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ROYAL AIR FORCE HISTORICAL SOCIETY

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SELECTED GLOSSARY

A&AEE	Aircraft & Armament Experimental Establishment
AAM	Air-to-Air Missile
ADM	Air Defence Missile
AEI	Associated Electrical Industries
AP	Air Publication
ARDE	Armament Research and Development Establishment
ARM	Anti-Radar Missile
ASGW	Air-to-Surface Guided Weapon
AWRD	Avro Weapons Research Division
BRIXMIS	British Commanders'-in-Chief Mission to the Soviet Forces in Germany
CG	Command Guidance
CP	Command Post
CRT	Cathode Ray Tube
CW	Continuous Wave
DHS	Data Handling System
DOD	(US) Department of Defense
ECM	Electronic Counter Measures
ECCM	Electronic Counter Counter Measures
FEAF	Far East Air Force
FMCW	Frequency Modulated Continuous Wave
FOB	Forward Operating Base
GBAD	Ground-Based Air Defence
GCA	Ground Controlled Approach
GPI	Ground Position Indicator
ICBM	Inter-Continental Ballistic Missile
IFF	Identification Friend or Foe
IFR	In-Flight Reference
ILS	Instrument Landing System
IMINT	Image Intelligence
INS	Inertial Navigation System
IR	Infrared
IRBM	Intermediate Range Ballistic Missile
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
JSTU	Joint Service Trials Unit

LCP	Launch Control Post
LOMEZ	Low Altitude Missile Engagement Zone
LPA	Launcher Plant Assembly
LWB	Long Wheel Base
MEZ	Missile Engagement Zone
MoS	Ministry of Supply
MRBM	Medium Range Ballistic Missile
NAS	Naval Air Squadron
NEAF	Near East Air Force
OCU	Operational Conversion Unit
ORB	Operations Record Book
OSD	Out of Service Date
PI	Photographic Interpreter
PPI	Plan Position Indicator
PPP	Programme for the Physical Protection (of airfields)
QWI	Qualified Weapons Instructor
RAE	Royal Aircraft Establishment
RBSU	Radar Bomb Score Unit
RPU	Rapid Processing Unit
RRE	Radar Research Establishment
SAC	Strategic Air Command
SAGW	Surface-to-Air Guided Weapon
SAM	Surface-to-Air Missile
SARH	Semi-Active Radar Homing
SD	Secret Document
SEAC	South East Asia Command
SHORAD	Short Range Air Defence
STANEVAL	Standards and Evaluation
SIGINT	Signals Intelligence
TACEVAL	Tactical Evaluation
TCC	Tactical Control Centre
TCR	Tactical Control Radar
TIR	Target Illumination Radar
TRE	Telecommunications Research Establishment
TSO	Target Selection Officer
TVM	TV Missile
VP	Vital Point
WCT	Weapon Control Team

GUIDED WEAPONS

RAF MUSEUM, HENDON, 1 APRIL 2015

WELCOME ADDRESS BY THE SOCIETY'S CHAIRMAN

Air Vice-Marshal Nigel Baldwin CB CBE

Ladies and gentlemen – good morning. It is good to see so many of you on this, the Royal Air Force's, 97th birthday.

Before I introduce our Chairman for the day, I must mark the fact that, since we met here last autumn, the Museum has appointed its first Chief Executive Officer, Maggie Appleton. It is to her and to her staff that I now make my customary 'thank you'. Meeting her earlier this morning, I stressed the importance of the relationship, that we have now had for nearly 30 years, between ourselves and this extraordinary place and expressed our gratitude for its invaluable support.

Secondly, the RAF's Centre for Air Power Studies – with whom we also have a close relationship – is co-sponsoring, with the Museum, a conference on *The Evolution of Aerial Intelligence and Reconnaissance* to be held here at Hendon on 15 and 16 April. It will start with the First World War and come right up to date with today's ISTAR platforms. The cost will be a very reasonable £35 for one day or £70 for two – which includes refreshments and lunch on both days. Details of the programme and registration forms are available here on the platform – I encourage you pick one up when we break for lunch.

