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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

Ex parte ANTHONY C. JONES, PATRICK M. LYDON, NAGAMANY THAYALAKHANDAN, and ERIC J. ALEXANDER

Appeal 2019-003085
Application 14/774,933
Technology Center 3700

Before MICHAEL J. FITZPATRICK, WILLIAM A. CAPP, and ARTHUR M. PESLAK, *Administrative Patent Judges*.

CAPP, Administrative Patent Judge.

DECISION ON APPEAL

STATEMENT OF THE CASE

Appellant[1] seeks our review under 35 U.S.C. § 134(a) of the final rejection of claims 1, 3–7, and 9–12 as unpatentable under 35 U.S.C. § 103 over Marchant (US 3,056,258, iss. Oct. 2, 1962). We have jurisdiction under 35 U.S.C. § 6(b).

We REVERSE.

[1] We use the word "Appellant" to refer to "Applicant" as defined in 37 C.F.R. § 1.42(a). Appellant identifies United Technologies Corporation as the Applicant and real party in interest. Appeal Br. 1.

THE INVENTION

Appellant's invention relates to jet engine propulsion for relatively small, unmanned aircraft. Spec. ¶¶ 2–7. Claim 7, reproduced below, is illustrative of the subject matter on appeal.

> 7. An aircraft comprising:
>
> a fuselage including at least two scoop inlets for delivering inlet air to an included gas turbine engine;
>
> said gas turbine engine including a nose cone including a nose cone upstream end, and
>
> an inlet housing including at least two separate flow paths at a housing upstream end which is downstream of said nose cone upstream end, said inlet housing including a mixing portion downstream of the housing upstream end which mixes airflow from the separate flow paths; and
>
> a rotor and a turbine driving a shaft to drive the rotor, with said shaft including a bearing mounted at a location downstream of said nose cone upstream end;
>
> wherein the airflow in the mixing portion generally surrounds 360 degrees of a rotational axis of the gas turbine engine; and
>
> wherein said gas turbine engine is a miniature gas turbine engine.

OPINION

Claim 7

The Examiner finds that Marchant discloses the invention substantially as claimed except for the size limitation, *i.e.*, "miniature." Final Action 4–7. The Examiner concludes that it would have been obvious to a person of ordinary skill in the art at the time the invention was made to miniaturize Marchant's engine. *Id.* 4–5. According to the Examiner, a miniaturized version of Marchant's engine would not perform differently than the full size version known in the prior art, and, therefore, is not patentably distinct. *Id.* at 5.

Appellant argues that Marchant discloses a "large" aircraft with a "very large and powerful gas turbine engine." Appeal Br. 2. Appellant also emphasizes that Marchant discloses a nozzle structure that differs from the typical configuration of aircraft that use miniature engines. *Id.* ("Marchant discloses a system having moveable nozzles to provide lift, or forward thrust"). *Id.*

> These nozzles are <u>why</u> Marchant has its inlet. One would not include the inlet in an engine that does not need the nozzles.
>
> A pilot would not be on an aircraft powered by a miniature gas turbine engine, (and certainly not one of the very limited thrust and size as set forth in the dependent claims). The entire function of Marchant and its nozzles is what provides the inlet that the Examiner points to. There is no showing why any of these features would translate into a "miniature" engine.

Id. at 3.

In response, the Examiner criticizes Appellant for relying on the Figure 3 embodiment of Marchant, which the Examiner states is different from the embodiment used in the rejection. Ans. 7. However, the Examiner's position cannot withstand scrutiny. Ans. 7. The identity and location of nozzles 23a, 23b, 28a, and 28b are all depicted and described in the embodiment of Marchant relied on by the Examiner. *See* Marchant, Figs. 1, 2, col. 2, ll. 12–59.

With respect to the size issue, the Examiner states:

> Examiner wishes to again make Appellant aware that where the only difference between the prior art and the claims is a recitation of relative dimensions of the claimed device and a device having the claimed relative dimensions would not

> perform differently than the prior art device, the claimed device is not patentably distinct from the prior art device.

Ans. at 7–8 (citing *Gardner v. TEC Systems, Inc.*, 725 F.2d 1338 (Fed. Cir. 1984).

In reply, Appellant argues that there would be no reason to include Marchant's complex nozzle structure in an engine with the low thrust of a miniature engine. Reply Br. 1.

Marchant is directed to an aircraft propulsion system that is configured to provide vectored thrust in a manner that can provide both lift and forward thrust. Marchant, col. 2, ll. 39–44. In order to provide this feature, Marchant's engine exhibits four primary nozzles. *Id.* col. 2, ll. 12–38, Figs. 1–2. Two nozzles (28a, 28b) are positioned downstream of the turbine section of the engine where they eject heated air that has been expanded through a combustor section and then passed through the turbine section. *Id.* The other two nozzles (23a, 23b) are disposed near the forward wing root of the aircraft. *Id.* The forward two nozzles eject an airstream from "additional" compressor 21. *Id.* Additional compressor 21 is spaced apart from the traditional components of a turbojet engine which comprise compressor section 17, combustion section 25 and turbine section 14. *Id.* Thus, Marchant employs two different compressor sections upstream of its combustor. The first compressor compresses air just prior to entering the combustor. The second or "additional" compressor provides vertically directed thrust to generate lift. The Examiner's finding of an inlet housing and separate flow paths relate to the fact that Marchant's engine requires separate inlets that skirt the "additional" compressor and then mix downstream thereof before entering the first compressor. Final Action 4.

Marchant's engine is equipped with various articulated torque transmission shafts, servos, and gearing to facilitate rotation of the nozzles from a downward direction, where engine thrust can produce lift to a rearward facing direction, where engine thrust can generate forward propulsion of the aircraft. *Id.* col. 3, ll. 3–23. When airborne at speeds that are less than sufficient to sustain aerodynamic lift over the aircraft wings and directional control over the various control surfaces (ailerons, elevators, etc.), pitch and roll control of the aircraft is maintained by auxiliary jet nozzles 46a, 46b, and 47 disposed near the wing tips and tail respectively. *Id.* col. 3, 24–34. Thus, Marchant's engine ejects various heated and unheated streams of gaseous fluid from not less than seven nozzles dispersed from wing root to tail and wingtip to wingtip of the aircraft.

Marchant is assigned to Bristol Siddeley Engines Limited of the United Kingdom. Marchant, p. 1. Persons familiar with military aviation will recognize Marchant's engine as related to the famous Hawker Siddeley Harrier "jump jet" aircraft that saw service in the Falkland Islands War.[2] The Harrier is perhaps the best known example of an operational Vertical Take Off and Landing (VTOL) aircraft.[3] Early versions of the Pegasus engine that powered the Harrier were rated at 9,000 lbs. of thrust.[4] Later versions of the Pegasus engine generated almost 24,000 lbs. of thrust.[5] The

[2] *See e.g.*, *https://en.wikipedia.org/wiki/Hawker_Siddeley_Harrier* (accessed 12/5/2019) (hereinafter "Harrier.") *See* Appendix "A" attached hereto.

[3] An American version of the Harrier was popularized in the *circa* 1994 movie "True Lies" starring Arnold Schwarzenegger and Jamie Lee Curtis.

[4] Harrier, p. 3.

[5] *Id.* p. 6.

Harrier had an empty weight of about 13,500 lbs., which allowed the Harrier to achieve vertical takeoffs and landings with a payload of about 10,000 lbs. in armament and fuel.

