THE RAF HARRIER STORY

ROYAL AIR FORCE HISTORICAL SOCIETY

The opinions expressed in this publication are those of the contributors concerned and are not necessarily those held by the Royal Air Force Historical Society.

First published in the UK in 2006 by the Royal Air Force Historical Society

ISBN 0-9530345-2-6

Printed by Advance Book Printing
Unit 9 Northmoor Park
Church Road
Northmoor
OX29 5UH

ROYAL AIR FORCE HISTORICAL SOCIETY

President	Marshal of the Royal Air Force Sir Michael Beetham GCB CBE DFC AFC
Vice-President	Air Marshal Sir Frederick Sowrey KCB CBE AFC

Committee

Chairman	Air Vice-Marshal N B Baldwin CB CBE FRAeS
Vice-Chairman	Group Captain J D Heron OBE
Secretary	Group Captain K J Dearman
Membership Secretary	Dr Jack Dunham PhD CPsychol AMRAeS
Treasurer	J Boyes TD CA
Members	Air Commodore H A Probert MBE MA
	*J S Cox Esq BA MA
	*Dr M A Fopp MA FMA FIMgt
	*Group Captain N Parton BSc (Hons) MA MDA MPhil CEng FRAeS RAF
	*Wing Commander D Robertson RAF
	Wing Commander C Cummings
Editor & Publications Manager	Wing Commander C G Jefford MBE BA

**Ex Officio*

CONTENTS

ABBREVIATIONS

AAA	Anti-Aircraft Artillery (aka *Flak*)
ACE	Allied Command Europe
ACMI	Air Combat Manoeuvring Instrumentation (Range)
ACOC	Air Command Operations Centre
AFB	(USAF) Air Force Base
AFVG	Anglo-French Variable Geometry (project)
AI	Air Interdiction
AIM-9L	Air Intercept Missile Type 9, aka Sidewinder
AMRAAM	Advanced Medium Range Air-to-Air Missile
APC	Armament Practice Camp
ARM	Anti-Radar Missile
ASOC	Air Support Operations Centre
AST/R	Air Staff Target/Requirement
ATAF	Allied Tactical Air Force
AWACS	Airborne Warning And Control System
BAe	British Aerospace
BAWA	Bristol Aerospace Welfare Association
BDA	Battle Damage Assessment
CAD	Computer Assisted Design
CAP	Combat Air Patrol
CAS	Close Air Support
CCA	Carrier Controlled Approach
COMAO	Combined / Composite Air Operations
CVF	Future Aircraft Carrier
CVS	Aircraft Carrier (the ‘S’ originally signified an anti-submarine role but this degree of specialisation is no longer recognised by the RN)
DFGA	Day Fighter/Ground Attack
DOB	Deployed Operating Base
EWR-Sud	*Entwicklungsring-Sud* (industrial consortium of Messerschmitt, Heinkel, and Bölkow)
FIBUA	Fighting In Built-Up Areas
FINRAE	Ferranti Inertial Rapid Alignment Equipment
FOB	Forward Operating Base
FWOC	Forward Wing Operations Centre
GOR	General Operational Requirement
GPS	Global Positioning System
HAS	Hardened Aircraft Shelter
HP	High Pressure

HSA	Hawker Siddeley Aviation
HUD	Head Up Display
INAS	Inertial Navigation and Attack System
JCA	RN/RAF Joint Combat Aircraft (the JSF)
JFH	Joint Force Harrier
JSF	Joint Strike Fighter (the Lockheed Martin F-35)
LERX	Leading Edge Root Extensions
LGB	Laser Guided Bomb
LP	Low Pressure
LRMTS	Laser Ranger and Marked Target Seeker
LTC	Long Term Costings
MANPAD	Man-Portable Air Defence System
MEXE	Military Experimental Establishment (pad)
NACA	(US) National Advisory Committee for Aeronautics
NAS	Naval Air Squadron
NASA	(US) National Aeronautics and Space Administration
NBMR	NATO Basic Military Requirement
NVG	Night Vision Goggles
PAR/ILS	Precision Approach Radar/Instrument Landing System
PCB	Plenum Chamber Burning (aka reheat)
PGM	Precision Guided Munitions
PTA	Practical Training Area
OCU	Operational Conversion Unit
OR	Operational Requirements (Branch of MOD)
QFI	Qualified Flying Instructor
QRA(I)	Quick Reaction Alert (Intercept)
RWR	Radar Warning Receiver
SACEUR	Supreme Allied Commander Europe
SAM	Surface-to-Air Missile
SSM	Surface-to-Surface Missile
STC	Strike Command
TACEVAL	**Tac**tical **Eval**uation
TIALD	Thermal Imaging Airborne Laser Designator
Unimog	*Universalmotorgerät*
VAAC	Vectored thrust Aircraft Advanced flight Control
VAK	*Vertikalstartendes Aufklärungs und Kampf-flugzeug*
viff(ing)	vectoring in forward flight
VJ	*Vertikal Jäger*
WAC	Weapon Aiming Computer
WARLOC	War Locations

THE RAF HARRIER STORY

BAWA, FILTON, 22 MARCH 2005

WELCOME ADDRESS BY THE SOCIETY'S CHAIRMAN

Air Vice-Marshal Nigel Baldwin

It is a pleasure to welcome you all here today, to the Bristol Aerospace Welfare Association's splendid conference facility. It is the Society's third visit. Eight years ago, we spent the day looking, with hindsight, at the TSR2. Just over three years ago, we studied the birth and early days of the Tornado. Both days were recorded in hardback. Spare copies of the Tornado book are still available if you wish to buy, but hurry, because they are becoming collectors' items.

On previous occasions, we were supported financially by both Rolls-Royce and British Aerospace. That was a great help in offsetting some of the costs of mounting a day such as this; I am delighted to say that both companies are helping us again and this time they have been joined by Cobham.

Before I hand over to our chairman for today, I must just say a thank you to George Brown, the Chairman of the BAWA, and to his staff who, for the third time, have bent over backwards to be helpful and hospitable to us. I hope we will return the compliment by producing yet another fascinating day.

Our Chairman today needs little introduction. Air Chf Mshl Sir Patrick Hine is one of the Royal Air Force's most distinguished post-war commanders. As a result of almost two years in command of the Harrier Wing at Wildenrath, we are aware that he knows as much about today's subject as any of us. Later, after being Commander-in-Chief of RAF Germany and then of Strike Command (and thus the British Joint Commander during the first Gulf War) and then Vice-Chief of the Defence Staff in London, he retired from the RAF to the relative calm of British Aerospace, and served as the company's senior military adviser for several years. So today we are in very good hands.

Sir Paddy, you have control.

OPENING REMARKS BY SEMINAR CHAIRMAN

EARLY HISTORICAL PERSPECTIVES AND EMERGING STAFF TARGETS

Air Chief Marshal Sir Patrick Hine

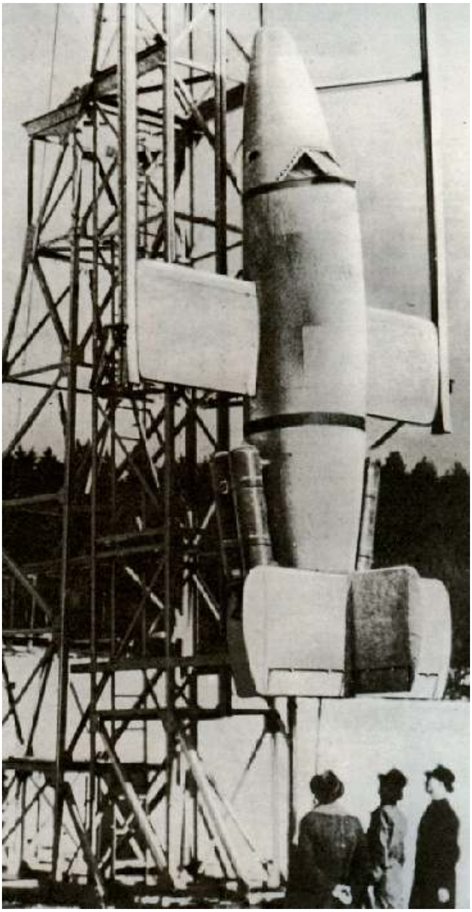
Thank you, Nigel, for your kind introduction. I am delighted to be chairing this Harrier seminar as I have always had a real affection for the 'little jet', or the 'bona jet' as it has sometimes been called, ever since I commanded the RAF Germany Harrier Force at Wildenrath in 1974-75. Those were great days – quite early on in the aircraft's operational life when we were still developing and refining our off-base concepts of operation for the support of NORTHAG and in particular of 1(BR) Corps.

You will have seen the outline for today's programme: it is ambitious and the timing is tight, calling for discipline by the speakers if we are not to encroach into the planned discussion periods. We are especially fortunate to have amongst our speakers some eminent aero-engineers who were closely involved with early jet-lift development and with the integration of vectored thrust into the P1127 and later the Harrier. I refer specifically to Professor John Coplin, Dr Gordon Lewis and Ralph Hooper who, along with John Farley who flew both the Short SC1 and the P1127/Harrier, have a unique story to tell and one which, for historical accuracy, we need to put on the record – whilst the going is still good!

Let me just make clear that the seminar will focus almost entirely on the Harrier in the RAF. Not only is there a severe time constraint but this is after all an event run by the RAF Historical Society; so, if some may feel that the programme is somewhat parochial, those are the reasons and I would ask you to accept them. However, wider Harrier issues can always be addressed if you wish during the discussion periods.

I will not spend time taking you through the programme but instead get straight on with my initial task of covering the 'Early Historical Perspectives and Emerging Staff Targets' that eventually led to the procurement of the Harrier.

Historically, airfields and aircraft on the ground have always been vulnerable to air attack; the question has been what to do about it. In

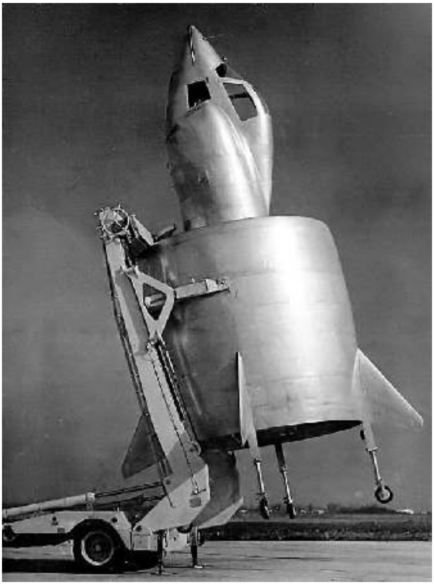


The Bachem Ba 349 Natter, ramp-launched VTO fighter which made only one (fatal) manned flight.

WW II large wings were usually deployed between their main base and two or more dispersal airfields, many with only grass strips, but tactical ground attack aircraft, operating in support of advancing armies, needed to be based well forward and were thus more exposed to enemy attack. By 1944, the Allies enjoyed virtual air supremacy and the threat to our airfields was minuscule, although even then we were caught out badly by some concentrated attacks against them by the *Luftwaffe* on New Year's Day 1945.

Recognising the potential of VTOL to offset vulnerability on the ground, the Germans worked during WW II on a manned interceptor, the Bachem Natter, that was launched vertically by a rocket motor. However, this aircraft never entered operational service. The Germans also designed a shipborne fighter, the Fa 269, which had a single radial engine driving two large-diameter propellers aft of the wing and which could be rotated downwards to provide vertical thrust. This project was abandoned, however, when the prototype and all design drawings were destroyed by allied bombing.

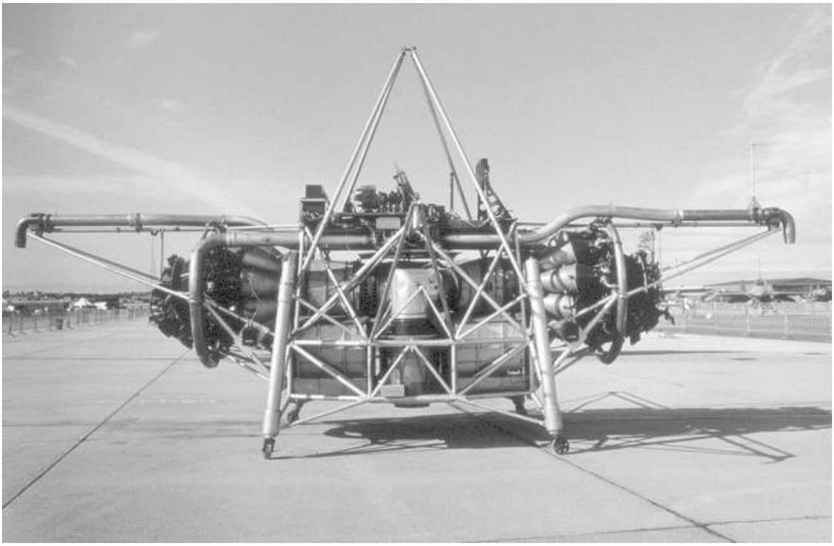
In the early 1950s, the US Navy and US Air Force both experimented with VTOL designs, both propeller-driven and jet-



(Left) The Convair XFY-1, the more successful of the US Navy's two tail-sitter turboprop fighter projects in that this one accomplished a transition from vertical to horizontal flight and back again in 1954. (Right) The radical French annular-winged. SNECMA C-450 Coléoptère which hovered in 1959 but crashed on its ninth flight before achieving a full transition.

powered. They were nearly all 'tail-sitters', rather than 'flat-risers', the better known being the Convair XFY-1, the Lockheed XFV-1 and the Ryan X-13; but none of these was taken beyond the experimental stage. The French too worked for some years on 'tail-sitter' VTOL technology, mainly with their P-series rigs, but following the crash of their one aircraft, the C-450, they abandoned this concept and focused instead on 'flat-risers' using lift-plus-cruise engine configurations.

In the UK, we had the Rolls Royce Thrust Measuring Rig research vehicle (better known as the Flying Bedstead) and the Short SC1 which incorporated four vertically-mounted lift engines around the aircraft's centre of gravity and a single cruise engine exhausting rearwards in the tail. We shall hear more about this aircraft later but suffice to say that its purpose was simply to exploit the concept of multiple lift-engine take-off and landing. There had been nothing

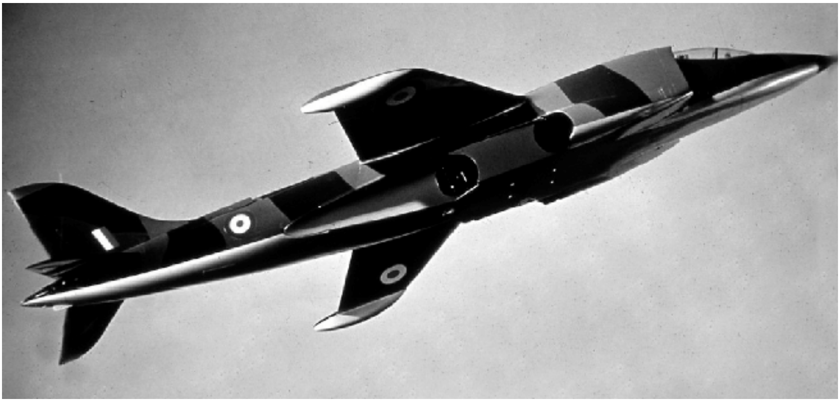


The UK's first essay in the field of practical VTO was Rolls-Royce's twin Derwent-powered Thrust Measuring Rig which made its first free hover in 1954.

included in the requirement to indicate that the SC1 might provide the basis for a military aircraft application.

By 1957 then, while there was general recognition in NATO that jet combat aircraft dependent on long hard-surface runways remained vulnerable to air attack when on the ground, there had been no V/STOL technology breakthrough anywhere in the world that offered an operationally viable means of minimising that vulnerability through on- or off-base dispersal. Coincidentally, 1957 was the year of the infamous Duncan Sandys Defence White Paper heralding the demise of fighter and fighter ground attack aircraft in favour of guided missiles. Hawkers' P1121 (a Hunter replacement) was the principal casualty of that misguided policy, but the RAF's requirement for a deep low-level strike/recce aircraft (the TSR2) managed to survive for a further few years.

At a time when Hawkers were desperate for a new project, their interest began turning towards jet lift as a possible area of future development in fighter aircraft. You will hear from the following speakers how Hawkers and Bristol Siddeley came together in the



Hawker's supersonic P1154 project in response to NBMR3.

P1127 project and how Bristol were involved with NATO on the development of the vectored thrust technology used on the Pegasus series of engines. Eventually, the thrust output of the Pegasus in the P1127 was high enough to offer a level of performance that fully met an Air Staff Requirement (ASR 345) for a subsonic V/STOL ground attack fighter – an operational requirement incidentally that the RAF had been pressed to raise, mainly for politico-industrial reasons, and to which it did not at that time give any real priority.

As the P1127 went through its early flight trials in 1960-61, which were encouraging enough to provide the catalyst for the British, American and German tripartite evaluation of the Kestrel, NATO came up with its Basic Military Requirement 3 (NBMR3) for a supersonic V/STOL ground attack fighter. This project assumed the status of a major international competition with many political, economic and industrial influences at work. Hawkers and Bristol Siddeley formally responded with what became known as the P1154 powered by a plenum chamber burning (PCB) version of the latest Pegasus (with hot front nozzles) known as the BS100, while their major competitor was the Dassault/Sud Mirage IIIV powered by eight Rolls-Royce RB 162 lift engines and a SNECMA-built Pratt and Whitney TF-30 cruise engine. There were also entries from Fokker/Republic, Breguet and Fiat, but the real competition was between the P1154 and Mirage IIIV. After much lobbying and jockeying for position, the P1154 was declared the 'technical' winner of the NBMR3 competition, which proved unacceptable to the French who decided to do their own thing. The French position apart, there was a real problem in funding NBMR3. NATO had no funds of its own to meet major operational requirements and therefore had to rely on the member nations to pay for them; in this case funds were not made available and thus the NBMR3 project fizzled out.

About this time, the RAF and RN came up with a national requirement around the P1154 but then spent the next two years trying to harmonise their conflicting needs: the RAF's (OR 356) for a low-level supersonic dash aircraft, and the RN's (AW 406) for a supersonic fleet air defence fighter. These conflicting operational requirements were further complicated by the Navy's strong preference (for carrier operations) for a twin-engine configuration based on a variation of the Rolls-Royce Spey, whilst both Services, but particularly the RN, became increasingly interested in the American F-4 Phantom. The incoming Labour Government of 1964 soon realised that the P1154 was an expensive project to which the RAF accorded a lower priority than to the TSR2, and from which the RN had by then withdrawn in favour of the Phantom. Not surprisingly, therefore, the project was cancelled.

The British aircraft industry (as it then was) was dealt a near mortal blow with the cancellation in quick succession of the P1154, HS 681 and TSR2, but with further orders for the Lightning, a commitment to the Anglo-French Jaguar programme, and the prospect of the Anglo-French Variable Geometry Aircraft, BAC had sufficient work to, at least partially, compensate for the loss of TSR2, while Hawkers, who had kept the P1127 going throughout the P1154 saga, were rewarded with an order for sixty of what became known as the P1127(RAF) and later the Harrier. The RAF was not initially very enthusiastic but nonetheless issued ASR 384 for this new subsonic V/STOL ground attack aircraft. Thus, the Harrier was born, with the first aircraft entering squadron service in 1969. An inauspicious beginning perhaps but one which over the following 35 years has developed into a great success story.

JET LIFT

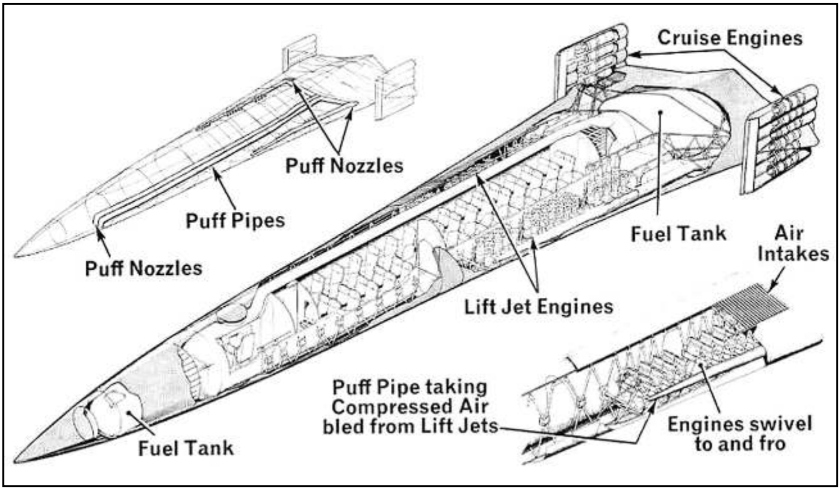
Professor John F Coplin

Having graduated from Imperial College in 1956 with a degree in Aeronautical Engineering, Prof Coplin joined Rolls-Royce, later becoming Chief Designer for the US/UK XJ99 lift jet engine and for the RB211. Eventually appointed as the company's Director of Technology and Design, he has also been Chairman of the Aerospace Technology Board, a Member of the Defence Scientific Advisory Board and of the Advisory Council for Applied Research and Development.

For Rolls-Royce the notion of powered lift began with Dr A A Griffith, Chief Scientist, Rolls-Royce who, in 1941, presented to the Aeronautical Research Council his paper on Jet Lift for vertical take-off and landing. Dr Griffith was an extremely sound scientist and visionary in all matters pertaining to jet propulsion and aircraft design, but somewhat impatient with the engineers who had to devise the demanding engineering solutions that would create the real machines that would fulfil his vision. I knew him well.

Dr Griffith recognised the huge potential of the jet engine for very high speed flight, and in particular for commercial aircraft that would carry passengers at speeds up to Mach 3 for transatlantic ranges. Success demanded a high lift:drag ratio from the airframe and a very low structural weight. He could see this being achieved with the conventional slender delta wing, but this left him with a severe problem for take-off and landing. He quietly and carefully thought through the options, leading him to reveal in 1952 his concept for the M2.6 cruise VTOL passenger aircraft illustrated on the facing page in a beautiful cutaway drawing in pencil, drawn by Donald Eyre, a superb artist – no CAD in those days! The drawing clearly shows the many small, high thrust/weight ratio jet engines that would lift the airliner and help accelerate it up to cruise.

Griffith argued that it would be lighter and more efficient overall to use jet lift than to compromise the wing aerodynamics and structure plus the provision of a very long and strong landing gear. He showed



1952 Concept for a Supersonic (Mach 2.6) VTOL Airliner by Dr A A Griffith, Chief Scientist, Rolls-Royce.

that there was a universal law that explained why small jet engines could achieve the highest thrust:weight ratio, so crucial to his concept. The Cube/Square Law explains that thrust varies with linear scale squared, while weight varies with the cube. All stresses remain constant. Sadly not all components know of this relationship, leading to a very strong push on high technology to make good the shortfall.

Adrian Lombard, the distinguished designer of early jet engines and, later, Engineering Director at Derby, was inspired by jet lift for its business potential and for its potential to advance lightweight engine technology. As a recently qualified apprentice, I was assigned as Lombard's PA for a few months. He really was committed to jet lift. He asked Geoff Wilde to prepare all the necessary technology.

The support for jet lift aircraft was very strong, and quickly led to the building of the Flying Bedstead which achieved its first free hover flight at Hucknall, Rolls-Royce Derby's flight test establishment, in 1954. The first specifically designed lift jet, the RB108 first ran in 1955, delivering about a ton of thrust at over 8:1 thrust:weight ratio. Very comprehensive research was undertaken, much of it at Hucknall, on all crucial aspects. In 1958, I collated for Geoff Wilde, a complete collection of basic technology into 'The Black Book' published, under a SECRET grading, for the MOD and the company. There were excellent wind tunnel and other large scale rigs for this advanced work.

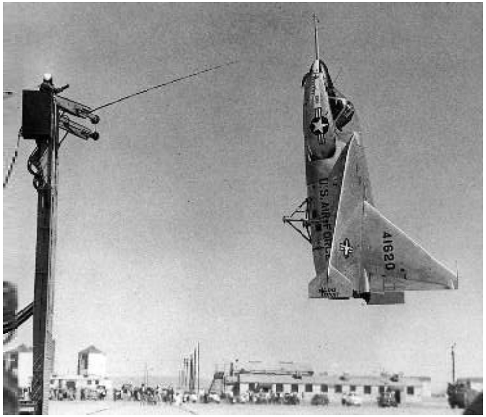
Aircraft designers across the world were drawn in by the excitement of jet lift to present their best aircraft project ideas on how real requirements could be met in practical aircraft. I counted more than thirty-seven active programmes, but there may have been more. All efforts were looking for the appropriate application where jet lift could provide a unique role of real value. Exploratory work embraced military fighter type roles, transport aircraft, especially short range inter-city transport from the railway station of one city to the equivalent in another. The Army wanted an armoured Ferret-type vehicle that could hop over rivers and buildings. There were fourteen varieties of jet lift aircraft built and flown, of which Rolls-Royce, as we know it today, powered ten. There were five fan lift borne aircraft flown, none of them Rolls-Royce powered, but a research fan, the RB144, was built and tested. Five tilt wing and tilt propeller aircraft were also built.

Work on lift jets proceeded vigorously. Lift engine thrust:weight ratio was doubled to 16:1 for the RB162 that first ran in 1961. A third generation lift jet, the XJ99 was jointly designed by Allison and Rolls-Royce under my design leadership. It was aimed at a US/FRG M2.5 supersonic V/STOL aircraft that was to be designed jointly by EWR of Germany and Republic of the USA. The vectorable lift jets were to be stowed at cruise then deployed for take-off and landing, as shown opposite. A very tiny volume for the engines was essential, as was a thrust:weight ratio of 20:1. Despite superbly innovative design by all parties, every role was compromised and the aircraft was cancelled at an early stage. The XJ99 lift jet programme continued in demonstrator form. Three engines were built. Two ran at Derby, the third at Indianapolis. The first run was at Derby in July 1968. The 20:1 thrust:weight and a very high thrust:volume were achieved with good temperature and speed margins. The 9000 lb thrust engine, had contra-rotating shafts, very high duty aerodynamics, a relatively high pressure ratio of 8 to keep the combustor short and allow a high firing temperature, no inter-stage turbine vanes and very innovative inlet and exhaust nozzle designs for short length and light weight. Whilst the

Joint US/FRG project for a V/STOL strike fighter employing retractable and vectorable lift engines and variable geometry wings.

second generation lift jet was able to benefit from glass fibre reinforced resin composites, all attempts to carry this through into the third generation failed miserably. Carbon composites were stronger, lighter and stiffer, in two dimensions, but the much thinner sections demanded by the transonic compressors demanded more. Titanium structures gave better thrust:weight ratios.

