CANADA AVIATION MUSEUM AIRCRAFT

HAWKER SIDDELEY AV-8A HARRIER
UNITED STATES MARINE CORPS BuNo 158966

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Introduction

As this is written approaching the 50th anniversary of the first flight of the prototype Hawker P.1127 aircraft, one cannot help to think about a sight as quite as incredulous as that of a small, yet mighty jet-powered fixed-wing aircraft, high in the sky, with an unparalleled cacophony emanating from its engine exhaust ducts – and to add to all of that, it's not moving!

For ages man has marveled at how the diminutive hummingbird could perform its daily routines while in a hover, pirouette on a dime and even fly backwards, all with seemingly little effort but with a furious beating of their tiny wings. Someone must have pondered how it would be to harness that energy and enable man and machine to perform similarly. In fact, famed American inventor Thomas Alva Edison, sometime in 1905 prophesied,

> *"The airplane won't amount to a damn until they get a machine that will act like a hummingbird – go straight up, go forward, go backward, come straight down and alight like a hummingbird. It isn't easy…Somebody will do it."*

To incorporate the furious flapping of wings in order to emulate the flight of birds on a manned flying machine was, now in hindsight, obviously impractical, and various early attempts to fly vehicles employing such a method failed miserably, many with unfortunate and sometimes humorous outcomes. Oftentimes these inspired efforts were recorded on film for posterity and now can be seen in old black and white newsreel footage, usually resulting in gales of laughter emanating from the now aviation technology savvy viewing audience. However, one such wing-flapping type of vehicle, the world's first human-powered *Ornithopter*, from the University of Toronto Institute of Aerospace Studies, did manage to fly for a short distance in Toronto, Ontario during 2006, silencing the critics, but this was a very remarkable exception.

An amazing cadre of collaborating leading British V/STOL aircraft design personnel involved directly in the unique *Harrier* aircraft design included; Sir Sidney Camm, the Technical Director of Hawker Aircraft and Ralph Hooper, designer draftsman at Hawker of the progenitor aircraft to the *Harrier*. Sir Stanley Hooker, Chief engineer at Bristol Aero-Engines simplified the original engine design and function, and John Fozard, project design engineer, came up with the practical concept of the bifurcating jetpipe making possible the practical application of four vectoring engine exhaust nozzles for aircraft control. This small first gathering of esteemed European aeronautical engineers began studies starting in mid-1957, at Hawker Aircraft Limited of Kingston-upon-Thames, on what was to become the first successful jet-powered Vertical/Short Takeoff and Landing (V/STOL) aircraft to see mass production. These aircraft, designated as the AV-8, would enter protracted military service in the western world with Britain, the United States, Spain and India during the 1960s and 1970s.

Cover Photo Caption:

United States Marine Corps AV-8A Harrier 158966 CG-09 of VMA-231, with the unit's 'Ace of Spades' insignia on the nose in September 1997. Here it poses resplendent outside for the first time since its refurbishment, assembled and painted in its last user markings by the skilled restoration staff of the National Aviation Museum (NAM). (CAvM Photo 33111)

Preliminary Jet V/STOL Aircraft Research

The story of the *Harrier* would not be complete without briefly acknowledging a few of the previous accomplishments in the field of deflected/vectored jet thrust and jet V/STOL test and research aircraft. Some of the antecedent manned test air vehicles that, to some extent, helped pave the way for the genesis and eventual success of the AV-8 series of the *Harrier* have included:

Bachem Ba 349 *Natter* (1944)
The Ba 349 was conceived as part of Germany's constant search for revolutionary aircraft and propulsion technologies. Not actually a jet, but an experimental German VTO rocket interceptor devised to go up against the Allied's large bomber fleet, the *Natter* was to be launched from easily hidden and mobile vertically positioned towers. In order to augment the lack of aero engines and thus aircraft available near the war's end, the Bachem Werke GmbH was tasked with the design and manufacture of the Bachem Projekt 20, later designated as the Ba 349 *Natter* series of small liquid fueled rocket-propelled aircraft. On 1 March 1945, a powerful 1,700 kg (3,750-pound) thrust HWK 509 A-2 rocket motor, augmented by a series of four 1,000 kg (2,200-pound) thrust solid-fuel rockets at takeoff, propelled hapless volunteered pilot Lothar Sieber on the singular manned VTO flight of this rocket interceptor aircraft. He did not survive the quick, brief flight, but unmanned flight tests continued. The project was eventually terminated just prior to the type's first operational deployment in the field.

Gloster G.41F *Meteor* F.Mk.IV (1954)
This deflected thrust testbed aircraft was not in the VTOL category, as it took off and landed rather conventionally. It was built and served originally as a Mk.IV for the RAF and was allocated the military serial number RA490. Following its service career, it became an engine testbed for the Saunders-Roe SR.A/1 flying-boat fighter, being modified and equipped with Metropolitan-Vickers F.2/4 *Beryl* turbojet engines. Following a landing accident on its second test flight, RA490 was turned over to the Westland Aeroplane Company to be modified for deflected jet thrust trials as part of a study on reducing the high approach speeds of jet powered naval aircraft. The *Beryl* engines were replaced with much greater thrust Rolls-Royce *Nene* 101 engines, mounted ahead of the wing spar with new, larger engine nacelles extended far forward to accommodate the new engine installation. Under each nacelle, at the aircraft's center of gravity, movable valves and exhaust ducts were installed to deflect some of the rearward efflux from the *Nene* engines downwards at a sixty-degree angle to the line of flight. This exhaust management effectively lowered the stall speed of the aircraft and significantly reduced its landing speed and rollout.

Bell Model 65 Air Test Vehicle (ATV) (1954)
Bell Aircraft Corporation undertook a private venture to design and build an experimental tiltjet aircraft to aid in developing horizontal-attitude designs of VTOL aircraft originally based on early US Navy (USN) requirements for a VTOL convoy fighter. After losing out to the Lockheed and Convair contra-rotating turboprop ("Pogo") tail-sitter designs, feasibility studies continued into the 1950s culminating in a simple design, first known as the Bell VTOL, civil registered as N1105V, being constructed from components of existing aircraft types. It was powered by two Fairchild J44 turbojet engines, mounted one on each side of the fuselage at the center-of-gravity position, each capable of pivoting between the vertical and horizontal positions. To provide pitch, roll and yaw control in the vertical takeoff, low-speed and vertical landing modes, small compressed air ducts were positioned at the tail and wingtips powered by a small air compressor mounted behind the cockpit. In December 1953, the first hover was accomplished. On 16 November 1954, the Bell Model 65, commonly called the ATV, became the world's first jet-propelled VTOL airplane when it performed its first untethered vertical flight, paving the way for Bell's X-14.