The Examiner concludes that it would have been obvious to reduce the dimensions of Marchant to make a "miniature" jet engine. Final Action 4–5. Miniature gas turbine engines are defined in Appellant's Specification as engines that supply 180 lbs. of thrust or less and have an axial length of less than 15 inches. Spec. ¶ 4. Miniature engines are used in unmanned aerial vehicles such as missiles or drones. *Id.*

The Examiner's conclusion that it would have been obvious to miniaturize Marchant's engine is based solely on the general legal principle espoused in the *Gardner* case, namely, that recitation of a relative dimension does not patentably distinguish over the prior art where the claimed dimension would not perform differently than the prior art device. Final Action 5 (citing *Gardner*, *supra*). The *Gardner* case involved an appeal to the Federal Circuit of a patent lawsuit tried before the Eastern District of Wisconsin. *Gardner*, 725 F.2d at 1338. During trial, the District Court received detailed evidence consisting of prior art, expert testimony, and test results. *Id.* at 1341–49. In *Gardner*, the patent challenger (TEC) was assigned the burden of proving that the claimed relative dimensions did not result in a performance difference vis-à-vis the prior art. *Id.* at 1345. On review of the District Court's findings, the Federal Circuit summarized the crux of the case in the following terms.

> If we are to agree with the trial court, we must have from it a finding supported by the record that TEC proved by clear and convincing evidence that a Gardner air bar coming within the claims of the '447 patent is not in any significant respect different from similar devices available in the prior art because

> structural differences over the prior art do not necessarily result in differences in performance over the prior art.

Id. at 1345–46. In applying the appropriate deferential standard on appellate review to findings of fact of the District Court, the Federal Circuit determined that:

> The trial court would not have been clearly erroneous in concluding that the dimensional limitations did not specify a device which performed and operated any differently from the prior art. Its decision therefore stands.

Id. at 1349.

Although the Examiner cites to a correct statement of law regarding relative dimensions, we are cognizant that we are sitting as the Board reviewing a decision by an Examiner. In the context of our proceedings, the Examiner bears the initial burden of putting forth a prima facie case of obviousness. *In re Giannelli*, 739 F.3d 1375, 1379 (Fed. Cir. 2014).

> The Patent Office has the initial duty of supplying the factual basis for its rejection. It may not, because it may doubt that the invention is patentable, resort to speculation, unfounded assumptions or hindsight reconstruction to supply deficiencies in its factual basis . . . we may not resolve doubts in favor of the Patent Office determination when there are deficiencies in the record as to the necessary factual bases supporting its legal conclusion of obviousness.

In re Warner, 379 F.2d 1011, 1017 (CCPA 1967). Only when a prima facie case of obviousness has first been made does the burden shift to Appellant to come forward with evidence and/or argument supporting patentability. *Giannelli*, 739 F.3d at 1379. We then perform our review of the Examiner's rejection based on the standard of a preponderance of the evidence. *See In re Caveny*, 761 F.2d 671, 674 (Fed.Cir. 1985) (explaining that preponderance of the evidence is the standard that must be met by the PTO in making rejections).

With the foregoing in mind, we look to the record for evidence or technical reasoning to support the Examiner's finding that miniaturizing Marchant would not result in different performance. Final Action 5. The closest thing to evidence from the Examiner that we can find on the subject is the following statement:

> Examiner is unable to determine from Appellant's arguments a compelling reason as to why the nozzle structure could not be miniaturized with the rest of the engine.

Ans. 7–8. An Examiner's inability to determine a compelling reasoning "why not" does not rise to the level of evidentiary support for a finding of fact. *Warner*, 379 F.2d at 1017. Given the facts and circumstances of this particular case, the foregoing statement from page 7 of the Answer is insufficient to support the Examiner's findings of fact.

Reducing the size of the Marchant/Harrier engine to a "miniature" turbine engine size would have entailed a reduction of two orders of magnitude, i.e., from about 18,000 lbs. of thrust to about 180 lbs. of thrust. Claim 7 requires both an aircraft and an aircraft engine. Claims App. Thus, the miniaturization process with respect to claim 7, would require a size reduction of both an aircraft and an engine. Unlike the *Gardner* case relied on by the Examiner, there is no evidence in the record before us by which we can reliably determine that a reduction in both physical size of the engine and a 99 percent reduction in rated thrust would not result in a performance difference with respect to the engine or the aircraft. In particular, in view of a lack of persuasive evidence on the subject, we consider it highly speculative that a miniaturized version of Marchant's engine and aircraft would have a thrust to weight ratio to lift an aircraft and fuel payload off the ground in a vertical takeoff, a vertical takeoff being the primary reason for providing the aircraft with vectored thrust.

Marchant's engine is particularly lengthy as it entails two different spaced apart compressors. Marchant, Fig. 2. Such added length would pose problems for an engine designer attempting to achieve an engine that is less than 15 inches in length. Furthermore, aircraft design requires delicate balancing of structural strength and weight. Over emphasis on strength tends to add weight that must be overcome with aerodynamic lift, thrust, and fuel consumption. Over emphasis on decreased weight can result in an aircraft that fails structurally when exposed to the forces encountered during flight. We are not persuaded that a *circa* 1960's, manned, VTOL aircraft design lends itself to miniaturization so as to be reasonably applicable to more modern era unmanned cruise missile and drone applications. A person of ordinary skill in the art designing a modern era cruise missile or drone would likely find that the complex and heavy mechanical subsystems necessary for vectoring thrust in the Marchant engine unnecessary and, indeed, undesirable. Missiles generally fly one-way missions and do not need to land, much less land vertically. Drones that are propelled with 180 lb. thrust engines typically do not require lengthy runways for takeoff or landing, hence obviating the need for vectored thrust, VTOL capability.

It is undisputed that miniature engines are known in the prior art. Spec. ¶¶ 28–29, Fig. 2. We are at a loss to understand how or why a person of ordinary skill in the art would miniaturize Marchant in view of what is already known in the art applicable to miniature engines.

In view of the foregoing discussion, we do not sustain the Examiner's unpatentability rejection of claim 7.

Claims 9–12

These claims depend, directly or indirectly, from claim 7. Claims App. The Examiner's rejection of these claims suffers from the same infirmity that was identified above with respect to claim 7. Thus, for essentially the same reason expressed above in connection with claim 7, we do not sustain the rejection of claims 9–12.

Claims 1 and 3–6

Claim 1 is an independent claim that is substantially similar in scope to claim 7 except that claim 1 is directed to just an engine instead of an aircraft. Claims App. Claims 3–6 depend, directly or indirectly, from claim 1. *Id.*

The issues and arguments raised by the Examiner and Appellant with respect to claim 1 are essentially identical to that with respect to claim 7 which we have previously discussed. Appeal Br. 2–4; Ans. 7–9. Essentially for the same reasons previously discussed, we do not sustain the Examiner's rejection of claim 1, nor that of claims 3–6 that depend therefrom.

CONCLUSION

Claims Rejected	**§**	**Reference(s)**	**Affirmed**	**Reversed**
1, 3-6, 7, 9-12	103	Marchant		1, 3-6, 7, 9-12

REVERSED

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Notice of References Cited	Application/Control No. 14/774,933	Applicant(s)/Patent Under Patent Appeal No. 2019-003085	
	Examiner	Art Unit 3745	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
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NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	Appendix A - Hawker Siddeley Harrier
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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Appeal 2019-003085
Application 14/774,933

APPENDIX "A"

WIKIPEDIA

Hawker Siddeley Harrier

The **Hawker Siddeley Harrier** is the first of the Harrier Jump Jet series of aircraft. It was developed in the 1960s as the first operational close-support and reconnaissance fighter aircraft with vertical/short takeoff and landing (V/STOL) capabilities and the only truly successful V/STOL design of the many that arose in that era. The Harrier was developed directly from the Hawker Siddeley Kestrel prototype aircraft, following the cancellation of a more advanced supersonic aircraft, the Hawker Siddeley P.1154. The British Royal Air Force (RAF) ordered the Harrier GR.1 and GR.3 variants in the late 1960s. It was exported to the United States as the AV-8A, for use by the US Marine Corps (USMC), in the 1970s.