I know that today we are focused on military strike aircraft, for which the requirement arose from the very comprehensive background work, as perhaps the only application of jet lift that was supportable by the highest proven technology of the day. The aircraft that helped formulate the decision to focus on the subsonic low level strike aircraft, included the Ryan X-13 tail sitter powered by a modified Avon. This was rejected because of its difficult and vulnerable landing characteristics. The supersonic VJ101C-2 had dangerous engine and system failure modes. Supersonic performance had no real value in a short range strike aircraft. The VAK191B with its optimised lift/cruise engine and a balanced pair of RB162 lift jets was tempting



The VTOL projects that set the pace between 1956 and 1971 were: the Ryan X-13 (above); the Hawker P1127 (below);

the VJ101C;

the VAK191B;

and the Dassault Mirage IIIV.

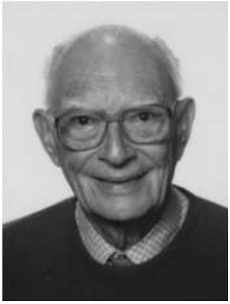
	Ryan X-13	P1127	VJ101C	Mirage IIIV	VAK 191B
Type	Tail-sitter research	Subsonic Strike	Supersonic Interceptor M2.0	Supersonic Strike M2.0	Subsonic Strike (supersonic capability)
First Flew	1956	1960	1965	1965	1971
Power	1 × Avon	1 × Pegasus	6 × RB145 (4 with reheat)	8 × RB162 + 1 × TF30	2 × RB162 + 1 × RB193

Salient characteristics of the projects illustrated on the facing page.

but had unsatisfactory engine out characteristics. Aircraft with separate lift engines needed at least six lift engines to deal with the single lift engine failure case and the Dassault Mirage IIIV, with its eight RB162 lift jets and single non-vectored cruise engine was the leader of this class. Finally there was the P1127, single vectored thrust concept that led on to the family of aircraft that gives us the real reason for our being gathered here today. While the Mirage may have had the potential of offering slightly more range and supersonic flight, its complexity outweighed any small advantage that may have existed. Moreover, the Mirage faced a much more difficult ground erosion problem. The single vectored thrust engine readily overcame that by directing the jet at the ground for only very short periods while the aircraft was surging forwards towards wing-born flight. For an aircraft intended for the strike role the decision was an easy one

EVOLUTION OF THE PEGASUS VECTORED THRUST ENGINE

Dr Gordon Lewis



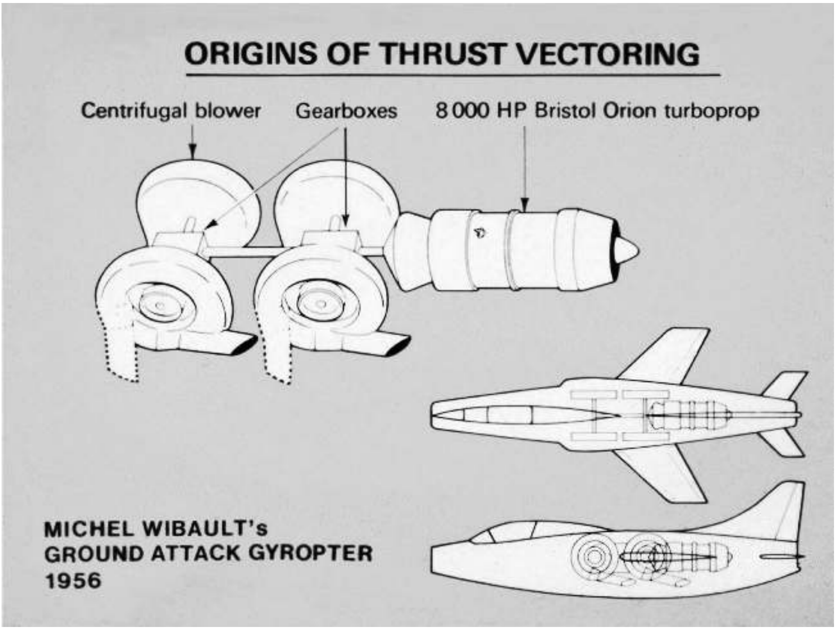
Dr Lewis joined Bristols from Oxford University in 1944 and was subsequently involved with all Bristol-based gas turbine engines until his eventual retirement from the post of Technical Director for Rolls-Royce in 1986. His most significant contributions have been his work on the innovative vectored thrust Pegasus engine, which earned him several international awards, and as Chief Engineer for the proposed engine for the AFVG and the RB199 which powers the Tornado, which led to his appointment as Managing Director of Turbo Union, and for initiating the technology demonstrator programme which led to the Typhoon's EJ200 engine.

The mainstream effort on VTOL in the UK was originally focused on the use of lightweight lift engines to provide vertical thrust in conjunction with conventional engines for propulsion, while the concept of a single vectored thrust engine emerged from studies associated with NATO requirements for dispersible strike aircraft.

In the early 1950s the Bristol Aeroplane Company's Engine Division, later to be absorbed into Bristol-Siddeley Engines and then into Rolls-Royce, had responded to a requirement for an engine to power a NATO Light Strike Fighter with a primary feature of operation away from main runways. This engine, the Orpheus turbojet, was selected for the Fiat G.91. Development was funded by the Mutual Weapons Development Programme, (MWDP), a United States agency with an office in Paris having the objective of supporting projects of potential value to the NATO forces.

The Fiat G.91, which later entered service with the German and Italian Air Forces, was to be followed by an aircraft with enhanced performance and, in a third phase, by a strike fighter with short take-off and vertical landing capability.

In March 1956, when MWDP was turning its attention to the third phase NATO requirement, a proposal was submitted to the Paris office



Michel Wibault's original design concept for a vectored thrust engine.

by Michel Wibault, then an aviation consultant. Wibault was well known in the pre-war period, his company having been responsible for a range of French transport and fighter aircraft He had produced schemes for a STOVL strike fighter which were entitled 'Ground Attack Gyropter' offering a solution to the problem of the G.91 successor.

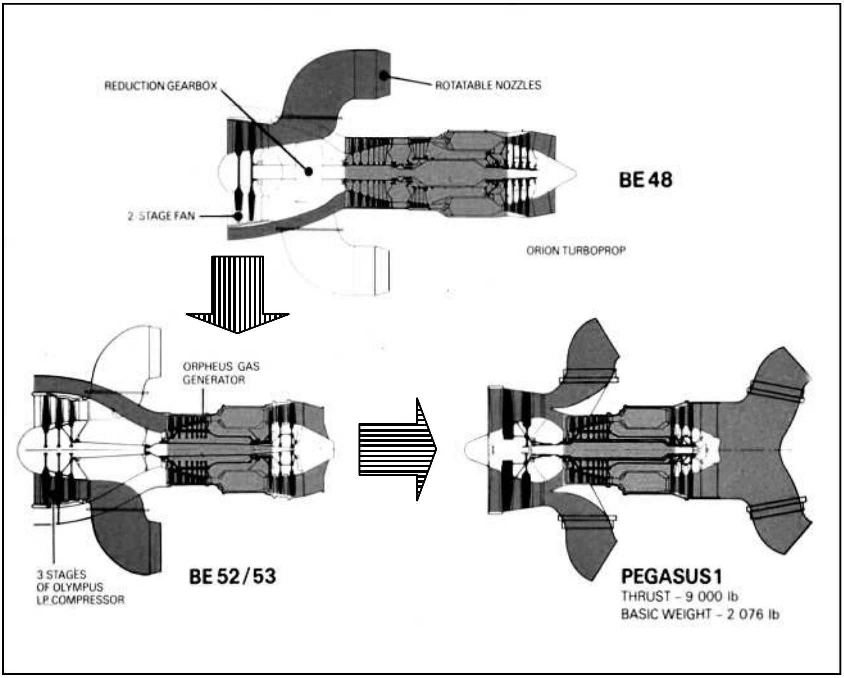
Wibault's proposal, based on the concept of thrust vectoring, described the basic principles of operation that would later be incorporated into the Pegasus engine and the Harrier. It consisted of a turboprop engine, the Bristol BE25 Orion of about 8,000 hp, driving, through a coupling gear train, four large centrifugal fans arranged like wheels at the sides of the fuselage, forming, in effect, a turbofan powerplant. The fan casings were to be rotated to achieve thrust vectoring as the scroll outlets directed thrust rearwards or downwards, or to intermediate positions for transition and short take off. The exhaust gas from the Orion engine was also used for vertical or horizontal thrust using a gas deviator mechanically coupled to the fan casings. Stabilisation in hover and low speed flight was to be by means of wingtip and front and rear fuselage jets fed by air bled from the fans. The gross weight of the Gyropter was quoted as 11,684 lb.

No favourable reaction to this proposal had been received before Col John Driscoll, at the time head of the MWDP office, sent the Wibault brochure to Dr (later Sir) Stanley Hooker at Bristol. While the merit of the principle of a single vectored thrust engine for STOVL was recognised, the mechanical complexity of the proposal was regarded unfavourably. The Bristol response was to suggest replacing the four centrifugal fans with the first two stages of the Bristol Olympus low pressure axial compressor, and vectoring the thrust through two rotating nozzles, one on each side of the engine. This, coincidentally, provided close to the brochure air flow and therefore overall performance similar to that of the Gyropter.

This layout, designated BE48, retained the Orion engine and a reduction gear to drive the fan, and offered substantial weight saving and a relatively compact installation. Wibault quickly accepted the changes and produced a scheme for a modified Gyropter using the BE48. This was presented to MWDP, where Col (later Brig Gen) Willis Chapman, who had replaced Driscoll, encouraged Bristol to proceed with design studies.

Further weight saving resulted from designing a power turbine running at the appropriate speed, dispensing with the reduction gear, and replacing the Orion with the simpler and lighter Orpheus turbojet already supported by MWDP. It was envisaged that a demonstrator engine could be launched, these studies being confined to the use of major components already in development. Several options were identified for the rear exhaust deviator but it was clear that progress towards a definitive project could only be made by collaboration with aircraft designers. No interest had been generated by May 1957 when Sir Sydney Camm contacted Sir Stanley Hooker to discuss possible STOVL projects. The results of the studies to date were communicated to the Hawker design office with provisional data on the current engine project, by that time the BE53 which used three stages of the Olympus compressor.

After some initial studies Ralph Hooper took the decisive step of proposing a rear thrust deflector close-coupled to the engine, instead of the assumed location at the end of a conventional jet pipe. This



Evolution of the BE48 concept into the Pegasus via the BE 53.

featured two rotating nozzles similar to those for the vectoring of the fan exhaust, and the now familiar four-nozzle engine design was adopted by Bristol. The consequences of this initiative were considerable and enabled redesign of the engine with much increased rear thrust while maintaining balance. A new design of fan supercharged the Orpheus core engine and contra-rotation of the two spools could then be adopted to virtually eliminate gyroscopic couples affecting stabilisation in the hover mode. This configuration was designated BE 53/2 (later Pegasus 1), and the potential merit of the P1127 based on this engine indicated that a viable programme could be launched.

Close collaboration between airframe and engine companies ensued and continued to be a strong feature of the eventual Harrier programme. Many important and new problems associated with STOVL had to be addressed, including intake aerodynamics, hot gas re-ingestion, control requirements, provision of stabilising bleed, nozzle design and actuation, and the effect of the intake and exhaust ducting on compressor and turbine blade vibration. Rig testing proceeded together with the definitive design of a flight worthy engine.

In mid-1958 a US contract was received via MWDP for a batch of development engines and two flight-cleared prototypes. The Bristol Company provided 25% of the estimated cost and the programme proceeded rapidly. The Pegasus 1, rated at 9,000 lb thrust, first ran on the test bed in September 1959. However the demand for high pressure bleed for the reaction control system of the P1127 required an increased flow version of the Orpheus compressor and this resulted in the 11,000 lb thrust Pegasus 2 which first ran in February 1960 and was cleared for flight in the prototype aircraft in October 1960, just twenty-nine months from the start of design.

The P1127 flight test programme revealed the need for increased thrust and the Pegasus 3, rated at 13,500 lb, ran on the test bed in April 1961 and flew twelve months later. Limited resources were available for Pegasus development due to the need to respond to the RAF requirement for supersonic STOVL with the BS100 programme. However the Kestrel Tripartite Evaluation aircraft requirement for engines of 15,500 lb was met and, in the design of the Pegasus 5, the opportunity was taken to introduce features that would facilitate further substantial uprating. With the cancellation of the P1154/BS100 and the launch of the Harrier programme Pegasus thrust was taken up to 19,000 lb initially, and then to 21,500 lb with the definitive production standard Pegasus 11 (Mk 103). While development continued to reduce life cycle costs and improve reliability it was not until 1986 that the Pegasus 11-61 first ran at 24,000 lb thrust following the XG-l5 technology demonstrator programme.

The current Pegasus retains the original layout with progressive enhancement of all the major components and the adoption of a Digital Control System.

THE ORIGINS OF JET-LIFT AT KINGSTON

Ralph Hooper

Ralph Hooper did an engineering apprenticeship with Blackburns and attended the first post-war course at the College of Aeronautics at Cranfield whence he joined Hawkers Experimental Drawing Office in 1948. There he worked on the Hunter and the P1121 before becoming the Project Engineer for the P1127, Kestrel and Harrier. He eventually became an Executive Director and Chief Engineer at HSA Kingston, later adding responsibility for Brough, and ultimately, Weybridge as well.

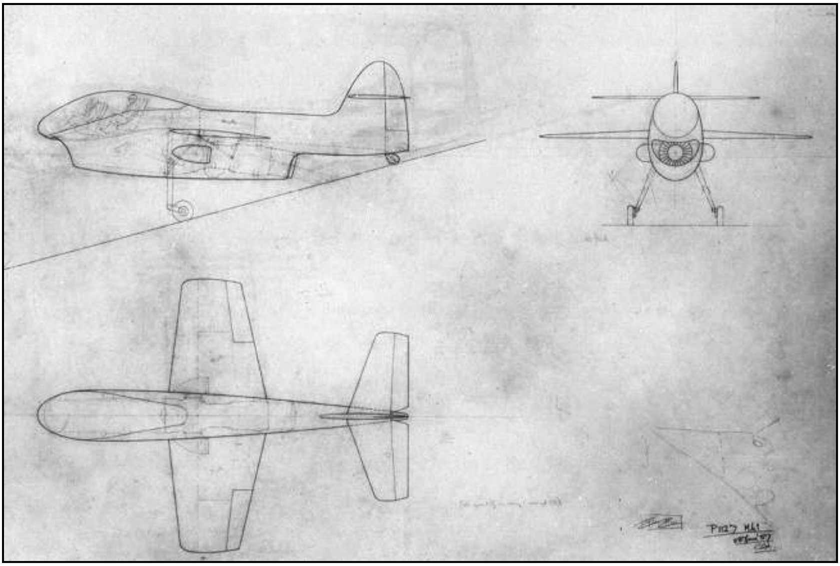
Hawkers were late into the jet era. The P1040 did not commend itself to a post-war air force already committed to the Meteor and Vampire. It was navalised as the Sea Hawk and production of all but the first batch was transferred to Armstrong Whitworth to make way for the new fighter to Spec F.3/48 which became the P1067, alias the Hunter. An intended development of the Hunter, the transonic P1083 was cancelled.

So, by the mid-1950s some urgency was felt at Kingston to find a follow-on to the Hunter and it was decided to commence a PV (Private Venture) supersonic fighter, the P1121.

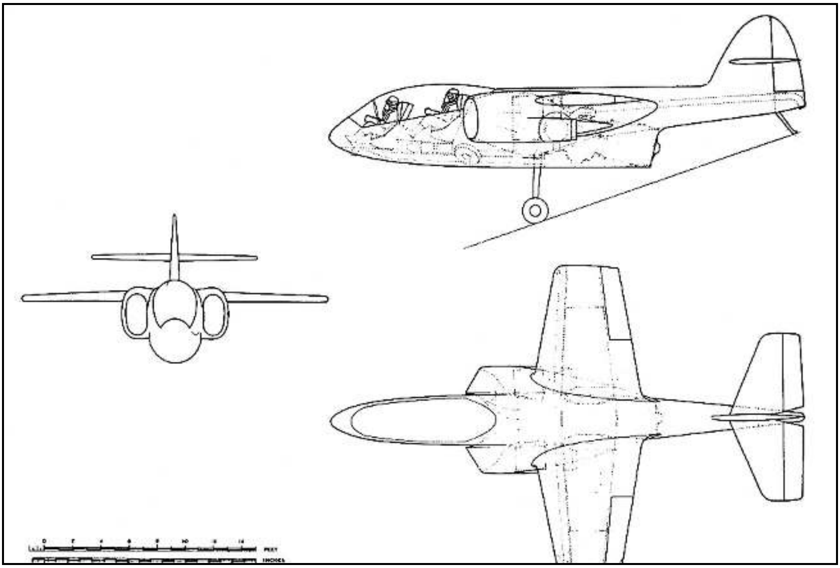
The prospects for this project received a set-back with the publishing of the Sandys White Paper. Initially the Company expressed confidence in the continuation of the P1121 but by October 1957 the design spend rate was cut by 20% and activity thereafter ebbed away as effort was transferred to the requirements which led ultimately to the TSR2, ie GOR339.

On 1 January 1959 Sir Sydney Camm was informed that the joint Avro-Hawker proposal in response to GOR339 had been unsuccessful. From this date, and in spite of efforts to find a more conventional alternative, the P1127 became our front runner.

Following the Sandys White Paper, meetings had taken place between the HSA Design Directors to discuss prospects within a diminished future. Jet lift was noted among possible areas of future



The VTOL concept of 1957 as a three-seater, above, and as a two-seater, below.



development. Perhaps as a result, Sir Sydney wrote to Stanley Hooker (later Sir Stanley) in May 1957 to enquire if he had any views on this subject and expressing his own reservations on the prospects of multiple lift engines.

Bristol responded with copies of Gordon Lewis's BE53 brochure, No PS17, and Hooker arranged a visit to Kingston a month later.

This meeting was mainly devoted to the prospects for a version of the P1121 re-engined with the Olympus, but preliminary sketches were tabled for an airframe making use of the BE53 as outlined in PS17. It was conceived as a three-seater which might be used for high speed liaison within an area of conflict.

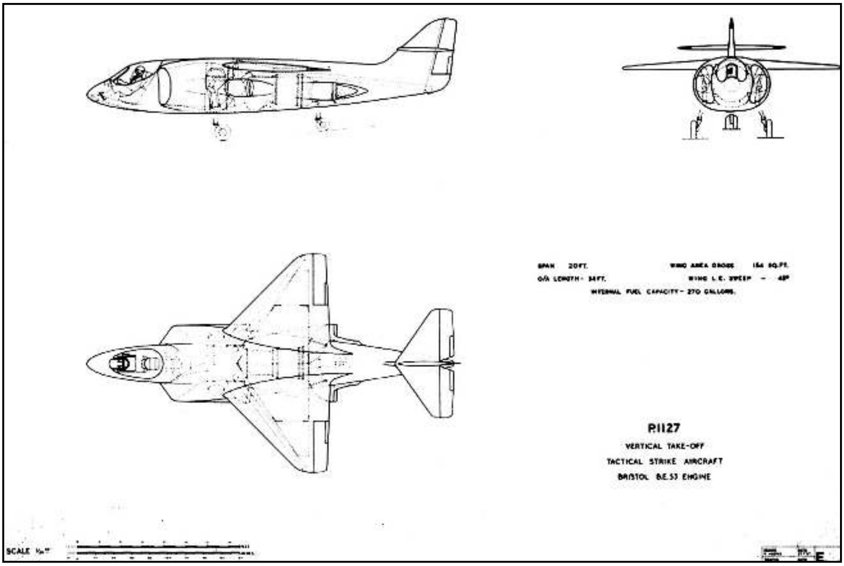
The meeting was sufficiently encouraging for work to continue on a part-time basis. As a result, the three-seater became a two-seater in an attempt to live within the gross thrust of 10,000 lb. It still failed to show much promise and at this point the project was saved from possible extinction by the idea of splitting the hot exhaust in a manner similar to the cold nozzles. This allowed the total installed thrust to be directed vertically, and Sir Sydney now ruled that the project must have 'a proper military capability.' The result was the very minimal ground attack aircraft, now numbered P1127 and illustrated on the following page.

Bristol had urged Kingston to contact Col Bill Chapman, USAF, of the Mutual Weapons Development Team in Paris, and this was done. He was encouraging but wanted double the radius of action then on offer. This led to the proposal to use water injection to boost take off thrust, thus allowing a near doubling of the fuel capacity.

By the end of 1957 the aircraft was described as having oblique, vaned nozzles, mechanically interconnected, and driven by an HP air bleed motor which also switched on the LP reaction controls as the nozzles reached 30^{o} deflection. The hope that the engine spools could be counter-rotated is noted in all the relevant aircraft documentation.

Only two or three people contributed to the P1127 in the Project Office during 1957, while from October support from the Experimental Drawing Office was generous. This imbalance continued through 1958.

By the Spring of 1958 Bristols had decided to rework the engine with a new fan which would supercharge the Orpheus compressor. This made counter-rotation possible, to our great relief. The airframe



An early drawing of the BE53-powered project now having 'a proper military capability' and assigned the company designation P1127.

to suit this engine introduced the outrigger undercarriage and 10° anhedral to go with it. It also moved the gearbox to the top of the engine, ahead of the wing structural box. The greater thrust now obviated the earlier need for water injection.

Confidence in the project increased and rig and tunnel work followed, but with the rapid progress being made in the Experimental Drawing Office it came too late to have much effect on the first prototypes.

By the end of 1958 all of the main features of the P1127 were in place – with one exception. We were still struggling with an economical but bulky LP, constant bleed, reaction control system and the installation problems were becoming insuperable. Then, in April 1959, Bristol proposed to replace the Orpheus 3 compressor with that of the Orpheus 12, the greater capacity making a constant flow HP system possible. Also from April 1959 the Ministry began to make a contribution to design costs, so ending nearly two years of PV coverage.

In mid-1959 Hawkers visited Bell Aircraft at Buffalo to learn

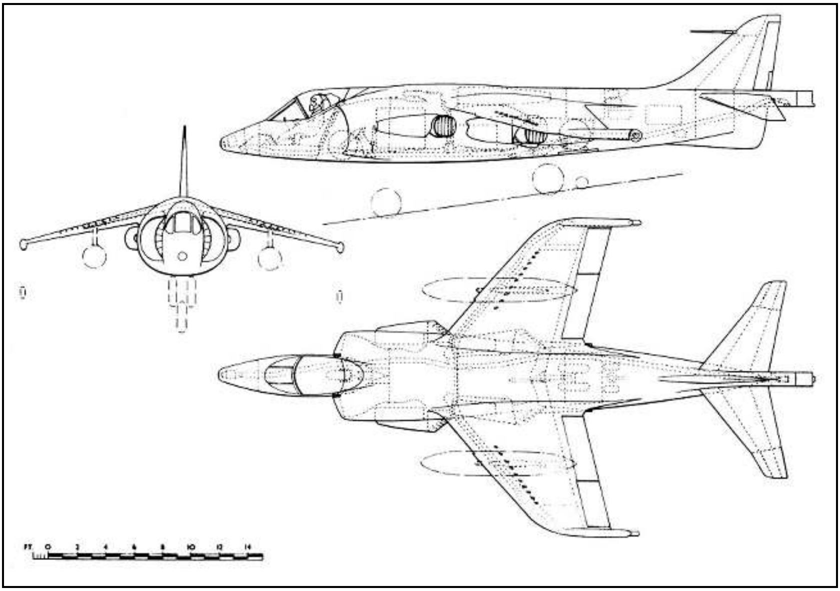
The first P1127, XP831, making an early tethered hover in 1960.

something of the X-14 (also a vectored thrust aircraft) and from there the visit moved to NACA Langley to talk to Marion McKinney and John Stack, the then Deputy Director. This resulted in their offer to build and test a model of the P1127 in their free-flight transition tunnel. The offer was accepted with alacrity. This was the only US support for the airframe and the results were most encouraging.

It was not until June 1960 that a contract was signed for the first two P1127 prototypes (three years from our first interest) and just one month later XP831 was delivered to Dunsfold. The first hover took place on 21 October with an engine giving 11,300 lb uninstalled thrust.

Subsequent development of the six prototypes introduced the demand reaction control system in time for the first transitions, and brought the last prototype, XP984, up to Kestrel standard aerodynamically, but not structurally.

The Kestrel itself was very nearly the aircraft that had been proposed in response to OR345, although lacking most of the operational systems. It benefited from increased roll reaction control (RC) power by way of the ‘up and down’ wing tip RC valves. It was stressed to have five 1,000 lb store stations (although only two were fitted) and to accept an 18,000 lb thrust engine. In the event the tripartite governments had no interest in an operational version of the



Half-way to a Harrier, the Kestrel had minimal operational capacity but was sufficiently capable to demonstrate the potential of the V/STOL concept.

P1127 so cost and timescale restraints resulted in an engine of 15,200 lb gross thrust, a figure deemed adequate to meet the trial objectives. At the time this resulted in the jibe that the Kestrel ‘couldn’t carry a packet of fags across a football pitch’ but the robust airframe did make development of the P1127(RAF) standard easier in 1965.

The collaboration between Bristol and Kingston was always good. It was a privilege to have been involved.

FLYING THE OPTIONS – THE SC1 AND P1127

John Farley

Prior to joining the RAF as a pilot in 1955, John Farley had completed an engineering apprenticeship at RAE Farnborough. Following a tour on Hunters, he was a QFI at Cranwell before going to the ETPS in 1963. He then joined RAE Bedford's Aerodynamics Research Flight, where he flew both the P1127 and the SC1. Thus began nineteen years of jet V/STOL testing. In 1967, he left the RAF and joined the Dunsfold test flying team. Eventually Chief Test Pilot, he retired in 1983.

