THROUGH THE SOUND BARRIER

This extract takes the reader from when Chuck Yeager took the rocket powered Bell X-1 through the sound barrier in October 1947 through to the concept of the Northrop Grumman B-21 Raider. Although anecdotal evidence exists that some pilots may have done so while dive-bombing ground targets during WWII, Chuck Yeager's was the first controlled, level flight, to exceed the speed of sound. Further barriers, this time of distance, fell in 1948 and 1952 with the first jet crossing of the Atlantic and the first non-stop flight to Australia respectively.

Bell X-1

The 1945 invention of nuclear bombs briefly increased the strategic importance of military aircraft in the Cold War between East and West. Even a moderate fleet of long- range bombers could deliver a deadly blow to the enemy, so great efforts were made to develop countermeasures. At first, the supersonic interceptor aircraft were produced in considerable numbers. By 1955, most development efforts shifted to guided surface-to-air missiles. However, the approach diametrically changed when a new type of nuclear-carrying platform appeared that could not be stopped in any feasible way: the intercontinental ballistic missile. The possibility of these was demonstrated in 1957 with the launch of Sputnik 1 by the Soviet Union. This action started the Space Race between the USA and USSR.

Sputnik 1

AND ON TO THE MOON

In 1961, the sky was no longer the limit for manned flight, as Yuri Gagarin orbited once around the planet in 108 minutes, and then used the descent module of Vostok I to safely re-enter the atmosphere and reduce speed from Mach 25 using friction and converting the kinetic energy of the velocity into heat.

The United States responded by launching Alan Shepard into space on a suborbital flight in a Mercury space capsule. With the launch of the Alouette I in 1963, Canada became the third country to send a satellite into space.

The space race between the United States and the Soviet Union would ultimately lead to the landing of men on the moon in 1969 in Apollo 11 crewed by Buzz Aldrin and Neil Armstrong who walked on the moon, and Michael Collins who flew the command module in lunar orbit while Aldrin and Armstrong were on the surface.

Neil Armstrong, Michael Collins & Buzz Aldrin

Aérospatiale/BAC Concorde

THE QUEST FOR SPEED

In 1967 the X-15 set the air speed record for an aircraft at Mach 6.1. This record was renewed and then exceeded by the X-43A in 2004 at Mach 9.6. Also that year the Hawker Siddeley Harrier, developed from the P.1127, first flew. It became the only truly successful V/STOL design and is still in service with the US Marine Corps, albeit as a much enhanced version. It is being replaced by the STOVL version of the Lightning II (F35B).

The same year that Armstrong and Aldrin walked on the Moon Boeing launched the 747, the largest every commercial passenger aircraft to fly at that time, and one that has proved to be immensely successful. It has only been overtaken in size by the airbus A380 which was launched in 2005 and over the years has proved to be a financial failure. Also in 1969 the Aérospatiale/BAC Concorde first flew. It had a maximum speed over twice the speed of sound, at Mach 2.04 (1,354 mph at cruise altitude) with seating for 92 to 128 passengers. Concorde entered service in 1976 and continued flying for the next 27 years. It is one of only two supersonic transports to have been operated commercially, the other is the Soviet-built Tupolev Tu-144, which operated in the late 1970s with limited success being very fuel inefficient.

Finally for 1976, the Lockheed SR-71 long range, high altitude, Mach3+ strategic reconnaissance aircraft set the world speed record for an air-breathing manned aircraft which still stands today, the X-43A being rocket assisted and unmanned.

Lockheed SR-71 'Blackbird'

The final quarter of the 20th century and the advent of the Third Industrial Revolution saw a turn away from speed towards the spread of digital technology in respect of avionics, fly-by-wire systems, aircraft design and manufacturing techniques. And the early 21st century has seen an increasing interest in fuel savings and the reduction of environmental pollution. Also there is a newfound interest in commercial supersonic flight, and the introduction of remotely operated or completely autonomous unmanned aerial vehicles. Indeed, UAVs are now an established feature of increasing civilian and commercial use and modern warfare.

MILITARY 'GENERATIONS'

Turning to warfare, it has become common to classify, albeit unofficially, jet fighters by 'generations' representing stages of development in design, performance and technology. The timeframes associated with each are inexact and are only indicative of the period when their design philosophies and technology employed enjoyed a prevailing influence. Broadly speaking, these generations are as follows.