During the Harrier's service the RAF positioned the bulk of the aircraft in West Germany to defend against a potential invasion of Western Europe by the Warsaw Pact forces; the unique abilities of the Harrier allowed the RAF to disperse their forces away from vulnerable airbases. The USMC used their Harriers primarily for close air support, operating from amphibious assault ships, and, if needed, forward operating bases. Harrier squadrons saw several deployments overseas. The Harrier's ability to operate with minimal ground facilities and very short runways allowed it to be used at locations unavailable to other fixed-wing aircraft. The Harrier received criticism for having a high accident rate and for a time-consuming maintenance process.

In the 1970s the British Aerospace Sea Harrier was developed from the Harrier for use by the Royal Navy (RN) on *Invincible*-class aircraft carriers. The Sea Harrier and the Harrier fought in the 1982 Falklands War, in which the aircraft proved to be crucial and versatile. The RN Sea Harriers provided fixed-wing air defence while the RAF Harriers focused on ground-attack missions in support of the advancing British land force. The Harrier was also extensively redesigned as the AV-8B Harrier II and British Aerospace Harrier II by the team of McDonnell Douglas and British Aerospace. The innovative Harrier family and its Rolls-Royce Pegasus engines with thrust vectoring nozzles have generated long-term interest in V/STOL aircraft.

Harrier GR.1, GR.3
AV-8A/C Harrier, AV-8S Matador

An AV-8S Matador in flight

Role	V/STOL ground-attack aircraft
National origin	United Kingdom
Manufacturer	Hawker Siddeley
First flight	28 December 1967
Introduction	1 April 1969[1]
Status	Retired (2006)
Primary users	Royal Air Force (historical) United States Marine Corps (historical) Spanish Navy (historical) Royal Thai Navy (historical)
Produced	1967–1970s
Number built	278[2]
Unit cost	£2.5 million to £3.5 million (1975)[3]
Developed from	Hawker Siddeley P.1127/Kestrel
Developed into	British Aerospace Sea Harrier McDonnell Douglas AV-8B Harrier II British Aerospace Harrier II

Contents

Development

Origins

The Harrier's design was derived from the Hawker P.1127. Prior to developing the P.1127 Hawker Aircraft had been working on a replacement for the Hawker Hunter, the Hawker P.1121.[4] The P.1121 was cancelled after the release of the British Government's 1957 Defence White Paper, which advocated a policy shift away from manned aircraft and towards missiles. This policy resulted in the termination of the majority of aircraft development projects then underway for the British military.[5] Hawker sought to quickly move on to a new project and became interested in Vertical Take Off/Landing

(VTOL) aircraft, which did not need runways.[N 1] According to Air Chief Marshal Sir Patrick Hine this interest may have been stimulated by the presence of Air Staff Requirement 345, which sought a V/STOL ground attack fighter for the Royal Air Force.[7]

Design work on the P.1127 was formally started in 1957 by Sir Sydney Camm, Ralph Hooper of Hawker Aircraft, and Stanley Hooker (later Sir Stanley Hooker) of the Bristol Engine Company.[8] The close cooperation between Hawker, the airframe company, and Bristol, the engine company, was viewed by project engineer Gordon Lewis as one of the key factors that allowed the development of the Harrier to continue in spite of technical obstacles and political setbacks.[9] Rather than using rotors or a direct jet thrust, the P.1127 had an innovative vectored thrust turbofan engine, the Pegasus. The Pegasus I was rated at 9,000 pounds (40 kN) of thrust and first ran in September 1959.[10] A contract for two development prototypes was signed in June 1960 and the first flight followed in October 1960.[10] Of the six prototypes built, three crashed, including one during an air display at the 1963 Paris Air Show.[11]

Tripartite evaluation

Hawker Siddeley XV-6A Kestrel in later USAF markings

In 1961 the United Kingdom, United States and West Germany jointly agreed to purchase nine aircraft developed from the P.1127, for the evaluation of the performance and potential of V/STOL aircraft. These aircraft were built by Hawker Siddeley and were designated *Kestrel FGA.1* by the UK.[12] The Kestrel was strictly an evaluation aircraft and to save money the Pegasus 5 engine was not fully developed as intended, only having 15,000 pounds (67 kN) of thrust instead of the projected 18,200 pounds (81 kN).[12] The Tripartite Evaluation Squadron numbered ten pilots; four each from the UK and US and two from West Germany.[12] The Kestrel's first flight took place on 7 March 1964.[13]

A total of 960 sorties had been made during the trials, including 1,366 takeoffs and landings, by the end of evaluations in November 1965.[14][15] One aircraft was destroyed in an accident and six others were transferred to the United States, assigned the US designation *XV-6A Kestrel*, and underwent further testing.[16][17][18] The two remaining British-based Kestrels were assigned to further trials and experimentation at RAE Bedford with one being modified to use the uprated Pegasus 6 engine.[19]

P.1154

At the time of the development of the P.1127 Hawker and Bristol had also undertaken considerable development work on a supersonic version, the Hawker Siddeley P.1154, to meet a North Atlantic Treaty Organisation (NATO) requirement issued for such an aircraft.[20] The design used a single Bristol Siddeley BS100 engine with four swivelling nozzles, in a fashion similar to the P.1127, and required the use of plenum chamber burning (PCB) to achieve supersonic speeds.[21] The P.1154 won the competition to meet the requirement against strong competition from other aircraft manufacturers such as Dassault Aviation's Mirage IIIV. The French government did not accept the decision and withdrew; the NATO requirement was cancelled shortly after in 1965.[22][N 2]

The Royal Air Force and the Royal Navy planned to develop and introduce the supersonic P.1154 independently of the cancelled NATO requirement. This ambition was complicated by the conflicting requirements between the two services—while the RAF wanted a low-level supersonic strike aircraft, the Navy sought a twin-engine air defence fighter.[24] Following the election of the Labour Government of 1964 the P.1154 was cancelled, as the Royal Navy had already begun procurement of the McDonnell Douglas Phantom II and the RAF placed a greater importance on the BAC TSR-2's ongoing development.[24] Work continued on elements of the project, such as a supersonic PCB-equipped Pegasus engine, with the intention of developing a future Harrier variant for the decades following cancellation.[25][N 3]


AV-8C Harrier taking off from an amphibious transport dock ship

Production

Following the collapse of the P.1154's development the RAF began considering a simple upgrade of the existing subsonic Kestrel and issued Requirement ASR 384 for a V/STOL ground attack jet.[24] Hawker Siddeley received an order for six pre-production aircraft in 1965, designated *P.1127 (RAF)*, of which the first made its maiden flight on 31 August 1966.[27] An order for 60 production aircraft, designated as Harrier GR.1, was received in early 1967.[28][29] The aircraft was named after the Harrier, a small bird of prey.