One could talk for a long time about the differences between the Short SC1 and the Hawker P1127 because, generally, when comparing them, the phrase that comes to mind is 'Chalk and Cheese'

But I do not see my job today as being simply to list all of their many differences. Rather I hope to try to explain, first, why the teams that produced these two aeroplanes finished up choosing such different ways of meeting what appeared to be the same requirement – namely a single-seat fixed wing jet aircraft that could take-off and land vertically – and, secondly, how these different approaches affected a pilot lucky enough to be asked to fly and compare them over forty years ago.

At the end you may be inclined to feel that it all boils down to Hawkers got it right and Shorts got it wrong. However, I do hope that that will not be the case, because such a conclusion requires the benefit of considerable hindsight – and believe me over forty years ago such hindsight about jet V/STOL was in remarkably short supply.

At the simplest level, of course, both aeroplanes were similar, because: both could fly on their wings; both could hover; both could transition to and from the hover and both used pure jet thrust to achieve all this.

Now for some differences. First and foremost the Short SC1 was conceived, specified, designed and purchased by the government for the Royal Aircraft Establishment (RAE) to do research into jet V/STOL. On the other hand, the Hawker P1127 was conceived by a

The second SC1 (XG502)

fighter design house, with a long history of supplying fighters to the Royal Air Force, as a possible way of achieving a jet fighter that could land and take off vertically. It was not originally designed to a government specification but to meet a need, as perceived within Hawkers, that the RAF and others, *needed* a V/STOL capability to counter the possibility that conventional aircraft could be grounded by attacking their runway.

This difference in objective was fundamental in determining why Hawkers finished up with a single-engined vectored thrust aircraft that they hoped they could make work but which had the potential to become a fighter, while Shorts employed four lift engines and one cruise engine as they had been instructed to do by Specification ER143T.

However such matters were not uppermost in my mind when I checked out in the first P1127 prototype (XP831) and the first SC1 (XG900).

The piloting differences between these two aircraft are best summarised by saying that it took me many flights in the P1127 before I could climb down the ladder without offering up thanks that I had not bent the thing. While, after shutting down the SC1, I always felt relief that it had not suffered one of several possible nasty failures.

Why this difference? Let us look at the basics. The SC1 had five Rolls-Royce RB108 lift engines, four for lift and one for propulsion. The aircraft was very heavily autostabilsed and used full authority autostabilisers in pitch and roll which had *priority over the pilot when it came to the reaction controls*. Plus, there was a manual mechanical back up control mode intended as a last ditch option for emergency use. The pilot controlled the thrust from the lift engines using a helicopter-like ‘collective’ throttle with the left hand.

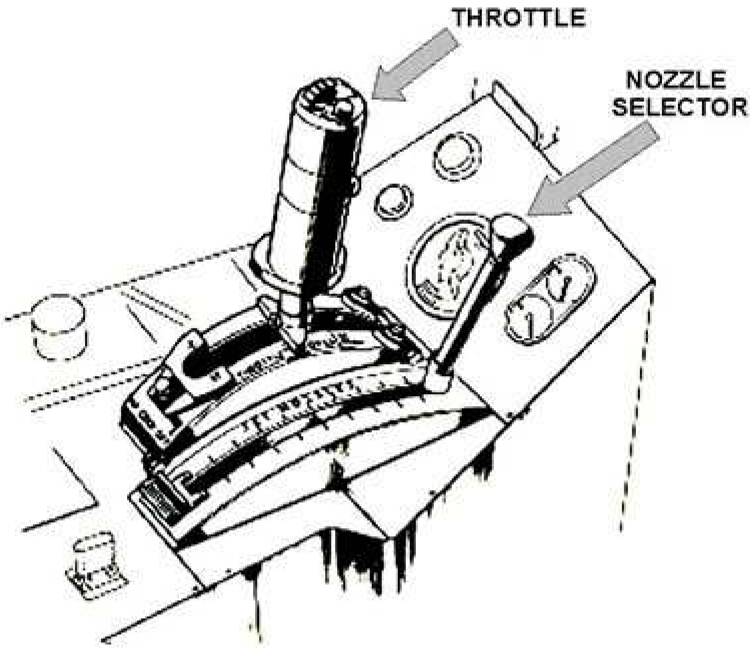
For reasons that we shall come to shortly, the SC1 had very easy handling, and later it was established that this good handling even extended to the manual mechanical backup control mode, but the aircraft was a real problem to operate due to very complex systems and the five engines which had to be looked after.

On the other hand, the Hawker P1127 had a single Bristol Pegasus engine for lift and propulsion, plus the aircraft was always mechanically controlled by the pilot and had optional low authority autostabilisers in pitch and roll. Piloting-wise the P1127 had demanding handling, due to its having two controls for the left hand and intake effects. However it was a delight to operate as it had no potentially dangerous systems and only one engine to be looked after.

So all this can be shown in a simple table:

	P1127	**Short SC1**
Operation	Easy	Demanding
Handling	Demanding	Easy

I think the differences in operation hardly need explanation. In the case of the SC1 you were operating a five-engined ‘bomber’ all by yourself. It had none of the benefits of automation that would be available today and so you had five of most things to deal with when it came to starting it up. In the air after take-off and getting on your wings, it was necessary to shut down the four lift engines because they were very thirsty, even at idle. Before landing the process of restarting them, one at a time, using bleed air from the cruise engine was also



The P1127's throttle box.

easy to get wrong. In some circumstances this procedure had to be done on short finals at below 500 ft. Then there was the issue of the full authority autostabs. These had full access to the roll and pitch reaction controls and unless you kept an eye on a gauge that was quite low down on the right side of the instrument panel, the first you knew that you had been robbed of all roll control was when you moved the stick and got no response!

Compare that to the operation of the P1127 which was, in effect, a single-seat fighter of the day, say a Hunter, with one extra lever in the cockpit to set the nozzle angle and two extra instruments – neither of which needed much attention. One instrument showed the nozzle angle set (but so did the nozzle lever) while the duct pressure gauge showed that the reaction controls were available (but so did moving the stick). P1127 handling though was quite another matter.

First let me try and put across why the P1127 was so tricky to handle because if you appreciate this it will become clear why the SC1 was no problem.

The P1127 throttle box, incorporating the throttle and the nozzle lever, was positioned on the left hand side of the cockpit where your left hand would naturally fall when sitting in the seat. Push the fat outboard throttle forward and the engine would go faster, pull it back and the engine would go slower. Every jet engine has one. An inboard slim nozzle lever set the angle of the nozzles, pull it back and the nozzles pointed downwards and the aircraft went slower, push it forwards and the nozzles pointed aft like a conventional jet. While this was a brilliantly simple way to achieve the full range of V/STOL manoeuvres it necessarily posed a piloting trap. Should you move the wrong lever by mistake then, whether it was possible to recover depended on luck as much as skill. Raising the nozzles in the hover would have you dart forward and downwards very rapidly. This has happened more than once in public – the first time being the P1127 at Paris over forty years ago and the most recent less than two years ago when a hovering Harrier fell in the sea during a display off the beach at Lowestoft.

The other problem was that, left to its own devices, a P1127 flying slower than about 100 kt wanted to go tail first. The pilot literally had to use his feet to keep the aircraft pointing into the airflow. This was directly analogous with the need for the pilot of a tail dragger aeroplane to use his feet to stop it swinging and ground looping when landing, especially if there was any cross wind.

The aerodynamic stabilising effects of the P1127's fin were no different from those of any other aircraft. They were dependent on the square of airspeed and so petered out as one got slower. Unfortunately there was a destabilising force that *increased* as flying speed *reduced* and so defeated the best efforts of the fin. This force was called intake momentum drag. It exists on all jet engine intakes and gets greater as RPM are increased. So, whenever you were flying slowly, and necessarily using jet lift not wing lift, up went your RPM and up went the intake momentum drag. To see why this destabilised the aircraft directionally we need to look at the airflow round the aircraft when viewed from above

In Fig 1 I have tried to indicate that, with your aircraft pointing directly into the airflow, everything is fine.

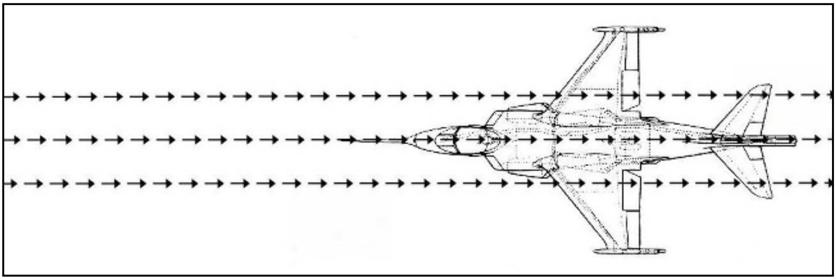


Fig 1.

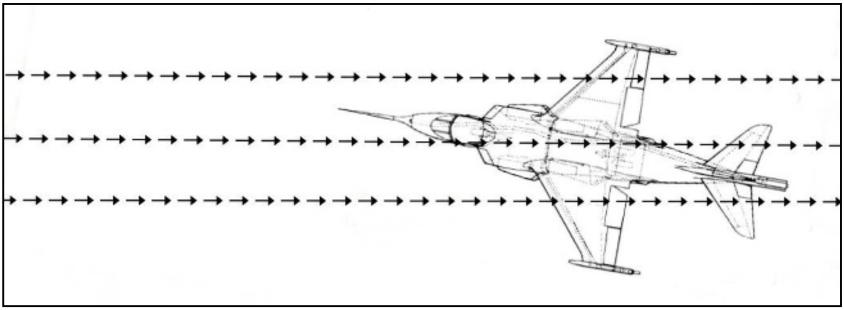


Fig 2.

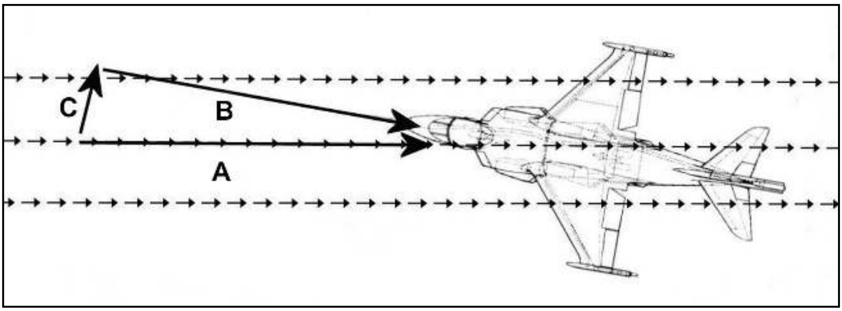


Fig 3.

Now let us imagine a little cross wind, or a deliberate sideways move of the nose by the pilot to track over the ground as he wanted or to get a better view of an obstacle – there are no end of reasons why this state of affairs could arise. This is shown in Fig 2. With the airflow now coming at an angle to the nose we must think about its three components as shown in Fig 3 where the A arrow shows the

The very simple practical solution to the critical (in a Harrier) problem of keeping the aircraft pointing into the airflow.

total airflow, the B arrow that part which is straight on the nose and the C arrow that part which is blowing directly across the nose.

The C arrow is, of course, the troublemaker because it acts at the intake, which is well ahead of the centre of gravity and so opposes the fin. Now you might think ‘so what?’ if the aircraft swaps ends and flies tail first – just embarrassing for the pilot in the debrief when he is told he must try harder on the rudder. Sadly, he is unlikely to make the debrief, because, as the aircraft goes seriously sideways, the leading wing will generate much more lift than the other and the aircraft will roll out of control – thanks to what is termed ‘rolling moment due to sideslip’. Such asymmetric lift can easily swamp both the ailerons and the reaction controls.

Clearly some exotic technology was called for to help the pilot keep the aircraft pointing into the airflow. It was the wind vane and is the same as that on any church steeple. It is just a hinged vane that points into the wind.

The intake momentum drag vector operated vertically downwards on the SC1, making its orientation, relative to the wind/airflow, irrelevant.

So much for why the P1127 had demanding handling. If we now look at the SC1 we see that the intake momentum drag arrow acts vertically down through the centre of gravity regardless of which way the aircraft is pointing with respect to the wind or airflow due to forward movement, allowing the fin to do its job, even as speed reduces. Hence the SC1's easy handling.

As experience was gained it became clear that the best way to fly the SC1 was in the unstabilised mechanical back-up mode, as this removed all the serious failure cases and was very good for one's peace of mind. That way the attitude control system became just like the P1127 with the stick position showing how much reaction control authority you had used up.

So there we are – 'chalk and cheese' certainly, but make no mistake, forty years ago both aircraft did great jobs in teaching us about how best to go about jet V/STOL.

THE KESTREL EVALUATION SQUADRON

Air Cdre D M Scrimgeour

David Scrimgeour, joined the RAF in 1945. He flew Tempests, Vampires, Meteors and Venoms and became a QFI before spending 1956-58 flying the F-86H and F-100 with the USAF Fighter Weapons School at Nellis AFB. Following tours as OC No 43 (Hunter) Sqn and at HQ Fighter Command, he became OC Kestrel Evaluation Sqn in 1964. Senior appointments included OC Wildenrath, OR tours concerned with the Harrier and Nimrod, management of the NATO AWACS Programme and Air Cdre Flying Training before retirement in 1982.

During the late 1950s and early '60s there was increasing concern in NATO countries about the vulnerability of aircraft on the ground, and of runways, to enemy air attack. This concern was reinforced by the result of the latest Arab/Israeli war. One solution was seen to be the use of V/STOL aircraft that could operate from dispersed sites away from their main bases.

In 1961 three nations, the UK, the USA and the FRG, agreed on the need for a practical evaluation of the V/STOL concept. There were several projects underway, but it was clear that, of these, the P1127 showed the most promise. So the three nations signed a tripartite agreement to buy nine aircraft, to be called Kestrels, and to form an evaluation squadron to carry out the necessary trials.

A tri-national Management Board was set up in the MOD to oversee the project and it was agreed that the squadron would have ten pilots – four each from the UK and USA, and two from the FRG, this being in line with the funding agreement under which the UK and USA provided equal shares and the FRG paid a little over half of one share. In addition, there would be a total about 200 groundcrew, again provided by the three countries. Among many other issues, the Management Board agreed, as an economy measure, not to fund the development of the Pegasus 5 engine to its full design thrust of 18,200 lb but to accept that it would be limited to 93% at full throttle – this would produce 15,200 lb of thrust on the test bed, reducing to

One of the nine production Kestrels.

about 13,200 lb when installed in the aircraft.

The Board also agreed that the squadron would be commanded by an RAF wing commander and that he would have two majors, one American and one German, as deputies. It is of interest that, of the four Americans, two, a lieutenant-colonel and a major were from the US Army; there was also a lieutenant commander from the US Navy and a major from the USAF. This was a result of the US funding arrangements whereby the US Army contributed 50% with the USN and USAF providing 25% each. The contribution from the *Luftwaffe* included a full colonel by the name of Gerhard Barkhorn – the second highest scoring ace of WW II – and a 24-year old captain, the youngest of the ten pilots. The previous experience of the pilots varied considerably: the RAF, *Luftwaffe*, USN and USAF pilots were all very experienced on fast jets; however, while the US Army pilots each had several thousand hours flying on helicopters and light fixed wing aircraft, neither had very much experience on fast jets. The groundcrews for the squadron came from all five Services – in the event, all of the American personnel proved to be senior NCOs. Thus it was, to say the least, an unusual squadron!

Detailed planning of the trial began in 1964 and it was decided that the evaluation should cover seven specific tasks. Broadly speaking, these were accomplished in three phases:–

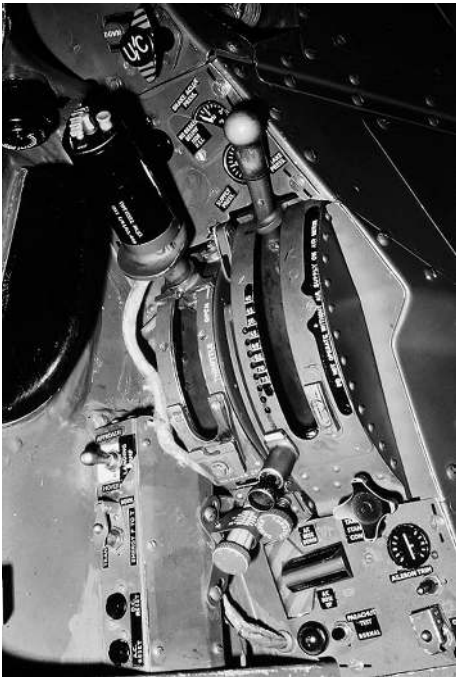
a. Operations from the main base.

The ten pilots who flew with the Kestrel Evaluation Squadron. Back Row: Sqn Ldr Fred Trowern; Lt Col Lou Solt; Wg Cdr David Scrimgeour; Col Gerhard Barkhorn; Flt Lt David Edmondston. Front Row: Capt Volke Suhr; Maj Al Johnson; Maj J K Campbell; Lt Cdr Jim Tyson; Flt Lt 'Porky' Munro.

b Operations from grass and artificial surfaces.
c. Dispersed operations from unprepared and artificial surfaces.

Conversion Programme

Before converting to the Kestrel, those pilots who had had no previous helicopter experience were given five hours of dual flying on helicopters; all agreed that this was very worthwhile. The Kestrel conversion began at Dunsfold in December 1964 starting with a comprehensive ground school course followed by ten flights totalling about three hours flying time. It was devised and supervised extremely well by Duncan Simpson – one of the three Hawker P1127 test pilots – and it was completed without incident. During March 1965, the pilots took their aircraft to join their groundcrews at RAF West Raynham.



Kestrel throttle and nozzle levers.

Phase I

Trials flying began in April and the first month was used to gain more experience on the Kestrel and to establish Standard Operating Procedures (SOPs) for all forms of take off and landing, instrument flying, recovery of aircraft, fuel reserves and formation flying. It became clear that once airborne, the normal fighter SOPs could be used. By far the most important feature of the aircraft was the tremendous benefit available from its short take-off (STO) capability. Today, this has been experienced by several hundred pilots, but to the Kestrel pilots, forty years ago, it was a revelation. The illustration shows the throttle lever and, alongside it, the nozzle lever and nozzle stop. To a pilot; this was the crowning success of the P1127 design – the fact that it needed only one additional lever in the cockpit. Before take-off you simply set the nozzle stop at a pre-computed position then, after lining-up on the runway, open the throttle; the aircraft accelerates extremely rapidly; at the pre-computed speed, usually at around 65kt, pull the nozzle lever back to the stop and the aircraft leaps into the air; move the nozzle lever smoothly forwards and, in a flash, you are in conventional flight – very exhilarating! Compared with a conventional take off with a full fuel load, an STO cuts the ground roll from 2,200 ft to 750 ft.

Turning now to vertical take off (VTO), as already noted, the Pegasus 5 in the Kestrel was limited to 93% rpm at full throttle which, installed in the aircraft, provided about 13,200 lb of thrust – and thrust is, of course, also affected by the ambient temperature. When empty the Kestrel weighed 10,360 lb, so the average fuel load for a vertical take off (VTO) was around 2,500 lb. Compared with the full fuel load that could be carried with an STO, the radius of action at low level after a VTO was reduced from 160 nm to 65 nm.

With regard to landing techniques, all the pilots found that it was the short landing that required the greatest concentration and skill, particularly if the length of landing strip demanded an accurate touch down and minimum ground run. This is because, by definition, the aircraft is above hover weight and the pilot has to use wing lift coupled with a combination of either a fixed nozzle angle and variable throttle setting or a fixed throttle and varying nozzle angle to control the rate of descent. Compare that with a vertical landing where the aircraft is below hover weight and, although the landing may require a slow forward speed at touchdown (described as a 'rolling vertical landing' or RVL) to avoid the ingestion of loose debris, it does not require any additional lift from the wing; the equivalent for take off is the RVTO. As training progressed, the pilots all began to regard the use of an STO followed by a VL or RVL as a routine procedure for a typical sortie which, if anything, was less demanding than flying a conventional jet fighter. In particular, this applied to radar approaches in very poor weather conditions when the pilot could come to a hover after breaking out below cloud and then manoeuvre if necessary to make a vertical landing! Hence the saying 'better to stop and land rather than land and have to stop!

Phase 2

The trial then went into the second phase and operations moved to RAF Bircham Newton, a grass airfield about 20 miles to the north of West Raynham. Several landing strips were marked out and repeated STOLs and RVTOLs were carried out to test the effect on the grass surface. Although the grass was scorched, in no case was the surface broken, nor was there any engine damage from the ingestion of debris. The illustration shows the effect of forty-two STOs and RVTOLs made from the same spot. Operations at Bircham Newton continued for about two months and the scorch marks faded gradually during that time. Although the marks were readily visible from the air, they gave no indication whether or nor the airfield was currently in use. With its low pressure tyres the Kestrel had no problems at Bircham; however, the aircraft could traverse quite boggy ground by using the

Left: not crop circles but grass scorching after forty-two STOs and RVTOLs. Right: the result of taxying over waterlogged ground with the nozzles at 45^o. Below: a MEXE pad.

nozzles lowered to 45 degrees.

Three different artificial surfaces were tested at Bircham: firstly, Class 30 trackway which is standard equipment used by the Army; secondly, a fibreglass material which was sprayed onto the grass –

both proved to be satisfactory. However, the most successful was the MEXE pad, so called because it was designed by the Military Experimental Establishment at Christchurch. It consisted of rectangular aluminium planks which locked together and were then securely pegged down around the edge to form a square-shaped mat. Initially a 70 × 70 ft square was tested successfully; the size was then reduced to 50 × 50 ft and this caused no problems, provided that care was taken to ensure that the jet efflux was kept clear of the edge of the pad. For that reason, the use of the larger size pad would be preferable for normal operational use. Operations on bare earth and desert type surfaces were tested at RAF Oakington, then the home of the Airfield Construction Squadron. A number of STOs were made successfully on a strip where the topsoil had been removed, and VLs were made on a 50 × 50 ft MEXE pad which had been laid on a 100 × 100 ft membrane.

Phase 3

This was the largest and most important part of the trial. Over 470 flights were made to examine the operational deployment of V/STOL aircraft and the associated problems of command and control and logistic support.

There are obviously many factors that will determine the best pattern of deployment, not least the threat of enemy air attack, the terrain and the available amount of logistic support. In a cold war situation such as existed in Europe the vulnerability of aircraft on the ground would be a prime consideration so maximum dispersal might be the right answer. However, when the threat of enemy attack is negligible, the ability to deploy quickly and operate from a wide variety of locations, such as small grass airfields or roads, offers great flexibility. In this, the Kestrel had the added advantage of not requiring any ground power equipment to start the engine or to keep some electronic equipment running.

New terminology was required for the concept of dispersed operations and it was decided that the main location for a squadron, or even a wing, with its HQ, operations room and main logistic support, would be called a Primary Site. This might be on a Class 1 military airfield, or a small grass airfield such as a flying club or even a road complex. Around the Primary Site would be a number of sub-sites,

The sub-site in the Thetford Training Area, about 20 miles south of West Raynham.

equipped with varying levels of logistic support depending on the chosen concept of operation.

Two concepts of operation were used during the trial:–

a. Sub-site to Target to Sub-site. This requires considerable logistic support at the site but provides maximum dispersal. The Kestrel had no armament but it did have a forward-facing camera, which was used for recce missions, so the sub-site had to be provided with a mobile film-processing trailer, a refueller and enough groundcrew to turn the aircraft round. Command and control was exercised from the primary site at West Raynham via single side band radio

b. Sub-site to Primary Site to Target to Sub-Site. The aircraft would be dispersed at all times except when being turned round at the primary site. This concept could be used for pre-planned missions and would require minimum support at the sub-site.

The sub-sites used during this Phase were completely unprepared and comprised a local farmer's field and a stretch of grass in an army training area about 20 miles south of West Raynham. The latter had a MEXE pad, laid beside a track leading to a wood where the aircraft could be refuelled and re-armed. There was also enough grass for an STO – you might say that nature had provided an ideal sub-site!

A high rate of aircraft serviceability is obviously required for dispersed operations. Throughout the trial 325 sorties were flown from sub-sites and it was always intended that the aircraft should return to the primary site at the end of each day. In fact, this was not possible on eleven occasions – five of these were due to bad weather and only six to unserviceability.

During the closing stage of the trial, a limited examination of night flying was carried out. STOs and RVLs were made on the runway and the grass at West Raynham. Vertical landings on a MEXE mat were made possible by placing two lights in line about 70 yards directly ahead of the mat, with two more at 90 degrees which allowed the pilot to position the aircraft directly over the mat. Finally, one test was made on a typical dispersed site located in a wood close to RAE Bedford. After a trial landing by day, a successful night landing was made using the system of lights described above. The main difficulty was in estimating the right height above the trees for decelerating to a hover. This would be greatly alleviated by having either a radar or radio altimeter.

Conclusion

A total of 960 sorties were made during the trial, including 1,366 take offs and landings. The Kestrel proved to be a thoroughly practicable, relatively simple aircraft which could be flown by experienced Service pilots. The aircraft could be operated repeatedly from good turf surfaces and ingestion of debris was not a problem if the right techniques and speeds were used. VTOLs could be made safely on aluminium mats of a minimum size of 50 × 50 ft.

The striking advantage of the aircraft was the great flexibility that it could provide in operation and deployment. Finally, the trial showed clearly that the optimum mission profile is a short take-off and a vertical, or rolling vertical, landing - that is to say STOVL.

CONVERTING THE RAF TO THE HARRIER

AVM Peter Dodworth

Peter Dodworth joined the RAF from university in 1961. He flew Hunters and Gnats until 1969 when he began a long association with the Harrier, initially as a QFI and later as the type specialist at HQ RAFG, as OC Ops and Station Commander at Wittering and as Air Commander Belize. More senior appointments included Director Personnel at MOD, Defence Attaché in Washington DC and with the Directing Staff of the RCDS. He retired from the Service in 1996.

