afghanistan was clearance for Pakistan to receive US warplanes – F-16s rather than the A-7 Corsair IIs originally requested.



Performance and Handling



Ready for takeoff on an air-combat mission with no external tanks, Fighting Falcon tips the scales at around half the weight of an F-4 or F-15 tasked with a similar mission. Even by the standards of classic lightweight designs such as the MiG-21 Fishbed and Dassault-Breguet Mirage III, the F-16 is still a light fighter, weighing about one third more than the Soviet fighter and twelve per cent more than the Dassault delta. The GD aircraft matches its light weight with combat performance which the Mirage or MiG pilot can only dream about and a weapon delivery accuracy better than that of the F-111.

A lightly loaded F-16 with full internal fuel has a thrust-to-weight ratio of just over 1:1 in full afterburner. Working with the lightweight YF-16 prototypes, GD test pilots carried out pre-takeoff engine and system checks at 80 per cent power. Application of full after-burning power would have caused the wheels to slide.

Fighting Falcon begins its take-off roll with the wing leading and trailing-edge flaps positioned 2deg up and 20deg down respectively. After brake release, the aircraft quickly picks up speed. Rotation is usually at around 125kt, liftoff at around 140kt.

When Robert Ropelewski of *Aviation Week* flew the F-16B for the first time in 1979, GD Chief test pilot Neil Anderson was able to demonstrate the takeoff performance: "Anderson ... rotated the nose upwards, stopping at 60deg pitch as the aircraft began climbing out". Given the 30deg reclining tilt of the Fighting Falcon ejection seat, this climb angle meant that the torsos of the two pilots were literally horizontal. The F-16 can climb vertically, but this would result in the pilot hanging head-down in his seat.

"Acceleration continued, even in that attitude", reported Ropelewski, "the aircraft passing through 170kt about 30 seconds after brake release. A wing-over manoeuvre was used to level the aircraft at around 8,000ft (2,450m) altitude, still within the length of the Carswell (AFB) runway. A USAF Northrop T-38 chase aircraft which had started its takeoff roll on the same runway five seconds after the F-16 was just lifting off the runway below."

When the undercarriage is retracted the leading edge changes to 20deg down, while the gain of the flight-control system is doubled to reach its normal flight value. (The 50 per cent reduction while on the ground was incorporated as a result of the inadvertent first flight of the original YF-16 prototype). Throughout the mission the flight-control system remains at full gain, except when the door which covers the refuelling receptacle is opened. The latter operation reduce the control response in pitch and roll by an amount designed to make the aircraft 'less nervous', during the approach to the tanker, refuelling and subsequent separation.

One of the most novel features of the F-16 cockpit is the sidestick controller used in place of the traditional control column. This is located on the starboard side of the cockpit, and incorporates an adjustable armrest mounted on the cockpit wall. This is essential in high-g flight conditions, and includes an optional wrist rest which may be folded back against the wall if not required.

The original pattern of sidestick controller did not move, but was force sensitive only. Although effective, this scheme provided no indication to the pilot of when maximum input was being demanded. To avoid sprained wrists in the excitement of high-g manoeuvres, the USAF decided to allow the definitive design of stick a few millimetres of movement to provide the required degree of 'feedback' to the pilot. The rudder pedals have around 0.5in (1cm) of movement.

The flight-control system ensures that the pilot cannot over-stress the airframe. No matter how hard he operates the controls, the angle of attack and load factor are limited, ensuring that he cannot demand more than 25deg angle of attack or 9g load factor.

In practice, the 9g figure is probably close to the limit that the human body can take while performing a useful military mission. In conventional cockpits, pilots often experience tunnel vision – commonly known as grey-out – at levels of around 6 or 7g, but the semi-reclining seat of the F-16 seems to extend this limit by up to 2g. *Aviation Week's* Robert Ropelewski noted no vision problems at manoeuvres of 8g or more, despite having had grey-out at around 7g in other aircraft.