The Harrier GR.1 made its first flight on 28 December 1967. It officially entered service with the RAF on 1 April 1969[30] and the Harrier Conversion Unit at RAF Wittering received its first aircraft on 18 April.[31] The aircraft were built in two factories—one in Kingston upon Thames, southwest London, and the other at Dunsfold Aerodrome, Surrey—and underwent initial testing at Dunsfold.[32] The ski-jump technique for launching Harriers from Royal Navy aircraft carriers was extensively trialled at RNAS Yeovilton from 1977. Following these tests ski-jumps were added to the flight decks of all RN carriers from 1979 onwards, in preparation for the new variant for the navy, the Sea Harrier.[33][34]

In the late 1960s the British and American governments held talks on producing Harriers in the United States. Hawker Siddeley and McDonnell Douglas formed a partnership in 1969 in preparation for American production,[35] but Congressman Mendel Rivers and the House Appropriations Committee held that it would be cheaper to produce the AV-8A on the pre-existing production lines in the United Kingdom—hence all AV-8A Harriers were purchased from Hawker Siddeley.[35] Improved Harrier versions with better sensors and more powerful engines were developed in later years.[36][37][38] The USMC received 102 AV-8A and 8 TAV-8A Harriers between 1971 and 1976.[39]

Design

Overview

The Harrier was typically used as a ground attack aircraft, though its manoeuvrability also allows it to effectively engage other aircraft at short ranges.[40] The Harrier is powered by a single Pegasus turbofan engine mounted in the fuselage. The engine is fitted with two air intakes and four vectoring nozzles for directing the thrust generated: two for the bypass flow and two for the jet exhaust. Several small reaction nozzles are also fitted, in the nose, tail and wingtips, for the purpose of balancing during vertical flight.[41] It has two landing gear units on the fuselage and two outrigger landing gear units, one near each wing tip.[42] The Harrier is equipped with four wing and three fuselage pylons for carrying a variety of weapons and external fuel tanks.[43]

The Kestrel and the Harrier were similar in appearance, though approximately 90 per cent of the Kestrel's airframe was redesigned for the Harrier.[44] The Harrier was powered by the more powerful Pegasus 6 engine; new air intakes with auxiliary blow-in doors were added to produce the required airflow at low speed. Its wing was modified to increase area and the landing gear was strengthened. Several hardpoints were installed, two under each wing and one underneath the fuselage; two 30 mm (1.2 in) ADEN cannon gun pods could also be fitted to the underside of the fuselage. The Harrier was outfitted with updated avionics to replace the basic systems used in the Kestrel;[N 4] a navigational-attack system


An RAF Harrier GR.1, on loan to the USMC, displaying its underside with a full load of bombs

incorporating an inertial navigation system, originally for the P.1154, was installed and information was presented to the pilot by a head-up display and a moving map display.[46][47]

The Harrier's VTOL abilities allowed it to be deployed from very small prepared clearings or helipads as well as normal airfields.[N 5] It was believed that, in a high-intensity conflict, air bases would be vulnerable and likely to be quickly knocked out.[N 6] The capability to scatter Harrier squadrons to dozens of small "alert pads" on the front lines was highly prized by military strategists and the USMC procured the aircraft because of this ability.[50][N 7] Hawker Siddeley noted that STOL operation provided additional benefits over VTOL operation, saving fuel and allowing the aircraft to carry more ordnance.[52]

> "I still don't believe the Harrier. Think of the millions that have been spent on VTO in America and Russia, and quite a bit in Europe, and yet the only vertical take-off aircraft which you can call a success is the Harrier. When I saw the Harrier hovering and flying backwards under control, I reckoned I'd seen everything. And it's not difficult to fly." -Thomas Sopwith[53]

The Harrier, while serving for many decades in various forms, has been criticised on multiple issues; in particular a high accident rate, though Nordeen notes that several conventional single-engine strike aircraft like the Douglas A-4 Skyhawk and LTV A-7 Corsair II had worse accident rates.[54] The *Los Angeles Times* reported in 2003 that the Harrier "...has amassed the highest major accident rate of any military plane now in service. Forty-five Marines have died in 148 noncombat accidents".[55] Colonel Lee Buland of the USMC declared the maintenance of a Harrier to be a "challenge"; the need to remove the wings before performing most work upon the engine, including engine replacements, meant the Harrier required considerable man-hours in maintenance, more than most aircraft. Buland noted however that the maintenance difficulties were unavoidable in order to create a V/STOL aircraft.[56]

Engine


Rolls-Royce Pegasus engine on display, sections have been cut out to provide an internal view

The Pegasus turbofan jet engine, developed in tandem with the P.1127 then the Harrier, was designed specifically for V/STOL manoeuvring. Bristol Siddeley developed it from their earlier conventional Orpheus turbofan engine as the core with Olympus compressor blades for the fan. The engine's thrust is directed through the four rotatable nozzles.[57] The engine is equipped for water injection to increase thrust and takeoff performance in hot and high altitude conditions; in normal V/STOL operations the system would be used in landing vertically with a heavy weapons load.[58] The water injection function had originally been added following the input of US Air Force Colonel Bill Chapman, who worked for the Mutual Weapons Development Team.[59] Water injection was necessary in order to generate maximum thrust, if only for a limited time, and was typically used during landing, especially in high ambient temperatures.[56]

The aircraft was initially powered by the Pegasus 6 engine which was replaced by the more powerful Pegasus 11 during the Harrier GR.1 to GR.3 upgrade process.[60] The primary focus throughout the engine's development was on achieving high performance with as little weight as possible,[60] tempered by the amount of funding that was available.[12] Following the

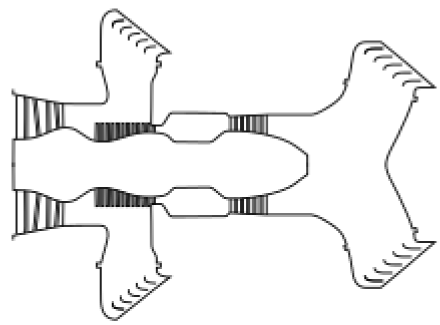
Harrier's entry to service the focus switched to improving reliability and extending engine life;[58] a formal joint US–UK Pegasus Support Program operated for many years and spent a £3-million annual budget to develop engine improvements.[60] Several variants have been released; the latest is the Pegasus 11–61 (Mk 107), which provides 23,800 lbf (106 kN) thrust, more than any previous engine.[61]

Controls and handling

Thrust vectoring nozzle on a Sea Harrier

The Harrier has been described by pilots as "unforgiving".[62] The aircraft is capable of both forward flight (where it behaves in the manner of a typical fixed-wing aircraft above its stall speed), as well as VTOL and STOL manoeuvres (where the traditional lift and control surfaces are useless) requiring skills and technical knowledge usually associated with helicopters. Most services demand great aptitude and extensive training for Harrier pilots, as well as experience in piloting both types of aircraft. Trainee pilots are often drawn from highly experienced and skilled helicopter pilots.[N 8][13]

In addition to normal flight controls, the Harrier has a lever for controlling the direction of the four vectoring nozzles. It is viewed by senior RAF officers as a significant design success, that to enable and control the aircraft's vertical flight required only a single lever added in the cockpit.[63] For horizontal flight, the nozzles are directed rearwards by shifting the lever to the forward position; for short or vertical takeoffs and landings, the lever is pulled back to point the nozzles downwards.[64][65]



Locations of the four nozzles on the aircraft

The Harrier has two control elements not found in conventional fixed-wing aircraft: the thrust vector and the reaction control system. The thrust vector refers to the slant of the four engine nozzles and can be set between 0° (horizontal, pointing directly backwards) and 98° (pointing down and slightly forwards). The 90° vector is normally deployed for VTOL manoeuvring. The reaction control is achieved by manipulating the control stick and is similar in action to the cyclic control of a helicopter. While irrelevant during forward flight mode, these controls are essential during VTOL and STOL manoeuvres.[66]