Rolls-Royce "Flying Bedstead" (1954)
The "Flying Bedstead" was the common nickname applied to Rolls-Royce's Thrust Measuring Rig (TMR), a tubular truss-type structure, supporting two Rolls-Royce *Nene* engines that provided lift and bleed air control for pitch, roll and yaw. The *Nenes* were mounted horizontally in tandem fore/aft, tail-to-tail with the exhausts ducted downwards through the center of gravity of the rig. Atop the engines, quite literally in the hot seat, sat the pilot and rig controls in an open cockpit arrangement. Two test vehicles were constructed to investigate and prove that the idea of jet-lift hovering by a V/STOL aircraft was a controllable operation. Although not officially an airplane, the first hover test vehicle did receive a military serial number, XJ314, and performed its first hovering free flight on 3 August 1954. A sister rig (XK426) was intended for use primarily for turbulence trials, however it crashed in November 1957 before significant testing could be accomplished. Although crashes were experienced by both of these vehicles during the test programme, the TMRs paved the way for further studies to be conducted with the Short S.C.1 research aircraft.

Ryan X-13 *Vertijet* (1956)
As was the *Natter*, the X-13 *Vertijet* was a very small, delta winged, tail-sitter type of VTOL, or more correctly referred to as a VATOL (Vertical Attitude Take Off and Landing), experimental test aircraft. A single Rolls-Royce *Avon* RA.28-49 turbojet engine powered the tiny aircraft. The Ryan Aeronautical Company had proposed this testbed aircraft in April 1947 based upon USN requirements and request for a Navy Convoy Fighter, however, funding was not readily available, so Ryan proffered the idea to the US Air Force who authorized the construction of two prototype research aircraft. The concept utilized a special mobile transportation, launch and retrieval trailer that had a flatbed that could be lifted to the vertical via two large hydraulic jacks. At the top point of the bed, when vertical, a short section of steel cable, horizontally suspended between two mechanical arms, was utilized as the launch and capture point for a small semi-retractable hook attached under the nose of the X-13. The engine exhaust nozzle was articulated to control the aircraft in pitch and small wingtip elbow pipes, utilizing engine bleed air, controlled the yaw attitude while in the hover. The X-13 performed its first VTOL flight on 28 May 1956, and its first full transition sequence from vertical launch, to conventional flight then vertical recovery to the trailer bed on 11 April 1957. Successful public demonstrations through 1957 exhibited the remarkable capabilities of this concept but funding was cut in 1958 and the project was eventually cancelled.

Bell X-14 (1957)
The single X-14 was designed and built originally for the United States Air Force (USAF) by Bell Aircraft as a vectored-thrust research vehicle to explore pilot ergonomics while flying a VTOL aircraft. It's design mission was realized when it became the first jet-powered, fixed-wing VTOL aircraft to takeoff straight up from the ground in the conventional horizontal position, translate to normal horizontal flight, hover, and then land vertically. All of this was accomplished utilizing specialized thrust diverters deflecting the jet efflux in the direction required to accomplish vertical lift for takeoff, hover and landing, or rearward for conventional flight. Starting in 1957, the single-place aircraft was flown in a systematic investigation of control power and damping requirements emulated for a variety of VTOL aircraft and their characteristics hovering in and out of ground effect. NASA received the X-14 for tests in 1959. Engineering flight data from the early trials of the X-14 was made available to Sir Stanley Hooker during the preliminary design phase of the Hawker P.1127 V/STOL aircraft. Hawker's experimental test pilots A. W. (Bill) Bedford and Hugh Merewether both flew familiarization flights in the X-14 at the NASA Ames Research Center in 1960 prior to their first flight attempts in the prototype P.1127. In a reciprocal gesture, the British welcomed NASA Langley Chief Research Test Pilot John P. (Jack) Reeder to test fly P.1127 serial XP831 on 13 June 1962, thus becoming the first foreign pilot to do so. The highly successful Bell X-14 aircraft was one of the longest serving examples of the NACA / NASA's renowned series of the so-called "X-Planes".

Short S.C.1 (1958)
In 1951, Rolls-Royce received a Gloster *Meteor* PR9, RAF serial number VZ608, dedicated for use as an engine testbed. After testing a variety of engines, the center fuselage area of VZ608 was extensively modified in 1955 to accept and flight test the vertical installation of a Rolls-Royce RB.108 lift engine, designed for use with the new Short S.C.1 research aircraft. A special ram air intake was originally installed atop the engine bay to feed the powerful little engine, later replaced by an intake arrangement representative to that on the S.C.1. The exhaust was discharged via a port where the ventral fuel tank had been. Two S.C.1 aircraft were built by Shorts, each powered by a series of five of the Rolls-Royce RB.108 direct lift engines, to investigate Lift-Cruise VTOL utilizing turbojet engines, becoming the United Kingdom's first fixed-wing V/STOL aircraft programme. Over the course of many years the S.C.1s were used to familiarize pilots from other nations for their respective V/STOL aircraft programmes, including Canadair Limited experimental test pilots selected for the CL-84 V/STOL tilt-wing aircraft evaluations.

Grumman A2F-1 (1960)
Later to become more famously known as the tadpole-shaped Grumman A-6 *Intruder* all-weather attack aircraft of the USN and US Marine Corps (USMC), the first seven prototype Grumman A2F-1 aircraft incorporated variable geometry, or tilting, tailpipes to provide some kind of short-field capability for USMC requirements. Somewhat similar to the Gloster *Meteor* IV Deflected Thrust testbed idea, this feature provided marginal STOL capability with the engine thrust available at the time and was soon dispensed with altogether. The deployment of the aircraft's existing large air brakes, mounted directly behind the engine exhausts, was seen as a more efficient means of control in the low speed regime.