I pick up the story with the introduction into RAF service of the Harrier GR1 which was a minimalist development of the Kestrel, offering sufficient operational capability to satisfy ASR 384. The GR1 had the Pegasus 6 (RAF Mk 101) engine with 19,000 lb thrust, a significant improvement over the 15,500 lb of the Pegasus 5 in the Kestrel. The GR1 also had the Inertial Navigation and Attack System (INAS) complete with a Weapon Aiming Computer (WAC), from the TSR2/P1154 and this, with the other operational equipment, gave quite a crowded cockpit. It also had a Head Up Display (HUD) which was new to RAF aircraft.

For jet-borne flight the four nozzles could be rotated together to vector the thrust from fully aft to about 15^{o} forward of the vertical. The nozzle actuation system was operated by a single lever just inboard from the throttle: forward for the nozzles fully aft, back to the vertical for hovering and further back for the braking position. Control in jet-borne flight was by reaction controls situated at the extremities of the aircraft, fed by air bled from the compressor and controlled by shutters connected to the associated flying control surface.

The GR1 was supersonic in a dive, would go about 500 nm at low level and carried two 30 mm ADEN cannons and a variety of weapons, fuel tanks and a reconnaissance pod on its five pylons – it was a fully operational combat aircraft. The Harrier entered RAF service in April 1969 and was immediately entered for the *Daily Mail* Air Race. The race was to commemorate the 50th anniversary of the

A GR1 fast and low.

first crossing of the Atlantic by Alcock and Brown in a Vickers Vimy.

On 5 May 1969 Sqn Ldr Tom Lecky-Thompson ran from the top of the Post Office Tower in central London to a helicopter which took him to St Pancras railway station where he took off vertically in a Harrier GR1 (XV741). He refuelled at Mach 0.88 from a Victor tanker; landed vertically at Bristol Basin in Manhattan and roared through New York on a motor bike to reach the top of the Empire State Building in the winning time of 6 hours, 11 minutes and 57.15 seconds. Sqn Ldr Graham Williams flew the return leg on 9 May in XV744 using an E-Type Jaguar in New York and landed in a cloud of coal dust at St Pancras before a helicopter and motor bike took him to the top of the Post Office Tower just 5 hours, 49 minutes and 58 second after leaving the top of the Empire State Building. This gave great publicity to the Harrier, particularly in America where it was their first real exposure to the aircraft. The Air Race was the only time I can recall that the ferry tips were used. These eighteen-inch extensions were bolted on to the wing tips – 'cheap variable geometry' John Fozard called them – and gave improved cruise performance at height but carried limitations that precluded their use for low level operations.

While all this excitement was going on, the introduction of the Harrier into RAF service was taking place at Hawker Siddeley

1969 - The Harrier Conversion Team. From the left: Flt Lt Richie Profit, Flt Lt Pete Dodworth, Duncan Simpson (HSA), Sqn Ldr Dick LeBrocq (the CO) and Flt Lt Bruce Latton.

Aviation's airfield at Dunsfold. I shall describe the early pilot conversions starting with the Harrier Conversion Team (HCT) and finishing with the formation of the OCU. I shall then briefly mention the specific modes of operation associated with the Harrier's main concepts of operations.

The HCT consisted of four pilots with Hunter and QFI backgrounds specially selected by weight – over 7 cwt in all – and began its conversion in January 1969 under the watchful eye of Duncan Simpson, the Deputy Chief Test Pilot at Dunsfold. The ground training phase lasted ten weeks and included systems courses at Dunsfold, Rolls-Royce, Ferranti and Specto Aviation for the HUD, Miles aviation for the simulator, and the Royal Navy Weapons School at Whale Island for computerised weapon systems. Our briefings on V/STOL aerodynamics were given by John Fozard – then Chief Designer Harrier. From all this we devised and prepared the lectures for the subsequent HCT ground school.

The flying phase started with a short Hunter refresher at Chivenor and a bespoke helicopter course at Ternhill on the Whirlwind which

Taxying to 120 kt & PNB*	—
Conventional flight	1.00
VTO/VL & Hovers x 2	0.30
Transition (VTO to conventional & back to VL) x 2	0.30
Boom run, general handling, VTOL	1.10
STO Hops & SLs	1.10
STOL on grass	0.50
Formation, LL Nav, IF, V/STOL x 2	1.50
VLs on pads in woods x 2	1.00
Total	**8.00**

**Power Nozzle Braking – Harrier-style 'reverse thrust'.*

The practical exercises within the HCT syllabus.

gave us six hours of hovering and transitioning experience. The Harrier course involved about eight hours flying in the single-seat GR1 – it was about two years before the two-seat trainer would enter service. The conversion started with a conventional flight, chased by Duncan in a Hunter, which culminated in a 160-knot conventional landing; the most dangerous of all in a Harrier!

Vertical take offs and landings followed and then a series of sorties transitioning to and from vertical flight. We did a 'dual' on this exercise with the four of us being flown round the circuit at Dunsfold by Duncan in a Dove – 'Take 40^{o} nozzle as you cross this road; drop flap about here – as you pass this building with a red roof' and so on. Short take offs and landings were the final discipline to be covered from both runway and grass. Subsequently, with our own students, we started with short landings, then VTOL and transitions, leaving the conventional landing until later. The early aircraft were not equipped with INAS; we just had a variable depression weapon aiming sight. We finished our conversion with a VL on a 50 ft pad in the middle of a wood near Boscombe Down. This was fairly bold, as one had to come all the way down through the trees using a couple of dayglo panels in the trees at 12 o'clock and 3 o'clock as hovering cues and the pad was only sighted at about 15 ft. Subsequently 75 ft pads were normally used. It was not all flying, as there were a lot of performance calculations to learn and we produced a V/STOL computer. We also spent a long time learning about the INAS and WAC so that we could produce digestible instruction on it when it finally arrived. While we were at Dunsfold the RAF groundcrew who had been posted to the Harrier were attending a variety of courses at the Hawker Siddeley Instructional School and their training had been completed in time for our departure.

On 16 May we took four Harriers to RAF Wittering and started converting the existing Hunter squadrons, a flight at a time. The first flight of No 1 Sqn included Sqn Ldr 'Porky' Munro who had been on the Kestrel Evaluation Squadron. The VTOL and transitions were done on detachment to West Raynham where better quality concrete pads – built for the Kestrel – were available. The second flight of No 1 Sqn included its new CO, Wg Cdr Ken Hayr, who was to play a key part in developing the aircraft's operational role. It also included Capt Bud Hall, the USAF exchange officer and Maj Bud Iles of the USMC who was gaining experience prior to helping to convert the USMC onto the AV-8A.

As a result of our experiences, the basic conversion was now twice as long. Without a two-seat trainer we found that we needed extra sorties to consolidate the exercises. The Harrier was not intrinsically difficult to fly but the acceleration was fierce and one needed to think all the time about the correct control to use. Although the use of the nozzles was intuitive, the need to apply substantial power rather than pull the 'stick' back to control rate of descent was not. Similarly it was vital in semi-jet borne flight to eliminate any yaw. At certain angles of attack and yaw the induced roll could exceed the authority of the roll controls and a number of aircraft were lost through this. We chased sorties in our two faithful Hunters – named 'Fred' and 'Nuts' by Duncan who had not yet adapted to the 'new' phonetic alphabet – and also occasionally in Harriers. We also offered advice over the radio from a caravan situated by the VTOL pad or STOL strip.

With a conversion to the INAS, weapons, recce and Air Combat Training (ACT) now included, the duration of the course was about four months. Our third intake was the first flight of No 4 Sqn (a re-badged No 54 Sqn – previously Hunters at West Raynham) and included Gp Capt David Scrimgeour en route to becoming the first Harrier Station Commander at Wildenrath. They were followed in June 1970 by the second flight of No 4 Sqn. The HCT gave all the ground school lectures from airframe/engine systems to the operation

The first two-seat trainer, the T Mk 2, became available in the autumn of 1970 permitting first tourists to be introduced to the type by the newly established No 233 OCU, which absorbed the HCT.

of the INAS, WAC and HUD – we even designed and fitted out the lecture and briefing rooms.

The students all found the aircraft exhilarating with so many new activities from V/STOL to INAS navigation, live weapons training, recce, landing in fields and woods and using the nozzles in air-to-air combat.

Then, in August 1970, we converted the pilots who would become the OCU staff and in October 1970 the last single-seat course was the first flight of the new No 20 Sqn and the first USMC course. On it were Sqn Ldr Dave Edmondston, who had been on the Kestrel, en route to No 20 Sqn, and Capt Harry Blot, USMC, who eventually became the commander of US Marine aviation as a lieutenant general and was a leading light in Lockheed Martin's Joint Strike Fighter team.

With the arrival of the Harrier T2, the two-seat trainer, in October 1970, No 233 OCU formed, absorbed the HCT and started full operational conversions for first tourists. The T2 was a fully operational aircraft and a very effective trainer. The arrival of the Pegasus 10 (Mk 102) with an increase of 1,500 lb of thrust conveniently offset the T2's extra 1,400 lb weight. Towards the end of 1972 the early Harriers started to be converted to the GR3 with the Pegasus 11 (Mk 103) with 21,500 lb thrust and, subsequently, equipped with the Laser Rangefinder and Marked Target Seeker. The GR3, with the associated T4, became the standard Harrier in RAF service until the advent of the 'second generation' GR5 and T10.

The OCU courses lasted six months and started with a week's helicopter flying. They involved considerable ground school and simulator time and about 75 hour's flying. The OCU was divided into a Basic and an Advanced Squadron. The Basic Squadron introduced students to V/STOL, instrument, formation and night flying, and ACT with the Advanced Squadron handling low level navigation, attack profiles, recce and a lot of weapons training. The OCU course was geared to the concept of operations that developed. The normal way of operating from field sites or airhead dispersals was to do a short take off from a taxiway, road, MEXE strip or grass and then, with weapons and most of the fuel gone, to do a Vertical Landing onto a MEXE pad or a Rolling Vertical Landing on a strip.

The aircraft operated mainly at low-level and would primarily use 30 mm cannon, SNEB rockets and cluster bombs against armour and other targets as well as conducting recce with the port oblique camera or recce pod. All of these disciplines were taught at the OCU and specialist courses were run most years to teach experienced pilots to become Weapons Instructors, Recce Instructors or Instrument Rating Examiners. Overall, both the single-seat conversions and the full OCU courses were very effective training programmes that were geared to the changing requirements of the operational units. The success rate of students was similar or better than comparable operational training on other aircraft and the V/STOL dimension did not become the problem many had forecast.

THE COLD WAR CONCEPTS OF OPERATION FOR THE RAF HARRIER FORCE

Gp Capt Jock Heron

Jock Heron emerged from Cranwell in 1957 to fly Hunters and, during a USAF exchange tour, F-105s. Following a stint working on the MRCA project he spent ten years in the Harrier world, flying it in Germany, and as a staff officer at both Rheindahlen and MOD. He commanded RAF West Drayton and RAF Stanley before leaving the air force to spend the next ten years with Rolls-Royce as their Military Affairs Executive. He is Vice-Chairman of this Society and has been the mastermind behind the planning of today's seminar.

The Kestrel trials confirmed that dispersed operations offered the dual attractions of reduced vulnerability to air attack and speedier response to tasking. The tripartite squadron's recommendations were refined during the next four years and were used as the basis for the two different concepts of operation which were proposed for the RAF Harrier Force. These were, first, the Wittering-based No 1 Sqn's role on the NATO flanks in support of the ACE Mobile Force (Air) and as part of SACEUR's Strategic Reserve (Air) and, secondly, the larger RAF Germany Force comprising initially Nos 3, 4 and 20 Sqns based for six years at Wildenrath as part of 2ATAF before the wing was restructured and moved east to Gütersloh. Both concepts employed the Harrier in the classic offensive air support role providing close air support, battlefield air interdiction and tactical air reconnaissance for the relevant army units. The aircraft's unique STOVL capability was a very useful feature for the flank options but was vital to the concept for the RAF Germany force.

In 1969 No 1 Sqn received its first aircraft and, under the command of Wg Cdr Ken Hayr, several operational techniques were explored. Its Harrier GR1s were flown from dispersed sites in the UK, Norway and Cyprus. Shipborne trials were also flown from the conventional carrier HMS *Ark Royal* several years before the Sea Harrier's procurement was approved for the Royal Navy. By 1972 No

A Harrier GR1 aboard HMS Ark Royal.

1 Sqn's primary basing options were confirmed as Tromsø in Norway and Vandel in Denmark while the longer range deployments to the Southern Flank, which involved air refuelling, remained as secondary options. In time the squadron was to be committed to nine nominated deployment bases ranging from Northern Norway through the Central Region to Greece and Turkey. These options required access to the host base for accommodation, aircraft parking, preferably in HAS or dispersed hides on the airfield perimeter, and bulk refuelling.

The squadron was tasked by the appropriate ASOC and a typical sortie profile involved a short take off from either the airfield's main runway or from the perimeter track, armed with guns, BL755 cluster bombs or SNEB 68 mm rockets. Targets were expected to be the standard range of Warsaw Pact armoured vehicles moving west along the few routes through the Finmark and Norwegian mountain passes. Sortie radius was around 150 miles with drop tanks and duration about 50 minutes. Navigation and target acquisition were visual, aided by the analogue inertial navigation and attack system with head up and moving map displays, assisted by forward air controllers. After 1976, as part of a major modification package, acquisition and aiming were augmented by the laser ranger and marked target seeker which were accommodated in an extended 'thimble' nose and radar warning receivers were fitted in the extended fin. Normally, recovery involved a semi-jet borne slow landing on the appropriate strip, rather than vertically on to a prepared pad, although the latter technique remained an option. By early 1975 all Harriers had been modified to GR3 standard by retrofitting more powerful engines and the improved performance enabled the aircraft to hover with higher fuel reserves and with some external stores.

The typical threats from the air were *Fishbeds* and the longer range Sukhoi *Flagons* and the ground threat was mainly from mobile SA-6, man portable SA-7 and mobile AAA such as the ZSU-23/4. Tactics to counter these were similar to the Standard Operating Procedures in the Central Region using low flying, avoidance and evasive procedures, augmented by RWRs, and later by using chaff and flare dispensers. Support on and around the designated airhead was provided by British Army sappers for field engineering and signallers from the Tactical Communications Wing whose roles were vital to the squadron's capability. All of these elements were exercised during the routine annual training programme which included deployments within the UK and overseas to Tromsø in March for snow operations and to Vandel in the summer months for TACEVAL.

In the Central Region the RAF Germany Harrier concept was entitled WARLOC, an abbreviation of war locations, and it evolved after 1970 when the first of No 4 Sqn's Harriers arrived at Wildenrath, one of the modern NATO 'Clutch' airfields west of Mönchengladbach. Within two years Nos 20 and 3 Sqns had followed to form the thirty-six-aircraft RAF Germany Harrier Force which, in transition to war, would have been reinforced by up to twelve aircraft and pilots from the Harrier OCU at Wittering. The force had the option of operating from the main base at Wildenrath using the runway, parallel taxiways, revetment access tracks and a few nearby road strips but the preferred concept was WARLOC which was a complicated plan to deploy the Harrier Force forward to locations within the 1(BR) Corps area of responsibility. It embraced six pre-surveyed flying sites, two per squadron, housing up to eight aircraft per site when reinforced by the OCU, with six further sites earmarked as step ups, the mobile Forward Wing Operations Centre (FWOC) and two logistics parks. Force deployment involved the support convoys and ground parties moving forward to these dispersed war sites when ordered to do so by HQ RAFG on receipt of the relevant NATO alert measure. Timing was crucial because, ideally, the first war sorties were tasked to fly from the main base after the sites were activated, execute the mission and land vertically at the allotted war site, whose grid reference, identity and characteristics would have been briefed to the pilots shortly before take off – quite a challenge!

These sites would have been requisitioned under emergency legislation and, in the 1970s, the German country and urban roads built to the *schnellweg* standard, with integral cycle tracks on the shoulders of the carriageways (the equivalent of modern UK B Classification roads), were ideally suited as short take off strips. Main roads and autobahns were not considered for the Harrier Force as several of these were expected to be used for other military purposes such as convoy routes and emergency airfields. Sorties from the sites would usually have been tasked by the 1(BR) Corps ASOC, or by HQ 2ATAF through the appropriate ACOC, and flown in the Short Take Off mode, without drop tanks, to maximise the preferred weapons load of BL755 cluster bombs. High sortie rates were achieved in training and pilots remained in the cockpit during operational turnrounds being tasked over the telebrief and given fresh target maps by the Ground Liaison Officer's runner. Although the cluster bomb was the preferred weapon the SNEB 68 mm rocket was a suitable alternative. The predicted targets were second echelon Warsaw Pact armoured formations and mobile first echelon equipments where a rapid response for close air support was needed. No 4 Sqn, which was assigned to NATO in the dual roles of attack and tactical air reconnaissance, carried the five-camera recce pod on the centreline station. Almost invariably vertical landing was the method of recovery and each site had a 70 × 70 ft MEXE pad laid adjacent to the hide areas to ensure that aircraft were hidden quickly after landing.

It became clear fairly quickly that Wildenrath was not the ideal mounting base for the Harrier because of the distances involved in the road deployment and the time taken to activate the sites. On average it took the convoys about six hours to reach the forward operational areas so when the Lightning force was disbanded in 1976 and the

A GR3 using Gütersloh's dummy road strip.

longer range Phantom assumed the air defence commitment, the opportunity was presented to revise the RAF Germany basing posture by moving the Phantoms to Wildenrath and basing the Harriers at the old *Luftwaffe* station at Gütersloh, close to 1(BR) Corps headquarters at Bielefeld. This basing arrangement meant also that the Harrier Force was much closer to the predicted operational areas and better placed to counter a surprise Warsaw Pact armoured thrust from the Inner German Border, north of the Harz mountains. At Gütersloh the squadron accommodation had been designed for two units so the Harrier Force was reorganised into two eighteen-aircraft squadrons and No 20 Sqn's numberplate was transferred to a new Jaguar squadron at Brüggen. Although much smaller than its Clutch counterpart, Gütersloh was adapted quickly for its new role. Two MEXE pads were laid and later a representative road strip was built for routine training. Thus the station became the home of the RAF Germany Harrier Force for almost twenty years.

Naturally the war sites could not be exercised but the force trained realistically both on its main bases and in the field where conditions were simulated routinely by undertaking three two-week deployments per year. Normally the training sites were in woodland settings using natural grass surfaces as short take off strips around and within the British Army Sennelager training area some twenty-five miles to the east of Gütersloh, although temporary metal planking surfaces were

Inside one of the Marshall Cabin box-bodied vehicles used to accommodate much of a field site's infrastructure.

used in particularly wet conditions. Other military training areas and occasionally short stretches of suburban public roads were used from time to time. The latter were authorised for temporary closure by the German highways department, usually prior to major road works being carried out. Normally all of a site's infrastructure was housed in tents or Marshall Cabin box-bodied vehicles most of which were protected against NBC conditions.

Flying from natural surfaces presented major difficulties in wet weather and a combination of our groundcrew and sappers from the site's Royal Engineers helped to de-bog many an errant Harrier. So, many of the lessons learned from these deployments were applicable solely to our training circumstances and irrelevant to the improvement of our concept of operations. Exercise names such as MARCH HARE, OAK STROLL and HAZEL FLUTE were allocated to these field deployments and while I do not recall who invented these titles they are stamped indelibly on the memories of all who, from time to time, had to seek refuge from the cold and damp in the relative comfort of a 'twelve by twelve' tent and a paraffin heater.

So, our intentions in the early 1970s were to create several

One of the occasions when 'sappers from the site's Royal Engineers helped to de-bog many an errant Harrier'.

permanent training sites using stretches of road within the Sennelager military training area. The most representative of these dispersed sites was the tank road at Eberhardt at the north end of Sennelager which we surveyed in 1974 and drew up its specification as the first of such training sites with the Force Commander, then Gp Capt Paddy Hine. It was operational by 1975 and went on to serve the RAF Germany Harrier Force for over twenty years.

A subsequent attempt in 1981 to create a further permanent training site in Sennelager in conjunction with Army plans for a FIBUA village came to naught however but in due course a number of other hard strips were laid down in Sennelager and these were used for routine field deployments with occasional intensive periods of live weapon carriage which trained the groundcrew in operational turnaround procedures and the aircrew in aircraft handling with a full weapons load when flying from a strip of restricted length. Normally the annual training pattern involved a station evaluation during the spring deployment with the MAXEVAL, the Command Headquarters' evaluation, in the summer. The cycle was completed with the Phase Two TACEVAL which occurred during the autumn deployment. Also, occasional mid-winter deployments to a single hard site

Above and opposite – a small supermarket and a straight stretch of road such as these constituted a viable WARLOC site.

provided a better understanding of the problems of operating in freezing conditions away from the comforts of the main base.

Reconnaissance of the war sites was an interesting activity because their whereabouts were very highly classified and known only to the respective Site Commanders, a small number of officers within the station's Operations and Engineering Wings and the Commanding Officers of 21 Sqn, Royal Signals, and 38 Regt, Royal Engineers, whose support was vital to the concept. After the move to Gütersloh the two larger squadrons were allocated three sites each so that the main features of WARLOC remained unchanged. These war locations were identified by preliminary discreet surveys of likely sites by the Harrier Plans office, part of Operations Wing, and allotted to the squadrons for detailed planning. For example the recce of a flying site involved the Site Commander, accompanied by our signals and sapper colleagues. We would rendezvous in civilian clothes and drive to a suitable car park near the site, armed with a selection of airborne recce photographs taken by the Site Commander beforehand.

The site specification was straightforward. It demanded a straight unobstructed road, of at least 500 metres by a minimum of 10 metres, with access from likely operational areas. Typically these would be light industrial estates or supermarkets with buildings which would

have provided aircraft hides and housed the site's infrastructure. Proximity to other sites and the FWOC was important as were good communications 'shoots' for the secure speech Bruin telephone network. This covered all the sites and was extended widely within 1(BR) Corps. Onlookers might have been puzzled by the sight of men in Barbours or sports jackets and tweed hats taking measured strides across a road and exhibiting more than a passing interest in the characteristics of nearby buildings and the access to and from car parks. In case we were approached by inquisitive locals or site security people we had a simple cover story and were prepared to ask the question in fractured German, '*Vo ist der BP tankstelle bitte*?'

Towards the end of the Harrier's career at Gütersloh the GR3 was replaced by the much more capable GR7 but at the same time the threat from the Warsaw Pact disappeared so the justification for WARLOC had been overtaken by events. By then, however, the vision, aspirations and determination of those who had conceived the Harrier Force thirty years earlier had been vindicated. Although sixty Harriers were probably mere pawns on the great Cold War chessboard, history shows that the aircraft, its support equipment, the quality of training and the lessons learned in the operation of both elements of the deployed Harrier Force, particularly the expeditionary role of No 1 Sqn on the NATO flanks, were put to very good use elsewhere.

MORNING DISCUSSION PERIOD

Wg Cdr Jeff Jefford. Although the RAF bought the first generation Harrier, and deployed them in Germany, the Germans themselves, who had been fully involved in the Kestrel programme, evidently lost interest. Do we know why they weren't that sold on the concept?

Air Cdre Scrimgeour. I think that the Germans were probably far more interested in the vectored thrust engine than in the Kestrel itself, their eventual aim being to build their own aircraft, the VAK191B. The German position was clearly demonstrated at the end of the Kestrel trial when they gave their share of the airframes to the Americans in exchange for some of their Pegasus engines. I think the German wanted to use them on a V/STOL tactical transport aircraft which would have been used to supply forward areas.

Air Chf Mshl Sir Patrick Hine. Another consideration might have been the fact that, at much the same time, the mid-1960s, the Germans were having problems introducing the F-104G into service. There had been no *Luftwaffe*, between 1945 and '55, of course, and, despite having accumulated some initial experience on Sabres and Fiat G.91s, it was an enormous leap to switch to the Starfighter, particularly on the engineering and support side. I think that the prospect of becoming

The third, of three, prototypes of the Do 31 transport programme of 1967-70. Power was provided by a Pegasus 5 engine under each wing plus a battery of four podded RB162 lift engines at each wingtip.

involved in another programme which was pushing the state of the art, technically, and one which introduced more unknowns in terms of supportability in the field, may have been enough to put them off.

Air Mshl Sir Reginald Harland. I was the Project Director for the Harrier at the Ministry of Supply for the two years before it came into service. I would like to offer some comments. Firstly on funding. While I was involved with the Harrier, Rolls-Royce came up with a proposal to uprate the engine for an extra £10M. Clearly, we wanted to support their bid; the problem would be in persuading the Treasury to agree. I put it to the Treasury that an uprated engine would permit us to increase the uplift of fuel, weapons and so on. That would enable the Ops staff to get their results with fewer aircraft. The resultant savings would easily cover the cost of upgrading the engine. Always interested in saving a pound, the Treasury bought it immediately. I had another little tussle with the Treasury later on, this time in the context of the expense (and risk) involved in participating in the Transatlantic Air Race. I presented a similar argument, this time based on our need to prove the aircraft's flight refuelling capability, which had not been started when the Air Race was first suggested. We won our case by arguing that the race would be used to offset some of the costs of the refuelling trials programme.

My second observation concerns specifications. When I had been at the Central Servicing Development Establishment, then at Swanton Morley, working on the Lightning's reliability and serviceability, we were directed not to bother about any problems that might arise from using the aircraft overseas, because, we were told, the Lightning would never serve outside the UK. Needless to say, while stationed in Singapore some years later, one of my jobs was to prepare to receive the Lightnings that were to be deployed to Tengah. The moral of this story, of course, is that you cannot rely on forecast usage. One should not take at face value injunctions that might cripple an aeroplane's long term use. When I joined the Harrier programme, I was briefed that there was no way that the Navy would ever get its hands on the aircraft. However, having previously discussed the aircraft's potential with Captain Law, who had commanded HMS *Bulwark* during the deck trials of the Kestrel in 1966, I agreed with John Fossard that, apart from the wheels, we would eliminate all magnesium from the airframe. Magnesium, as you will know, corrodes quickly in sea water. Our tacit ignoring of that aspect of the specification avoided what would undoubtedly have represented a major future handicap for the aircraft's deployment.