The wind direction is a critical factor in VTOL manoeuvres. The procedure for vertical takeoff involves facing the aircraft into the wind. The thrust vector is set to 90° and the throttle is brought up to maximum, at which point the aircraft leaves the ground. The throttle is trimmed until a hover state is achieved at the desired altitude.[52] The short-takeoff procedure involves proceeding with normal takeoff and then applying a thrust vector (less than 90°) at a runway speed below normal takeoff speed; usually the point of application is around 65 knots (120 km/h). For lower takeoff speeds the thrust vector is greater.[63] The reaction control system involves a thrusters at key points in the aircraft's fuselage and nose, also the wingtips. Thrust from the engine can be temporarily syphoned to control and correct the aircraft's pitch and roll during vertical flight.[67]

Rotating the vectored thrust nozzles into a forward-facing position during normal flight is called vectoring in forward flight, or "VIFFing". This is a dog-fighting tactic, allowing for more sudden braking and higher turn rates. Braking could cause a chasing aircraft to overshoot and present itself as a target for the Harrier it was chasing, a combat technique formally developed by the USMC for the Harrier in the early 1970s.[68][69]

Differences between versions

The two largest users of the Harrier were the Royal Air Force and the United States Marine Corps (USMC). The exported model of the aircraft operated by the USMC was designated the AV-8A Harrier, which was broadly similar to the RAF's Harrier GR.1.[70] Changes included the removal of all magnesium components, which corroded quickly at sea, and the integration of American radios and Identification Friend or Foe (IFF) systems; furthermore the outer pylons, unlike the RAF aircraft, were designed from delivery to be equipped with self-defence AIM-9 Sidewinder heat-seeking air-to-air missiles.[39] Most of the AV-8As had been delivered with the more powerful Pegasus engine used in the GR.3 instead of the one used in the earlier GR.1.[70] Two-seat Harriers were operated for training purposes; the body was stretched and a taller tail fin added.[71] The RAF trained in the T.2 and T.4 versions, while T.4N and T.8 were training versions the Navy's Sea Harrier, with appropriate fittings.[72] The US and Spain flew the TAV-8A and TAV-8S, respectively.[73][74]

All RAF GR.1s and the initial AV-8As were fitted with the Ferranti FE541 inertial navigation/attack suite, but these were replaced in the USMC Harriers by a simpler Interface/Weapon Aiming Computer to aid quick turnaround between missions. The Martin-Baker ejection seats were also replaced by the Stencel SEU-3A in the American aircraft.[75][76] The RAF had their GR.1 aircraft upgraded to the GR.3 standard, which featured improved sensors, a nose-mounted laser tracker, the integration of electronic countermeasure (ECM) systems and a further upgraded Pegasus Mk 103.[36][37] The USMC upgraded their AV-8As to the AV-8C configuration; this programme involved the installation of ECM equipment and adding a new inertial navigation system to the aircraft's avionics. Substantial changes were the Lift Improvement Devices, to increase VTOL performance; at the same time several airframe components were restored or replaced to extend the life of the aircraft.[38] Spain's Harriers, designated AV-8S or VA.1 Matador for the single-seater and TAV-8S or VAE.1 for the two-seater, were almost identical to USMC Harriers differing only in the radios fitted.[77]

The Royal Navy's Fleet Air Arm (FAA) operated a substantially modified variant of the Harrier, the British Aerospace Sea Harrier. The Sea Harrier was not intended for ground-attack duties and, unlike the standard Harrier, was equipped with radar and Sidewinder missiles for air combat duties and fleet air defence.[N 9] The Sea Harrier was also fitted with navigational aids for carrier landings, modifications to reduce corrosion and a raised bubble-canopy for greater visibility.[78][79] The aircraft were later equipped to use AIM-120 AMRAAM beyond-visual-range anti-aircraft missiles and the more advanced Blue Vixen radar for longer range air-to-air combat, as well as Sea Eagle missiles for conducting anti-ship missions.[80]

The McDonnell Douglas AV-8B Harrier II is the latest Harrier variant, a second-generation series to replace the first generation of Harrier jets already in service; all the above variants of the Harrier have mainly been retired with the Harrier II taking their place in the RAF, USMC and FAA. In the 1970s the United Kingdom considered two options for replacing their existing Harriers: joining McDonnell Douglas (MDD) in developing the BAE Harrier II, or the independent development of a "Big Wing" Harrier. This proposal would have increased the wing area from 200 to 250 square feet (19 to 23 m^2), allowing for significant increases in weapons load and internal fuel reserves.[81] The option of cooperation with MDD was chosen in 1982 over the more risky isolated approach.[82]

Operational history

Royal Air Force

The first RAF squadron to be equipped with the Harrier GR.1, No. 1 Squadron, started to convert to the aircraft at RAF Wittering in April 1969.[24][83] An early demonstration of the Harrier's capabilities was the participation of two aircraft in the *Daily Mail* Transatlantic Air Race in May 1969, flying between St Pancras railway station, London and downtown Manhattan with the use of aerial refuelling. The Harrier completed the journey in 6 hours 11 minutes.[84][85] Two Harrier squadrons were established in 1970 at the RAF's air base in Wildenrath to be part of its air force in Germany; another squadron was formed there two years later. In 1977, these three squadrons were moved forward to the air base at Gütersloh, closer to the prospective front line in the event of an outbreak of a European war. One of the squadrons was disbanded and its aircraft distributed between the other two.[86]

A No. 1453 Flight Harrier GR.3 at Stanley Airport in 1984

In RAF service, the Harrier was used in close air support (CAS), reconnaissance, and other ground-attack roles. The flexibility of the Harrier led to a long-term heavy deployment in West Germany as a conventional deterrent and potential strike weapon against Soviet aggression; from camouflaged rough bases the Harrier was expected to launch attacks on advancing armour columns from East Germany.[87] Harriers were also deployed to bases in Norway and Belize, a former British colony.[87] No. 1 Squadron was specifically earmarked for Norwegian operations in the event of war, operating as part of Allied Forces Northern Europe. The Harrier's capabilities were necessary in the Belize deployment, as it was the only RAF combat aircraft capable of safely operating from the airport's short runway;[88] British forces had been stationed in Belize for several years due to tensions over a Guatemalan claim to Belizean territory; the forces were withdrawn in 1993, two years after Guatemala recognized the independence of Belize.[89]

In the Falklands War in 1982, 10 Harrier GR.3s of No. 1 Squadron operated from the aircraft carrier HMS *Hermes*.[90] As the RAF Harrier GR.3 had not been designed for naval service, the 10 aircraft had to be rapidly modified prior to the departure of the task force. Special sealants against corrosion were applied and a new deck-based inertial guidance aid was devised to allow the RAF Harrier to land on a carrier as easily as the Sea Harrier.[91] Transponders to guide aircraft back to the carriers during night-time operations were also installed, along with flares and chaff dispensers.[92]

As there was little space on the carriers, two requisitioned merchant container ships, *Atlantic Conveyor* and *Atlantic Causeway*, were modified with temporary flight decks and used to carry Harriers and helicopters to the South Atlantic.[93] The Harrier GR.3s focused on providing close air support to the ground forces on the Falklands and attacking Argentine positions; suppressing enemy artillery was often a high priority.[94][95] Sea Harriers were also used in the war, primarily conducting fleet air defence and combat air patrols against the threat of attacking Argentine fighters.[93] However, both Sea Harriers and Harrier GR.3s were used in ground-attack missions against the main airfield and runway at Stanley.[96]