FIRST GENERATION (SUB-SONIC, MID-1940S TO MID-1950S)

In addition to the Gloster Meteor and Me 262, examples were the Lockheed P-80 Shooting Star, the de Havilland Vampire, the MiG-15 and later the North American F86 Sabre. The latter two going head-to-head in the Korean War. These aircraft moved from straight wings to swept wings, and innovations included the ejection seat, air brakes and all-moving tail planes.

The Grumman F9F Panther was one of the first aircraft to employ afterburn. Improving radar was employed to facilitate all-weather/night fighters, and early versions of infra-red and radar-guided air-to-air missiles such as the AIM-9 Sidewinder and AIM-7 Sparrow respectively were introduced.

North American F-86 Sabre

Soviet MiG-15

SECOND GENERATION (MID-1950S TO EARLY 1960S)

Technological advances, lessons from aerial battles in the Korean War, and a need to conduct operations in a nuclear warfare environment, shaped the second generation fighters. Advances were made in aerodynamics, propulsion and materials (especially aluminium alloys). The ability to sustain supersonic speeds in level flight became common; improved electronics enabled on-board radars to keep shrinking, and the detection beyond visual range and guided missile development continued apace.

Also, the prospect of a third world war featuring large mechanized armies and nuclear strikes led to a degree of specialization along two different approaches for fighter aircraft: interceptors such as the English Electric Lightning and MiG-21F; fighter-bombers such as the Republic F-105 Thunderchief and the Sukhoi Su-7B. Television and IR guided air-to-surface missiles were introduced to augment gravity bombs, the latter including, in some cases, nuclear.

English Electric Lightning

Soviet MiG-21F

THIRD GENERATION (EARLY 1960S TO CIRCA 1970)

This generation was marked by a return to mobility. Over the 60's increasing combat experience with guided missiles demonstrated that combat would devolve into close-in dog fights. Also analogue avionics began to appear in cockpit instrumentation, enhancements to aerodynamic performance were introduced such as canards, powered slats and blown flaps, and a number of technologies would be tried for vertical/short take-off and landing. Nevertheless, whilst cannons remained standard equipment, air-to-air missiles became the primary weapons for air superiority fighters. Additionally, there was an expansion in ground attack capabilities, including terrain avoidance systems, laser guided bombs and chain-guns which involved the introduction of dedicated ground attack aircraft such as the Grumman A-6 Intruder and the SEPECAT Jaguar. Two other iconic aircraft should be mentioned. First the variable geometry wing supersonic F-111 and, most important of all, the McDonnell Douglas F-4 Phantom which became both a versatile strike-bomber and air combat aircraft. Finally, this third generation (albeit delivered in 1979) saw the first Chinese designed and manufactured fighter, the Shenyang J-8D.

Anglo-French SEPECAT Jaguar

A USAF McDonnell Douglas Phantom II

Shenyang J-8D

One other aircraft during this period deserves a special mention: the British Aircraft Corporation TSR-2 was a cancelled Cold War strike and reconnaissance aircraft developed by the British Aircraft Corporation (BAC) for the Royal Air Force (RAF) in the late 1950s and early 1960s. The TSR-2 was designed to penetrate a well-defended forward battle area at low altitudes and very high speeds, and then attack high-value targets in the rear with nuclear or conventional weapons. Another intended combat role was to provide high-altitude, high-speed stand-off, side-looking radar and photographic imagery and signals intelligence, and aerial reconnaissance. Only one airframe flew, and test flights and weight-rise during design, indicated that the aircraft would be unable to meet its original stringent design specifications. The design specifications were therefore reduced.

However, the aircraft became the victim of ever-rising costs and inter-service squabbling over Britain's future defence needs, which together led to the controversial decision in 1965 to scrap the programme. It was decided to order an adapted version of the General Dynamics F-111 instead, but that decision was later rescinded as costs and development times increased. The replacements included the Blackburn Buccaneer and McDonnell Douglas F-4 Phantom II, both of which had previously been considered and rejected early in the TSR-2 procurement process. Eventually, the smaller swing-wing Panavia Tornado (see 4th generation) was developed and adopted by a European consortium to fulfil broadly similar requirements to the TSR-2.