Another observation on specifications concerns the Harrier's wings and its manoeuvrability. The Operational Requirement was for an ability to pull 6g, flying at a specified height and all-up weight. However, during early development trials, an RAF test pilot reported to the Ministry of Defence that the aircraft was producing only 5.6g. I was called and told that, since 6g had been specified, I should insist that we got it. I discussed this with John Fossard, who simply dismissed the problem as not being worth solving. Clearly, I was going to need something a little more persuasive than that. I asked him to provide me with a short paper giving broad answers to three questions. First, what would it cost each of the development and production programmes, in time as well as money, to guarantee that 6g, and what higher g might be obtained in guaranteeing the '6'? Secondly, if 6g was to be aimed for but not guaranteed, what would that cost? Thirdly, just continuing with the present development plans, what capability might be guaranteed (probably still that 5.6g) and what might be obtained in the ordinary course of development, whilst maintaining the programme on time and within budget (as it already was). A suitable paper was produced. I passed it to the OR people who promptly said that they would take the aeroplane as it was. The lesson here is that you must never give orders to your bosses by saying 'we have now got to do this.' You have to let them decide for themselves. So, you offer them three alternatives; but you just have to ensure that the obvious answer is the right one. Thank you.

AVM George Black. I was the Harrier Force Commander at Wildenrath in 1972-73 and I would like to take this opportunity to compliment the team that designed and built this excellent aircraft which we then had the responsibility of getting into the field. I well remember a visiting party from Hawker Siddeley, observing us operating from six sites in the forward area, being deeply impressed by what they saw, the way in which we employed the aircraft totally vindicating the original concept.

Rather than ask a question, I would like to offer a comment on the concept of operations. Having found ourselves at RAF Wildenrath, which was a good 150 miles from the 1(BR) Corps area. I think the Army had some reservations about how well we could meet our obligations, and deploying from Wildenrath was certainly a very difficult operation. It required more than 400 vehicles to get us up to the forward area with much of our supplies not to mention all the weapons that had to be outloaded from Bracht, which was just north of Brüggen, having to travel by rail via the Ruhr. I think that the fact that we were demonstrably able to pull it off reflected great credit on everyone involved. It was a very difficult exercise with many pitfalls to be avoided – we could all too easily have ended up without aircraft, without fuel, or, if the roads were too congested, without groundcrew. So the move to Gütersloh was well conceived, timely and operationally essential. As to the capabilities of the aircraft itself, in the course of a single twelve-hour period, under exercise conditions, while being assessed by the TACEVAL Team, we flew just short of 450 sorties. That really was a most impressive performance which, if nothing else, served to convince 1(BR) Corps that we really would be there when they needed us. I think that that early exercise established our reputation and set the seal on the future of the Harrier Force in Germany.

Hine. Taking up George’s point, moving the weapons forward from Bracht to the 1(BR) Corps area was still a major problem for us, even after the aircraft had been moved to Gütersloh. If we had been able to progress through NATO’s Formal Alert System, that is to say from Simple through Reinforced to General Alert, there would almost certainly have been sufficient time to move the weapon stocks to where they were needed. It would have been far trickier if, despite the intelligence indicators that were supposed to permit us to detect malign Soviet intentions, we got it wrong. If that were the case we would have been faced with a counter-surprise situation – State Orange and/or State Scarlet – which would have meant that we had really been caught with our pants down. If the Warsaw Pact had attacked out of the blue in the early days we would have been forced to operate from Wildenrath until such time as sufficient weapons could be moved up to the war sites. I was never too concerned about a formal alert but, as the Commander, I was far less confident about the counter-surprise option. Our Intelligence experts insisted that it would never happen, but I was never totally convinced about that.

Gp Capt Michael Watkins. Why is the Harrier difficult to land conventionally?

AVM Peter Dodworth. When the aircraft is landing in a slow configuration, you have the nozzles pointing down and you reduce speed to 100-120 knots, but you had the puffers to help with roll control. Landing 'conventionally', the Harrier's relatively small wings and high wing loading meant that you needed to come in at about 160 knots. With its rather unusual undercarriage arrangement, one central wheel under the fuselage, rather than two nice big ones under the wings, it was a little bit bouncy, up and down, so a conventional landing was just uncomfortable. John Farley, who I don't think ever did a 'conventional' landing, will now give you the real test pilot's interpretation!

John Farley. As Peter says, the aeroplane was landed at about 160 knots and you needed to keep the nose wheel off the ground. The central leg was the one which was designed to absorb the impact, so you had to maintain a slightly nose-up attitude. As you entered ground effect with the main wheel still about 3 or 4 feet off the ground, there was a pronounced nose-down trim change, because the tailplane was now getting very close to the ground at the back and this lifted the tail. You needed to anticipate this by putting in full back stick when you were still about a foot up and you would then just grease it on nicely, without damaging the tail bumper. It was a bit of a trick, however; the aircraft was simply not designed to be put on the ground at a 160 knots all the time.

Hine. If I remember rightly, before you are allowed to go solo in this beast, you actually have to do a conventional landing, just in case you have a nozzle failure of some kind when you are on your first trip.

Mr M Budd. I notice that there has been no mention of helicopter support. Was there any, to provide support at the forward sites?

Hine. RAF Germany did have a Support Helicopter Force, which, by the mid-1970s included both Pumas and Chinooks, but these assets were assigned to COMTWOATAF so, despite being fielded by the

British, they were not dedicated to the exclusive use of RAF Germany – or BAOR. We could certainly have made a bid for them, of course, especially in a counter-surprise situation, but the Harrier Force was just one of many potential customers and we could not assume that any helicopters would be made available to us on the day. As a result, our plans did not take account of them and, as you have heard, we had to rely on trains and MT.

Gp Capt Jock Heron. I would add that from time to time we did see the odd helicopter, usually disgorging men in suits and blue uniforms who didn't like to get their feet dirty – our VIP visitors whom we hosted remarkably well under field conditions! (*Laughter*)

Hine. Sir Michael Beetham was not one of those of course! (*Laughter*)

Dodworth. Oh yes he was! (*Laughter*)

Mr J P Hassell. Did you do much in the way of air combat training in Germany and, if so, against what types and how did the Harrier perform?

Heron. Yes, we did, but it was mainly Harrier v Harrier because our task in Germany was strictly air-to-ground operations, although we recognised that we might need to deal with a 'bounce' – and by a bounce aircraft that would probably be more manoeuvrable than us. Broadly speaking, we aimed to get down as low as possible and evade. That said, the training syllabus did call for the occasional air combat sortie at medium level but I suspect that Sir Peter Squire will probably enlarge on this later on, in the context of the Falklands Campaign.

Mr C J Farara. Were there any design options that were not accepted for development?

Ralph Hooper. I think that I would have to express regret that we more or less allowed the next stage of development of the aircraft to take place across the Atlantic, but that was probably inevitable. That said, our own 'next stage' Harrier would also have had a big wing, a metal wing, with both ends of the aeroplane tidied up a little. But I don't think that there was any other specific area of technology that we should have pursued.

LOGISTICS SUPPORT

AVM Pat O'Reilly

Having read engineering at university, Pat O'Reilly joined the RAF via Hawker Siddeley in 1969. His initial experience was on the Hercules leading to fast-jets including a tour as SEngO on No 23 (Phantom) Sqn. He later commanded the Engineering and Supply Wings at Wittering and in the Falklands and, as an air commodore, RAF St Athan. His final Service appointment was as Director General Technical Services and President of the Ordnance Board. He is currently Director of Military Support at Claverham Limited in Bristol.

As a result of its unconventional design, and as training and operations were carried out in some very demanding places, the Harrier presented a particular challenge to the generation of engineers and others who supported it on the ground. Surprisingly, the most fundamentally unconventional aspects of its design gave the engineers fewer problems than might have been expected. Its four swivelling jet efflux nozzles and the Reaction Control System, with extremely hot air bled to every corner of the aircraft, proved impressively robust – clearly, the designers had given those aspects some serious thought. However, support of the more conventional aspects of the aircraft was demanding, particularly as the aircraft was critically dependent on a single engine – effectively also a primary flight control – with a very large intake only too willing to Hoover in debris or birds. Early difficulties such as fan blade cracking, and problems with accessories, including Gearbox Quill Drive failure and Fuel Control Unit malfunction, required extensive checks to be carried out at high frequency, often in the field. Inherited from the TSR2 and P1154, the avionics of the aircraft pushed the boundaries of analogue computing and also employed early, discrete component digital technology – very primitive by today's standards. As a consequence, the Head Up Display (HUD) and Inertial Navigational System (INAS) were highly unreliable and a challenge to keep serviceable, whether on base or deployed. Those who have far greater computing capacity in their

Fg Off O'Reilly investigates the innards of a Harrier's moving map display under the anxious gaze of an instrument fitter.

modern car, but who are nonetheless frustrated by the difficulty of reaching anything under the bonnet, would have enjoyed the elegance of the access achievable in the Harrier with its wing lifted off after the removal of only six bolts. Not quite the whole story but again an operation that could be carried out under field conditions. Indeed, it was the only way to gain access to the engine and many other systems, and portable hangars developed to facilitate this kind of work in the field later proved invaluable elsewhere, notably in the Falklands.

From the earliest days, the aircraft was used 'to reach those parts that others couldn't'. Very shortly after the aircraft was received into service, it was seen by the world, enveloped in a cloud of coal dust in a yard behind St Pancras Station, in the successful attempt to win the Transatlantic Air Race. Deployment and operations from bizarre locations was the aircraft's *raison d'être*. For No 1 Sqn, the objective was to work up the airborne options covering the UK's NATO commitments to Norway and Denmark in the north and to Italy, Turkey and Greece in the south. But first it was necessary to develop the art of field operations with early deployments in the woods around RAF Wittering and later to the Stamford PTA in Norfolk. In November 1973, the first full-scale exercise to Denmark, the NATO N2 option, was mounted by No 1 Sqn. The airlift bill was very large for these deployments, with as many as sixty Hercules being required, or even more if a full simulated weapons outload was included. A prodigious logistics requirement, that was nonetheless limited to vehicles of Land Rover size. Most equipment was in cardboard boxes and on pallets, and requiring multiple handling. Even then, the attraction for such expeditionary operations of larger aircraft was apparent; an aspiration eventually satisfied with the acquisition of the C-17. Host Nation Support was welcome but not extensive. There was very limited pre-stocking of equipment and none of ammunition. Domestic accommodation was provided but very little technical accommodation, although a war option included the allocation of Hardened Aircraft Shelters. Requirements, such as fuel and oxygen, were provided by our hosts.

For the Northern Flank option, conditions were harsh. Early issues of cold weather clothing were inadequate with much of the kit too bulky and the gloves too thick for the dextrous operations required. Nonetheless, the groundcrew rapidly learned, not only to survive in these conditions themselves, but also to apply the husbandry lessons learned in ensuring the aircraft remained remarkably serviceable. In one three-day intensive period of operations on that first full Denmark deployment, 364 sorties were flown by ten aircraft in three days, an impressive achievement by both aircrew and groundcrew. Options to the Southern Flank were supported with similar levels of logistic airlift and Host Nation Support, but without the climatic and runway surface challenges presented in the north. Interestingly, it was the combination of training for these options that ensured that No 1 Sqn was poised to discharge its UK National Commitment when Guatemala threatened Belize in 1975. The Harriers deployed, with the Hercules Force rapidly delivering its now well-defined and rehearsed package of logistic support. With a ground party and a change of aircrew positioned at Nassau, mission capable aircraft were able to land in the sparse conditions of Belize and immediately maintain a professionally supported, credible deterrent. The viability of the logistic concept was thus convincingly proved ‘in anger’, and was to be reapplied in subsequent operations there and in the South Atlantic. The return of the aircraft from this first Belize deployment was less flamboyant, as they had suffered from a growing number of fuel leaks that could not be repaired in field conditions. The Harriers were therefore airlifted to the UK in ex-RAF Belfasts hired for the purpose.

In RAF Germany, it was also necessary to learn the art of deploying the Harrier in harsh, unsupported conditions unfamiliar to those used to operating and supporting fixed-wing aircraft from static bases. Some lessons were learned from the Helicopter Force, with No 18 Sqn collocated at Wildenrath. Also, it was wise to take the advice of the Army majors attached to the squadrons as Ground Liaison Officers, and from the sappers who installed the pillow tanks and laid landing pads, all of whom were well practised in having mud on their boots. The Central Regional option called for support to be deployed by road, with an option (never fully exercised) to deploy munitions by rail from Wildenrath. After some local exercises in the woods around the station, No 4 Sqn made its first four-aircraft deployment to Geilenkirchen in late 1970 in an assortment of support vehicles. Tradesmen, grappling with the challenge of engineering in the field, also had to learn fieldcraft and in many cases become qualified HGV drivers. This first deployment was very much a learning exercise, and the realisation on the evening before the aircraft deployed that the towing arms had been left behind was rectified by a high-speed road dash with only minutes to spare.

Larger deployments soon followed as No 20 Sqn joined No 4 Sqn in mounting Wing exercises to multiple sites. Lessons of convoy discipline and organisation known to British Forces in the past were re-learned – often the hard way. Convoys, fifty vehicles-strong proved unwieldy, not to say embarrassing, on the occasion when one became locked in place having driven up a cul-de-sac in a town in central Germany. The assistance of the German police motorbike outriders to lead the way was welcomed by all, including the local populace. The pitfalls of having all the tents or all the spares in a given convoy element soon became apparent, and the norm became packages of six to eight vehicles with balanced loads. By the time No 3 Sqn had joined the Harrier Wing, full off-base exercises were mounted from Wildenrath, and later Gütersloh. These involved up to 1,000 vehicles

One of No 20 Sqn's GR 1s being marshalled into a rural hide.

and trailers, deploying to six Aircraft Sites and two or more Logistics Parks, and establishing, 'in the field', all of the infrastructure and facilities, including bulk fuel storage, to be found on a Main Operating Base (MOB). This was a departure from the original concept in which forward sites were to have had only a First Line capability, while relying on the MOB for deeper support. The deployment, instead, of virtually a whole station into the field was a considerable challenge and a great success.

The Wing deployed with a large number of specialist vehicles covering not only the engineering and logistics requirements of the aircraft, but providing all the operational and domestic accommodation and facilities required for the whole Wing to operate in field conditions. Much of the equipment, such as that supporting the Reconnaissance Intelligence Centre (RIC), would have been deployed to war sites just as it was to training locations, but much other equipment (tentage, latrines, electrical generators, water tankers, etc) would not have been required in the better-found war locations and a much smaller transport bill would have been incurred. Early Central Region deployments made use of ancient German military transport vehicles that had been claimed as reparations by the Allies at the end of WW II. They were at best a mixed blessing, and were soon abandoned except in a number of cases where the cabins of the

To support operations under field conditions, the right tool for the job proved to be Mercedes-Benz' Unimog.

vehicles were used as the basis of mechanical, armament and avionic mobile workshops, which were then deployed on flat bed trailers. These workshops were later replaced by Marshall Cabins, purpose-built for use both on the Flanks and in the Central Region. A much happier encounter with German vehicle engineering occurred in a very wet exercise when aircraft became bogged in the mud and, one after another, the standard hard-surface tractors normally used on base also became bogged down. Always a good spectator sport for the local population, a friendly farmer watched with some amusement as the aircraft and vehicles disappeared into the mud, before offering the use of his Mercedes-Benz *Unimog*, an all purpose, heavy terrain towing vehicle. A sound investment of a couple of bottles of whisky by the Force Commander, secured the loan of the *Unimog* which proved to be exactly what the Harrier Force needed for these difficult conditions. HQ RAF Germany was rapidly persuaded of their value and following a three-week trial of six vehicles loaned by Mercedes-Benz, a very fast-track procurement was put in place to provide them for the Wing.

The *Unimog* story is only one illustration of the particular difficulty associated with using the peacetime field sites rather than the sites that would have been requisitioned in war with buildings and

'.....all of this activity being conducted while encumbered by NBC clothing and gas masks.'

hard surfaces. Exercise MARCH HARE in 1973 was an extreme case in point. On at least one site it proved possible to bring in only one aircraft at the beginning of the exercise, and to recover it to base at the end, without any other flying taking place. The site was established in amongst tall conifer trees, characteristic of northern Germany, and weather conditions became so dangerous, with trees being blown over and crashing into the tented accommodation, that it proved necessary to evacuate the entire site in the middle of the night. The convoy drove into the teeth of a very strong snow storm to RAF Gütersloh, then a Lightning base, but destined to see much more of the Harrier Force in due course. On return to the site in the morning, it was a scene of devastation, but fortunately no one was seriously hurt and the single aircraft was unscathed.

Support of operations in the field was always demanding and, although a full Wing deployment included reinforcements from Second Line, the manpower was scaled on the basis of on-base day operations. It was a true test to maintain, safely, remarkably high aircraft serviceability rates while simultaneously maintaining 24-hour-a-day field operations in a simulated hostile ground environment. Sites were frequently relocated to step-up locations under combat conditions, all of this activity being conducted while encumbered by NBC clothing and gas masks. Engineering and logistics, pillow tanks plumbed to supply in-hide refuelling, and telebriefing facilities were all focused on supporting autonomous six-aircraft sites, permitting very high intensity operations to take place. Pilots were often repeatedly re-briefed without leaving the cockpit, while operational turnrounds, simulated with 'half up, half down' weapon loads, were carried out in as little as eleven minutes. The nominal maximum sortie rates, of ten per aircraft and six per pilot per day, were frequently exceeded. No 4 Sqn established a record of fifteen on a given aircraft only to be surpassed by No 20 Sqn a couple of days later who claimed twenty sorties on a single aircraft. This was truly impressive, albeit that it remains questionable whether this intensity of operations could have been sustained under field conditions, given the required scale of munitions outloading. All of this activity was subject to tactical evaluation by NATO, No 4 Sqn being the first to be declared and evaluated in the Central Region in late 1973. Using 'standard checklists', the Dutch and Belgian evaluators were a little slow to understand the concept and were happy to give full marks for runway camouflage but eager to make deductions for lack of perimeter fencing and Hardened Aircraft Shelters! Common-sense eventually prevailed, and the effective deployment and value of this new concept was fully recognised.

These novel operating conditions, with rapid and close interaction between aircrew and the groundcrew of many branches, resulted in exceptional *esprit de corps* and high morale. The challenges and many opportunities for autonomous operation and self-reliance brought out the best in officers, NCOs and airmen. They may or may not have recognised it at the time, but they were fortunate to be enjoying an adventure when most of their contemporaries were locked into Cold War, static Main Base 'Citadel' Operations. As a result of Harrier support lessons, the logistics structure of the RAF changed following RAF Germany's lead, with Engineers and Suppliers brought within, effectively, an integrated Logistic Wing. Lessons were learned, and in some cases re-learned, on this first generation aircraft that stood the Harrier Force in good stead for live operations in Belize and the Falkland Islands. The Force set a standard for logistic support of forward operations that is emulated today by not only the current Harrier but by other force elements deployed widely under current UK expeditionary defence doctrine.

SHAPING LATER MOD POLICY

Air Chf Mshl Sir Patrick Hine

Sir Paddy flew with Nos 1, 93 and 111 Sqns before commanding Nos 92 and 17 Sqns and RAF Wildenrath. His senior appointments included DPR, SASO and CinC RAF Germany, ACAS (Pol), VCDS, AMSO and AOCinC STC (and overall Commander of the British Forces assigned to the 1991 Gulf War). On leaving the Service he spent 1992-99 as Military Advisor to British Aerospace.

With the Harrier well established in RAF service by 1975, and with morale in the front line high as a result of excellent TACEVAL results, it is timely to return to the MOD (as, coincidentally, I did that year) to see how future policy was evolving. It was not encouraging for the Harrier, despite an attrition buy order for a further twelve GR3s and two T4s (as they had become by then). Let me explain why.

The initial Air Staff Requirement (AST 396) for a single aircraft with which eventually to replace the Harrier and Jaguar (both perceived by the RAF hierarchy as stop-gap aircraft arising from political expediency) was drafted as early as 1969. Given the perceived need for maximum operating flexibility, a STOVL capability was specified along with the normal speed, weapons payload, manoeuvrability and operational radii of action parameters. AST 396 was progressively updated over the next few years but by 1974, as the introduction into service began of the highly-agile F-14, -15, -16 and -18-series fighter aircraft with the US Air Force and Navy, a much stronger RAF focus on air combat performance emerged. AST 396 was cancelled and a new AST (403) was raised for an agile multi-role fighter capable of operating in both the air superiority and ground attack roles. The authors of this new AST on the Operational Requirements Staff (none of whom at the time had Harrier experience) were against including the requirement for STOVL for two main reasons: first, STOVL would have precluded an off-shore procurement of a variant of F-16 or F-18 (the preferred military option) or made agreement on an alternative European

The Harrier's flexibility, in the context of events in Central America, was instrumental in changing attitudes towards V/STOL. This is a GR3 of No 1417 Flt in its Belize Airport hide circa 1980.

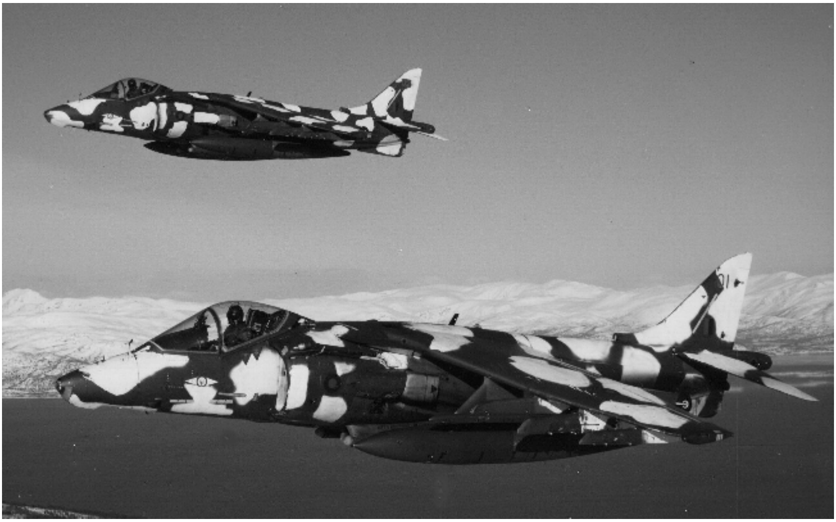
collaborative programme more difficult; and secondly, they believed that experience to date with the Harrier had shown that the performance penalties of accommodating STOVL (in terms of range and payload but particularly manoeuvrability – they virtually ignored the advantages of 'viff' (vectoring in forward flight) which at that time was not well understood – and the high costs of logistic support for the off-base deployment option, were simply too high. In short, many critics regarded the Harrier as a bold but failed experiment. There were also arguments about the Harrier's allegedly poor flight safety record.

While there were valid counter-arguments in defence of the Harrier which by 1975, as I have said, was performing very well, it had few proponents at the time in MOD. Staffing of AST 403 within the Air Force Department's Policy, Operational Requirements and Operations Divisions for a single replacement aircraft had led to planning assumptions that the Harrier would be replaced from 1985 and the Jaguar about ten years later. Harrier Force funding was to be limited to flight safety modifications and minimum mid-term operational enhancements to maintain capability for ten years.

However, the Belize crisis of late-1975 began to change perceptions in MOD. The Harrier was the only RAF combat aircraft capable of operating safely from Belize Airport's short runway and of providing offensive air support and limited air defence in the face of the Guatemalan military threat, and it was quite soon recognised that there were indeed advantages in retaining real operating flexibility in part of the RAF's front line. In parallel, a trickle of staff officers with current Harrier experience into key positions in MOD began to redress the strongly-held prejudices of the disbelievers. The combined effect was that within a year the Air Staff had reversed its policy for the shorter-term acquisition of replacement offensive air support aircraft; twenty-four Harrier GR3s were ordered as a further attrition buy and forward provision in the LTC for twenty-four additional Jaguars was removed.

Given this respite for Harrier, attention turned towards identifying cost-effective measures for improving the aircraft's operational effectiveness. The main focus was on the retrofit of a larger wing (increasing area by 25% from 200 to 250 square feet) that could carry significantly more internal fuel, provide space for extra underwing pylons and improve manoeuvrability through reduced wing loading. Dr John Fozard and his Kingston team responded enthusiastically and formal proposals for a feasibility study into a 'Big Wing' Harrier (designated the GR5 but still envisaged as a major modification programme) were circulated and agreed. With the Pegasus Mk 103 offering substantial improvements in hover performance, there was scope for accommodating this larger wing, offering a 35% increase in fuel capacity, plus leading edge root extensions (LERX) and six underwing pylons. The specification called for a manoeuvrability performance equivalent to that of the Hunter, and the same radius of action with six bombs and two Sidewinder air-to-air missiles, as had the GR3 with two external fuel tanks and two bombs but without any air-to-air missiles. Guns and ammunition were common to both aircraft marks. The GR5 specification, which HSA were confident of meeting, represented a very significant overall improvement in the Harrier's operational performance.

During the 1981 Defence Review, a decision was taken to delay the procurement of an agile fighter under AST 403 pending further efforts to harmonise operational requirements with prospective European partners, notably the French and Germans. Part of the funds freed up by this decision (£50M) were allocated to the Experimental Aircraft Programme (EAP) which, co-funded with industry on a 50:50 basis, was designed to prove some of the technologies required to meet AST



A pair of No 1 Sqn's big-wing GR5s in temporary winter camouflage en route to Norway for a late (1990) Cold War deployment exercise to NATO's Northern Flank.

403 and to put British companies in a leading position on a future European collaborative programme. Of more relevance to today's theme, however, was that funding also became available for the acquisition of a new and much more capable variant of the Harrier GR5 rather than continuing to pursue the original modification package. LTC provision for sixty new aircraft was made but before a firm decision was taken to proceed with BAe's 'Big Wing'-based proposals, an alternative option was presented.