Now to today's Chairman, Air Marshal Sir Roger Austin. Like many of us, Sir Roger finished his RAF career in the Ministry of Defence, in his case in the Procurement Executive, eventually becoming the Deputy Chief of Defence Procurement (Operations) from 1995 to 1996 and a member of the Air Force Board.

He had begun his career as a flying instructor on Jet Provosts before flying Hunters with No 20 Sqn at Tengah during the Confrontation with Indonesia in the mid-1960s. He subsequently commanded No 54 Sqn at West Raynham before converting to the, then new, Harrier GR1 as a Flight Commander on No 4 Sqn in Germany. Then to Wittering as OC the Harrier OCU before commanding Chivenor and its Tactical Weapons Unit. Further promotion and staff jobs included Gp Capt Ops at High Wycombe and a stint as Station Commander at RAF Stanley immediately after the Falklands War in 1982. Later still he took charge of the Central Tactics and Trials Organisation – which has some relevance to today's subject – and was Commandant of the RAF College at Cranwell. Since leaving the Service, he has been the National President of the Royal British Legion, the President of the Victory Services Association and a Trustee of the RAF Benevolent Fund.

This is the second time he has presided over one of our seminars – a unique distinction!

Sir Roger – you have control

THE NUCLEAR DIMENSION – THE DEVELOPMENT OF WARHEADS FOR THE ROYAL AIR FORCE 'SPECIAL WEAPONS'

Katherine Pyne

Kate became a Licensed Aircraft Maintenance Engineer in 1973, subsequently working as such, mainly in South East Asia, until 1991 when she switched to academia. She graduated from Queen Mary & Westfield College, London, with first class honours in modern history in July 1994, spending the next two years at Harwell, assisting the historian Lorna Arnold in writing the book Britain and the H-Bomb,[1] *before taking up her present post as the historian at the Atomic Weapons Establishment, Aldermaston.*

Note. The views expressed in this article do not necessarily represent those of the Departments and Organisations concerned. That said, the text has been officially vetted and cleared for publication and, as such, is Crown Copyright.

Introduction

This paper is intended to show the connections and continuity between successive nuclear warheads developed for Royal Air Force 'Special Weapons'. The directions such developments took in Britain were very much influenced by the relatively modest resources available and the changing demands of Government, Foreign and Defence Policy and those of the Armed Forces. British inventiveness led to the best use of the effort and experience from past projects over the years and in the process, still managed to produce a number of innovations.

The long-standing nuclear relationship with the United States, despite occasional setbacks, has remained a valued cornerstone of the UK nuclear warhead programme.

Historical Background

Early in 1940, the first practical scheme for an 'atomic bomb' was drawn up in a memorandum written at Birmingham University by two scientists, Dr Otto Frisch and Professor Rudolf Peierls – both refugees from Nazi tyranny.[2] It is instructive to contrast this document with the letter signed by the great scientist Albert Einstein, which was sent to President Roosevelt in 1939.[3] It explained that research in America into the possibility of nuclear chain reactions might make it possible to produce ‘vast amounts of power’ and ‘powerful bombs’. The bombs would be too heavy to be taken to a target by aircraft and would therefore have to be delivered by ship to an enemy harbour.[4] The final paragraph contained a hint of comparable research going on in Nazi Germany. A similar warning featured in the Frisch-Peierls Memorandum, as well as a set of scientifically feasible instructions on how to construct and safely assemble an atomic warhead small enough and light enough to be made into a bomb that *could* be carried in a bomber. Additionally, a sentence in the memorandum stated that the most effective ‘reply’ to such a weapon[5] ‘would be a counter-threat with a similar bomb’ – the concept of nuclear deterrence, almost as an aside, outlined in March 1940.