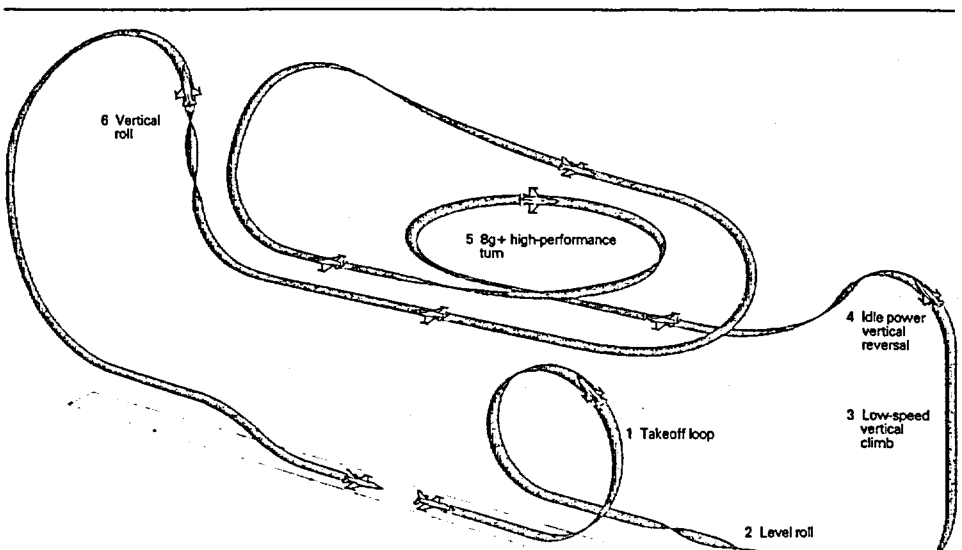
Above: Even in dry thrust the F-16 is capable of impressive aerobatics. In combat, the added impetus of the afterburner offers the pilot 'brute force' solutions to any desired manoeuvre, while his opponent might have to conserve energy.

Right: The superb visibility of the F-16's canopy is illustrated by this view of aircraft from the 8th TFW. If the pilot looked round he would be able to see his own vertical stabilizer.

The brisk acceleration of the F-16 is a feature which has attracted much comment from pilots. Neil Anderson quotes one of the USAF pilots who tested the YF-16 as saying that flying the F-16 was '... like riding on top of a telegraph pole. Every time you light the after-burner, you are a little nervous that it is going to run out from under you'.

Any feeling that the pilot rides on top of the Fighting Falcon rather than within it is heightened by a bulbous canopy large enough to allow the pilot to look over his shoulder and observe his vertical stabilizer and see whether or not he is leaving a con-trial. Pilots used to the more traditional pattern of low-drag canopy used on such aircraft as the F-4 or A-7 are likely to feel somewhat exposed. At relatively modest bank

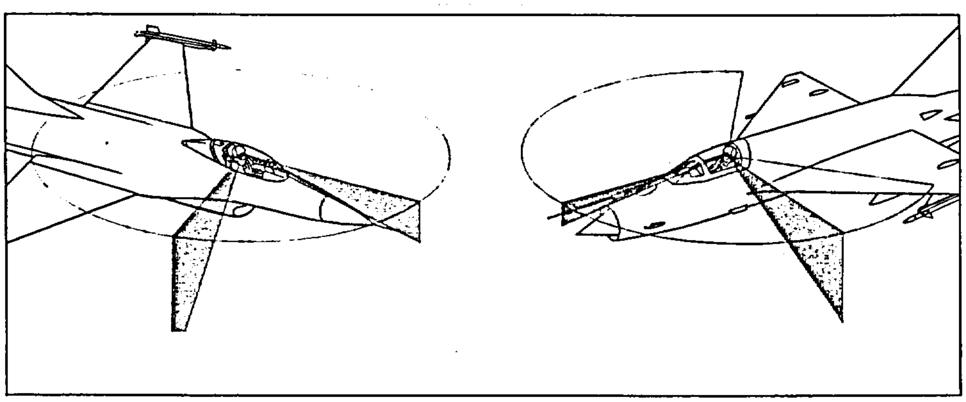
Above: Neil Anderson (left), Chief Test Pilot at General Dynamics, played a major role in the F-16 programme. Colleague James McKinney (right) flew the aircraft during the 1979 and 1981 Paris Air Shows.