The US Marine Corps, which had acquired a GR3 equivalent (the AV-8A) in the early 1970s, was programming a significantly improved variant designated the AV-8B which had a larger and thicker wing, made from composite materials, that carried an extra 800 lb of internal fuel and offered other attractive improvements, although its top speed at low level was considerably lower. Following a lengthy and detailed study of the respective development, production and life cycle costs, performance comparisons, the political and industrial attractions of a joint programme, and the relative merits of the two designs, it was decided in early 1982 that the UK would become fully involved in a joint AV-8B programme. BAe became a major sub-contractor to McDonnell Douglas for the whole programme of some 400 aircraft, manufacturing all the rear fuselages, and the Harrier GR5 became an anglicised version of the AV-8B, with final assembly being carried out at Dunsfold. The first of the sixty new aircraft was delivered in 1988, and since then the aircraft has been modified and further developed through the GR7 and GR9 variants. We shall hear about those improvements later.

With the longer-term future of the Harrier secured through the GR5 programme, the debate turned to whether or not STOVL (rather than STOL) should be a prime requirement in the aircraft that would eventually replace the Jaguar in the ground attack role and the Tornado F3 in the air superiority/air defence role. By now there were some heavyweight proponents of STOVL on the Air Staff – ACAS(Pol) and ACAS(Ops) – who were well able to deploy the arguments in favour, and there was an extensive debate throughout much of 1982 on the pros and cons of STOVL, both on paper and in high-level discussions, some chaired by CAS himself. Eventually, it was agreed in principle that the RAF should include STOVL in their requirement for the new aircraft (Kingston had some promising designs, notably the P1216), but we could not afford a national programme. It was thus necessary to persuade, if possible, our prospective partners (Germany, France, Italy and Spain) of the need for STOVL; alas, in the event, we could not, ostensibly for cost reasons, but almost certainly more because a STOVL option would have given the UK, with its extensive Harrier experience, a dominant position in the programme. Thus, what became known as the European Fighter Aircraft (EFA) programme (covered by AST 414 which superseded AST 403) was for a STOL rather than STOVL aircraft. I mention this latter debate for historical reasons as it illustrates the extent of change in Air Staff thinking on STOVL from sceptic to believer over the seven years from 1975 to 1982.

OPERATIONS – GR3

Air Chf Mshl Sir Peter Squire

Sir Peter graduated from Cranwell in 1966 and spent the early years of his career flying Hunters, both as a DFGA pilot and as a QFI. Converting to the Harrier in 1975, he commanded No 1 Sqn during Operation CORPORATE. Following command of the TTTE at Cottesmore, his senior appointments included SASO HQ STC, AOC 38 and 1 Gps, ACAS, DCDS (Programmes and Personnel) and AOCinC STC. He was CAS 2000-03 since when he has been Deputy Chairman of Trustees for The Imperial War Museum and a Commissioner for the Commonwealth War Graves Commission.

Jock Heron has described the development of the Concepts of Operations for the Harrier Force as applied to the Central Region and Flanks of NATO. They were different, but complimentary in maximising the flexibility of the aircraft, and for me it was a great thrill to operate a sophisticated aircraft from distinctly *un*sophisticated surroundings.

Our Chairman has reminded us that it was the aircraft's unique flexibility that allowed it to be deployed to Belize in 1975. Indeed, the Harrier was the only combat aircraft in front-line service capable of operating from the short single runway at Belize Airport.

In response to the Guatemalan threat of invasion, No 1 Sqn was placed at seven day's notice to move on its return in October of that year from an APC at Decimomannu. Following a short period of frantic preparation, the squadron deployed six aircraft with Victor tanker support to Belize via Goose Bay and Bermuda. Of interest, because of Fidel Castro's support for Belizean independence and his stance, therefore, against Guatemala, the squadron was denied US landing rights and facilities.

In preparing for the deployment, Peter Taylor had argued strongly against the use of ferry wing tips which would delay generating the aircraft for operations on arrival. He won the debate and the first two aircraft were airborne again on CAP within twenty minutes of landing.

Harrier hides at Belize Airport.

There is no doubt that the presence of the Harrier with its air-to-air and air-to-ground capability deterred any outbreak of hostilities which, given the paucity of Belizean troops and the small size of the British garrison, would have been difficult to control.

For those who recall Belize International at that time, the term 'International' was distinctly flattering, but the theatre did offer a range of useful training opportunities during the four months of Operation NUCHA, as it was named. For protection against surprise attack, the aircraft were dispersed to three pairs of hides – where the groundcrew lived, with the aircrew accommodated in the somewhat crowded Garrison Mess.

The detachment recovered to Wittering just after Christmas of 1975, following an earthquake in Guatemala City and the renunciation of the territorial claim to Belize. However, just eighteen months later, in July 1977, the squadron deployed again in response to a renewed threat of invasion. On this occasion, the detachment was to last for several years and, rather like the longstanding Tornado F3 detachment in the South Atlantic, became a serious strain on the force as a whole. Initially, No 1 Sqn was increased in size to permit a return to NATO training but from August 1978 manning of the detachment became a Harrier Force responsibility, and I led the first RAFG deployment from Gütersloh that summer. One of the quaint features of operations from Belize was that, for compass swinging purposes, we would fly the aircraft in question to Caye Chapel where a somewhat rudimentary check would be carried out normally followed by a demonstration of operational low flying in front of an assembled crowd, before landing back at Belize Airport.

Given the focus we all had at that time on the Soviet threat in Europe, the crisis of 1982 in the South Atlantic came as a bolt from the blue. You will recall that the most likely area for No 1 Sqn's employment was the Northern Region – either Norway or Denmark – and, indeed, in March of 1982 the squadron was north of the Arctic Circle operating off snow at Tromsø. If anyone had suggested that within two months we would be fighting a war from an aircraft carrier 8,000 miles further south, I would not have believed them.

However, a warning order on 8 April – the Thursday before Easter – told us to prepare for embarked operations from within the Total Exclusion Zone. At this stage it was quite unclear as to what our concept of operations would be.

Would our role be air-to-air or air-to-ground? Would we remain embarked or deploy ashore to a Forward Operating Base once this had been constructed? Getting answers to such questions was difficult and at times frustrating, but in the first instance our deployment was seen as a means of providing attrition replacements for Sea Harriers lost in combat – against a prognosis that the Fleet Air Arm would lose an aircraft each day.

Modification of the aircraft, to 'navalise' them as well as to improve their operational capability, was a high priority. Navalisation included sealing panels against salt water, fitting shackles to the outriggers to permit lashing the aircraft to the deck, and the embodiment of an I-Band transponder to permit recoveries to the carrier in bad weather. Incidentally, whilst embarked in *Ark Royal* in 1971, Ken Hayr had already demonstrated the Harrier's ability to operate from the deck in weather well below the limits for conventional jet aircraft, and this was proven again – several times – during operations in the South Atlantic. In cloud bases of 200 ft and visibility of half a mile, Harriers slowed to 60 knots on the CCA, descended to 100 ft, identified the carrier's wake and motored slowly forward until the superstructure appeared from the gloom, leaving just time to establish a hover alongside FLYCO.

'Initiation into the Ski-Jump Club'.

In terms of operational effectiveness, we were able to use the time available before deployment to good effect, equipping the aircraft, most importantly, with an air-to-air missile capability. Remarkably, this was achieved from a standing start – from design to in-service clearance – in just three weeks. Interestingly, the case for an air-to-air missile capability had been made prior to the first Belize deployment, but had not been approved.

Later modifications included the installation of an I-Band jammer, a flare and chaff dispenser and the ability to carry and fire both LGBs and American ARMs.

Whilst the modifications were being carried out, nominated pilots went through an intensive work up period. This included realistic air combat training against French Mirage and Etendard aircraft, air-to-air missile firing (of which we had had no previous experience), weapon delivery profiles using level break out procedures, operational low flying and initiation into the Ski-Jump Club.

Getting men and machines to the Total Exclusion Zone presented the next challenge. Following a detailed survey in Liverpool Docks, it was decided that, along with a great many other stores and fighting equipments, we would make the transit in the container ship *Atlantic Conveyor* and suitable modifications to the ship were carried out. In all, some twenty-four aircraft – eight Sea Harriers, six Harrier GR3s,

The crowded deck of the Atlantic Conveyor.

six Wessex and four Chinooks – were either loaded in the UK or at Ascension for the passage south with other elements of the Amphibious Task Group.

Landing on the forward spot in a heavy rolling swell off Georgetown (Ascension) was probably one of the more demanding flying events of our deployment but, having safely embarked and bagged the aircraft against the salt, we rightly became a most lucrative target to the Argentinian Air Force. To counter this, a Sea Harrier was kept at deck alert whilst we remained within tanker range of Ascension. I suspect that those pilots nominated to hold QRA(I) were relieved never to be launched. However, the use of *Atlantic Conveyor* as a carrier of aircraft with the ability to launch and recover whilst in transit, is an interesting reflection of the Harrier's versatility.

The ten-day transit from Ascension gave my crews, both air and ground, plenty of time to prepare their thoughts for subsequent operations, whether it be resistance to interrogation or skills in battle damage repair. At the same time, a small team of service engineers tried manfully, but sadly unsuccessfully, to get the Ferranti manufactured FINRAE equipment, which would allow the Harriers' IN platform to align on a moving deck, to work. Without this we would have no navigational or weapons aiming information, in other words, back to map and stopwatch and fixed depression sighting for weapons delivery.

While offered the opportunity to select my eight pilots from across the Harrier Force, I had in fact chosen my team from within the squadron in such a way as to leave my deputy with a balanced group for any second push that might be required. As a result, we had a wide range of experience from the most junior being made combat ready within days of the deployment to others with three or more tours on the aircraft. From these I selected four Leaders and four Number Twos with the aim of flying as constituted pairs. This stood the operational test extremely well as the pairs developed into cohesive units with individuals mastering their respective skills in navigation and lookout. We debated in detail what aircraft snags we would accept on operational sorties and how we would get the maximum performance out of our aircraft systems – specifically the engine and its complex matrix of configuration and temperature limits.

Despite this preparation, there remained for most a finite transition from a peace to a wartime mentality – brought home with some starkness by the Captain of *Hermes* who initially ruled that our first sortie from the deck should be at night. Having been on deck alert for some two hours and watched the twilight come and go, we were eventually stood down to complete our arrival briefings on deck procedures before a busy programme of acclimatisation sorties the following day and the first operational sortie – an attack on a fuel dump at Fox Bay – the day after that.

In all, we flew some 126 operational attack or reconnaissance sorties between 20 May and 13 June, in the course of which we lost four aircraft. But what did we achieve? At the macro level, the concept of embarking RAF aircraft and crews was proved, albeit significant restructuring of the CVS' operations staff was needed properly to meet the requirements of a dedicated offensive support force. At the operational level, we demonstrated the importance of tactical recce and, incidentally, this remains a major strength of the RAF in comparison with many other air forces. We provided at Goose Green graphic proof of the effectiveness of Close Air Support – a skill that we need urgently to refresh following a decade of largely 'air only' operations in the No Flying Zones, prior to Iraq in 2003.

In other areas, and despite considerable effort and some ingenuity, we were less successful. Attacking the runway at Stanley was, of course a high priority. The BLACK BUCK sortie of 1 May had left a sizeable crater but there remained a concern that the airfield could be used as an FOB for Etendards or A-4 attack aircraft, and for re-supply at night by C-130s. The use of cluster bombs against the runway surface almost certainly ruled out the possibility of operating aircraft with high pressure tyres and, while we hit the runway with retard 1,000 lb weapons, fusing errors resulted in the weapons skipping before exploding with reduced effect. We also delivered free fall 1,000 lb bombs from loft profiles flown in close formation with Sea Harriers, using their inertial attack computer, but with uncertain results. Finally, and without the availability of laser markers, we attempted to use the aircraft's own LRMTS system to guide free fall LGBs, unaware that the two systems were incompatible.

Laser Target Markers were eventually deployed with land forces, and loft deliveries flown against pinpoint targets on 12 June showed that we now had a precision weapon for use against a variety of key facilities, be they command and control, storage areas or runway surfaces. And so the RAF's first operational use of PGMs was achieved in the final throes of this short but intense war. Although not fired in anger, we had also reached the point of being able to launch an attack with a Shrike ARM. A small number of missiles crated in assembly form had been air-dropped from a Hercules into the water alongside *Hermes* and my groundcrew – with no previous experience – had completed the build from the instructions that came with them.

Although the pace of events did not allow us to employ the Shrike – for the Argentinians surrendered the very day that we had our first operational round assembled – this anecdote, typical of what was happening across the Force as a whole, reflects the crucial nature of the Urgent Operational Requirement process available to the front-line then, and indeed today, and the resourcefulness of our personnel. In a period of just three months we had seen a step change in the operational capability of the GR3: AIM-9L missiles, chaff and flares, an I-Band jammer and precision weapons including LGBs and ARM.

It would, however, be quite wrong to suggest that we had it all our own way. Indeed, the loss of an aircraft on our second day of operations was a swift reminder that we were unlikely to come

Alert Argentinian troops ready to fire both Blowpipe and SA-7, but clearly unaware of the direction from which the threat is approaching.

through unscathed. Experience quickly showed that our greatest threat was from ground-to-air weapons, which varied from surface-to-air missiles to small arms fire. The two main SAM systems were Roland and Tigercat and we had a fair idea as to where these were located. We planned, therefore, to fly outside or below their respective engagement zones and, although a substantial number of both types were launched at us, none was successful. The remaining SAM threat came from the shoulder-launched variety, which were in plentiful supply. The accompanying photograph, taken by my No 2, confirmed the presence of both Blowpipe and the Russian SA-7, although, fortunately for us, the operators were looking in the wrong direction. Again, our tactics of flying low and fast seemed to negate this threat, although it is almost certain that the first of our aircraft to be shot down was engaged by Blowpipe.

The Argentinians were also equipped with a large quantity of AAA ranging from 20 mm to 35 mm, some of which were linked to Fire Control Radars. Although these tended to be sited in known areas, they posed a high threat and we lost an aircraft to AAA in the attack on Goose Green. However, what hit us most frequently was small

'Imaginative repairs' to battle damaged aircraft meant that none was down for more than 48 hours.

arms fire and in the latter stages of the conflict, when most missions took us close to Stanley, of every four aircraft launched one would return with holes. Apart from one aircraft, which suffered a fuel leak and just failed to make it back to the carrier, all the others returned safely. This was very encouraging as it had been thought that the Harrier would be particularly susceptible to battle damage. Not only did this prove to be incorrect, but once back on board my engineers were able to effect some imaginative repairs and no aircraft spent longer than 48 hours in the hangar before it was flying again.

As a result of our losses, which by 8 June had totalled four (the fourth being a crash landing at the FOB at San Carlos), replacements were flown from Ascension direct to the Task Force – long and apprehensive flights indeed for the pilots who, without diversions en route, had 8½ hours to prepare for their first ever deck landing.

Following the cease fire, a full site was built ashore at Port Stanley and on 4 July 1982, the GR3 Detachment, now armed with Sidewinders and in the air defence role, went ashore and, despite atrocious conditions early on, maintained a presence at RAF Stanley until May 1985, when the strategic airfield at Mount Pleasant was

Despite occasionally atrocious conditions, a GR3 detachment remained at Port Stanley until 1985.

opened. At that stage, the task of the Harriers was complete and their involvement in the Falklands was ended.

The four major lessons that I took from No 1 Sqn's involvement in Operation CORPORATE – most of which had a wider application – were:

- Effectiveness of precision weapons.
- Importance of strategic reach and the requirement for a sizeable tanker force.
- Need for appropriate support to mount expeditionary deployments.
- Viability of RAF fixed wing STOVL operations from a carrier.

I am delighted that all four areas have been properly addressed in successive planning rounds – not least in the decision to replace the *Invincible*-class carriers with new larger carriers with embarked RAF/RN squadrons of JSF in the offensive support role.

OPERATIONS IN THE HARRIER GR7

Gp Capt Andy Golledge

Andy Golledge joined the RAF in 1979 and has been flying the Harrier GR3, 5 and 7 in the UK and Germany since 1982. Along the way he has commanded the Harrier OCU and No 1 Sqn, flown on operations over Iraq, Bosnia, Serbia and Kosovo, accumulated 3,200 hours on type and been awarded a DSO. He has been Station Commander at Cottesmore since 2003.

The night attack Harrier GR7 entered RAF service in December 1990 at the beginning of the post-Cold War era. Although too immature an aircraft to participate in Gulf War I in 1991, it has played a leading role since then, alongside the Tornado, in RAF fast-jet operations. Only in 2002 did a year pass by without an operational commitment for the GR7. Indeed, uniquely, the GR7 has flown in all theatres of operations where the RAF has employed a fast-jet offensive support capability. This impressive achievement spans Northern Iraq from 1993 to 1995[1], Bosnia from 1995 to 1997[2], Southern Iraq during 1998[3], Kosovo and Bosnia from 1999 to 2001[4], Sierra Leone during 2000[5], Gulf War II during 2003[6] and Afghanistan from 2004[7] onwards (currently still ongoing).

These operations have been diverse in terms of command and control, intensity, type of mission and enemy threat. The GR7 has served under NATO's leadership in the Balkans and Afghanistan, alongside Coalition partners in Iraq and Afghanistan, and under purely national control in Sierra Leone. The intense bombing campaign of the Kosovo War in 1999 lasting 78 days[8] involved 870 GR7 sorties and 894 weapons expended; this contrasts with the three-week excursion into Sierra Leone where only 48 GR7 sorties were flown and no weapons were expended. Yet both operations achieved the desired effect. A variety of mission types have been flown from 'Presence' and Tactical Reconnaissance sorties at the low intensity end of the spectrum to CAS and AI in the face of considerable enemy threats. These threats have predominately been SAM and AAA, but there was also a credible Serbian air-to-air threat at the beginning of the Kosovo

War and an Iraqi SSM threat during the early part of Gulf War II where ground support personnel donned full Individual Protective Equipment (IPE) two or three times a day.

The Harrier GR7 is setting the pace for battlefield air support and has developed into the RAF's top CAS platform. To substantiate this assertion I will consider the aircraft's capability, its flexibility of basing and the flexibility of its pilots.

Aircraft Capability

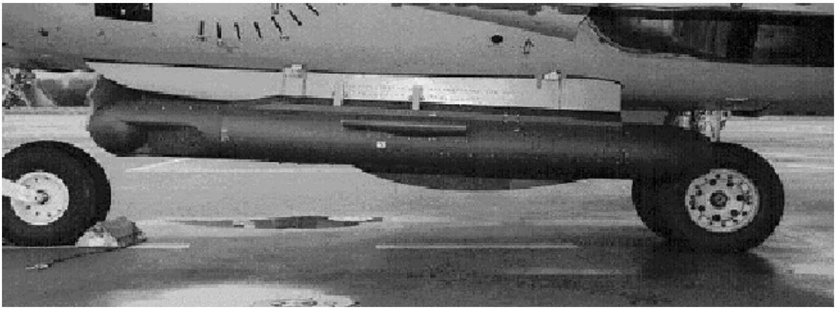
The GR7 is a truly multi-mission offensive support aircraft able to conduct AI, CAS, Presence and Tactical Reconnaissance. During AI and CAS missions it has attacked a broad range of targets from fielded forces in Kosovo through to more strategic targets such as bridges and Integrated Air Defence System (IADS) nodes in Bosnia. Presence missions have been flown to great effect in Sierra Leone when Harriers roared over the capital, Freetown, at low level, announcing the arrival of a naval carrier group off the coast. More recently, in Afghanistan this type of mission has proved to be an excellent deterrent against terrorist activity. Tactical Reconnaissance is always in high demand and the Vicon GP1 'wet-film' Pod was used extensively over Bosnia to provide Battle Damage Assessment (BDA). It was also utilised effectively over Kosovo to locate sixty-two pieces of tactical equipment on the ground, fifty-four of which were subsequently attacked and destroyed by Harriers and other NATO aircraft. The GP1 Pod's successor, the Vicon Electro-Optical Pod, provides an impressive stand-off capability and it was utilised in a crucial urban reconnaissance role in support of ground troops during Gulf War II. Importantly, the GR7 can perform any combination of these four mission types during a single sortie. As demonstrated in Kosovo and Afghanistan, whilst tasked for CAS, AI or Presence in the primary objective area, the Tactical Reconnaissance pod was being utilised for surveillance during transit to and from the area and for BDA.

The air campaign over Bosnia in 1995 was the first in which the majority of ordnance expended was precision guided munitions (PGMs), and this had an immediate and compelling effect on political decision making. It also set a clear and developing trend. However, the requirement for line-of-sight from the aircraft to the target to

Harrier GR7 armed with a pair of Maverick AGMs.

deliver laser-guided bombs (LGBs) is a severe limitation in cloudy weather conditions, as proved in Kosovo when 33% of all Harrier LGB attacks were aborted. A PGM that could penetrate cloud and poor weather was urgently needed, and the capability rapidly emerged in the form of the Enhanced Paveway 2 bomb that was first dropped in anger from the GR7 during Gulf War II. This superbly flexible weapon not only utilises GPS guidance to attack targets in all weather conditions but also retains the man-in-the-loop, laser-guided mode as an option for engaging mobile targets. Additionally during Gulf War II, the Maverick PGM was employed on the Harrier for the first time, providing a flexible point-and-shoot, fire-and-forget weapon optimised to penetrate armour; thirty eight of these munitions were launched.

In order to guide LGBs, the GR7 was initially equipped with a laser designator pod (TIALD) in 1998 for operations over Southern Iraq. Three years earlier when delivering LGBs in Bosnia, Jaguar aircraft provided laser designation for the Harrier's bombs. Incredibly, at the start of the Kosovo War in 1999, not one of the Harrier pilots had experienced dropping and guiding a LGB during peacetime training due to the scarcity of TIALD pods. Thankfully, this unacceptable situation has since improved but greater numbers are still



TIALD pod on a GR7.

needed to train and fight. Moreover, better resolution is required to be able to identify and attack small targets at night and in poor conditions. Notwithstanding, the acquisition of TIALD pods has also furnished the GR7 with a limited Intelligence, Surveillance and Reconnaissance (ISR) capability.

Although two of the seven air-to-ground weapons carriage stations on the GR7 are normally loaded with fuel to maximise range and persistence, a mixed array of munitions can be carried on the remaining five stations. Various combinations of guided *and* unguided weapons, or unguided weapons, first introduced in Kosovo, allow engagement of broad target sets in all weather conditions and optimise weapons-to-target matching. This flexible and potent capability requires simple and accurate weapons aiming software for the pilot; unfortunately, this data was not initially available causing pilots undue workload in the target area and subsequently much engineering effort was undertaken to generate precise weapon ballistics information.

Another area where capability has been enhanced has been with the aircraft's air-to-air communications. During Kosovo, incompatibility with allies caused problems with the free exchange of operationally sensitive information. Although some allied aircraft (including the GR7) used frequency-hopping technology and transmission security measures to provide a degree of protection, a lot of sensitive targeting information was communicated 'in clear' and I am certain that this information was exploited in a timely manner by Serbian forces. This was recognised as a key lesson of the conflict and soon afterwards the GR7 was upgraded with encrypted communications equipment.

The GR7 is equally at home operating from land bases of varying degrees of sophistication or from the deck of an aircraft carrier.

Aircraft Flexibility of Basing

The Harrier's inherent STOVL characteristics give the aircraft great flexibility when it comes to basing options on land and at sea. In general, land-basing maximises aircraft fuel and weapons loads while sea-basing requires less host-nation support. The latter was demonstrated in May 2000 when GR7s were embarked in HMS *Illustrious* off the coast of Portugal participating in a NATO exercise, LINKED SEAS. On 8 May the CVS was diverted towards Sierra Leone arriving in-theatre on 11 May and the first operational Harrier mission was flown on 17 May.

The acquisition of the uprated Pegasus Mk 107 engine in 2003 has made a significant improvement to aircraft performance and effectively permits world-wide, all-year-round CVS operations. Previously, basing at sea in the Gulf (as in 1998) was restricted to between the months of November and April due to high ambient temperatures that limited engine take off and landing performance. Similarly, in Sierra Leone, even though the GR7 was flown without external fuel tanks, the weapons bring-back to the CVS was limited by engine landing performance to one 540 lb bomb. Generally, the capability to deliver GR7 offensive operations from the CVS has improved markedly since 1998; communications for planning and co-ordinating missions with coalition partners are more robust, further GR7 weapons have been cleared for use and CVS navigational recovery aids are being enhanced.

Turning to land-basing, the GR7 is equipped and resourced to operate from a well-found base, an austere base or a bare base.[9] Its short take-off performance fully laden is impressive. Currently in

A GR7 toting rocket pods and a pair of Sidewinders.

Afghanistan the entire runway at Kandahar is undergoing a resurfacing programme where the full length of the operating area is not always available. In these conditions during the high ambient temperatures of summer, neither the Tornado nor the Jaguar is able to operate.

Flexibility of Pilots

The Harrier has always attracted pilots who have excelled during fast-jet training because of the increased workload and capacity required to handle the aircraft in the V/STOL regime. These pilots are handed responsibility early in their flying careers and are trained to be able to adapt to the significant challenges of flying the GR7 in today's dynamic battlespace.

CAS is arguably the most difficult mission to fly, and almost all of the GR7 missions during Gulf War II and the majority in Kosovo were in this role. Aircrew did not know their target area before take-off and could be dispatched to any area of interest once airborne. Many missions involved searching for opportunity targets using mainly onboard sensors rather than with the assistance of any external cueing. Young pilots, barely combat ready, were trusted to lead missions and attack targets. They did so with meticulous regard for the rules of engagement and to minimise the risks of any civilian death, injury or damage. Indeed, if ever the pilots were in any doubt about the targets, they did not drop their munitions; of the 870 sorties flown in Kosovo, 350[10] returned with weapons still intact.

The ground-to-air threat to pilots during GR7 operations has been considerable. In particular, during Kosovo and Gulf War II the threat was continual from SAMs (SA-3, SA-6 and MANPAD) and AAA. Despite countermeasures deployed by the aircraft's impressive EW Defensive Aids Suite (ZEUS), there was always a risk. It is a testimony to the exceptional skill of the aircrew, who were forced to manoeuvre aggressively and jettison stores to defeat the threat from these weapons, that no aircraft were shot down.

As mentioned above, observation of the rules of engagement is a vital component of warfare. The ongoing GR7 deployment in Afghanistan contributes to two different operations: the fight against terrorism under Coalition leadership and the promotion of peace and security under the NATO banner. These diverse operations clearly have their own specific rules of engagement. As GR7s are sometimes tasked to support both operations on a single sortie, it is crucial that pilots are alive to all rules of engagement and are able to switch quickly between them.