Bristol *Pegasus* Engine (1959)
The creation of a new engine for a new aircraft was and is an expensive business. In the case of the P.1127 and its later development into the *Kestrel*, this placed a huge R&D burden upon only one customer. At the beginning, a lot of cost went into producing only a handful of functioning airplanes. In Europe during the mid-1950s, standard civilian airfields and vulnerable military air bases with multiple long paved runways, taxi strips and supporting buildings abounded in congested and sometimes conflicting areas of flight operations. Most of these aerodrome areas had been carved and hacked out of the dense European forests leaving great expanses of visible cleared scenery and aircraft readily discernible and vulnerable from the air to opposing air forces. French aircraft designer Michel Wibault sought to eliminate the visible expanses of concrete necessary for fixed wing aircraft types with the idea of minimizing the storage and aircraft operations areas to a small amount of space hidden under the visually protective umbrella of the camouflaging trees. To store and operate aircraft in such areas, he had the idea of using fixed-wing VTOL type of aircraft, with a new engine design, that could be prepared and flown from small, semi-cleared areas with little possibility of detection due to the leafy overgrowth. The design expertise of Wibault resulted in his *Gyroptère* design in 1956, a diminutive fighter to be powered by a single Bristol BE.25 *Orion* turboprop engine. In the fuselage, a rectangular arrangement of four separate centrifugal compressors (blowers), two per side, were to be driven by the *Orion* resulting in the generated air being capable of raising the aircraft vertically. Once airborne, the compressors were to slowly rotate horizontally aft to propel the *Gyroptère* forward, reversing the process to land. Bristol Aero-Engines was brought in and soon revised the cumbersome design by eliminating the compressors and *Orion* engine, installing an *Orpheus* turbojet to power the front fan of an *Olympus* turbojet, and revising the rotating exhaust nozzles. This engine configuration resulted in the initial Bristol, later Bristol-Siddeley, BE.53 turbojet engine, this finally evolving into the famed Rolls-Royce *Pegasus* series of powerplants.

Hawker V/STOL Developments

Hawker P.1127 Prototypes

The concept to explore the first vectored-thrust jet tactical fighter capable of vertical takeoff and landing resulted in the first two prototype aircraft emerging from Hawker's plant for ground testing in early 1960. The premiere flight of the first prototype P.1127 (serial number XP831) on 21 October 1960 was a planned VTO one, loosely tethered to the ground by steel cables over a grid-covered pit to deflect the engine exhaust away from the aircraft. The Hawker test pilot selected to perform the inaugural flight was A. W. (Bill) Bedford, even though he had broken his leg a few days earlier in an automobile accident. Bedford shared pilot duties alongside fellow Hawker test pilot Hugh Merewether, both pilots having been inaugurated to this new world of V/STOL flight, flying a Sikorsky S-51 helicopter, the NASA V/STOL simulator, and the Bell X-14. The promised available thrust from the Bristol Siddeley *Pegasus 2* engine was only 50.26 kN (11,300 lbf), which was marginally more than the empty weight of the aircraft. This necessitated that the aircraft be stripped of all non-essential items (landing gear doors, nose instrumentation boom, airbrake, ram air turbine, and even the radios) to enable the engine to vertically heft the prototype aircraft off the ground. As it was, the first aircraft could only carry about two minutes of fuel, therefore much of the early testing had to be completed in relatively short amounts of time. On 19 November 1960, XP831 shed its tethers and performed its first free hovering flight. The first conventional flight of the P.1127 prototypes occurred on 13 March 1961, again with XP831. On 12 September 1961, the first successful transition from vertical to conventional flight was performed at Dunsfold. A Minister of Defence official was supposed to be on site early to officially approve the transition attempt. When the official still had not arrived in due time, Bedford, impatient with the delay, effected the transition flight, recording it in the official flight report as 'unintentional'. He and Merewether continued transitions that day.

The first P.1127 prototype is viewed in an untethered hover at its Dunsfold flight-test base. For publicity purposes, the new aircraft's identifier "Hawker P.1127" is seen displayed prominently on the nose. A more stylized variation would soon replace this logo branding for the upcoming premiere appearance of the P.1127 at the Paris Air Show in June 1963. (Photo Courtesy BAe/Bill Upton Collection)

The prototype P.1127, XP831, piloted by Bill Bedford, performs the first ever jet V/STOL at-sea trials aboard HMS Ark Royal (R09) during February 1963. Round, segmented black and white targets, for photo calibration and tracking purposes, are clearly seen on the intake splitter and aft fuselage. A long instrumentation boom is attached at the nose of the aircraft. (Photo Courtesy BAe/Bill Upton Collection)

The first aircraft, with Bedford at the controls, made another spectacle by accident at a most inopportune time. During a very public flight demonstration at the June 1963 Paris Air Show, there was a problem with the nozzle drive system after a speck of dirt somehow jammed its servo mechanism. The aircraft lost lift control and landed hard in front of spectators and media cameras. Bedford was unhurt. Following repairs, XP831 continued preparations towards progressive transition flight trials and the gradual exploration of the prototype aircraft's flying characteristics throughout higher flight regimes.

The second prototype P.1127 aircraft (XP836) had been built to examine the low-speed and conventional flight regime. Later modifications, including engine/nozzle control enhancements, which greatly improved aircraft control, permitted transition envelope expansion trials to take place. This aircraft first took to the air on 7 July 1961. Then, in early December, P.1127 XP836 became the first jet V/STOL aircraft to achieve supersonic speeds when it was dived to a high speed of Mach 1.2.

The last built of a follow-on development batch of four P.1127 aircraft (XP984), incorporated a new wing, a 22.86 cm (9.0 in) rear fuselage extension, a longer span tailplane, and was retrofitted with the more powerful *Pegasus* 5 engine. It was touted to serve as the prototype trials aircraft for the next generation of the series, called the *Kestrel*, and had its first flight on 13 February 1964.

Hawker Siddeley *Kestrel* F(GA) Mk.1

Nine *Kestrel* F(GA) Mk.1 (Fighter, Ground Attack) operational evaluation aircraft were built for joint United States (Air Force/Navy/Army), British Royal Air Force (RAF) and West German (Luftwaffe) evaluations. At this time, the USMC wasn't an active participant in the *Kestrel* Tripartite programme, however, later, following the arrival of the newly designated XV-6 aircraft in America, a few Marine pilots had the opportunity to fly the aircraft. These Tripartite evaluation aircraft were allocated the British military serial numbers XS688 to XS696 and were powered by the newer and upgraded 68.95 kN (15,500 lbf) thrust *Pegasus* 5 turbofan engine. Armament capabilities for initially proposed external loads of bombs, napalm tanks, or rockets were not incorporated except for a simple tracking gunsight and a reconnaissance camera installed in the forward part of the nose in lieu of the instrumentation data boom. Provisions for 455 litre (100 Imperial gallon) drop tanks were made that consisted of the installation of a plumbed hardpoint beneath each wing.

The first jointly funded *Kestrel* aircraft (XS688), performed its maiden flight from Kingston on 7 March 1964. All of the 'Tripartite Nine' aircraft were subsequently based at RAF West Raynham, Norfolk, formed on 15 October 1964, originally as the Kestrel Evaluation Squadron (KES). From April through September 1965, the KES became more commonly known as the Tripartite Evaluation Squadron (TES).