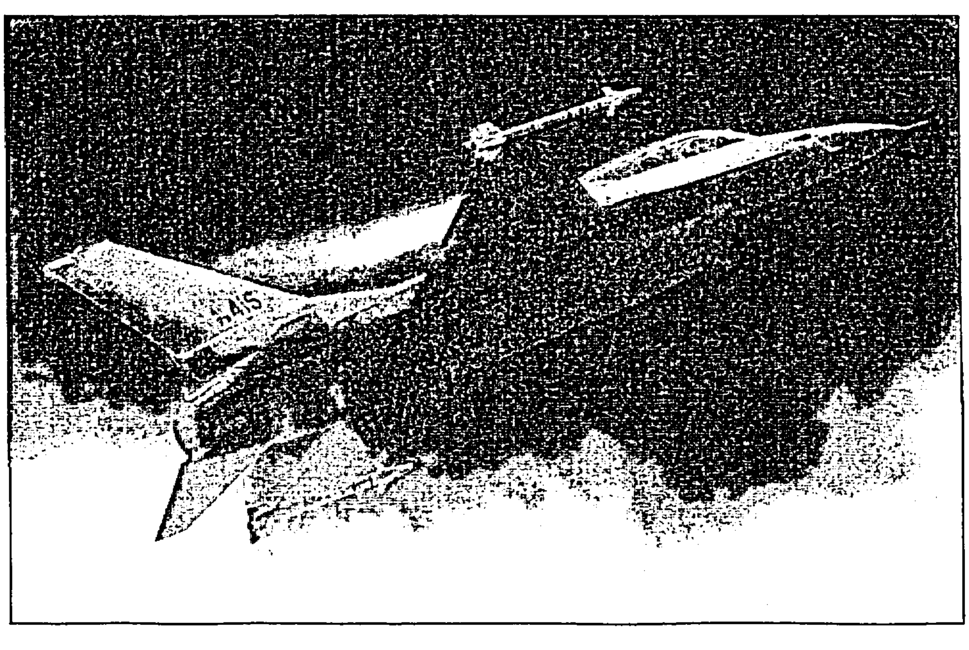


Left: This composite diagram illustrates some of the manoeuvres flown by the F-16 at Farnborough and Paris Air Shows during the late 1970s.

angles the pilot is able to look vertically downward at the terrain below, while the absence of canopy frames in the forward field of view removes the reference points by which pilots instinctively position the horizon during normal flight. During initial Fighting Falcon sorties, new pilots are recommended to fly by instruments until they become accustomed to the external view.

In high-speed cruise the wing leading and trailing-edge flaps are positioned 2deg above centre. Should the pilot attempt maximum-rate manoeuvres, the leading edge will move to 25deg down and the trailing edge will move to neutral. Vortexes generated by the leading-edge strakes play a significant part in improving the handling of the Fighting Falcon, producing improved airflow over the wings and vertical tail. Lift, pitch and directional stability are all improved, while buffet intensity is reduced. Hard manoeuvring at high supersonic speeds can result in some buffeting, according to GD, but for most of the performance envelope Fighting Falcon is buffet-free. Transition through the transonic region is smooth, with only a slight buffeting as speed is increased through Mach 0.95.





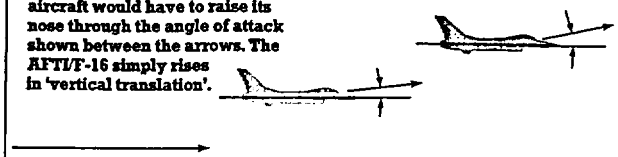
Above: Visibility from the cockpit of the F-16 is greatly superior to that from the MiG-21bis.

Left: F-16B two-seater flies an impressive-looking 9g climbing turn.

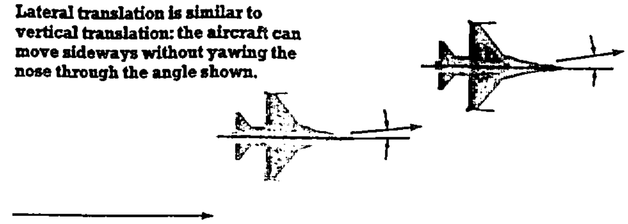
Full details of the performance of the F-16A and C had not been released by June 1983. Unclassified brochures on the J79-powered version include the manoeuvre-capability charts reproduced here, but the equivalent charts for the F-16 bear no numerical data. During test flights, however, the F-16 has been flown at speeds in excess of Mach 2, and at altitudes greater than 60,000ft (18,300m). Thanks to the massive thrust of the F100, Fighting Falcon can climb at virtually any airspeed.

New ways to fly

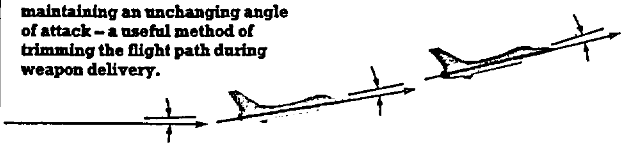
To fly upward, a conventional aircraft would have to raise its nose through the angle of attack shown between the arrows. The AFTI/F-16 simply rises in 'vertical translation'.



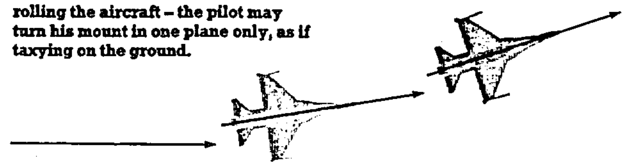
Lateral translation is similar to vertical translation: the aircraft can move sideways without yawing the nose through the angle shown.



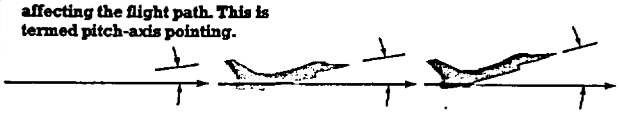
Using direct lift the aircraft can climb or descend while maintaining an unchanging angle of attack – a useful method of trimming the flight path during weapon delivery.