If most of the Sea Harriers had been lost, the GR.3s would have replaced them in air patrol duties, even though the Harrier GR.3 was not designed for air defence operations; as such the GR.3s quickly had their outboard weapons pylons modified to take air-to-air Sidewinder missiles.[91] From 10 to 24 May 1982, prior to British forces landing in the Falklands, a detachment of three GR.3s provided air defence for Ascension Island until three F-4 Phantom IIs arrived to take on this responsibility.[97] During the Falklands War, the greatest threats to the Harriers were deemed to be surface-to-air missiles (SAMs) and small arms fire from the ground.[98] In total, four Harrier GR.3s and six Sea Harriers were lost to ground fire, accidents, or mechanical failure.[99] More than 2,000 Harrier sorties were conducted during the conflict—equivalent to six sorties per day per aircraft.[100]

Following the Falklands war, British Aerospace explored the Skyhook, a new technique to operate Harriers from smaller ships. Skyhook would have allowed the launching and landing of Harriers from smaller ships by holding the aircraft in midair by a crane; secondary cranes were to hold weapons for rapid re-arming. This would potentially have saved fuel and allowed for operations in rougher seas.[101] The system was marketed to foreign customers,[N 10] and it was speculated that Skyhook could be applied to large submarines such as the Russian Typhoon class, but the system attracted no interest.[103]

The first generation of Harriers did not see further combat with the RAF after the Falklands War, although they continued to serve for years afterwards. As a deterrent against further Argentine invasion attempts, No. 1453 Flight RAF was deployed to the Falkland Islands from August 1983 to June 1985.[104] However the second generation Harrier IIs saw action in Bosnia, Iraq, and Afghanistan. The first generation Hawker Siddeley airframes were replaced by the improved Harrier II, which had been developed jointly between McDonnell Douglas and British Aerospace.[105]

An RAF Harrier GR.3 in Belize, 1990

United States Marine Corps

The United States Marine Corps began showing a significant interest in the aircraft around the time the first RAF Harrier squadron was established in 1969, and this motivated Hawker Siddeley to further develop the aircraft to encourage a purchase.[107] Although there were concerns in Congress about multiple coinciding projects in the close air support role,[N 11] the Marine Corps were enthusiastic about the Harrier and managed to overcome efforts to obstruct its procurement.[109]

> "In my mind the AV-8A Harrier was like the helicopter in Korea. [It] had limited capability, but that's how the first-generation automobile, boat, or other major systems evolved... it brought us into the world of flexible basing and the Marine Corps into the concept of vertical development"
>
> Major General Joe Anderson.[106]

The AV-8A entered service with the Marine Corps in 1971, replacing other aircraft in the Marines' attack squadrons.[110] The service became interested in performing ship-borne operations with the Harrier. Admiral Elmo Zumwalt promoted the concept of a Sea Control Ship, a 15,000-ton light carrier equipped with Harriers and helicopters, to supplement the larger aircraft carriers of the US Navy. An amphibious assault ship, USS *Guam*, was converted into the *Interim Sea Control Ship* and operated as such between 1971 and 1973 with the purpose of studying the limits and possible obstacles for operating such a vessel.[111][112] Since then the Sea Control Ship concept has been subject to periodic re-examinations and studies, often in the light of budget cuts and questions over the use of supercarriers.[113][114][N 12]

A pair of USMC AV-8A from *VMA-513* in formation flight in 1974.

Other exercises were performed to demonstrate the AV-8A's suitability for operating from various amphibious assault ships and aircraft carriers, including a deployment of 14 Harriers aboard USS *Franklin D. Roosevelt* for six months in 1976.[111] The tests showed, amongst other things, that the Harrier was capable of performing in weather where conventional carrier aircraft could not.[111] In support of naval operations, the USMC devised and studied several methods to further integrate the Harrier. One result was *Arapaho*, a stand-by system to rapidly convert civilian cargo ships into seagoing platforms for operating and maintaining a handful of Harriers, to be used to augment the number of available ships to deploy upon.[116][N 13]

When the reactivation of the *Iowa*-class battleships was under consideration, a radical design for a battleship-carrier hybrid emerged that would have replaced the ship's rear turret with a flight deck, complete with a hangar and two ski jumps, for operating several Harriers. However, the USMC considered the need for naval gunfire support to be a greater priority than additional platforms for carrier operations, while the cost and delay associated with such elaborate conversions was significant, and the concept was dropped.[117][118]

The Marines Corps' concept for deploying the Harriers in a land-based expeditionary role focused on aggressive speed. Harrier forward bases and light maintenance facilities were to be set up in under 24 hours on any prospective battle area. The forward bases, containing one to four aircraft, were to be located 20 miles (32 km) from the forward edge of battle (FEBA), while a more established permanent airbase would be located around 50 miles (80 km) from the FEBA.[119][N 14] The close proximity of forward bases allowed for a far greater sortie rate and reduced fuel consumption.[119]

A pair of USMC AV-8A Harriers refuelling from a Lockheed Martin KC-130 tanker

The AV-8A's abilities in air-to-air combat were tested by the Marine Corps by conducting mock dogfights with McDonnell Douglas F-4 Phantom IIs; these exercises trained pilots to use the vectoring-in-forward-flight (VIFF) capability to outmanoeuvre their opponents and showed that the Harriers could act as effective air-to-air fighters at close range.[68] The success of Harrier operations countered scepticism of V/STOL aircraft, which had been judged to be expensive failures in the past.[120] Marine Corps officers became convinced of the military advantages of the Harrier and pursued extensive development of the aircraft.[121]

Starting in 1979, the USMC began upgrading their AV-8As to the AV-8C configuration—the work focused mainly on extending useful service lives and improving VTOL performance.[38] The AV-8C and the remaining AV-8A Harriers were retired by 1987.[122] These were replaced by the Harrier II, designated as the AV-8B, which was introduced into service in 1985.[123] The performance of the Harrier in USMC service led to calls for the United States Air Force to procure Harrier IIs in addition to the USMC's own plans,[119] but these never resulted in Air Force orders. Since the late 1990s, the AV-8B has been slated to be replaced by the F-35B variant of the Lockheed Martin F-35 Lightning II, a more modern V/STOL jet aircraft.[124]

Like the next generation AV-8Bs, nevertheless, the AV-8A/C Harriers suffered many accidents, with around 40 aircraft lost and some 30 pilots killed during the 1970s and 1980s.[125]

Other operators

A Spanish Navy AV-8S Matador aircraft

Due to the Harrier's unique characteristics it attracted a large amount of interest from other nations, often as attempts to make their own V/STOL jets were unsuccessful, such as in the cases of the American XV-4 Hummingbird and the German VFW VAK 191B.[N 15] Operations by the USMC aboard USS *Nassau* in 1981 and by British Harriers and Sea Harriers in the Falklands War proved that the aircraft were highly effective in combat. These operations also demonstrated that "Harrier Carriers" provided a powerful presence at sea without the expense of big deck carriers.[126][N 16]

Following the display of Harrier operations from small carriers, the navies of Spain and later Thailand bought the Harrier for use as their main carrier-based fixed-wing aircraft.[N 17] Spain's purchase of Harriers was complicated by long-standing political friction between the British and Spanish governments of the era; even though the Harriers were manufactured in the UK they were sold to Spain with the US acting as an intermediary.[130] During tests in November 1972, the British pilot John Farley showed that the wooden deck of *Daedalus* was able to withstand the temperature of the gases generated by the Harrier. Since 1976, the Spanish Navy operated the AV-8S Matador from their aircraft carrier *Dédalo* (formerly the USS *Cabot*); the aircraft provided both air defence and strike capabilities for the Spanish fleet.[131] Spain later purchased five Harriers directly from the British government to replace losses.[132]