The first Kestrel F(GA) Mk.1, XS688, is seen on an early test flight in early 1964 bearing the standard RAF roundels and fin flash. Note the somewhat longer and more humpbacked appearance of the fuselage compared to the original P.1127 prototype. A long nose mounted instrumentation boom was originally installed for test purposes, then soon dispensed with, on this first of nine aircraft and was replaced by a nose mounted combat strike camera. (Photo Courtesy BAe/Bill Upton Collection)

XS688, now in the unique colours and markings of the NATO Tripartite Evaluation Squadron, on an early pre-delivery test flight. The aircraft also sports "Hawker Siddeley P.1127" on the nose, although it wasn't really a P.1127. The special wing roundels were designed to represent each of the three participating TES nation's insignia and were seen to be 'handed' uniquely on this aircraft. The colorful fin flash consists of vertical bands of each nation's insignia. (Photo Courtesy BAe/Bill Upton Collection)

Like its P.1127 predecessor, the *Kestrel* also performed deck trials when it operated alongside helicopters from the Royal Navy's Commando Carrier HMS *Bulwark* (R08) in 1966 as part of it's potential role in a naval jet strike force. These trials helped to solidify the notion that this aircraft type was well suited to support operations with naval vessels.

One *Kestrel* (XS694) was heavily damaged in a ground-loop accident at West Raynham early in the TES evaluations and was written off as a spares support for the rest of the fleet. In early 1966, following the brunt of the Tripartite trials, six of the aircraft were purchased by the United States for Tri-Service Team trials with the remaining two aircraft (XS693 and XS695) allocated for other test work with the British Royal Aircraft Establishment (RAE). Aircraft XS693, the *Pegasus* 6 testbed for the P.1127(RAF), piloted by a US Army pilot, crashed during a short take-off accident in September 1967. Then, XS695 crash-landed while with the RAE at Boscombe Down in March 1967. For all of the ground breaking work with the *Kestrel* trials, no orders for additional aircraft were forthcoming from any of the armed services of the participating Tripartite members.

XV-6A *Kestrel*

Two P.1127 aircraft were requested by the US Air Force, for VTOL research purposes, with the designation VZ-12-HS and were allotted the serial numbers 62-4507 and 62-4508, however, these aircraft were never delivered. When the US military aircraft designation system was overhauled during 1962, the VZ-12 designation became the XV-6A-HS and retained the *Kestrel* name originally bestowed upon it. Later, in early 1966, six of the *Kestrel* F(GA) Mk.1 Tripartite Evaluation Squadron aircraft (three from the United States' batch and the three from the German allocation) were shipped to the USA for Tri-Service Team trials with the US military organizations. Serial numbers for the original nine *Kestrel* aircraft were assigned in the USAF 64-18262 to 64-18270 range, but only 64-18262 to 64-18267 were actually used, as the rest of the aircraft order was cancelled.

Following an initial series of ground support trials with the US Army at Fort Campbell, five of the aircraft were assigned to the Naval Air Test Center (NATC) at Patuxent River, Maryland, during 1966, conducting performance, operations and simulated carrier trials at that location. Aircraft 64-18266 (ex-XS692) performed sea trials from the aircraft carrier USS *Independence* (CVA-62) and 64-18262 (XS688) from the smaller deck of the Marines' USS *Raleigh* (LPD-1) in May 1966. These sea trials, particularly those from the *Raleigh,* showed the USN/USMC community that V/STOL operations could be successfully carried out from the decks of small support ships, such as those of the helicopter (LPH) ships utilized regularly by the Marines. This helped to set in motion the eventual groundbreaking appearance of a USMC delegation, including pilots Colonel Tom Miller and Lieutenant-Colonel Bud Baker, at the 1968 SBAC show at Farnborough, England. Colonel Miller requested and was granted a flight in a RAF *Harrier*, becoming the first American to do so, with Lt. Col. Baker evaluating the aircraft shortly thereafter. Their positive reports and continued reinforcement of the idea of such aircraft becoming part of the USMC inventory helped to pave the way for the rare US military acquisition of these foreign-built aircraft.

The Canadian National Research Council (NRC) in Ottawa became involved in the active training role towards evaluating the flight and handling characteristics of varied V/STOL air vehicles at the time. Their research vehicle, called the V/STOL Airborne Simulator, a suitably modified Bell 47G3B1 helicopter, was flown at the NRC facilities as a dynamic aid towards training the initial cadre of P.1127 *Kestrel* pilots. This process was later repeated towards training potential production AV-8A *Harrier* service pilots with the characteristics of a proposed stability augmentation system for the aircraft while at transitional speed in forward flight under both visual and simulated instrument conditions.

This paint-worn XV-6A, as number '2', wears USAF serial number 64-18262 on the tail and 'U.S. AIR FORCE' on the side of the air intake above the forward exhaust nozzle fairing. It was formerly the first Kestrel F(GA) Mk.1, XS688, then numbered '8' (the last digit of its then serial number) and is seen here being prepared in September 1987 for static display at the USAF Museum Annex at Wright Patterson AFB, Ohio. (Bill Upton Photo)

Four of the XV-6A *Kestrel* aircraft were later assigned for acoustic and flight tests at Edwards Air Force Base, California bearing "U.S. AIR FORCE" titles on the sides of the fuselage replacing the former Tri-Service markings. These aircraft were test flown during the trials by pilots of the USAF, USN, USMC, and the US Army. NASA obtained two of the Air Force machines (64-18267 and 64-18263) in July 1966. These aircraft were then based at the NASA Langley Research Center, Virginia towards evaluating the unique new capabilities of (Thrust) Vectoring In Forward Flight (VIFF) during trials. They were originally allocated the NASA registration numbers NASA 520 and NASA 521, then later appeared on the US civil aircraft register as N520NA and N521NA respectively. All of the remaining XV-6A *Kestrel* aircraft were finally retired in 1974, having provided much in the way of information and doctrine pertaining directly to the future operations of such special V/STOL aircraft by the US Marines.

P.1127(RAF) / *Harrier* GR.1

In February 1965, while the *Kestrel* trials were still ongoing, the British Ministry of Technology ordered an additional six preproduction aircraft as a development towards a close support fighter for the RAF. This Development Batch of aircraft consisted of airframes XV276; XV277; XV278; XV279; XV280; and XV281 powered by the 84.52 kN (19,000 lbf) *Pegasus* 6 Mk.101 engine. Initially called the P.1127(RAF), these aircraft eventually were the first of the breed to acquire the formal assigned name, *Harrier*.

The new P.1127(RAF) examples were the earliest of the type to demonstrate a warload capability, being equipped with five pylon positions (4 underwing and 1 centerline), and two Aden 30mm gun pods, where the longitudinal fuselage strakes had been. A photo reconnaissance pod, capable of carrying up to five cameras could be mounted on the centerline hardpoint. An inflight refueling probe could also be provided. The first flight of the P.1127(RAF) prototype aircraft (XV276), with test pilot Bill Bedford at the controls, was held on 31 August 1966.