Even though GR7 operations over the years have been largely carried out at medium altitudes, the ability to fly at low level is still required. In Kosovo at the end of the intense bombing campaign, pilots were on 24-hour ground alert over a two-week period to provide support to UK ground troops; had the troops needed assistance, low level flying was the only viable option under cloudy weather conditions. Additionally, in Sierra Leone and Afghanistan, low flying Presence runs were prosecuted to provide deterrence. Low flying skills are quickly perishable and regular training is necessary, both by day and by night.

Areas for Improvement

Looking ahead, the Harrier GR9 is due to enter front-line service in mid-2005. This latest mark of the Harrier incorporates advanced avionics, communications and weapons that will ensure relevant capability for combat operations over the next decade and a half. Crucial to its success will be three essential enhancements. First, a smaller and smarter PGM that will minimise collateral damage and be suitable for urban CAS. Secondly, a data link for situational awareness and interoperability with the USA and other allies, and a key enabler for Network Enabled Capability. And finally, an improved targeting pod[11] in greater numbers than currently exist that will provide better resolution to permit pin-point and area targets to be located and positively identified under combat conditions.

In conclusion, the Harrier GR7 has played a major role in UK operations over the past twelve years and in so doing has established an enviable reputation as a multi-role offensive support platform. The keys to the aircraft's outstanding combat success are: its unique ability to fly from almost anywhere, on land and at sea; its sophisticated avionics and weapons capability; and the high calibre of its pilots. While able to operate in a variety of roles, the GR7's capabilities are optimised for CAS, at which the aircraft excels and it can rightly claim to be the RAF's – and one of the world's – most effective day, or night, battlefield attack aircraft.

Notes:

[1] Part of a British contribution designated Operation WARDEN that enforced a no-fly zone and established a safe haven for Kurds.

[2] GR7s flew 144 bombing and reconnaissance sorties in fifteen days of Operation DELIBERATE FORCE in 1995, designed to contain Serb aggression against Bosnia-Herzegovina and save lives. It was the first use of offensive air power in Europe since 1945. A follow-up operation, DECISIVE EDGE, policed a no-fly zone.

[3] A two-month contribution, embarked in HMS *Invincible* and HMS *Illustrious*, to Operation BOLTON that sought to coerce Saddam Hussein into co-operating with UN weapons inspectors.

[4] The Kosovo War, from March to June 1999, Operation ALLIED FORCE, eventually halted the ethnic cleansing of the Kosovo Albanians by Milosevic. Thereafter, Operation ALLIED FORGE continued surveillance over the Balkans.

[5] Protection of UN peacekeepers following an eight-year civil war, designated Operation PALLISER.

[6] During Operation TELIC, GR7s flew 1,126 sorties and expended 560 munitions.

[7] GR7 contributions to the Coalition's fight against terrorism and NATO's peace and security operations.

[8] The longest offensive aerial bombing campaign since Vietnam.

[9] A short tin strip over a cratered or damaged area of the runway or taxiway could be used for take-off and landing.

[10] This figure includes those sorties aborted due to cloud cover over the target area.

[11] The data link and improved targeting pod are, as yet, unfunded.

THE JOINT FORCE HARRIER CONCEPT

Cdre Bill Covington

Bill Covington began flying in 1975, first on the Gannet and then the Sea Harrier (including a tour on AV-8s with the USMC). He has commanded Nos 801 and 899 NASs, served as Cdr(Air) at Portland and aboard HMS Illustrious *and flown combat missions in the South Atlantic. Following a variety of staff appointments and command of Yeovilton he became Commodore JF2000 and Senior Naval Officer at HQ STC in 2003.*

The birthplace of the Joint Force Harrier concept was within the 1998 Strategic Defence Review. The Review stressed the importance of joint operations in the delivery of warfighting capabilities and included within it the announcement of the creation of Joint Force 2000. This force was to be based on a single, common aircraft type which was to be equally capable of operating from land and sea. It was recognised that such a capability would not be fully achieved until the introduction into service of the Joint Combat Aircraft (JCA) and new larger aircraft carriers post-2012. Prior to that the JF2000 concept would be taken forward in the form of Joint Force Harrier (JFH). I note, for posterity, that it was so named, rather than the easier-to-say Joint Harrier Force, to avoid possible confusion with the abbreviation for the Joint Helicopter Command (JHC) and the sometimes-used JHF for Joint Helicopter Force.

Joint Force Harrier is the pilot scheme for the JCA/CVF era and the JF2000 study left an imprint that guided our initial thinking. JF2000 sought a balanced and joint JCA force, organised as four front line squadrons, two light blue heavy, in manning terms, and two dark blue heavy. They would be brigaded, with a RAF and a RN squadron operating together as a 'wing'. This was to encourage convergence of best practice for land and sea operations whilst anchoring that vital fighting ethos within squadron badges for each colour of uniform. I should add that, within the concept of being 'equally' capable of operation from land and sea the term, 'equally' was more to provide a sense of equality in capability and similarity in operations if not actually identical in every way. It certainly provided the impetus behind the adaptation of today's *Invincible*-class aircraft carriers for Harrier operations.

Initially, Joint Force Harrier was based on a multi-role capability provided by utilising the legacy platforms in their core roles of offensive support for the Harrier GR7 and air defence for the Sea Harrier FA2. You have heard from Gp Capt Golledge of the successful employment of CVS-based RAF Harriers operating over Iraq and Sierra Leone. The latter was a particularly good example of JFH elements: No 3 Sqn and No 801 NAS, working together in an extremely successful operation where the desired effect was produced by noise and the mere 'presence' of air power, plus the limited but, as it happened, critical recce capability represented by the Sea Harrier's side-facing F95 camera.

Unfortunately, one drawback of a force with two aircraft types to provide one combined capability is that it doubles the cost if both platforms require the same upgrade. Faced with a shortfall in funding for the GR9 programme, and a reduced air defence requirement in the present decade, this doubling of cost was particularly significant in the context of the Harrier 'big engine' debate. For carrier operations in the hot temperatures of the post-Cold War 'arc of crisis', both aircraft required the Pegasus 11-61 engine and its extra 1,500 to 2,500 lb of installed thrust. But, and many would say regrettably, there was only sufficient money for one, and that, quite clearly, had to be spent on the more relevant offensive capability, and the newer airframe, of the GR7.

I believe that the decision to pay off the FA2 early was both bold and imaginative. With some potential risk to one layer of maritime air defence it meant that JFH could fund the GR9 programme and match that capability with the CVS. It also, and more importantly, reflected the latest thinking in terms of the UK's air power requirements in that it afforded priority to offensive support over air defence. One must also remember that without the 11-61 engine the FA2, in my opinion, represented a somewhat hollow capability because of the constraints imposed on deck operations by high ambient temperatures.

The result was a 'balance of investment' decision that the pragmatic way ahead was to invest in just one mark of Harrier, the

The first GR9 trials aircraft – note the figure 9 on the starboard wing.

RAF GR7, and to upgrade it to the GR9 standard. The three RAF squadrons would also be reorganised to create four squadrons of nine aircraft each, brigaded in pairs, in accord with future plans for JCA. The need for four squadrons is based on deployability. Post-Sea Harrier, the GR9 will have to sustain sea-based training and detachments in addition to land-based activities. This results in some twenty-one weeks of sea time per year vice the present six. It also creates a slightly enhanced manpower requirement in order to underpin the annual exercise programme and ensure that operations are achievable within the harmony guidelines for RN and RAF personnel. It is believed that four deployable units will provide the best baseline structure for this, and this format and its adaptability in terms of scaling detachment sizes and shapes for operations will be tested before JFH makes way for JCA.

The concept is for a RAF and a RN squadron to work together when at RAF Cottesmore, the main JFH operating base. When deployed, the principle will be for the RAF squadrons to lead on land-based operations and for the RN squadrons to lead when embarked. As with most plans, this is merely an assumption and the final execution will depend on availability and which squadron is best suited to deal with a particular event. However, we do wish to maximise the opportunities for cross-pollination of core experience and best practice in both environments. For example, No 4 Sqn found going to sea last September that much easier for having RN personnel within its ranks and, likewise, RN personnel, now in Afghanistan, have learned new skills from their RAF colleagues. Pairing of the squadrons and maintaining an option for personnel of each Service to serve with the other colour of squadron will also maximise interaction without upsetting single-Service ethos and the morale of our people. This we must never forget.

The last Sea Harrier unit, No 801 NAS, will be decommissioned in March 2006. At the same time No 3 Sqn will hand over their Harrier baton to No 800 NAS before going on to become the first operational Typhoon squadron. The four-squadron organisation will stand to in the following October so the next eighteen months are going to be very busy for JFH personnel.

Let me now turn to the equipment programme for Joint Force Harrier. The Pegasus 11-61 engine programme is already being implemented, refitted airframes being designated as GR7A or GR9A. It will, of course, be no surprise if I point out that the extra thrust makes the re-engined Harrier the aircraft of choice, not only for embarked operations but also for hot and high airfields – like Kandahar in Afghanistan – and for any form of tactical flying. It is already a great success. Next up will be the GR9 conversion programme which is proceeding on schedule; the first two aircraft are currently awaiting clearance to start flying with the Operational Evaluation Unit. The GR9 overcomes obsolescence and provides new avionics and open architecture software to support the next generation of weapons. The aircraft will be cleared for the new precision guided bomb, Brimstone, legacy weapons, secure comms and an enhanced recce capability with the Joint Recce Pod. In all, a potent punch that will sustain the Harrier well into the next decade when it is to be replaced by the Joint Combat Aircraft.

This audience will be familiar with recent developments in the application of air power and flying from Deployed Operating Bases (DOB). Gp Capt Golledge has previously highlighted some facets of this in the specific context of the Harrier. Let me, therefore, concentrate on the development of the CVS to support Harrier operations.

There have been many changes to the CVS since the GR7 first went to sea. The Sea Dart missile system has been removed to improve air munition magazine space and to extend the flight deck. This makes operating fourteen or fifteen aircraft comfortable with an

HMS Illustrious *with ten assorted RN and RAF Harriers ranged.*

overload capacity of up to eighteen if required. Most significantly the satellite communications bandwidth has been increased to improve connectivity – particularly for mission planning, aircrew video conferencing for COMAO planning, and reachback for the handling of recce products.

Deck lighting is now NVG-compatible and a TACAN will become standard fit with PAR/ILS to come. Inside the ships, the aircrew briefing facilities have been upgraded and workshop and store rooms have been reconfigured to support the Harrier in a flexible manner, making best use of the supply chain whilst providing a robust ability to sustain operations while at sea. The key message is that this is not a re-birth of a naval-only aviation component but the development of a, truly joint, fast jet capability that will be available to a Joint Force Air Component Commander (JFACC) and represent the most efficient expression of British air power.

The operational concept for JFH is fairly straightforward. The training programme is written to sustain all elements of the squadron, exercising both deployed operating base and carrier teams, to provide flexible options to the military planners. Dependant upon political assessments and objectives, the geography of a crisis area, and the availability of access, basing and overflight for the deployment phase, JFH can deploy as required. This may be direct to a DOB, self-ferried or with in-flight refuelling. Or it could equally be to a CVS at Portsmouth or to a deployment point overseas. If range or persistence requires extension, a Forward Arm and Refuel Point (FARP) could be involved to exploit the potential represented by the CVS or DOB, although the full details of this concept are still being refined.

I emphasise the notion of flexibility. To the taskers in a Joint Force HQ, or to a target set, or to the army for CAS, it is largely immaterial whether the Harriers have come from an airfield or an aircraft carrier. There are benefits to both and it will be a political/military decision as to which is the best way to deploy. Once in theatre the aircraft can move between sites if necessary. The limiting factor being airlift and transport between the sites. All these options have been trialled recently and will continue to be tested. The objective is not only to exploit the unique capabilities of today's Harriers but also to pave the way for the introduction of the STOVL JCA.

In conclusion, whilst there are still a number of convergence issues to overcome, and the GR9 and personnel migration programmes are still in their infancy, Joint Force Harrier is well on its way to delivering a truly joint, global and flexible capability that harnesses the best of the RAF's and the RN's unique operating patterns with seamless connection to air command and control and the application of air power. To take the strap lines of the two Services: JFH has every intention of ensuring that 'The Team Works' to 'Rise Above the Rest'.

AFTERNOON DISCUSSION

Peter Symes. I have two questions. Passing reference has been made to 'viffing' and I wonder if someone could elaborate on that. Secondly, I have read of a blue-on-blue incident where coloured identification markings displayed on the ground were not recognised because cockpit displays are in black-and-white. Is there, therefore, a need for colour imaging?

Cdre Bill Covington. Taking the second point first, camouflage and ground colours are an interesting area. It is often the case that black-and-white provides the best results when showing up irregularities in shape and form to reveal hidden items. Work is going on in the field of colour displays and the associated technology is improving but I am not in a position say exactly how much progress has been made or what the pros and cons are. It could be that, as with some infra red systems, which allow you to select black-on-white or white-on-black, depending on what you're looking for, the ultimate answer may be to include colour options with the ability to select the one best suited to the particular circumstances.

Sir Patrick Hine. Could anyone comment on how the risk of blue-on-blue engagements was minimised during Gulf War II?

Gp Capt Andy Golledge. I would offer the observation that our current targeting pod, the TIALD pod, does have some limitations in that its discrimination is not really adequate from 20,000 feet, which was the kind of altitudes at which many sorties were flown. For the future, for the GR9, we are going to need a targeting system with much better resolution; we need to be able to detect and identify individual vehicles, rather than just an indeterminate blob on the ground. During Gulf War II I would say that deconfliction was generally achieved by procedural means verified and amplified by use of the radio.

As to 'viffing' I would have to say that the GR7 is a dedicated ground attack aircraft and, although we do some viff training, it is not a preoccupation. We don't have much use for it in the air-to-air case, because the Harrier does not operate in the fighter role and we would hope to avoid such an engagement. Nevertheless, when obliged to deal with an incoming missile, the use of viff can provide a very high initial turn rate and the 'angle off' that that creates may well be sufficient to break lock.

Sir Peter Squire. I would agree with that, although viffing does have an offensive application too – if you are trying to use your own missile, viff could be used to displace your sightline sufficiently to permit it to lock on. On the other hand, if your nozzles are deflected for any length of time, you loose a lot of speed very quickly, which, in turn, reduces your manoeuvrability. If you are up against two fighters, the loss of energy involved in viffing may mean that you avoid being an air-to-air target for the first one only to finish up as an air-to-ground target for the second. I don't think that it was used much in air-to-air engagements in the Falklands; perhaps Bill could comment.

Covington. No, it wasn't, because most of the air combats were high energy and short duration. However, from the air defender's perspective, putting down 20° or 30° of nozzle can give you a bit more temperature rise on the engine, which keeps your performance levels up, but, more importantly, it also gives you some extra nose-up pitch. So, if you need extra nose-up authority, just dropping a bit of nozzle can improve sustained turn rates, or if used fairly aggressively, can pump the nose up to where it needs to be to get a missile away. The other situation where it can be useful is if you are bounced and find yourself in a tail chase situation but with little nose-tail separation. The use of viff will slow you down and, at the same time, increase your barrel roll performance. The combination of these factors should cause the adversary to overshoot and put you back in the driving seat. So viffing can be useful, although it does need to be done judiciously and with skill. Having said that, I did once use the nozzles to stop myself hitting the ground when I had a control restriction and I then flew the aircraft for almost 15 minutes on nozzles for pitch control until the constriction cleared.

Hine. I would just add that the US Marine Corps probably did most to refine viff techniques, not least because they needed to demonstrate to people in Washington that the AV-8 could look after itself in air combat against the USAF's hot rod F-15s and -16s, and, of course, the Navy's F-14s and F/A-18s. As Sir Peter has said, a Harrier could certainly hold its own in a one-on-one situation and I believe that when pitted against such highly agile fighters in trials the Marines won more engagements than they lost.

Gordon Lewis. Having spent several years of my life trying to solve the problems of the power unit for the P1154, I wonder whether there have been any operational situations where the Harrier has been disadvantaged by not being supersonic?

Squire. Not in my experience, because my involvement with the aeroplane has always been to do with air-to-ground operations and, in that context, a supersonic capability would not have been particularly helpful. On the other hand, I am sure that it would have been an advantage to a Sea Harrier pilot obliged to deal with an opponent having a similar or better performance.

Covington. I would certainly endorse that. Speaking from personal experience, during the Falklands campaign a lack of a supersonic dash capability meant that an A-4 and three Mirages got away from me. I simply couldn't get to them.

Richard Lambert. Some reference has been made to the lack of a naval air defence capability once the Sea Harrier has been withdrawn. Was any consideration ever given to grafting their radar noses onto some of the second generation Harriers, to create an equivalent to the Marine Corps' AV-8B Plus? A combination of a modern airframe, the bigger engine and at least some air defence potential would surely be valuable, particularly for seaborne operations?

Covington. I think we missed the opportunity to exploit that possibility in about 1986, when OR(Sea), in conjunction with OR(Air), looked at whether the Royal Navy ought to change tack from the Sea Harrier and go for the Harrier II Plus option. It was concluded that, in the prevailing Cold War situation, it would have been the wrong answer. The Sea Harrier is not supersonic, of course, but it is faster than the RAF's Harriers, especially at altitude, and it was considered that that speed differential was well worth retaining. That said, there was a lot of work being invested in the FA2 – the FRS2 as it was then – and this produced a very good radar with significant spin-off for the Typhoon project. In fact the capability of the fully developed Sea Harrier FA2 really surprised us. I suspect that many people are unaware of just how effective the combination of its radar and missile system made it.

In answering whether the UK should have put the radar into the GR7 today, as an equivalent to the AV-8B Plus, you do have to bear in mind the problems of having to decide priorities within the constraints imposed by finance and it would have cost a fortune to have embarked on a radar-nosed second generation Harrier programme. For Air Defence of the Fleet, the present decade is also very different from the Cold War era and, on balance, it is not very likely that we are going to need a seaborne air superiority fighter before the introduction of the Joint Combat Aircraft. That is not to say that we might not need to take out, for instance, a shadowing reconnaissance aircraft, but a relatively undemanding engagement of that sort does not require a dedicated air superiority capability. In the meantime, it is difficult to see us operating without being part of a coalition, and one's ally of choice is more than likely to be able to provide whatever capability we lack, our contribution to the joint enterprise being bombs on target, rather than air defence.

Hine. That is true, although the Typhoon will provide us with a very sophisticated air combat fighter, so, even if we were faced with having to establish air superiority, we will have the ability to do that, while permitting other aircraft to conduct ground-to-air operations. Once a favourable air situation has been achieved, of course, the Typhoon then has the flexibility to be re-roled into an equally capable ground attack aircraft. That flexibility has been at the core of the Eurofighter project going back twenty years or more.

AVM Pat O'Reilly. Perhaps I could just clarify a point. I wasn't sure from the question whether it was being suggested that one might have been able simply to remove the radar from a Sea Harrier and install it in a GR5. It is a lot more complicated than that. I was the Project Manager for the Sea Harrier's BLUE VIXEN radar and having seen what was involved in merely adapting that system to cater for AMRAAM, I can assure you that it was by no means a trivial matter. Installing an entirely new radar in an existing airframe and then integrating it into the aircraft's systems would have been a major design and engineering project.

Golledge. If you were to ask the pilots on the squadrons, they would say that they would love to have a radar. But not for air-to-air work; they would want it to be able to see what was going on – to improve their situational awareness. It's that blue-on-blue problem that we were discussing a few minutes ago. It was a potential problem over Kosovo and over Iraq – scores, even hundreds, of (probably) friendly aeroplanes, many of them without radar, and everyone clamouring to talk to the AWACS for reassurance – 'second hand' situational awareness. At times, I think that we were probably lucky to have avoided mutual shoot-downs. For the future, we definitely need a data link to permit everyone to know what everyone else is up to.

AVM George Black. When I was the Defence Advisor at Ferranti, we studied the idea of equipping two squadrons of GR7s with BLUE VIXEN, but it was a very expensive option and I think that that probably killed it off. Nevertheless, BLUE VIXEN was an excellent radar and much of the development work read across to the Typhoon's ECR 90 radar so nothing has been lost.

Mr M Budd. I believe that the carrier-borne Harrier was the aircraft that saved the Falklands. We are getting new aircraft carriers but, as I understand it, they will not be to 'the full specification', which seems to me to be very short-sighted policy Would anyone care to comment?

Covington. Well I would have to agree that the Sea Harrier and the GR3 were key factors in the South Atlantic, alongside Amphibious Forces and a few other things. But as to the CVF, we haven't really got there yet. These ships are certainly going to be big – 60,000 tons – because we don't want to find, 25 years from now, that we had built them fifteen feet too short – as the French discovered when they tried to put E-2C Hawkeyes on the *Charles De Gaulle*. They had to extend the catapult system, which was a hugely expensive undertaking; much better to have invested in a little more relatively cheap steel from the outset. A carrier does need to be robust, of course – able to cope with a mine, for instance – and, in that context, size certainly helps. So just how big does it need to be? We need hangarage and a flight deck able to handle up to thirty fast jets routinely, with an overload capacity, to include all roles, of perhaps forty – jets and helicopters combined. I doubt that the overload situation would arise very often, but we just might want to mount a high-intensity two/three-day surge operation

'Whether the aeroplanes are provided by the RAF or the RN is not important' – a RN Sea Harrier FA2 keeps company with an RAF Harrier GR7.

involving a whole fistful of JCAs but a small scale operation would probably involve no more than eight to twenty aircraft. To do that, of course, one needs all the infrastructure of workshops, fuel and weapons storage and so on, but we don't need to go for a truly gold-plated solution – we aren't trying to build a US Navy style strike carrier. We need a ship that is right for the UK – the ability to deliver air power at minimum cost when a land base is not a practical option. Whether the aeroplanes are provided by the RAF or the RN is not important in itself.. What does matter is that they are the right kind of aeroplane; one which has the necessary range, appropriate weapons and is being flown by a competent pilot. I think that the Navy is being very realistic in its approach to the carrier project. We are aiming for ships, that we can actually afford, that will give us the capability that we need now and that will be big enough to cope with possible changes in operational concepts over a period of perhaps fifty years.

CHAIRMAN'S CLOSING REMARKS

Air Chf Mshl Sir Patrick Hine

Ladies and Gentlemen, we have had a long day, so my closing comments will be brief.

That the Harrier has been a great success, despite its less than enthusiastic embrace by the Air Staff in MOD in the early 1960s, is I believe indisputable. That success has been based on the relative simplicity of operation afforded by vectored thrust; and much of the credit for that must go to people like Gordon Lewis and Ralph Hooper and those skilled engineers who worked with them on the Harrier programme in the early days. In passing, my personal view is that had the P1154 gone ahead in the mid-'60s, with all the problems of operating off-base with a PCB (reheated) engine, the whole STOVL concept as developed would have been made much more difficult and might even have stalled.

Whether or not the operational concepts developed for the Harrier in the Central Region and on the Flanks of Allied Command Europe would have worked well in war, we shall now never know. I believe that they would have proved robust and that their effectiveness would have been limited only by the weapons available at the time, the lack of a viable night capability (not then unique to Harrier of course) and the aircraft's comparatively short radius of action. With successive variants of the Harrier – through the GR5 and GR7, and now to the GR9 – and the acquisition of smart weapons, these limitations have been progressively overcome. Certainly, today's Harrier is a very capable and versatile ground attack aircraft in almost all weather conditions – as we have heard from Andy Golledge. There was that time in MOD in the mid-'70s when the future of Harrier in the RAF was in real doubt, but fortunately the Belize experience and changing staff perceptions combined to take the aircraft's development forward in the way you have heard today. The decisions taken then have been more than justified by subsequent events.

We have focused today, for the reasons I gave at the outset, on the RAF's experience with Harrier, but that is only part, albeit a very major one, of the overall Harrier story. The RN's decision to procure the Sea Harrier and the ASW carriers gave the UK's armed forces a capability without which we could not have re-possessed the

Falklands. Nor could the RAF's Harriers have participated in that conflict without the carriers. Then, of course, there is the USMC which since the late-1960s has been a totally dedicated proponent of STOVL and the Harrier, and which has by some way the largest Harrier force. While, as you have heard, the RAF's Harriers played no part in Gulf War I, the USMC's AV-8Bs flew more sorties (some 3,400) during that conflict than any other coalition aircraft type, and dropped a higher weight of ordnance (around 2,700 tons) than any type other than the B-52. These are facts which are either not known by most or sometimes conveniently overlooked.

So, if the 'bona jet' has more than proved itself in service with the RAF, RN, USMC and other air arms, what about the future? It is still possible that there could be a further development of Harrier – a so-called Harrier III as the USMC would call it – but that is only likely if the STOVL variant of the Joint Strike Fighter does not go into production. There are difficulties with this variant, notably weight growth and cost overrun, but we must hope that these problems will be overcome within affordable bounds and that the aircraft does enter service with the successor to the Joint Harrier Force, probably around 2014. In the meantime, I confidently expect the UK's Harriers to continue making a valuable contribution to expeditionary and peace enforcement operations.

Finally, I would like to thank all the other speakers who have given so freely of their time to address us today, and John Farley for also helping out so well with the visual aids. It is perhaps worth reminding you that all of our speakers have first-hand experience of the Harrier in one form or another, either as a designer, test pilot, operator, logistics supporter or commander. Two – Sir Peter Squire and Andy Golledge – have taken the two generations of RAF Harrier to war, and in Jock Heron we really do have the fount of all (or nearly all) knowledge of the Harrier. Certainly, no-one amongst those who have operated this unique aircraft, have fought for it so hard. He has been an unswerving advocate, both when on the staff and throughout his many years with Rolls-Royce, and has an encyclopaedic grasp of its genesis and history. Without him this seminar would not have come together so well and probably would not have got off the ground at all. In the audience today we have had many other Harrier experts, including Duncan Simpson who first flew the P1127 as long ago as

1962. Time prevents me from mentioning others. As I said at the beginning of the day, it was very important to tap into this hands-on Harrier experience and the memories of our speakers, especially those of more 'mature' years (if I can put it that way!), as *tempus fugit* and we ran the risk of failing to write a very significant chapter in the RAF's history.