BAC TSR-2

TSR-2's 'successor' – the Panavia Tornado

FOURTH GENERATION (CIRCA 1970 TO MID-1990S)

This period continued the trend towards multirole configurations, and fighters were equipped with increasingly sophisticated avionics and weapons systems. Designs were also heavily influenced by energy-manoeuvrability theory to get inside an adversary's decision making cycle. Particular innovations during this period were enabled by increasing development in computers which led to fly- by-wire flight control systems, pulse-doppler fire control radars which enabled look-down-shoot-down capability, head-up displays, and hands on throttle-and-stick controls. Furthermore digital technology was increasingly introduced which enhanced engine controls, infrared search and track sensors became widespread, and the first long-range active-radar homing missiles entered service.

Other innovations included the introduction of composite materials, enhanced ease of maintenance, and the overall reduction of parts in more complicated equipment such as engines. But the most novel technology introduced was that of stealth which involved the use of low-observable material and design techniques to reduce detection by sensor systems, especially radar. The first stealth aircraft introduced were the Lockheed F-117 Nighthawk in 1983 and the Northrop Grumman B-2 Spirit in 1989. Typical aircraft of this lengthy period were the General Dynamics F-16 and MiG-29 in respect of lower cost multirole fighters, and the F-15 and Su-27 in respect of high-capability and cost dedicated air-superiority fighters. Examples of dedicated ground attack aircraft were Fairchild Republic A-10 Thunderbolt II and the Sukhoi Su-25.

F-16

MiG-29

McDonnell Douglas F-15 Eagle

Sukhoi Su-27

Fairchild Republic A-10 Thunderbolt II

Lockheed F117 Nighthawk

Northrop Grumman B-2 Spirit

The end of the Cold War in 1991 led many governments to significantly decrease military expenditure. R&D programmes on 5th generation fighters were substantially reduced, with many being cancelled or 'stretched out'. Whilst annual costs reduced this led inevitably to overall programme and unit costs in the long-term increasing. However, it also permitted designers to take advantage of the amazing achievements being made in the field of electronics largely due to advances in microchip and semiconductor technology in the 1980s and 1990s. These advances enabled companies to improve 4th generation designs (and contribute to the development of 5th generation technologies) to the point where they became half-way to the next full generation, hence the term **4.5 generation** (1990s to 2000).

Typical advances involved digital avionics, signature reduction, highly integrated systems and weapons, aerospace materials, thrust vectoring, GPS guided weapons, solid-state phased-array radars, helmet mounted sights, more secure and jamming resistant datalinks, varying degrees of stealth, and 'supercruise' (beyond Mach 1 without afterburn). These aircraft have been designed to operate in a network-centric battlefield and are primarily multirole. They are either based on existing airframes, such as the Boeing F/A-18E/F Super Hornet and the Sukhoi Su-30MKK, or new airframe designs making extensive use of carbon fibre composites such as the Eurofighter Typhoon. It is most likely that many of these fighters will continue in production, and certainly operation, alongside 5th generation aircraft. An example of this is the RAF's operation of Typhoons alongside the F35 (a 5th generation fighter) until replaced in circa 2035 by a 6th generation aircraft such as the proposed Tempest.

Boeing F/A-18E/F

Eurofighter Typhoon

FIFTH GENERATION (LATE 1990S TO DATE)

These fighters are characterized by being designed from the beginning to operate in a network-centric combat environment, and to feature extremely low, all-aspect, multi-spectral signatures employing advanced materials and shaping techniques. Their sensors, along with advanced avionics, glass cockpits, helmet mounted sights and improved, jamming-resistant data-links, are highly integrated to provide multi-platform, multi-sensor fusion for vastly improved situational awareness and much reduced pilot workload. Additionally, further enhanced stealth, 'vehicle health monitoring' for ease of maintenance, fibre optic data transmission, thrust vectoring and supercruise are all included. Finally, their Active Electronically Scanned Array radar (a key feature of a 5th generation fighter which is being retrofitted to 4.5 generation aircraft) enables the fighter to operate as a 'mini-AWACS' providing ESM and EW functions.

These aircraft, being so sophisticated, are expensive, and the first example was the Lockheed Martin/Boeing F-22A which is no longer produced, but is likely to receive a mid-life update in 2024 onwards. It is not available for export, although a possible export variant is under consideration. A later example of a 5th generation fighter is the Lockheed Martin F35 which is a multi-role aircraft and already in service with several air forces including those of the USA, UK, Australia, Israel, Italy, Japan, Netherlands, Norway and South Korea. It has three variants: F35A conventional take-off and landing; F35B STOVL; and F35C which is carrier based with the USN. In the UK, as the F35B, it will operate with the RAF, the RN and the US Marine Corps on board the new Queen Elizabeth Class Carriers. Lockheed Martin's principal partners in this programme are BAE Systems and Northrop Grumman.