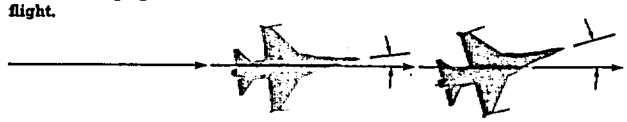
Direct sideforce turns do not involve rolling the aircraft – the pilot may turn his mount in one plane only, as if taxying on the ground.

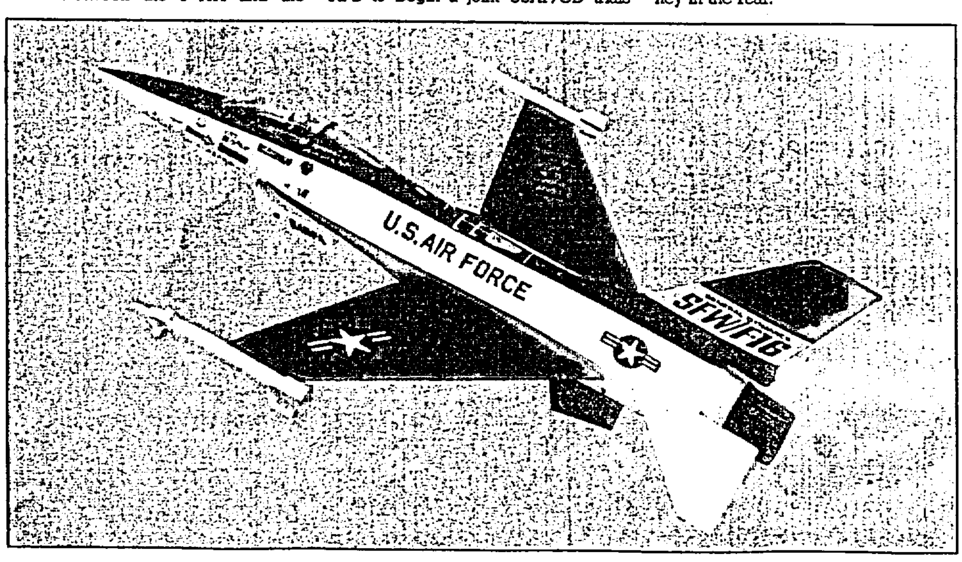


When carrying out air-to-air gun attacks, an AFTI/F-16 is able to raise or lower its nose without affecting the flight path. This is termed pitch-axis pointing.



Like pitch-axis pointing, yaw-axis pointing allows the nose to be moved without changing the direction of flight.





1980, and featured a 'cranked' delta wing, a configuration proposed to the USAF by GD in February 1980. Although the programme was at this stage a private venture by the manufacturer, the USAF did provide support, and the third and sixth full-scale development F-16s were returned to GD in the summer of 1981 for conversion to the new configuration.

Given the large production base of the F-16, GD designers tried to capitalize on existing components and experience in order to reduce the potential cost of the new variant. Wings and horizontal tail account for about 11 per cent of the total cost of the F-16, and these are the main all-new components in what was now designated the F-16XL. Although the rebuild did involve a modest fuselage stretch, the new designation did not, as some humorists suggested, stand for 'Xtra Length'!

Despite the significant external differences between the F-16A and the F-16XL, the airframe of the latter has more than 70 per cent commonality with the standard fighter. If a production version were to be ordered by the USAF, this would probably have MSIP-standard avionics, including the modified radar and LANTIRN.

F-16XL flight tests

First flight of the F-16XL took place at Fort Worth on July 15, 1982. This first sortie was all-subsonic, the aircraft reaching a top speed of Mach 0·9, a height of 30,000ft (9,000m), a maximum load factor of 3g and 20deg of angle of attack. At takeoff the angle of attack was 8deg, rising to 10deg at landing. Both values are well below those associated with traditional delta designs. Test pilot Jim McKinney reported that handling was 'very different' from that of the basic F-16, offering a 'solid ride'.

Following a small number of flights, the aircraft was transferred to Edwards AFB to begin a joint USAF/GD trials programme. Due to run for 240 flights over a period of nine months, this exercise involved both prototypes – the single-seat F100-powered version and the later GE F110-powered two-seater. Tests assessed the 'ride' which the aircraft offers at low level, and the use of high-speed tactics for defense penetration without the use of afterburner.

The second F-16XL is a two-seat rebuild of a full-scale development F-16A which was damaged in a landing accident. Ground proof-load tests of this aircraft suggested that the aft wing spar would fail at around 85 per cent of the planned limit, so the centre 22in (56cm) section of aluminium spar was replaced by a steel component.