The last of the batch (XV281), configured as a build-standard for the new production aircraft, with an engine output of 88.96 kN (20,000 lbf) thrust and enlarged air intakes with new blow-in doors around each intake lip, performed its maiden flight on 14 July 1967. Shortly thereafter a full order for sixty production examples was placed by the RAF as the world's first V/STOL fighter aircraft, the *Harrier* GR.1. Chief Test Pilot Duncan Simpson performed the primary flight of the first GR.1 (XV738) on 28 December 1967. Newly operational RAF *Harrier* GR.1 XV744 of No 1(F) Squadron successfully achieved the first ever trans-Atlantic flight by a jet V/STOL aircraft. Squadron Leader Tom Lecky-Thomson flew it from the heart of London to central New York City during the "Daily Mail Trans Atlantic Air Race" in May 1969. RAF Handley Page *Victor* air-to-air tankers were assigned to provide multiple inflight refuellings of the *Harrier* during the long Atlantic Ocean crossings.

Harrier GR.1A and GR.3

In 1971, following the initial production run of the GR.1, an engine upgrade was initiated and the aircraft entered RAF squadron service with the newer 91.18 kN (20,500 lbf) thrust Rolls-Royce *Pegasus* 10 Mk.102 engine. This variant became the *Harrier* GR.1A and squadron conversion with the new type was completed in 1974. A further upgrade to the *Harrier* family was with the appearance of the GR.3, fitted with the more powerful 95.64 kN (21,500 lbf) static thrust *Pegasus* 11 Mk.103 powerplant.

Initially the *Harrier* GR.1, GR.1A and GR.3 models all had an externally physical resemblance. The profile of the GR.3 soon changed dramatically following modifications to upgrade the aircraft's avionics capabilities. Conspicuous external mods included the incorporation of antennas on the tailcone and on the leading edge of the fin for the Passive Warning Radar (PWR) system and a radical recontouring of the nose to house Ferranti Laser Ranging and Marked Target Seeking (LRMTS) equipment.

A RAF Harrier GR.1A of 233 OCU is displayed loaded with BL755 Cluster Bomb Units hanging on all the wing stations. (Photo Courtesy BAe/Bill Upton Collection)

This laser-nosed Harrier GR.3 model shows how the wraparound camouflage scheme blends into the background. (Photo Courtesy BAe/Bill Upton Collection)

AV-8A *Harrier*

Following the initial development of the P.1127, *Kestrel* and RAF variants, the *Harrier* became the first export order of the type when the USN placed orders for 102 examples of the British Mk.50 (equivalent to the RAF's *Harrier* GR.1A) in lieu of ordering additional McDonnell Douglas F-4J *Phantoms*. These new assets were to become known as the AV-8A *Harrier* in the United States military designation system.

The chief role for the AV-8A in service with the USMC was for close air support of the Marines on the ground with the capability of providing amphibious assault either from a ship's deck or from a beachhead. Secondary missions included interdiction or carrying a five-camera pod under the fuselage for reconnaissance duties. The AV-8A supplemented the various attack helicopter and troop landing craft assets that were, and still are, coveted and utilized by the Corps, a resource that has been employed successfully since the Korean conflict. The added potential of employing the *Harrier* as an air-to-air dogfight aircraft with amazing maneuverability was embraced enthusiastically by its flight crews.

The AV-8A *Harriers* were procured in five batches, originally designated as Mk.50s in the United Kingdom, bearing the USN Bureau Numbers (BuNos):
158384-158395 (UK serial numbers XW644-XW655 were initially allocated, but not worn), 158694-158711, 158948-158977, 159230-159259, and 159366-159377.
Beginning in January 1971, all of these aircraft were air delivered from the United Kingdom to the United States as cargo aboard a number of USAF Douglas C-133 and Lockheed C-141 military transport aircraft.

The basic operational AV-8A *Harrier* aircraft ordered were assigned to three Marine Attack Squadrons; VMA-513, VAM-542, VMA-231 and training squadron VMA(T)-203. The first service work up of the type began in April 1971 with VMA-513 at MCAS Beaufort in South Carolina.

The first ten AV-8As delivered to the Marines were equipped with the 88.96 kN (20,000 lbf) static thrust Rolls-Royce *Pegasus* 10 Mk.102 (F402-RR-400). All subsequent aircraft were delivered with the improved 95.64 kN (21,500 lbf) static thrust *Pegasus* 11 Mk.103 (F402-RR-401) that was employed in the RAF's *Harrier* GR.3 model. Eventually, this engine was also installed onto the original ten aircraft for commonality. The final AV-8As therefore had family ties to both the *Harrier* GR.1A, from an airframe structure and dimensional point of view, and the RAF's GR.3 variant, regarding power and performance.

The 10th production AV-8A Harrier 158393 (XW653) sporting underwing fuel tanks and Zuni rocket pods is seen at Marine Corps Air Station (MCAS) Cherry Point, North Carolina, in VMA-231 (CG-4) markings during 1974. (Bill Upton Collection)

AV-8A SPECIFICATIONS and PERFORMANCE:

Powerplant:	Rolls-Royce *Pegasus* 103 (F402-RR-401) vectored thrust turbofan engine
Thrust:	95.64 kN (21,500 lbf) static thrust
Wing Span:	7.70 m (25 ft 3 in)
Length:	13.90 m (45 ft 7 in)
Height:	3.45 m (11 ft 4 in)
Empty Weight"	5,533 kg (12,200 lbs)
Max. T-O weight:	11,429 kg (25,200 lbs)
Max. Level Speed:	643 knots (1,190 km/h / 740 mph)
Service Ceiling:	15,605 m (51,200 ft)
Range (unrefuelled):	3,760 km (2,340 mi)
	Long range external fuel tanks slung on underwing pylons and a bolt-on flight refuelling probe (onto the top of the port intake) could be installed for extended range deployments.
Armament:	Two Aden 30mm guns in detachable fuselage pods for strafing ground targets; 2,268 kg (5,000 lbs) of bombs and unguided folding fin aerial rockets (FFAR); AIM-9 *Sidewinder* air-to-air missiles on outboard underwing pylons.