The aircraft will probably receive an upgrade in circa 2035 and is likely to remain in service until at least 2070. China is developing the Shenyang J-31 and Russia Sukhoi Su-57, both of which are now in the early stages of production.

F-22A Raptor

Lockheed F-35B Lightning II

HMS Queen Elizabeth which, along with HMS Prince of Wales, will be the F35B's RN home, often embarking aircraft of the US Marine Corps

SIXTH GENERATION (LATE 2020S/EARLY 2030S ONWARDS)

There are currently six fighter programmes in development:

- Boeing F/A-XX Program (United States). A development and acquisition program for a future air superiority fighter to replace the United States Navy's F/A-18E/F Super Hornet beginning in the late-2020s. This USN program has also been referred to at different times as the Next Generation Air Dominance program.

- F-X Program (United States), also known as Penetrating Counter Air or Next-Generation Air Dominance. The USAF hasn't chosen a manufacturer or design for its F-X sixth-generation fighter yet. However, the USAF Research Laboratory recently released a video showing a conceptual design of an F-X sixth-generation fighter and other futuristic technology. The video shows a sleek, stealthy design with a laser powerful enough to destroy an enemy fighter.

- BAE Systems Tempest (United Kingdom). A proposed stealth fighter aircraft to be designed and manufactured in the United Kingdom for the Royal Air Force. It is being developed by a consortium known as "Team Tempest", consisting of the UK Ministry of Defence, BAE Systems, Rolls-Royce, Leonardo S.p.A. and MBDA, and is intended to enter service from 2035 replacing the Eurofighter Typhoon aircraft in service with the RAF. £2 billion will be spent by the British government on the project by 2025. It was announced by the British Defence Secretary Gavin Williamson on 16 July 2018 at the Farnborough Airshow as part of the UK Combat Air Strategy and has now been joined by Italy and Sweden.

- Mikoyan MiG-41 (Russia). A 6th generation interceptor aircraft reported to be in development as a replacement for the MiG-31. It has been speculated that it could enter service by the mid-2020s or 2030s. According to Director General of RSK MiG, Ilya Tarasenko, it would be a new construction capable of Mach 4 - 4.3, equipped with an anti-missile laser, and able to operate at very high altitudes, even in near space. To achieve the high speeds rumoured for the aircraft, the aircraft would need to be equipped with ramjet or turboramjet engines. He also stated that it could be transformed into an unmanned version later. If purchased by the Russian Air Force, he claimed that the first production MiG-41 would be completed in 2025.

- Future combat air system (FCAS) (France and Germany). France's Dassault Aviation and European aerospace consortium Airbus have announced an agreement on the FCAS, a combat platform aimed at replacing existing Rafale, Eurofighter and F-18 Hornet fighter aircraft in European air forces. According to Airbus the first flight is expected in 2040.

- Huolong (Fire Dragon) Stealth Hypersonic Fighter Jet (China). Shanghai News has reported that China is actively working on the creation of a multi-functional fighter aircraft of the sixth generation.

While at an early stage of development, several distinct characteristics common to nearly all nations' sixth-generation fighter concepts have emerged.

- De-emphasis of the stealth characteristics of fifth-generation fighters in favour of increased speed and range.

- More modular design going beyond wing hardpoints with primary aircraft components able to be swapped within hours to optimize mission capabilities and ease the introduction of future upgrades.

- Single-seat-only cockpits with training occurring mostly in simulators.

- Optionally manned, with the same airframe capable of conducting remote controlled or AI-controlled missions.

- Able to control a swarm of drones acting in both a defensive and/or reconnaissance role for the controlling fighter.

- Battlefield data fusion with the aircraft acting as a network node capable of receiving and relaying data to multiple other platforms such as other aircraft, ground vehicles or satellites, and processing that data onboard to generate new target lists or update mission parameters as the mission develops.

- Increased-range stand-off weapons, with the drones conducting reconnaissance within enemy airspace and supplying targeting data to the fighter which remains safely outside enemy airspace.