First flight of the second F-16XL took place on October 29, 1982, again from Fort Worth. This aircraft, powered by the GE F110 turbofan, reached Mach 1.4 on its first sortie, with test pilot Alex Wolf in the front cockpit and Jim McKinney in the rear.

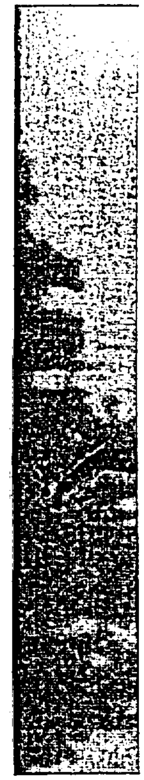
During the first 53 hours of F-16XL flight tests a total of seven GD and USAF pilots flew the aircraft. Highlights of this first period of testing included speeds approaching Mach 2·0 and altitudes of up to 50,000ft (15,240m). The aircraft refuelled from a KC-135 tanker, reached a speed of Mach 1·2 while carrying 12 Mk 82 bombs, and ripple-released the same ordnance load during dropping tests. After a brief grounding while further vibration trials were carried out and a braking parachute was installed, the aircraft began a series of stability and control tests, including an exploration of high angles of attack.

An evaluation of the two cranked-wing F-16XL prototypes by the USAF began in the summer of 1982. The FY 1983 budget included $21 million to cover the cost of the two F-16XL prototypes, as well as $57 million for the rebuilding of an F-15 Eagle fighter to the proposed F-15E strike configuration.

At one time the existence of the F-16 seemed to threaten USAF plans to develop a heavy strike fighter based on the F-15. The GAO asked the service in the summer of 1981 to justify its announced need for dedicated strike versions of the McDonnell-Douglas fighter and the F-16. Throughout the tests, the USAF was careful to avoid suggestions that the aircraft were in competitive evaluation, but the US Congress will not allow the USAF to buy both types.

One exotic F-16 variant which never left the Fort Worth drawing boards was the SFW/F-16 developed for the Defense Advanced Research Projects Agency (DARPA) forward-swept wing programme. Forward-swept wings offer good low-speed handling characteristics and low drag, but are very difficult to manufacture using conventional technology. The use of advanced composite materials allows the wing to be made strong enough to prevent the unwanted flexure which aerodynamic stresses

Left: The F-16 that never was – the forward-swept wing demonstrator proposed to DARPA in the mid-1970s.



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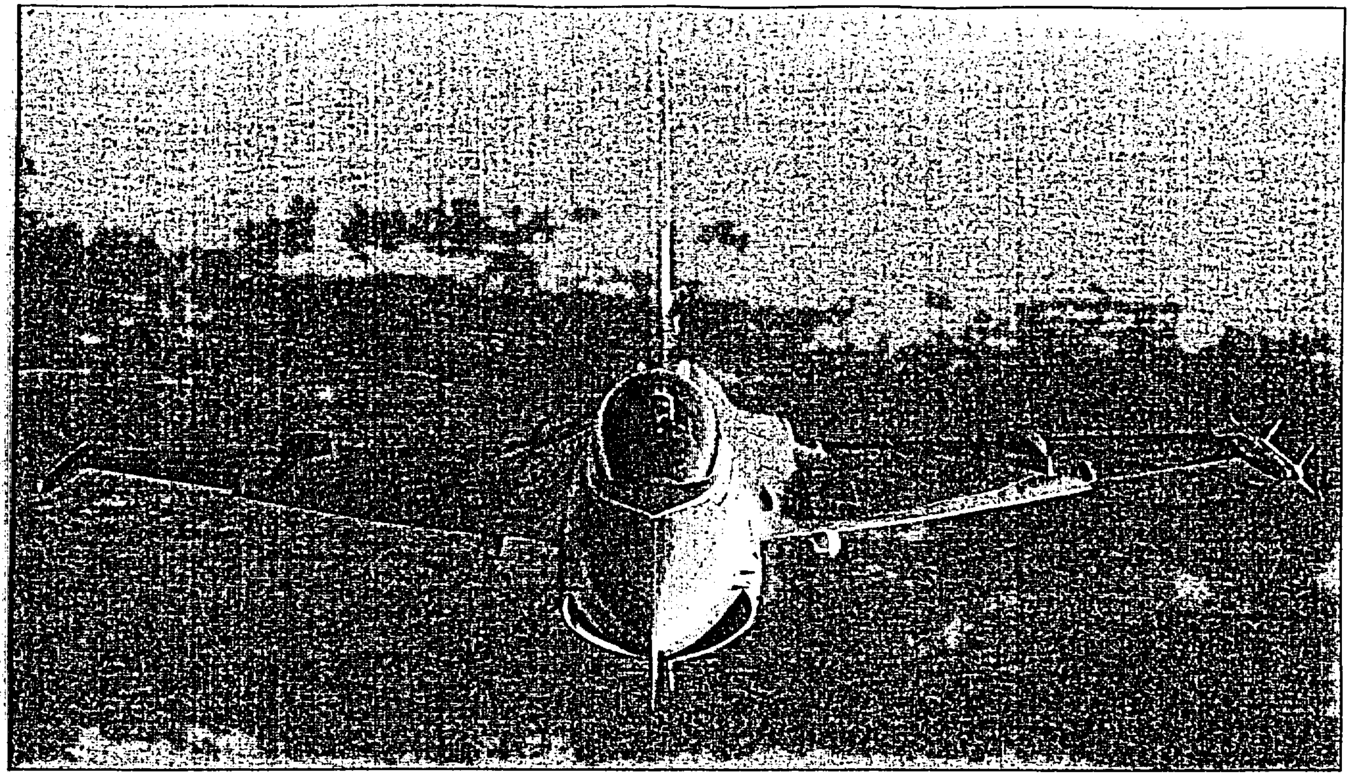