Hawker Siddeley aggressively marketed the Harrier for export. At one point the company was holding talks with Australia, Brazil, Switzerland, India and Japan. Of these only India became a customer, purchasing the Sea Harrier.[133] At one point China came very close to becoming an operator of the first generation Harrier. Following an overture by the UK in the early 1970s, when relations with the West were warming, China became interested in the aircraft as it sought to modernise its armed forces; British Prime Minister James Callaghan noted significant hostility from the USSR over the sales bid.[134][135] The deal was later cancelled by the UK as part of a diplomatic backlash after China invaded Vietnam in 1979.[136]

The Spanish Navy, Thai Navy, Royal Air Force, and U.S. Marine Corps have all retired their first-generation Harriers. Spain sold seven single-seat and two twin-seat Harriers to Thailand in 1998.[132][137][N 18] The Royal Thai Navy's AV-8S Matadors were delivered as part of the air wing deployed on the new light aircraft carrier HTMS *Chakri Naruebet*.[139] The Thai Navy had from the start significant logistical problems keeping the Harriers operational due to a shortage of funds for spare parts and equipment, leaving only a few Harriers serviceable at a time. In 1999, two years after being delivered, only one airframe was in airworthy condition.[140][141] Around 2003, Thailand considered acquiring former Royal Navy Sea Harriers, which were more suitable for maritime operations and better equipped for air defence, to replace their AV-8S Harriers; this investigation did not progress to a purchase.[142] The last first-generation Harriers were retired by Thailand in 2006.[143]

Variants

A Royal Air Force Harrier GR.3 aircraft parked on the flight line during Air Fete '84 at RAF Mildenhall.

Harrier GR.1, GR.1A, GR.3

Single-seat versions for the RAF.[36][37][144] The RAF ordered 118 of the GR.1/GR.3 series,[145] with the last production aircraft delivery in December 1986.[146] 122 built.[2]

AV-8A, AV-8C Harrier

Single-seat versions for the US Marine Corps.[70] The USMC ordered 102 AV-8As (company designation: Harrier Mk. 50).[145] The AV-8C was an upgrade to the AV-8A.[38] 110 built.[2]

AV-8S Matador

Export version of the AV-8A Harrier for the Spanish Navy, who designated them as VA-1 Matador;[74] later sold to the Royal Thai Navy. 10 built.[2]

Harrier T.2, T.2A, T.4, T.4A

Two-seat training versions for the RAF, with a stretched body and taller tail fin.[71] 25 built.[2]

Harrier T.4N, T.8, T.60

Two-seat training versions for the Royal Navy and Indian Navy with avionics based on the Sea Harrier.[72]

TAV-8A Harrier

Two-seat training version for the USMC, powered by a Pegasus Mk 103.[73]

TAV-8S Matador

Two-seat training version for the Spanish Navy and later sold to the Royal Thai Navy.[74]

Operators

India

- Indian Navy (see Sea Harrier)


A USMC TAV-8A Harrier from *VMAT-203* on the flight line

Spain

- Spanish Navy[147]

Thailand

- Royal Thai Navy[148]

United Kingdom

- Royal Air Force[149]
- Royal Navy[150]

United States

- United States Marine Corps[151]

Aircraft on display


Former Harrier GR.1 that crashed in 1971 and used as a static engine test bed by Rolls-Royce, seen on display at the Bristol Aero Collection, Kemble, England

Belize

GR.3

- ZD669 – Philip S. W. Goldson International Airport, Ladyville, Belize[152]

Canada

AV-8A

- 158966 – Canada Aviation and Space Museum, Ottawa, Ontario[153]

China

GR.3

- XZ965 – Beijing Aviation Museum (北京航空館)[154]

Germany

GR.1

- XV278 – Luftwaffenmuseum der Bundeswehr, Gatow[155]

GR.3

- XZ998 – Flugausstellung Hermeskeil at Hermeskeil[156]

Poland

GR.3

- XW919 – Polish Aviation Museum, Kraków, Poland[157]

New Zealand

GR.3

- XZ129 – Ashburton Aviation Museum, Ashburton, New Zealand[158]

Thailand

AV-8S

- 3109 – Royal Thai Air Force Museum


AV-8S Royal Thai Navy in Royal Thai Air Force Museum

United Kingdom

GR.1

- XV277 – National Museum of Flight, East Fortune[159]
- XV281 (Under Restoration) – South Yorkshire Aircraft Museum, Doncaster, South Yorkshire

GR.3

- XV744 – Tangmere Military Aviation Museum, Chichester, West Sussex[160]
- XV748 – Yorkshire Air Museum, Elvington[161]
- XV751 – Gatwick Aviation Museum, Surrey[162]
- XV752 – South Yorkshire Aircraft Museum, Doncaster, South Yorkshire[163]
- XV753 – Classic Air Force, St Mawgan, Newquay, Cornwall[164]
- XV779 – RAF Wittering (Gate Guardian)[165]
- XZ133 – Imperial War Museum, Duxford[166]
- XZ968 – Muckleburgh Collection, Norfolk[167]
- XZ997 – RAF Museum, Hendon[168]
- XZ971 – MoD Donnington, Telford
- ZD667 – Bentwaters Cold War Museum, Suffolk[169]

Mk.52 G-VTOL

- ZA250 – Brooklands Museum, Surrey[170]

T.2

- XW269 – Airworld Aviation Museum Caernarfon Wales

T.4

- XW934 – Farnborough Air Sciences Trust, Farnborough, Hampshire[171]
- XW268 – City of Norwich Aviation Museum, Norfolk[172]

AV-8A

- 159233 – Imperial War Museum North

United States

AV-8A

- 158695 – Air Park, Yuma MCAS, Yuma, Arizona[173]
- 159239 – San Diego Air and Space Museum, San Diego, California[174]
- 158963 – Craven County Regional Airport, Grantham, North Carolina[175]
- 158976 – City of Havelock, Havelock, North Carolina[176]
- Cockpit on display at Moffett Historical Museum, Moffett Federal Airfield, California

TAV-8A

- 159381 – Oakland Aviation Museum, Oakland, California[177]
- 159382 – Pima Air & Space Museum, Tucson, Arizona[178]

AV-8C

- 158387 – Flying Leatherneck Aviation Museum, Marine Corps Air Station Miramar, San Diego, California[179]
- 158710 – Quonset Air Museum, North Kingstown, Rhode Island[180]
- 158959 – Pacific Coast Air Museum, Santa Rosa, California[181]
- 158975 – National Naval Aviation Museum, NAS Pensacola, Pensacola, Florida[182]
- 158977 – Museum of Flight, Seattle, Washington[183]
- 159232 – Intrepid Sea, Air & Space Museum, New York City, New York[184]
- 159238 – Hangar 25 Museum, Webb AFB (formerly), Big Spring, Texas[185]
- 159241 – Pima Air & Space Museum, Tucson, Arizona[186]
- 159247 – Naval Inventory Control Point (NAVICP) Philadelphia, Philadelphia, Pennsylvania[187]
- 159249 – United States Naval Museum of Armament and Technology, NCC China Lake (North), Ridgecrest, California[188]

Specifications (Harrier GR.3)

Data from Jane's All The World's Aircraft 1988–89[189]

General characteristics

- **Crew:** 1
- **Length:** 46 ft 10 in (14.27 m)
- **Wingspan:** 25 ft 5 in (7.75 m)

29 ft 8 in (9 m) with ferry tips fitted

- **Height:** 11 ft 11 in (3.63 m)
- **Wing area:** 201.1 sq ft (18.68 m^2)