A committee of the best atomic scientists in Britain, later known as the MAUD Committee for security reasons, was given the job of evaluating the military use of uranium as outlined in the Memorandum.[6] Its July 1941 Report stated, amongst other things, that such a warhead would work. The MAUD Report broadened the statement on Deterrence in the Memorandum by stating that, ‘No nation would care to be without a weapon of such decisive possibilities.’[7] It led to a powerful determination that one way or another, Britain would become a nuclear power. Valuable basic research on separating the fissile material uranium-235 was carried out in North Wales as part of the Tube Alloys Project on the problems of developing an atomic bomb, starting in the autumn of 1941.

1941 was also the year that the United Kingdom began sharing its scientific and technical knowledge from its research into the atomic bomb with the still neutral United States. This had developed as part of the burgeoning exchange resulting from the Tizard Mission to the United States the previous year.[8] Included in this arrangement were MAUD Committee Progress Reports and ultimately, a copy of the July 1941 MAUD Report, delivered personally by the MAUD Committee Chairman G P Thomson. It helped to persuade the US National Academy of Science that an atom bomb *was* possible and *could* be built. But early British co-operation with America dried up as their atom bomb project was greatly expanded in the wake of the

Japanese attack on Pearl Harbour in December 1941.[9] By 1943, consideration of the likely post-war international scene underlined the British need for the atomic bomb. What was the way round this difficulty?

The American Project had set tight deadlines for an operational atomic bomb, which looked increasingly doubtful by the middle of 1943.[10] The August 1943 Quebec Agreement between President Roosevelt and the British Prime Minister, Winston Churchill, allowed British scientists to work on the atomic bomb in the American Manhattan Project. Hard-driven from both sides, it can be seen as a classic example of UK pragmatism and US flexibility in shaping and satisfying common needs. These stemmed from the requirement that both the US and UK wanted the war to end as soon as possible. To do that the atomic bomb might have to be used and the very tight US schedule for the bomb meant that help was needed to get on top of the burgeoning problems, but the only source of informed assistance was clearly the United Kingdom. For its part, the UK wanted interchange with US work on the bomb for post-war purposes. The record of meetings with Manhattan Project leaders and key American scientists and engineers, after the first of some thirty first-rate UK scientists had joined the Manhattan Project, showed where help was most needed. In the context of the gaseous diffusion process for separating the uranium-235 isotope, for instance, UK knowledge was, in some respects, ahead of US work.[11] Most of the British scientists then went on to Los Alamos to assist in solving the many problems thrown up by the use of the recently discovered element plutonium and its use as a fissile material.

UK wartime work on the bomb stopped – an American condition of the Quebec Agreement to ensure total UK commitment. According to a declassified US document, the British contingent made substantial contributions to the science of the bomb.[12] The United States was able to achieve its aim of getting operational atomic weapons by its 1945 timescale. There is no doubt that it could have solved all the problems using its own considerable resources, but whether it could have achieved its targets in time without UK assistance is at least a moot point. The plain fact is that, junior partner or not, the UK got the best possible bargain for itself in its conditional participation in the Manhattan Project – experience and 'know-how'.