- Greater electrical power generation to enable equipping with directed-energy weapons such as a laser close-in weapons system.
- Virtual cockpit helmet-mounted display allowing the pilot 360-degree vision, therefore eliminating cockpit displays.

A UK Tempest mock-up was featured much earlier; here is a possible US F-X design.

Fighter Versatility

One final comment. The fighter design has also been adapted to other roles in addition to ground attack, such as reconnaissance (armed, such as the Tornado GR4A, or unarmed such as AA810) buddy-buddy air refuelling, or electronic warfare, such as the Boeing EA-18G below.

RAAF EA-18G 'Growler'

THE STRATEGIC BOMBER

Having mentioned fighter-bombers (the F-4 Phantom could carry as much ordnance as a WWII B24) let us now turn to pure bombers. During the Cold War, the United States and United Kingdom on one side and the Soviet Union on the other, kept strategic bombers ready to take off on short notice as part of the deterrent strategy of mutual assured destruction (MAD).

Most strategic bombers of the two superpowers were designed to deliver nuclear weapons. For a time, some squadrons of Boeing B-52 Stratofortress bombers were kept in the air around the clock, orbiting some distance away from their fail-safe points near the Soviet border.

The British produced three different types of 'V bombers' for the Royal Air Force which were designed and designated to be able to deliver British-made nuclear bombs to targets in European Russia. These bombers would have been able to reach and destroy cities like Kiev and Moscow before American strategic bombers. While they were never used against the Soviet Union or its allies, two types of V bombers, the Avro Vulcan and the Handley Page Victor were used in the Falklands War towards the end of their operational lives, albeit that the Victor had been converted to the air tanker role.

The Soviet Union produced hundreds of unlicensed, reverse-engineered, copies of the American Boeing B-29 Superfortress, which the Soviet Air Forces called the Tupolev Tu-4. The Soviets later developed the jet-powered Tupolev Tu-16. And the People's Republic of China produced a version of the Tu-16 on license from the Soviet Union in the 1960s which they named the Xian H-6.

During the 1960s France produced its Dassault Mirage IV nuclear-armed bomber for the French Air Force as a part of its independent nuclear strike force, the Force de Frappe, using French-made bombers and IRBMs to deliver French-made nuclear weapons. Mirage IVs served until 1996 in the bomber role, and to 2005 as a reconnaissance aircraft. Today the French Republic has limited its strategic armaments to a squadron of four nuclear-powered ballistic missile submarines, with 16 SLBM tubes apiece. France also maintains an active force of supersonic fighter-bombers carrying stand-off nuclear missiles such as the ASMP, with Mach 3 speed and a range of 500 kilometres. These missiles can be delivered by the Dassault Mirage 2000N and Rafale fighter-bombers.

Avro Vulcan

Later strategic bombers such as the Rockwell International B-1B Lancer, the Tupolev Tu-160, and the Northrop Grumman B-2 Spirit designs incorporate various levels of stealth technology in an effort to avoid detection, especially by radar networks. Despite these advances earlier strategic bombers, for example the B-52 (last produced in 1962 but with continuing electronic and weapons upgrades) or the Tupolev Tu-95 remain in service and can also deploy the latest air-launched cruise missiles and other "stand-off" or precision guided weapons such as the JASSM and the JDAM.

Tupolev Tu-160M2

Northrop Grumman B-21 Raider

The Russian Air Force's new Tu-160M2 strategic bombers are expected to be delivered on a regular basis over the course of 10 to 20 years. In addition, the current Tu-95 and Tu-160 bombers will be periodically updated, as was done during the 1990s with the Tu-22M bombers. Consideration is being given to arming the B-52 with defensive laser weapons to protect against incoming missiles.

The Northrop Grumman B-21 Raider is an American heavy bomber under development for the United States Air Force. As part of the Long Range Strike Bomber program (LRS-B), it is to be an advanced very long-range, large, heavy-payload stealth intercontinental strategic bomber able to deliver conventional and thermonuclear weapons. It is expected to enter service by 2025 to complement existing the Rockwell B-1 Lancer, Northrop Grumman B-2 Spirit, and Boeing B-52 Stratofortress bomber fleets in U.S. service, eventually replacing them.

Fighter and bomber aircraft, of whatever emphasis and employment, are not the only military aircraft; earlier we mentioned drones, more correctly called unmanned aerial vehicles (UAVs). These are now an increasingly important element of the military inventory.