The Museum's AV-8A Aircraft

The Museum's aircraft (as were all of the AV-8A and TAV-8A fleet of aircraft) was built on the Hawker Siddeley Aircraft, Kingston-upon-Thames production line, and was designated initially as a *Harrier* Mk.50 bearing the construction number 712127/49. It was allocated for FY1973 in the third batch of USN procured AV-8A aircraft ultimately destined for the USMC. The maiden flight of this aircraft was performed on 23 August 1973, whereupon it received the USN BuNo 158966 (all Marine Corps aircraft are numbered per the USN system). This aircraft's acceptance and delivery occurred on 21 September 1973.

USMC Service

AV-8A 158966 first served with Marine Attack Squadron VMA-542 (WH), "Flying Tigers", at Marine Corps Air Station (MCAS) Beaufort, South Carolina starting on 24 September 1973. This squadron's name is not related to that of the famed "Flying Tigers" American Volunteer Group (AVG) of the Second World War and subsequent US Air Force's 23rd Tactical Fighter Wing unit, nor to the Flying Tiger Line cargo aircraft.

158966 of VMA-542, WH 24 at Beaufort. (via Patrick Martin Collection)

While still at Beaufort, this *Harrier* crossed the field, so-to-speak, and became a tenant of the first established USMC *Harrier* unit, VMA-513 (WF), popularly known as the "Flying Nightmares", in May 1974. At this time the squadron was in preparation for some upcoming West Coast military exercises.

158966 of VMA-513, WF 11 (via Patrick Martin Collection)

158966 of VMA-513, WF 11 (via Patrick Martin Collection)

Following a cross-country trip to North Island Naval Air Station (NAS), California, 158966 was soon thereafter forward deployed to MCAS Iwakuni, in Japan, making the journey aboard the aircraft carrier USS *Tripoli* (LPH 10), for a 27 month assignment starting on 28 August 1974. At this same time, some of its squadron stablemates were spending time aboard the amphibious assault ship USS *Guam* (LPH-9) at that time stationed in the Mediterranean.

The aircraft returned stateside in November 1976, and remained principally West Coast based, still with VMA-513, at MCAS Yuma, Arizona, until June 1977. It was seen during October 1977 bearing the squadron identifier number '04' on the nose while assigned to VMA-513.

158966 of VMA-513, WF 04 during a visit to MCAS Yuma in 1980. (Trevor Bartlett Photo)

Basing alternated between Yuma, Cherry Point, and North Island until August 1979, whereupon the aircraft was forward deployed to Kadena Airfield, Okinawa. It then went to MCAS Kaneohe Bay, Hawaii, from November 1979 to February 1980 under the Unit Deployment Program. Additional deployments followed in 1981 to Atsugi, Japan, where 158966 spent a couple of days aboard the USS *Guam* in May.

Following a rotation back to Yuma, March 1982 was spent aboard the *Tarawa*-class amphibious assault ship USS *Peleliu* (LHA-5), then the aircraft was returned back to Yuma until the early part of the new year. At that point, in March 1983, 158966 finally became a tenant of VMA-231 (CG), "Ace of Spades", at Cherry Point, now bearing the aircraft's new squadron identification number '09' on the nose.

158966 of VMA-231, CG 09 at McChord (Doug Remington via the Pat Martin Collection)

June and November 1983 saw the aircraft visit 29 Palms in California, then a short stint aboard the USS *Inchon* (LPH-12) in February 1984 before returning for good to Cherry Point. There it remained until withdrawn from service and placed into long-term storage at the Aerospace Maintenance and Regeneration Center (AMARC) near Tucson, Arizona, in August 1985.

AV-8C *Harrier*

The USMC, foreseeing more extensive uses of the type, planned to acquire a dramatically improved Short Take Off and Vertical Landing (STOVL) version of the *Harrier* (later to become the AV-8B or also to be known as the *Harrier II*). This new variant, eventually to be manufactured by McDonnell Douglas in the United States, would replace the older AV-8s and Douglas A-4 *Skyhawk* aircraft in the light-attack force.

As an interim measure, while awaiting the development of the AV-8B, some 60 examples of the existing AV-8A fleet were chosen to be modified, as part of a conversion in lieu of procurement (CILOP) programme. These modifications were part of a joint Hawker Siddeley/McDonnell Douglas activity to include some of the features planned for the new *Harrier* model to obtain benefit of the proposed AV-8B's abilities more quickly. As the AV-8B was already in the design phase, the 60 upgraded interim *Harriers* received the subsequent model designation suffix, hence they became the AV-8C variant.

Some information sources report that AV-8A *Harrier* BuNo. 158966 had been converted to the AV-8C configuration (only 47 out of the planned 60 AV-8A aircraft were actually converted) but official aircraft activity charts, maintenance records, and obvious physical evidence does not show this reconfiguration having taken place to the Museum's aircraft. Readily noticeable modifications, if it had been converted to a 'C' model, would have included:

- Lift Improvement Devices (LIDs), an interim development for the follow-on AV-8B *Harrier* II variant, incorporating fixed, large longitudinal ventral fuselage strakes and a retractable cross-dam immediately behind the nose gear.

- A new electronic countermeasures (ECM) suite that included the lower rear fuselage mounted AN/ALE-40 chaff/flares dispenser.

- Radar Warning Receiver (RWR) antennae on the rear tailcone and forward wingtips.

- Deletion of the nose mounted oblique combat camera and its associated bulged housing.

The F95 oblique combat camera and its view port installation are still on 158966. A small, swiveling weathervane (missing here) is normally installed atop the small post directly ahead of the cockpit. This is used as a reference for the pilot to hold the Harrier's nose into the wind during hovering flight. (Bill Upton Photo)

Aircraft 158966 was in its original AV-8A configuration still carrying the black subdued, (low visibility) camouflage and markings of the last unit it operationally served with, VMA-231 (CG-09), "Ace of Spades", upon reception at the National Aviation Museum (NAM) in Ottawa, Ontario.

AMARC Preservation

The Marine Corps began to retire some of its fleet of AV-8A aircraft in mid-1985, and *Harrier* 158966, with a total accumulation of 2,917 flight hours, was one of the first of its type to be preserved. It was sealed with white Spraylat material and put into extended storage at the vast AMARC facilities located next to Davis-Monthan AFB, in Tucson. Arriving on 15 August 1985, 158966 obtained the AMARC inventory or park code number 7A001, which was stenciled in white on the nose and rear fuselage of the aircraft.

National Aviation Museum Acquisition

The tale of how the AV-8A *Harrier* came to Ottawa originated on 21 October 1993 during a rare visit to Canada by the famed Royal Air Force aerobatic team, the *Red Arrows*. The *Red Arrows* were flying the British Aerospace *Hawk* trainers at the time, aircraft that Canada was considering for use in its own training fleet, to possibly replace the venerable Canadair CT-114 *Tutor* in the Canadian Armed Forces. What began as an off-the-cuff remark by Sir Patrick Hine, then Chairman of British Aerospace, to Christopher Terry, Director General of the National Aviation Museum, stating that a *Harrier* would be an excellent addition to the Museum's collection, eventually launched a four year collaborative effort involving BAe, its partners, and the US government.