Post-War

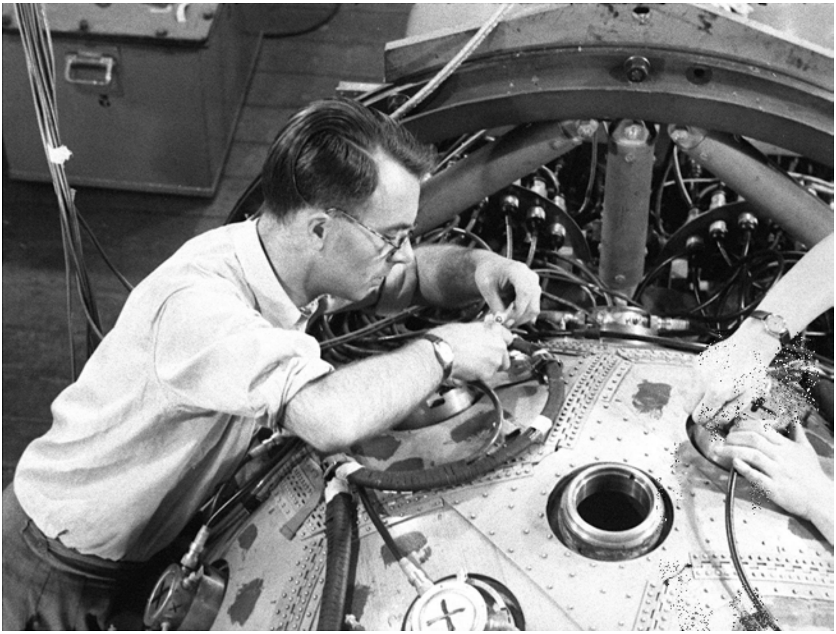
In August 1945, *before* Japan officially ended the war, by signing the surrender document on the deck of the giant battleship USS *Missouri* in Tokyo Bay, the secret UK GEN 75 Committee dealing with atomic affairs began its meetings. In December, GEN 75 authorized the production of the fissile material plutonium, thereby launching the enormous task of designing and constructing the huge industrial base needed. At the same meeting it was decided that the 'Chiefs of Staff would submit a report on our requirements for atomic bombs.'[13] Although not in themselves amounting to a specific, formal decision on developing a UK atomic bomb, it is difficult to argue that such a decision was not implicit in such moves.

The US/UK wartime collaboration ended with the August 1946 American McMahon Act[14] but the knowledge and experience picked up on the Manhattan Project by British scientists was by then in the process of being written up in detail. It became the basis of the post-war UK atomic bomb project ordered in January 1947.[15] Despite the poor state of the post-war UK economy, an atomic bomb was considered so important that the necessary resources were clawed together. The Foreign Secretary, Ernest Bevin, had famously insisted that, 'We have got to have this thing over here, whatever it costs' and furthermore that, 'We've got to have the bloody Union Jack on top of it',[16] meaning that it had to be designed and built in Britain so as to be under exclusive British control.

Work on the warhead for the bomb formally began in June 1947 in a very secret enclave at Fort Halstead, Home of the Armament Research Department.

Continuity

There is a continuity between UK knowledge and experience gained on the Manhattan Project and how the UK made use of it. At a meeting in October 1947, it was stated that the development of the UK atomic bomb excluded anything other than, 'copying designs already known'.[17] Because a decision had already been taken to use plutonium rather than uranium-235 as fissile material, there was, in effect, only one design – the warhead used in the weapon dropped on Nagasaki. Physics issues meant that plutonium could only be used in a Nagasaki-type warhead using the implosion principle, ie one in which a sub-



The BLUE DANUBE warhead was same size as the Trinity device and used the same principles, number of detonators and type of explosive charges. But it was a completely different engineering design.

critical mass of plutonium becomes critical when its density is increased by the simultaneous explosion of specially designed high explosive charges arranged around it. The nuclear explosion would then be initiated by a simultaneous flash of neutrons.

The word ‘copying’ quoted above must not be misunderstood. By the middle of 1952, the essential features of the device tested in the July 1945 US Trinity shot, the world’s first live nuclear test, had been turned into a warhead for the UK’s BLUE DANUBE bomb. In June 1952, two were assembled for the first UK nuclear test, Operation HURRICANE, to be carried out on 3 October. One was designated for firing in the test and the other was taken along as a ‘spare’.[18]

A design difference with respect to the parent US design

The British design differed from the original because of an RAF requirement, formulated in 1950 for safety reasons, to be able to load the plutonium core into the bomb at the last possible moment before

Trial of manual 'Last Minute Loading'.

dropping it onto the target. This meant the development of an elaborate mechanism, mounted in the bomber, capable of both loading and *unloading* the plutonium core. If, for some reason, the bomb had to be jettisoned, the in-flight loading mechanism would have to be capable of retrieving the expensive plutonium component. So the BLUE DANUBE warhead had to be provided with a large hole through the high explosive charges to give access to its interior.