tend to set up, but without an unacceptable weight penalty.

DARPA awarded study funds to GD, Grumman and Rockwell International under a project which started in 1976. Several configurations were studied by GD, including one with canards and an aft-mounted wing, but the final SFW/F-16 design was rejected by DARPA in January 1981 in favour of the Grumman 712 – now designated X-29A.

Both the USAF and US Navy are already considering next-generation fighters, and plan to test-fly technology demonstrators based on current aircraft. Fighting Falcon is a natural candidate for these programmes. In 1986 or 1987 the USAF intends to test-fly a flight-technology demonstrator as part of its study effort into next-generation fighters. This could involve a heavily modified F-16 airframe, perhaps mated with a more modern engine such as the P&W PW1130 derivative of the F100.

STOVL proposal

The most exotic F-16 derivative currently under study is the STOVL (short takeoff/vertical landing) E7 design offered by GD as a solution to the US Navy's specification TS169. This demanding requirement calls for a technology demonstrator capable of hovering for up to four minutes while using only 5 per cent of its fuel load; accelerating from Mach 0·8 to 1·6 at 35,000ft (10,700m) in only 80 seconds; and carrying out a sustained turn rate of 5·5g at 10,000ft (3,000m).

The service wants the aircraft to be built around existing hardware, so GD plans to mate a delta wing with an F-16-derived fuselage, installing a 28,000lb (12,700kg) thrust General Electric F110 (formerly F101 DFE) turbofan engine. To give hovering ability, an ejector system based on a de Havilland Canada design would be used. Air from the engine fan would be collected in a plenum chamber then used either to help provide vertical lift or to boost forward speed during transition and horizontal flight.

In the case of the Rolls-Royce Pegasus engine used in the British Aerospace Harrier, air from the fan is ducted to the forward pair of swivelling nozzles, while core exhaust is ducted to the rear nozzles – the 'four-poster' configuration. In the hover, the E7 would rely on a 'three-poster' scheme having two forward-located thrust sources and a single aft-mounted vectoring nozzle. The forward thrust component would be provided not by vectored nozzles but by the ejector system.

Fan air would be ejected from a series of nozzles arranged in a fore-and-aft line at the root of each wing. Fuselage and wing-mounted doors would direct the fan air downwards. This flow of fan air would draw a further supply of air through a series of louvres in the upper surface of the wing, augmenting the thrust.

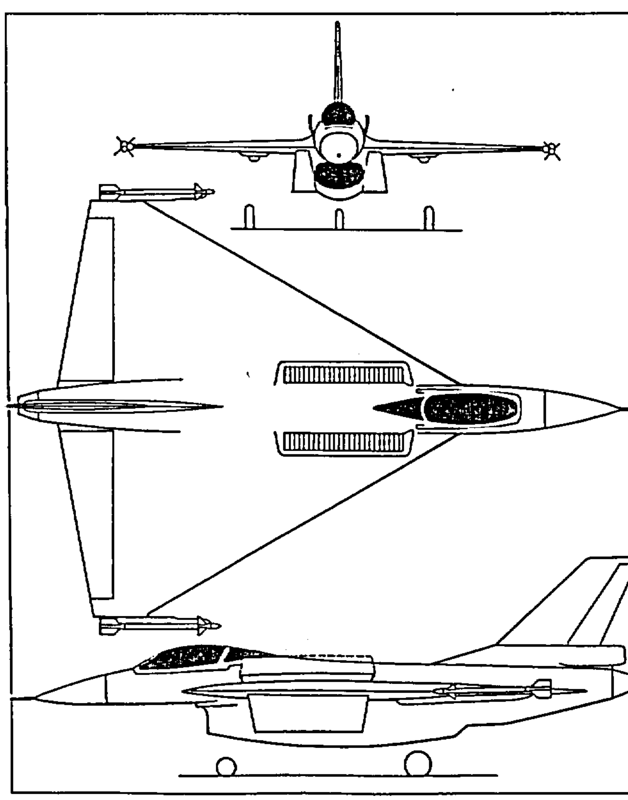
In theory, such a scheme could augment fan-air thrust by a factor of up to 1·7, but in practice the gain will be less. The designers of the ill-fated Rockwell XV-12A of the mid-1970s used an augmentation scheme based on ejectors arranged laterally along the wing, but because of unpredicted losses in augmentor efficiency their creation stubbornly refused to hover. As a result of subsequent research into augmentors, GD considers that the technique is now usable. Its great advantage over afterburning 'four-poster' configurations is that it minimizes ground erosion and heating. The hot 'footprint' left by an afterburning Harrier derivative would allow the take-off point to be detected by infra-red sensors long after the aircraft had departed.