Having been carefully disassembled and prepared for shipment by the experienced AMARC personnel at Davis-Monthan AFB on 16 June 1997, and coordinated through the Naval Inventory Control Point in Philadelphia, *Harrier* 158966 arrived at the NAM via three flatbed trucks on 23 June 1997.

The rather shabby looking USMC AV-8A Harrier fuselage rests atop its transport pallet upon arrival at the NAM. (CAvM Photo 35-72-03)

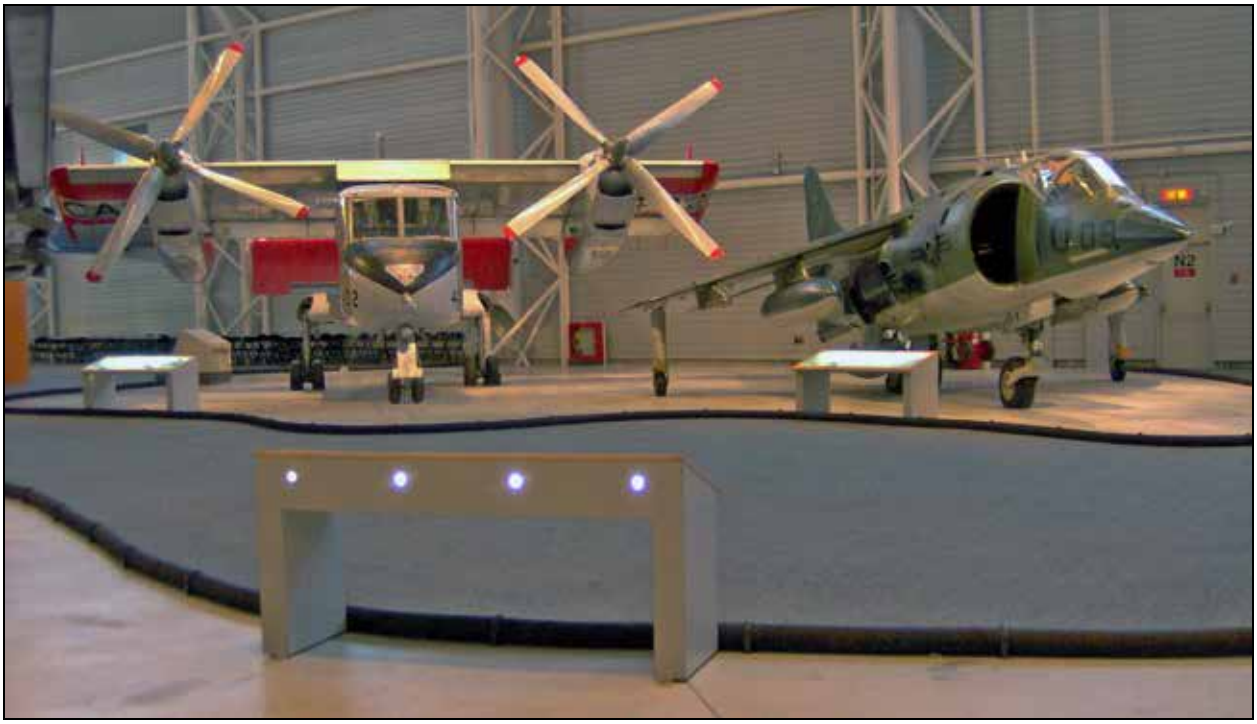
The aft fuselage of Harrier 158966 still bears witness to its former park code number when it was stored at the AMARC. (CAvM Photo 35-65-20)

The skilled staff of the NAM gently lowers the complete wing assembly onto the fuselage of 158966 in July 1997. Such a technique permits complete access to the engine for ease of removal or maintenance as necessary. (CAvM Photo 35-66-22)

By 3 September 1997, aircraft 158966 was nearing completion, with the wings and empennage mated, and was just about ready for some paintshop work. Remnants of the original squadron markings are still visible. (CAvM Photo 32994)

The newly rebuilt and resplendent AV-8A *Harrier* made its debut on display at the NAM, comfortably nestled appropriately within the Museum's Naval Island area during acceptance ceremonies conducted on 5 October 1997. Unveiled in a ribbon cutting ceremony by the Museum's Director, Christopher Terry, the acquisition of this aircraft from the US Navy was made possible in large part by British Aerospace, Rolls-Royce, Smiths Industries and the United States government.

The general public had its first viewing of this new aircraft on 7 October. This NAM exhibit was particularly notable as being the first military aircraft exhibit acquired for the Museum's collection bearing United States national markings. Wearing the standard lo-viz camouflage scheme of the type, it bears the squadron markings of United States Marine Corps VMA-231, with the tail code "CG" and the modex number "09" on the nose. The distinctive "Ace of Spades" squadron insignia adorns the sides of the nose below the cockpit. The aircraft had been assigned specifically to Captain G.F. Leblanc USMC, and per US Navy / Marine Corps tradition, his name is stenciled below the cockpit sill. Captain Leblanc had also been assigned the callsign "Bone" by his squadron mates, also per longtime naval aviator tradition.



On long-term loan from the USMC, AV-8A Harrier 158966 resides in the renamed Canada Aviation Museum (CAvM) setting apropos for the type in 2006, next to another significant V/STOL aircraft that played an important part in the development of later Harrier variants. That is the second Canadair CX-84 V/STOL tilt-wing aircraft. (Bill Upton Photo)

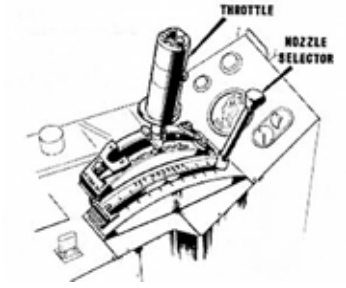
The show stopping and combat maneuvering V/STOL capabilities of the *Harrier* are dependent upon many factors, most notably the powerful Rolls Royce *Pegasus* turbofan engine. The *Pegasus* requires vast amounts of air to produce enough thrust in order to permit the *Harrier* to achieve its top speed and hovering capabilities as evidenced by the massive size of the dual side bell-mouth type air intakes. The ram air effect through the intakes during conventional flight funnels the air to directly feed the engine, however this effect changes dramatically when the aircraft approaches the low speed regime or is stationary in the hover. A single row of auxiliary inlet ducts around the intakes oftentimes simply called blow-in or suction intake doors, aerodynamically open at low speeds to allow supplementary air to feed the engine, which is usually at very high power settings when the aircraft is hovering.