216 sq ft (20 m^2) with ferry tips fitted

- **Aspect ratio:** 3.175

4.08 with ferry tips fitted

- **Airfoil: root:** Hawker 10% ; **tip:** Hawker 3.3%[190]
- **Empty weight:** 13,535 lb (6,139 kg)
- **Max takeoff weight:** 55,556 lb (25,200 kg)
- **Fuel capacity:** 5,060 lb (2,295 kg) internal

2x 100 imp gal (120 US gal; 450 l) (790 lb (358 kg)) drop-tanks for combat
2x 330 imp gal (400 US gal; 1,500 l) (2,608 lb (1,183 kg)) drop-tanks for ferry

- **Powerplant:** 1 × Rolls-Royce Pegasus 103 Vectored-thrust high-bypass turbofan engine, 21,500 lbf (96 kN) thrust with water injection

Performance

- **Maximum speed:** 635 kn (731 mph, 1,176 km/h) at sea level
- Maximum diving speed: **Mach 1.3**
- **Combat range:** 360 nmi (410 mi, 670 km) ho-lo-hi with 4,400 lb (1,996 kg) payload

200 nm (1.2×10^{-10} mi; 2.0×10^{-10} km) lo-lo with 4,400 lb (1,996 kg) payload

- **Ferry range:** 1,850 nmi (2,130 mi, 3,430 km) with 330 imp gal (400 US gal; 1,500 l) drop-tanks

3,000 nmi (3,500 mi; 5,600 km) with one AAR

- **Endurance:** 1 hour 30 minutes combat air patrol 100 nmi (120 mi; 190 km) from base.

7 hours plus with one AAR

- **Service ceiling:** 51,200 ft (15,600 m)
- **g limits:** +7.8 -4.2
- **Time to altitude:** 40,000 ft (12,192 m) in 2 minutes 23 seconds from a vertical take-off
- **Take-off run CTOL:** 1,000 ft (300 m) at max TO weight

Armament

- **Guns:** 2× 30 mm (1.18 in) ADEN cannon pods under the fuselage
- **Hardpoints:** 4× under-wing & 1× under-fuselage pylon stations with a capacity of 5,000 lb (2,268 kg),with provisions to carry combinations of:
  - **Rockets:** 4× Matra rocket pods with 18× SNEB 68 mm rockets each
  - **Missiles:** 2× AIM-9 Sidewinders Air-to-air missiles
  - **Bombs:** A variety of unguided iron bombs, BL755 cluster bombs or laser-guided bombs
  - **Others:**
    - 1× Reconnaissance pod
    - 2× drop tanks for extended range/loitering time

Avionics

- Ferranti LRMTS
- Marconi ARI 18223 RWR
- Plessy U/VHF comms

- Ultra standby UHF
- GEC Avionics AD2770 TACAN
- Cossor IFF
- Ferranti FE541 INAS
- Sperry C2G compass
- Smiths HUD

Popular culture

See also

- Aircraft in Fiction – the Harrier

Aircraft of comparable role, configuration and era

- Rockwell XFV-12
- Yakovlev Yak-38

References

Notes

1. The development of a V/STOL jet was not Hawker's primary objective as it had put in a joint bid with Avro to meet the GOR.339 Requirement (which resulted in the BAC TSR-2 development programme), but had been unsuccessful. The inability to obtain work on conventional aircraft in a hostile political climate was perhaps the greatest motivation for Hawker to proceed with the development of the Harrier.[6]
2. The Mirage IIIV had been rejected mainly because of its excessive complexity, using nine engines compared with the P.1154's single engine approach.[23]
3. The supersonic Harrier is not to be confused with the Big Wing Harrier. Neither concept would result in a successor aircraft.[26]
4. Some avionics systems used in the Harrier had been carried over from the cancelled BAC TSR-2, such as the Weapon Aiming Computer.[45]
5. The area needed for a Harrier to comfortably take off was said to be less than a tennis court, while the majority of aircraft required a two-mile-long runway.[48]
6. Experience from the Second World War had made this vulnerability abundantly clear to many Air Force officers around the world; this perception of vulnerability contributed heavily to the interest in and development of VTOL aircraft like the Harrier.[49]
7. Some officers went so far as to deride conventional aircraft, unfavourably comparing to the Maginot Line, as static and highly vulnerable.[51]
8. In preparation for flying the Kestrel, pilots of the Tripartite Evaluation Squadron were provided with several hours of helicopter piloting tuition, all of whom agreed on the effort being highly worthwhile preparation.[13]
9. While the USMC Harriers had Sidewinder missiles, they still lacked radars.
10. In the early 1990s, following Japanese interest in acquiring Harriers, Skyhook was suggested as a means to operate onboard their helicopter destroyers.[102]
11. These other projects were the Lockheed AH-56 Cheyenne and the Fairchild Republic A-10 Thunderbolt II.[108]
12. Spain would adapt the American Sea Control Ship concept with the addition of a ski jump, launching the vessel as the *Principe de Asturias*, which carried AV-8S Matador Harriers.[115]

13. Arapaho would have been operationally similar to the British container ship *Atlantic Conveyor*, which not only transported Harriers but was modified to enable crude flight operations as well.
14. Dispersed forward bases were heavily reliant on effective transportation to refuel and rearm the Harriers; possessing a large fleet of air transports, helicopters or ground vehicles to support such operations was identified as crucial by USMC senior officers. It was planned that supplies would to be regularly ferried by Sikorsky CH-53E Super Stallions from main bases to all forward bases.[119]
15. Kevin Brown of *Popular Mechanics* described the development efforts of performance vertical aircraft as having "long eluded the best efforts of the aviation industry", and noted that several American efforts had been "spectacularly unsuccessful".[41]
16. Politically, the British government had decided not to use aircraft carriers after the 1960s, due to the costs involved. The *Invincible*-class aircraft carriers had been developed under the official guise of being an anti-submarine Through Deck Cruiser, but the approved development of the Sea Harrier and the addition of ski-jumps to the design enabled ships of the *Invincible* class to perform as light aircraft carriers.[127][128]
17. Italy also became an operator of a "Harrier Carrier", but they only operated the second-generation McDonnell Douglas AV-8B Harrier II.[129]
18. Spain sold its AV-8S Matadors following the introduction of new second generation Harrier II aircraft; as a result the Harrier I models were outdated and no longer required.[138]

Citations

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Further reading

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- Polmar, Norman and Dana Bell. *One Hundred Years of World Military Aircraft*. Annapolis, Maryland, USA: Naval Institute Press, 2003. ISBN 1-59114-686-0.

External links

- Harrier history website (http://www.harrier.org.uk)
- Harrier page on globalsecurity.org (http://www.globalsecurity.org/military/world/europe/harrier.htm)
- Harriers lost in the Falklands (http://www.naval-history.net/F63braircraftlost.htm)
- Harrier GR.3 in Beijing Aviation Museum, China (http://www.afwing.com/gallery/beijing.htm)
- "Harrier – World's First Fixed-wing V/STOL Weapons System" (http://www.flightglobal.com/pdfarchive/view/1967/1967%20-%202128.html) a 1967 article in *Flight*
- "Harriers for the United States?" (http://www.flightglobal.com/pdfarchive/view/1969/1969%20-%203336.html) 1969 *Flight* article on the USMC case for the Harrier
- "Woodland Warfare" (http://www.flightglobal.com/pdfarchive/view/1972/1972%20-%201202.html) a 1972 *Flight* article on Harrier dispersed operations

- "V for Two" (http://www.flightglobal.com/pdfarchive/view/1972/1972%20-%202593.html) a 1972 *Flight* article on the two-seat Harrier T.2
- "In the Air – Harrier" (http://www.flightglobal.com/pdfarchive/view/1973/1973%20-%201501.html) a 1973 *Flight* article on flying the Harrier

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