I hope that you have all enjoyed the day as much as I have, and found it interesting and informative. The RAF Harrier story is certainly one worth covering in this form; I only hope that we have done it justice. Have a safe journey home and please continue to support these seminars of the RAF Historical Society. Thank you.

THE HARRIER AND THE MINISTRY OF TECHNOLOGY, 1967-1969

AM Sir Reginald Harland

In amplification of his comments from the floor at Bristol, AM Harland has offered the following extract from his autobiography covering the period he spent dealing with the Harrier while it was still undergoing trials prior to its entry into squadron service. **Ed**

Project Management

Project management is the balancing of quality against time and cost. I was most fortunate that my predecessor as project director for the Harrier (then called the P1127) at the Ministry of Technology (Air Commodore Stanley Bonser) had got agreement to a specification, a budget (£50 millions) and a time scale (ending on 31 March 1969) that were all three realistic.

Nevertheless, the balancing act still needed to continue against the unknown factors being found almost daily. I had at hand three techniques to use against them – value engineering, credibility diagrams and financial forecasting. Each could deserve a paper of its own, but not here and now. Another key feature in my inheritance from Stan was that I had full financial control of that £50 millions. That proved invaluable in solving several of the problems met during development, as you may see below.

Flying Accidents

When I was appointed Harrier project director in the Ministry of Technology in January 1967, it was clear to me that nothing could cause so much trouble to the project as the loss of an aircraft during development flying. I therefore got my staff to review the number of flying accidents that had occurred to other jet-engined aircraft (like the Meteor, Vampire, Venom, Hunter, Canberra and Lightning), during development flying, over the last ten or twenty years. It seemed that there had been about one such accident per one thousand development flying hours. The Harrier was due to do about that same number of development flying hours. Statistically, therefore, we were likely to have none, one or two accidents, each putting development aircraft out of action for long periods.

Each of the six development aircraft were due to be instrumented to carry out different aspects of the trials, like engine development, airframe performance, armament trials, radio trials, nav/attack equipment, etc. Delays in any one of these would hold up critically the aircraft's date of entry into service. I arranged, therefore, with the aircraft manufacturer, that each trials aircraft would be wired so that it could carry out trials of more than one role; and that the extra instrumentation needed would be bought and held in reserve. Thus, if any one or even two aircraft were lost, the work could continue by using the others more intensively than the standard five day week. If one were lost, they would work on the remaining five aircraft on six (instead of five) days a week; and, if two were lost, they would work on the remaining four for seven days a week until we were able to wire one of the early production aircraft. I told the manufacturers what was expected of them, adding that, if three aircraft were lost, I would expect the programme to be cancelled.

I also told my aircraft development management board that, should there be an accident, (and that I was expecting one or two), that there need be no delay to the programme, and that they should await the outcome of the accident enquiry before starting to worry. In the event, when there was an accident which resulted in the loss of the engine trials aircraft, there was no panic. Everything went on as planned until the reason for it had been determined, after which it was put right and we got on with the trials using one of the other development aircraft.

Wings

This section, dealing with the '6g requirement', has been deleted as the topic was adequately covered at Bristol – see page 66. **Ed**

Birdstrikes

Bird strike tests were carried out on a number of points on the aircraft, including the engine intake fairings, using the standard 1 lb-bird at 400 knots. If a bird broke up the intake, the metal pieces would almost certainly wreck the engine, resulting in the loss of the whole aircraft.

I watched that test at Bristol. It was most spectacular. It finished with the engine stopping in a fraction of a second, with bits of compressor blades sticking out like a hedgehog. There would be a significant weight penalty in strengthening the air intake sufficiently to withstand the bird; and the manufacturers were strongly opposed to that. However, I calculated that the cost of the extra weight, assessed from the loss of aircraft performance, would be much less than the costs of lost aircraft. The latter was calculated from the number of bird strikes likely on that part of the aircraft over the total flying life of the fleet – as I remember it, one such bird strike is likely per square foot of frontal area per one million miles of flight at low level. I authorised the one million pound cost of an additional engine for a further test, as Bristol's said that they knew how to fix it with extra bolts holding the compressor blades in more firmly.

A few days later on, Bristol rang up to say that, on looking back, the spot at which the bird had been aimed could not have been hit in actuality, as it would have been shielded by the side of the fuselage! Nevertheless, the engine modification was approved also before a second (successful) test was held.

Starter Motor

At one time, we were having problems with the reliability of the starter motor. An aircraft whose starter motor refuses to start is not much use operationally. My financial adviser, who, fortunately had no power of veto over my decisions, suggested that we just tell them to get on with the job for which they were being paid.

However, I was conscious that any delay over a minor contractor could cost millions of pounds on the major contracts. I, therefore, instructed him to give the contractor concerned an additional contract to produce reliability substantially higher than was specified in the original contract; but he was also to see that they never got another one from our department.

Navigation/Attack System

Although in 1967 there was no sophisticated computer system available, Ferranti's Nav/Attack system was to have a moving map for navigation and a head-up display for bombing and gun firing. Using my credibility diagrams, I soon found that Ferranti's forecasts of deliveries of sets of equipment and other dates were hopelessly optimistic. Typically, they were anywhere between 50% and 300% optimistic, i.e. the time taken to achieve any event took 1.5 to four times as long as had been forecast.. That compared badly with Hawker's forecasts for the completion of trials aircraft and Rolls for the delivery of engines, each of which were consistently only 15%

late. ‘Only optimists invent these things,’ as John Fozard, the Harrier designer, said when I upbraided him for his optimistic forecast aircraft completion dates.

As time went on, it became clear that the Nav/Attack system could not be ready for the planned in-service date. It was agreed with Hawkers that other equipments could be installed temporarily to allow the service to get experience in flying this extraordinary aircraft on the declared date and to have the Nav/Attack system retro-fitted later on.

Finale

Towards the end of 1968, I got my next posting - to the one-year 1969 course at the Imperial Defence College (IDC), now the Royal College of Defence Studies RCDS). I was somewhat disappointed, as I had hoped to work on the Harrier until the end of March 1969, its in-service date.

My successor at the Ministry of Technology was to be Air Commodore Eric Burchmore. Eric and I had worked together for a year in the Technical Training branch of the Air Ministry in 1946 when I had returned from Italy, so we knew each other well. At least the project was, by then, on time and within budget, even if the Nav/Attack system would be late.

The fully developed first-generation Harrier – the GR3.

A V/STOL FLIGHT CONTROL JOURNEY ENABLED BY RAE SCIENTISTS

John Farley

On 16 May 2005 Justin Paines, a QinetiQ civilian test pilot, pressed the 'coffee bar button' and thereafter everything happened exactly as intended and just like I had wanted it to for years.

The 'coffee bar button' was in the rear cockpit of Harrier XW175 (the second two-seater ever to fly, way back in 1969) and the result of Justin pressing it was that '175 looked around, sniffed the air with its satellite navigation system, decided where Justin's coffee bar was located, took him to it and landed him safely, gently and of course vertically, on board HMS *Invincible*.

This first fully automatic recovery of a Harrier to a ship was the end of a journey on which RAE scientists had embarked in 1952. Yes, that is correct. The journey started eight years before Bill Bedford broke his ankle and the doctors decided the only thing he was then fit to 'fly' was the first prototype P1127 tethered to the grid at Dunsfold.

Just what were RAE (later to become DERA and now QinetiQ)

16 May 2005 and only another foot to go. The VAAC trials two-seater about to touch down on Invincible *after the first automatic recovery.*

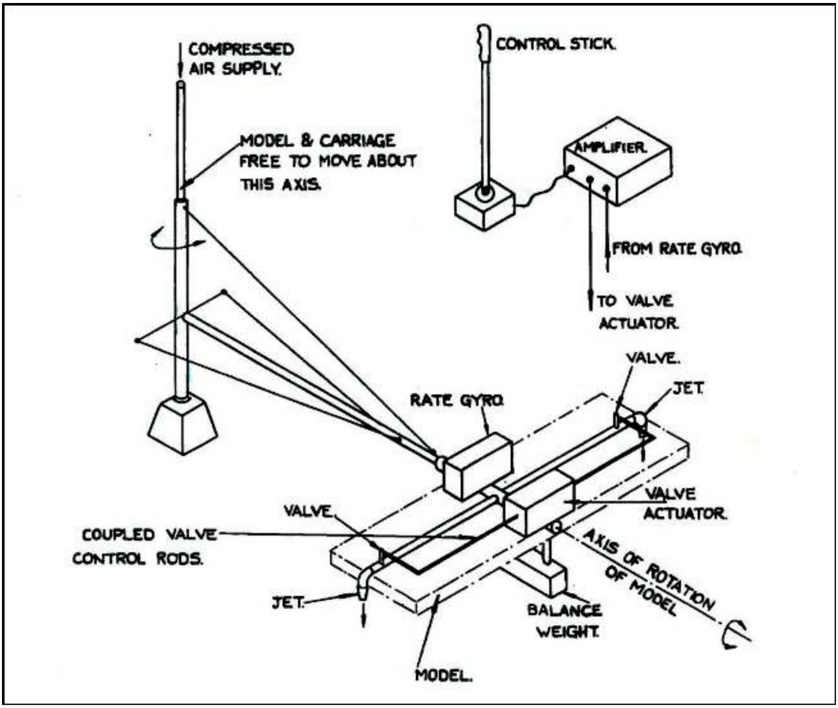


Fig 1. Dennis Higton's 1952 RAE rig.

scientists up to all that time ago that eventually led to the *Invincible* landing fifty three years later? Also why was I so keen for such a capability to be developed? I will try to explain.

By 1951 the senior management of RAE realised that the thrust of jet engines was increasing all the time and that one day an aircraft with a thrust greater than its weight would become possible. But how could the attitude of such an aircraft be controlled in the hover?

In an attempt to answer this question Dennis Higton, a former RAE apprentice who had joined the Aerodynamics Research Flight at Farnborough at the end of his apprenticeship in 1942, devised a rig to investigate the feasibility of controlling the attitude of a hovering aeroplane by means of small jets mounted in the nose, tail and wingtips.

The layout he first used had two jets and is shown in Fig 1, copied from RAE Tech Memo 286 of April 1952 in which Higton reported his work.

These early experiments showed that a reaction control system was indeed suitable and enabled Higton, working with colleague Roger Duddy, to draw up the specification for a full size piloted rig to be used by the RAE. This rig, which first hovered tethered under a safety gantry at Rolls-Royce Hucknall in 1953, flew free for the first time in 1954 and was known as the Flying Bedstead.

From those early days the scientists of the Aerodynamics Research Flight at RAE – or simply Aero Flight as they were known – worked continuously to develop and improve the handling qualities of jet lift aircraft. After the Flying Bedstead they commissioned the Short SC1 which they operated from the new RAE research airfield at Thurleigh, near Bedford.

From the start the RAE approach to the control of jet V/STOL aircraft was to use a high degree of autostabilisation to make the handling as easy as possible for the pilot. Hawkers on the other hand favoured simplicity as a means of reducing the control system failure cases. Accordingly, the initial Hawker P1127, Kestrel and Harrier aircraft could be flown without artificial aids, relying on the pilot to compensate for any inherent handling deficiencies.

With hindsight both teams were correct. The RAE approach was without doubt the ideal way ahead for the pilot but – and it was a big but – the reliability of the electro-mechanical engineering in autostabilisers in those days was far from assured given the technology then available. Because of this, the Hawker approach of simplicity and reliance on the pilot to compensate was absolutely correct during the 1960s and enabled the Harrier to happen.

Once the Harrier went into service, there was a slow but continuous programme to add devices to it that made control easier and safer for the pilot at low speeds. Not surprisingly the RAE Aero Flight input into the development and certification of these aids was considerable and from 1964 onwards they were helped in this work by having their own P1127.

By 1964 six P1127s had been flown at Dunsfold and naturally the later aircraft incorporated lessons learned from the earlier ones. Because of this the standard of the original prototype, XP831, was by then looking fairly unrepresentative so the Ministry allocated it to Aero Flight at Bedford. At that time I happened to be serving there as an RAF flight lieutenant and was fortunate enough to be given the job of collecting it from Dunsfold. Three years later, following the retirement of Bill Bedford, my luck continued and I took my uniform off and joined Dunsfold as their new junior test pilot.

Later in 1970 Dunsfold Chief Test Pilot, Hugh Merewether, asked me to represent him at a meeting being held at RAE Farnborough. Hugh explained that it appeared the RAE boffins had ideas for making life easier for jet V/STOL pilots and so he needed somebody to go and keep tabs on them. He pointed out that, as a former RAE apprentice, I was obviously the bloke for the job and anyway he had better things to do that afternoon.

At that meeting it was clear to me that the eventual aim of the scientists was to hand over control of the aircraft to a computer leaving the pilot just to tell that computer what manoeuvre he wanted it to fly. If this happened it would mean the Harrier pilot's nozzle lever would no longer be needed because control of the nozzle angle – as well as everything else that the pilot hitherto controlled – would be left to the computer.

As I drove back to Dunsfold I was quite excited about what I had heard. After using my left hand to operate the nozzle lever and throttle for six years, it was clear to me that it was only a matter of time before I made a mistake and moved the wrong one with potentially disastrous results. Therefore I welcomed the boffins' ideas although I realised it might take a few years to turn them into reality (it actually took twenty nine!).

Meanwhile the RAF had only two year's experience with their Harriers and the provision of this single nozzle lever was seen as the simple masterpiece that had enabled V/STOL to happen. Rather naturally, at Kingston and Dunsfold any talk of removing the nozzle lever was as close to Harrier Heresy as you could get so care was needed when broaching the subject. Anyhow they were all so busy coping with the USMC decision to buy Harriers it was not reasonable to expect them to give serious consideration to futuristic ideas.

Time passed and I became increasingly frustrated that the RAE approach to specifying the modifications of a Harrier to start flight trials had turned out to be so conservative in that they were not intending to split the control of the four engine nozzles. I remember talking to Kingston aerodynamicist Robin Balmer about this in the mid-seventies and suggesting that if we let a computer put the nozzles down on one side only, we could get rates of roll in low speed combat that would make any opposition's eyes water. Equally by putting down the front or rear pair we could pitch in a way nobody else could even dream about.

While it seemed so obvious to me that the Pegasus offered a ready made way to endow the aircraft with unmatchable manoeuvrability such ideas were viewed as too way out. Not surprisingly the Kingston design office and spiritual home of 'Keep it simple, stupid' (and that is meant as a compliment not as a criticism) was not about to change horses in mid stream and take the lead in the brave new world of computer-based systems – or fly-by-wire as they are called today.

By 1982 the RAE programme, now called VAAC for Vectored thrust Aircraft Advanced flight Control, had laid the three key foundation stones needed for eventual success.

The first of these was the choice of a two-seat aircraft for the programme. Had the team chosen to modify a single seat Harrier, they would only have been able to test tomorrow's ideas on today's Harrier pilots – hardly the best way to conduct open minded research. (NASA went this route with a modified Harrier and I suspect lived to regret their decision)

The second was installing something termed the Independent Monitor (IM). The IM was essentially a special computer that was carried around in the test aircraft for many sorties during which time it was taught by the Harrier crew to recognise the safe limits of Harrier operation. It was then sealed and became the basis for the subsequent airworthiness certification of the aircraft as a research tool. When the trials proper started, the IM was thus able to keep an unblinking eye on what the (single channel) experimental equipment was attempting to do with the various Harrier controls. If it detected anything that looked like going outside what the human pilots had previously agreed was a limit, it instantly disengaged the experimental kit and handed the aircraft back to the safety pilot in the front seat. That way the safety pilot would always be left with a recoverable situation.

The third foundation stone was something called Unified. It was conceived by scientist Peter Nicholas and test pilot Flt Lt Peter Bennett, both of RAE Bedford. This was the notion that if the pilot wanted the aircraft to go up then the stick had to be pulled back and to go down the stick was pushed forward. Sound familiar? Well yes, but Unified was conceived for use at any speed. Helicopter pilots raise or lower a lever called 'the collective' to go up or down in the hover while Harrier pilots use the engine throttle for the same thing. The aim of Unified was to allow the pilot to fly from take off to landing using just the stick. You may prefer to think of it as eliminating the concept of a 'stalling speed'. When the pilot asked Unified to fly the aircraft slower than the stalling speed, the computer merely put the nozzles down and used the engine instead of the wings to support the weight. This of course was what human (superhuman?) Harrier pilots already did but only after special and expensive training. Unified enabled any fixed wing pilot to handle a Harrier in the circuit without extra training.

Easy though Unified may appear as a concept, it was in actual fact far from straightforward to optimise and approve all the necessary software. Indeed in the beginning the Unified notion was only one of several 'control law' possibilities that the VAAC team examined in their search for the optimum way to control a jet lift aircraft.

Any description of this work quickly becomes fairly technical but from an historical standpoint it clearly deserves a mention. However, to avoid spoiling the main story for the general reader these details have been provided separately in an annex.

To continue with the main story. In 1983 I turned into a pumpkin and retired from Harrier test flying but the VAAC team were kind enough to keep in touch with me and I was invited back in 1993 and again in 1999 to fly the aircraft and comment on how I thought they were getting on.

In 1999 my safety pilot was one Sqn Ldr Justin Paines. When I got out after our couple of sorties at Boscombe, I told him that I thought the team had cracked it and that Unified was the way ahead.

Shortly after that, following a detailed and quantitative evaluation trial where the VAAC was flown by many test pilots including several from the USA (some of whom had never been in a Harrier before) the VAAC team was able to convince the US Joint Strike Fighter Programme Office that Unified should form the basis of the JSF flight control system.

Again there was much more to selling Unified to the US than my account might suggest. Justin Paines, who led the final test pilot push, was in no doubt that the opinion of Harrier squadron pilots, on both sides of the Atlantic, was bitterly divided. While some saw the attraction of Unified others were seriously opposed to it. The opposition even included senior BAE SYSTEMS test pilots. As I saw it the opponents all had many years of successfully using the nozzle lever and arguably it was that skill that made them feel better pilots than those who had no such experience. It made them better in the circuit, better in the bar, and probably better in bed. As for the mistakes some other Harrier pilots had made over the years it was only lesser mortals, not people like them, who moved the wrong lever. Expecting such successful senior operators to vote for abolishing the nozzle lever was akin to expecting turkeys to vote for Christmas.

In the end I am glad to say that the VAAC team's arguments in favour of deskilling the process of flying jet V/STOL won the day, thus saving costly training as well as reducing the likelihood of accidents. The JSF will be in service for fifty years from now so many of its future pilots have yet to be conceived. Thankfully the aircraft is to be built with them in mind – not yesterday's nozzle lever men.

Finally what about my wish for a 'coffee bar button'? In many of the conversations I had with Harrier pilots about the controversial idea of Unified, I was at pains to point out that, although I wanted to get rid of their beloved nozzle lever, I was not a boffin's nark and against the operational pilot's point of view. In fact quite the reverse. I believed that while operational pilots were over the target (and being shot at on our behalf) their views about what they needed to do their job were paramount. However, once they turned their back on the target and their operational job was done, they should be able to press a 'coffee bar button' whereupon the aeroplane would then take them home safely, day or night, in any weather, regardless of whether they were exhausted, injured or (heaven forbid) it was just their day to make a mistake during their approach to land.

ANNEX – CONTROL LAW RESEARCH USING THE VAAC HARRIER

Two decades ago the controversial aspects of the Unified law were well appreciated by the VAAC team. This led them to thoroughly flight test various other concepts. By 1999 they were left with three serious contenders: Unified, Mode Change and Fusion.

UNIFIED. Unified was the most radical mode. Here the pilot pulls back on the stick to go up and pushes to go down, regardless of airspeed. At all speeds above 40 kt ground speed the stick commands flight path rate and so relaxing it to the centre position when the aircraft is flying level maintains height. If the aircraft is in a climb or a dive, relaxing the stick maintains the existing climb or dive flight path angle. As the aircraft decelerates through 40 kt the stick response blends to become a height rate control by 30 kt ground speed so, in the hover, with stick centre commanding zero height rate, it appears to the pilot as a height hold.

When flying up and away lateral stick commands roll rate. This blends between 130 and 100 kt to become a closed loop roll attitude control, so that relaxing the stick to centre below 100 kt commands wings level. Above 40 kt ground speed the rudder pedals command sideslip. Decelerating below this speed the pedals blend to a yaw rate command by 30 kt, providing a heading hold in the hover with feet central.

A throttle-type left hand inceptor, incorporating two detents, commands longitudinal acceleration.

Putting the inceptor in the centre detent holds the current speed. Acceleration or deceleration is selected by moving the lever forward or aft of the detent, with full travel demanding maximum available performance. Decelerating through 35 kt ground speed starts a blend and below 25 kt the aft detent commands zero ground speed. Either side of the aft detent gives the pilot a closed loop control of ground speed up to 30 kt forwards or backwards.

In summary, if the pilot centres both the stick and throttle when flying on the wings, the aircraft holds the existing speed, bank attitude and climb or dive angle. In the hover, centralising everything maintains the existing hover height, position and heading. Such hover characteristics are the stuff of dreams for every Harrier pilot at the start of their conversion although, as discussed earlier, many experienced Harrier pilots were critical of Unified.

MODE CHANGE. Given that no Harrier or helicopter pilot pulls back on the stick to go up when in the hover, the aptly (if at first sight awkwardly) termed Mode Change mode was conceived. At its simplest this requires the pilot to select either a conventional flight or a hover mode of control. In the hover mode the pilot controls height with the left hand as with the Harrier.

Given the ability of today's control engineers to offer excellent handling characteristics, it was only natural that this would be popular, especially with trained Harrier pilots. The down side was the risk of cognitive failure by the pilot inherent whenever a selection was required or available.

In conventional flight Mode Change provided the same detailed features as Unified but, following selection to hover mode, the throttle commanded height rate. The lateral and directional controls remained as described in Unified.

FUSION. The other main option was Fusion mode. This was designed to appeal to those military pilots who like to fly a 'back-side' approach, where power is thought of as primarily controlling flight path (as opposed to a 'front-side' approach where the stick is considered to be the primary control of flight path and throttle is used to set speed).

Thus in Fusion the left hand throttle controls flight path rate at all speeds down to 60 kt ground speed at which point it starts a blend to control height rate below 50 kt, providing a height hold when placed in the centre detent in the hover. Speed control is by a thumb wheel on the side of the throttle which commands longitudinal acceleration or deceleration, again with a centre detent for holding the current speed, analogous to a highly augmented Harrier nozzle lever.

Like the throttle, the stick also controls flight path rate but only down to 120 kt where it blends by an airspeed of 60 kt to become a longitudinal acceleration through pitch attitude control. Thus above 120 kt, given that the pilot needs to hold the stick for lateral control, the throttle action becomes redundant. Once again the lateral and directional controls are the same as in Unified.

ROYAL AIR FORCE HISTORICAL SOCIETY

The Royal Air Force has been in existence for over 80 years; the study of its history is deepening, and continues to be the subject of published works of consequence. Fresh attention is being given to the strategic assumptions under which military air power was first created and which largely determined policy and operations in both World Wars, the inter-war period, and in the era of Cold War tension. Material dealing with post-war history is now becoming available under the 30-year rule. These studies are important to academic historians and to the present and future members of the RAF.

The RAF Historical Society was formed in 1986 to provide a focus for interest in the history of the RAF. It does so by providing a setting for lectures and seminars in which those interested in the history of the Service have the opportunity to meet those who participated in the evolution and implementation of policy. The Society believes that these events make an important contribution to the permanent record.

The Society normally holds three lectures or seminars a year in London, with occasional events in other parts of the country. Transcripts of lectures and seminars are published in the Journal of the RAF Historical Society, which is distributed free of charge to members. Individual membership is open to all with an interest in RAF history, whether or not they were in the Service. Although the Society has the approval of the Air Force Board, it is entirely self-financing.

Membership of the Society costs £18 per annum and further details may be obtained from the Membership Secretary, Dr Jack Dunham, Silverhill House, Coombe, Wotton-under-Edge, Gloucestershire. GLI2 7ND. (Tel 01453 843362)

THE TWO AIR FORCES AWARD

In 1996 the Royal Air Force Historical Society established, in collaboration with its American sister organisation, the Air Force Historical Foundation, the *Two Air Forces Award*, which was to be presented annually on each side of the Atlantic in recognition of outstanding academic work by a serving officer or airman. The RAF winners have been:

1996 Sqn Ldr P C Emmett PhD MSc BSc CEng MIEE
1997 Wg Cdr M P Brzezicki MPhil MIL
1998 Wg Cdr P J Daybell MBE MA BA
1999 Sqn Ldr S P Harpum MSc BSc MILT
2000 Sqn Ldr A W Riches MA
2001 Sqn Ldr C H Goss MA
2002 Sqn Ldr S I Richards BSc
2003 Wg Cdr T M Webster MB BS MRCGP MRAeS
2004 Sqn Ldr S Gardner MA MPhil

THE AIR LEAGUE GOLD MEDAL

On 11 February 1998 the Air League presented the Royal Air Force Historical Society with a Gold Medal in recognition of the Society's achievements in recording aspects of the evolution of British air power and thus realising one of the aims of the League. The Executive Committee decided that the medal should be awarded periodically to a nominal holder (it actually resides at the Royal Air Force Club, where it is on display) who was to be an individual who had made a particularly significant contribution to the conduct of the Society's affairs. Holders to date have been:

Air Marshal Sir Frederick Sowrey KCB CBE AFC
Air Commodore H A Probert MBE MA

SECRETARY
Gp Capt K J Dearman
1 Park Close
Middleton Stoney
Oxon
OX25 4AS
Tel: 01869 343327

MEMBERSHIP SECRETARY
(who also deals with sales of publications)
Dr J Dunham
Silverhill House
Coombe
Wotton-under-Edge
Glos
GL12 7ND
Tel: 01453 843362

TREASURER
John Boyes TD CA
5 Queen's Close
Stansted
Essex
CM24 8EJ
Tel: 01279 814225

EDITOR and PUBLICATIONS MANAGER
Wg Cdr C G Jefford MBE BA
Walnuts
Lower Road
Postcombe
Thame
OX9 7DU
Tel: 01844 281449