Around the exterior of each intake are a series of fully floating supplementary suction intake doors. A ram air scoop for engine cooling is seen within the 'star' of the national insignia. (Bill Upton Photo)

The compressor fan face of the Pegasus 103 turbofan engine is readily visible in the bulbous port side air intake. The large intake centerbody fairing supports the front part of the engine. (Bill Upton Photo)

Apparently, at some point in the latter days of its USMC flying career, this particular Harrier had suffered a minor birdstrike, as witnessed by the little white seagull painted below the LH cockpit windscreen. On closer inspection, one can spot the related damage sustained to at least one of the low-pressure titanium compressor blades as seen in the photo at right through the aircraft's starboard bell mouth-shaped air intake. After a thorough cleaning and a detailed inspection process, the blade damages had been carefully blended and polished out per strict stress engineering specifications in order to permit continued - but most probably limited - flying. (Bill Upton Photos)

Attached to the unique *Pegasus* engine are twin sets of mechanically linked, swiveling exhaust nozzles on the sides of the aircraft that constitute the principal of the thrust-vectoring system. The four rotating nozzles, with directional louvers, direct the efflux, via the pilot's direct control inputs to the Nozzle Lever on the Throttle Box, to the desired direction of the thrust vector. A Throttle Lever on the Throttle Box controls the engine speed and hence the length of the thrust vector. The nozzles can be rotated from full aft, for STOL and conventional flight, up to 100 degrees for VTOL, hover and even backwards flight. In order to eliminate any undesirable gyroscopic effects generated by the rotating components of the engine while the aircraft is hovering, the two fan and compressor stages of the *Pegasus* engine rotate in opposite directions on concentric shafts. The low-pressure compressor side of the engine passes a relatively cool (110°C / 220°F) exhaust from the forward set of nozzles while the hot (680°C / 1200°F) turbine high-pressure air exhaust exits via the two rear nozzles.

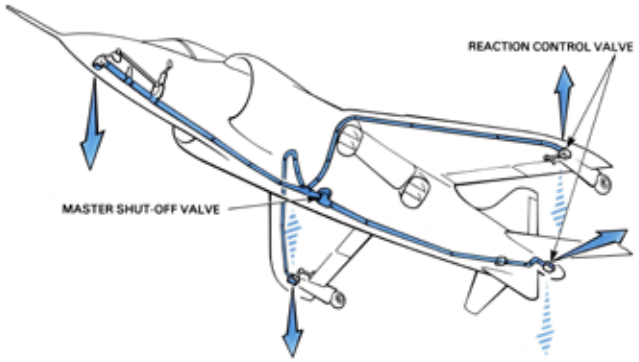


Although the exterior of the Museum's AV-8A *Harrier* is physically complete, unfortunately the cockpit layout is not. Some dials and gauges are missing from the main instrument cluster and, most notably, the entire Throttle Box assembly, was not provided for at its location on the left forward side control panel.

An angle of rotation index reference marking is seen on the forward (cool) starboard engine exhaust nozzle. This would align with the fuselage's black angle indicator lines as the pilot selects a required thrust vector angle thus rotating the nozzles in symmetry. Seemingly impossible rearward transitions of the aircraft during level flight are possible when all of the exhaust nozzles are rotated forward on the Throttle Box by the pilot to the 98-degree markings. (Bill Upton Photo)

The interior of the engine compartment as seen through the Harrier's two starboard exhaust nozzles shows the engine's (hot) last stage low-pressure turbine blades in the photo at left with the louvered rear portside exhaust nozzle visible beyond. Dessicant packs are on the floor of the relatively clean bifurcated exhaust pipe. In the photo at right is the Pegasus engine's combustion chamber assembly (centered), with some intake air ducting at far right (nearest the camera) as seen via the (cool) forward exhaust duct. (Dave Moryas Photos for Bill Upton)

Another unique design characteristic of the AV-8 *Harrier* are the small pitch, roll and yaw Reaction Control Valve (RCV) thrusters (oftentimes simply called “puffers” or “puffer ducts”) located on the nose, wingtips and tailcone of the aircraft. These thrusters supplement the normal aerodynamic controls of the airplane, which become ineffective when the aircraft is in the hover or in the low-speed flight regimes.



The Reaction Control System (RCS) bleeds high-pressure air from the engine and ducts it to the RCV thrusters once the exhaust nozzles are rotated from the horizontal position. The pilot’s normal control inputs to the stick and rudder pedals are redirected from the normal aerodynamic control surfaces and dictate the operation of the associated RCV thruster, thereby controlling minute changes in the aircraft’s attitude while in the hover.

RCS SYSTEM OF USMC AV-8A *Harrier* BuNo. 158966

Under the nose RCV pitch control nozzle installation. (Bill Upton Photo)

Tailcone RCV pitch and yaw (each side) control nozzles. (Bill Upton Photo)

The port upper wing RCV roll control nozzle. (Bill Upton Photo)

Port lower wing RCV roll control nozzle. (Bill Upton Photo)

Hawker Siddeley test and varied military service pilots exploited and further developed the technique of Vectoring in Forward Flight (VIFF) or “VIFFing”, following on from trials conducted previously in January 1970 with the XV-6A *Kestrel* aircraft at the NASA Langley Research Center. Some of the early simulated combat flying was conducted against Northrop T-38 *Talon* trainers. The developed tactics of the VIFF technique consisted of employing the rapid rotation of the engine exhaust nozzles to decelerate the aircraft rapidly. Along with the RCV ‘puffer’ system thruster jets, the pilot could also conduct a sharp turn in a small radius as a means to impart unique and unprecedented air combat maneuverability (ACM) capabilities to the V/STOL aircraft. The USMC had evaluated the AV-8A *Harrier’s* ACM capability against McDonnell F-4 *Phantoms* during training exercises with VMA-513 pilots that were conducted at NAS Point Mugu and NAS China Lake, in California during 1972. At roughly the same time, similar VIFF evaluation trials were performed by US and British pilots at RAF *Valley*, with the AV-8A flying ground attack manoeuvres and simulated dogfighting missions against an RAF *Phantom*, a Hawker *Hunter* and a RAF English Electric *Lightning*. Stories also abound about some Royal Air Force and Royal Navy *Harriers* reportedly having employed the VIFF technique during some of the air-to-air combat encounters in the early days of the 1982 Falklands conflict in the Atlantic.

The ultimate fate of a lucky few AV-8A aircraft, BuNo 158695 WF 00 of VMA-513 at MCAS Yuma, 1990 (Bill Upton Photo)

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