During transition the E7 would duct part of the plenum air to an aft-facing tailpipe, while still supplying some thrust via the ejector system. The core exhaust would be vectored and afterburned in the rear nozzle to balance and accelerate the aircraft. The tailpipe incorporates an afterburner, but this would not be used during transition. In horizontal flight the ejector system would be shut down, and all fan air ducted to the tail-pipe. The rear nozzle and tailpipe afterburners would be used as required.

There are still formidable technical problems to be solved, particularly with the ejector system, but GD plans to spend $2 million during 1984 on refining its design. Tactical radius and air-to-air performance of the E7 would be lower than that of the Fighting Falcon, but GD expects better manoeuvrability in the air-to-ground role.

Above: This head-on view of the F-16/XL illustrates the excellent shape of the basic F-16 canopy. The pilot has good downward visibility on both sides of the fuselage.

Below: Offered as a STOVL technology demonstrator to meet a US Navy requirement, the E7 is the most drastically modified F-16 proposed to date. Powerplant would be a single GE F110 turbofan.



Glossary and abbreviations

AIM-	US designation for air-to-air missiles
AFB	Air Force Base
AGM-	US designation for air-to-surface missiles
AFTI	Advanced Fighter Technology Integration
Algorithm	Mathematical process for achieving a desired result
AMRAAM	Advanced Medium-Range Air-to-Air Missile
Analogue	Electronic system in which quantities are represented by electrical signals of variable characteristics, i.e. by electrical analogues
ANG	Air National Guard
ALR-	US designation for a radar-warning receiver
APG-	US designation for a nose-mounted fighter radar.
APQ-	US designation for jamming system
Aspect ratio	Ratio of the span of a wing to its chord
ASPJ	Advanced Self-Protection Jammer
ASRAAM	Advanced Short-Range Air-to-Air Missile
Bypass ratio	Ratio of the total airflow through a turbofan engine to that passing through the core section
Camber	Curvature of the centreline of a wing aerofoil
Category 3 flight test	Operational stage of US certification process – now called Air Force Development, Test and Evaluation
CCV	Control-configured vehicle
Centre of pressure	Point at which all the lift on the chord of a wing would act if the distributed pressure were to be replaced by a single resultant force
c.g.	Centre of gravity
Chord	Imaginary line connecting the leading and trailing edge of a wing
CRT	Cathode-ray tube (computer/TV-style display screen)
DARPA	Defense Advanced Research Projects Agency
dB	Decibel (unit of gain or attenuation)
Dead-stick	Flight operation carried out with engine(s) shut down or otherwise inoperative
Digital	Electronic system in which quantities are as on/off signals coded to represent numbers
Drag-at-lift	Drag created under high-lift flight conditions
ECM	Electronic countermeasures
ECP	Engineering Change Proposal
ECP 350	MSIP modification scheme
Envelope	Engineering term for the area defined by a series of limits
Esc	see Escadrille and Escuadron
Escadrille	Squadron (Belgium)
Escuadron	Squadron (Venezuela)
Esk, Eskadrille	Squadron (Danish)
EW	Electronic warfare
FAéB	Force Aérienne Belge, or Belgian Air Force
Fail-operative	System element which will allow a system to continue to operate in its active state in the event of a failure
Fail-safe	System element which will revert to a safe condition should it fail
FBW	Fly-by-wire (term for electrically signalled flight-control systems)
FLIR	Forward-looking infra-red
g	Unit of acceleration
GAO	General Accounting Office (an investigative branch of the US Congress)
GD	General Dynamics
GE	General Electric
GHz	GigaHertz (Hertz × 1,000,000,000)
HUD	Head-up display
Hz	Hertz (unit of frequency)
I&A	Integration and assembly
IDFAF	Israel Defence Force – Air Force
IIR	Imaging infra-red
I/J-band	Radar frequencies from 8 to 12GHz
IOC	Initial operating capability
IR	infra-red
iron bomb	conventional free-falling high-explosive bomb
JTIDS	Joint Tactical Information Distribution System
KHz	kiloHertz (Hertz × 1,000)
KLu	Koninklijke Luchtmacht, or Royal Netherlands Air Force
kT	Kiloton
Ku-band	Radar frequencies from 12 to 20GHz
LANTIRN	Low-Altitude Navigation and Targeting by Infra-Red at Night
Mach	Unit equal to the speed of sound
MSIP	Multinational Staged Improvement Programme
MTU	Maintenance Training Unit
MW	Megawatt
nav/attack	Navigation and attack (e.g. 'nav/attack system')
Nr	Number (Dutch)
OCU	Operational Conversion Unit
Pacer Loft	Modification programme for European F-16s
P&W	Pratt & Whitney
Raster scan	Method of building up a TV-style image on a CRT by scanning the image in a series of lines
R&D	Research and development
RNethAF	Royal Netherlands Air Force
RNoAF	Royal Norwegian Air Force
RWR	Radar-warning receiver
PRF	Pulse repetition frequency
Program	Instructions for a computer
Programme	Spelling used to designate a programme of research or work
Ps	Engineering abbreviation for specific excess power
PSP	Programmable signal processor
SCAMP	Supersonic Cruise Aircraft Modification Programme
sfc	Specific fuel consumption (unit of fuel consumed per unit of thrust per hour)
SFW	Swept-forward wing
smart bomb	Free-falling bomb with built-in guidance system
Software	One or more programs for a computer
Synthetic-aperture radar	Technique by which a small radar antenna on a moving vehicle may simulate a larger unit in terms of resolution
TAC	Tactical Air Command
Taileron	All-moving tailplane able to move differentially as a substitute for traditional aileron control
TFG	Tactical Fighter Group
TFS	Tactical Fighter Squadron
TFTS	Tactical Fighter Training Squadron
TFW	Tactical Fighter Wing
Trim drag	Component of drag due to the deflection of an elevator or elevon in order to maintain lateral balance of an aircraft
TWT	Travelling-wave tube (power source used in many modern radar)
USAF	United States Air Force
USN	United States Navy
Wave drag	Component of drag resulting from the formation of shock waves
Wing loading	Weight of an aircraft divided by the wing area

Specification

	YF-16	F-16A	F-16/79A	F-16XL
Length	48ft 5in/14.75m	49ft 6in/15.09m	49ft 6in/15.09m	54ft 2in/16.51m
Wingspan	31ft 0in/9.45m	31ft 0in/9.45m	31ft 0in/9.45m	34ft 3in/40.92m
Height	16ft 3in/4.95m	16ft 8in/5.08m	16ft 8in/5.08m	17ft 7in/5.36m
Weights				
Empty	13,595lb/6,167kg	15,586lb/7,070kg	17,041lb/7,730kg	
take-off (air-to-air)	21,600lb/9,798kg	23,810lb/10,800kg		
Maximum take-off	27,000lb/12,247kg	35,400lb/16,057kg	35,400lb/16,057kg	
Wing area	300sq ft/27.87sq m	300sq ft/27.87sq m	300sq ft/27.87sq m	646sq ft/60.02sq m
Wing loading (air-to-air)		73lb/sq ft/30.81kg/sq m		
Thrust:weight ratio (air-to-air)		1.1:1		
Maximum speed	Mach 1.95	>Mach 2	>Mach 2	
Service ceiling	>50,000ft/15,200m	>50,000ft/15,200m		
Range				
Ferry (with ext. tanks)		>2,100nm/3,890km		
Tactical radius		>500nm/925km		c.730nm/1,340km
Internal fuel		6,972lb/3,162kg		c.12,700lb/5,760kg
No. of hardpoints		nine	nine	17
Maximum ordnance load		20,450lb/9,280kg	15,200lb/6,890kg	

USAF F-16 units

Wing	Base	Tail code
Tactical Air Command		
9th Air Force		
56th TTW	Macdill AFB, Florida	MC
363rd TFW	Shaw AFB, South Carolina	SW
12th Air Force		
388th TFW	Hill AFB, Utah	HL
474th TFW	Nellis AFB, Nevada	NA, WA
832nd Air Division		
58th TTW	Luke AFB, Arizona	LA
US Air Forces in Europe		
16th Air Force		
401st TFW	Torrejon, Spain	TJ
17th Air Force		
50th TFW	Hahn AB, West Germany	HR
Pacific Air Forces		
5th Air Force		
314th Air Division		
8th TFW	Kunsan AB, South Korea	WP
Air National Guard		
169th TFG	McEntire ANGB, South Carolina	