The US Trinity device had no such provision; final assembly of the device was carried out with the plutonium core already in place.[19] Because the UK design was modelled on Trinity, it raised the question of a possible effect on the way the explosive charges were supposed to work when detonated. Protracted difficulties were encountered in the development of a reliable mechanical means of inserting the core in flight, leading to the substitution of manual insertion prior to take off in order not to delay entry of the weapon into service with the Royal Air Force. The manual technique was called Last Minute Loading (LML).

Even when its development had been completed, mechanical In-Flight Loading (IFL) was problematic. It is believed to have been used in RAF service only briefly. In any case, it was still necessary to determine the effects of the hole on the implosion system's performance and to do that, experiments were needed.

These were carried out at the Foulness Site on Potton Island, a part of the Shoeburyness Gunnery Range. In 1948, the first proof firings of the big explosive charges intended to form the implosion systems began. Instrumented and photographed with very high speed cameras, the charges were fired singly and in groups until, eventually, with barely any time left for modifications in the event of a serious fault, several full scale firings of the complete implosion system, including the hole and the insertion tool, were carried out. The designers were reassured by the results. Which was just as well, as the two warheads assembled for the first UK test were already en route to the test site in the Monte Bello Islands off the North-West Coast of Australia.

Knowledge and experience gained from these trials and other research at Foulness built up and eventually something useful emerged. It began to fit with other trains of thought. The smallest of the high explosive charges in the UK warhead weighed 35 kg, about 75 lb. This was a direct result of deciding to model the first UK nuclear warhead on the Trinity/Nagasaki warhead as an economy measure on the grounds that at least it worked – there was no need, in the short term at least, for expensive research to find better ways of doing things. As already seen, the original concept for an atomic warhead, first described in the March 1940 scheme outlined at Birmingham University[20] and embodied in the weapon dropped on Hiroshima, used uranium-235 as a fissile material. Separating this isotope from natural uranium proved to be difficult and the processes used were late getting underway and initially very slow. By the time of the intended attacks on Germany and Japan, the American planners realised there would only be enough uranium-235 for a single warhead, let alone a test device.[21] This meant that *additional* weapons would have to use the newly discovered element plutonium, which could *not* be used in a Hiroshima type warhead.

The Nagasaki warhead had to work first time. Vast amounts of money and resources had been committed on the authority of Congress without its being given any details, other than an assurance that it was vitally important for the war, and indeed for the future position of the United States on the world stage after the war had ended. There was high technical risk associated with developing the implosion technique to a tight schedule. For it to succeed, a series of difficult and subsidiary problems also had to be solved. The result of such pressure was a conservative approach to the engineering design. For example, far more high explosive was used than later experience would show was necessary.

By 1951, the first calls for improvement, along with a possible new but smaller warhead, were heard. Better ways of doing things had indeed surfaced, more or less in parallel with work at Foulness on proofing the BLUE DANUBE implosion system with the hole for the insertion tool. Interest began to focus on smaller weapons with a yield of about 15 kilotons in order to equip new designs of fighter aircraft with an atomic strike capability. Two types of weapon began to be considered:

1. An earth penetrator designed to explode after plunging deep into the earth for targets such as underground factories or submarine pens.
2. An air burst weapon

There were doubts about an implosion warhead being able to survive deep earth penetration. The robust form of warhead used in the Hiroshima bomb might do, but this used uranium-235 as a fissile material which would not be available in the UK until the mid-1950s. Thus, a deep earth penetrator was effectively a non-starter so the new small warhead would use the plutonium implosion principle.

The technology needed for ‘small’ implosion warheads was a valuable by-product of research going on at Foulness which had progressed from proof testing large high explosive charges for the BLUE DANUBE warhead to evaluating palliatives designed to retain the performance of the implosion system with the ‘big hole’. In May 1952, the code-word RED BEARD was issued. At this stage, it merely referred to a ‘possible new warhead system [*based on*] promising research’.[22] The codename RED BEARD was, curiously, given to both the new warhead and the bomb casing that contained it.

The actual research work was in the hands of a relatively small group of scientists and engineers based at the remote research establishment located at Foulness.[23] In charge at the time was Roy

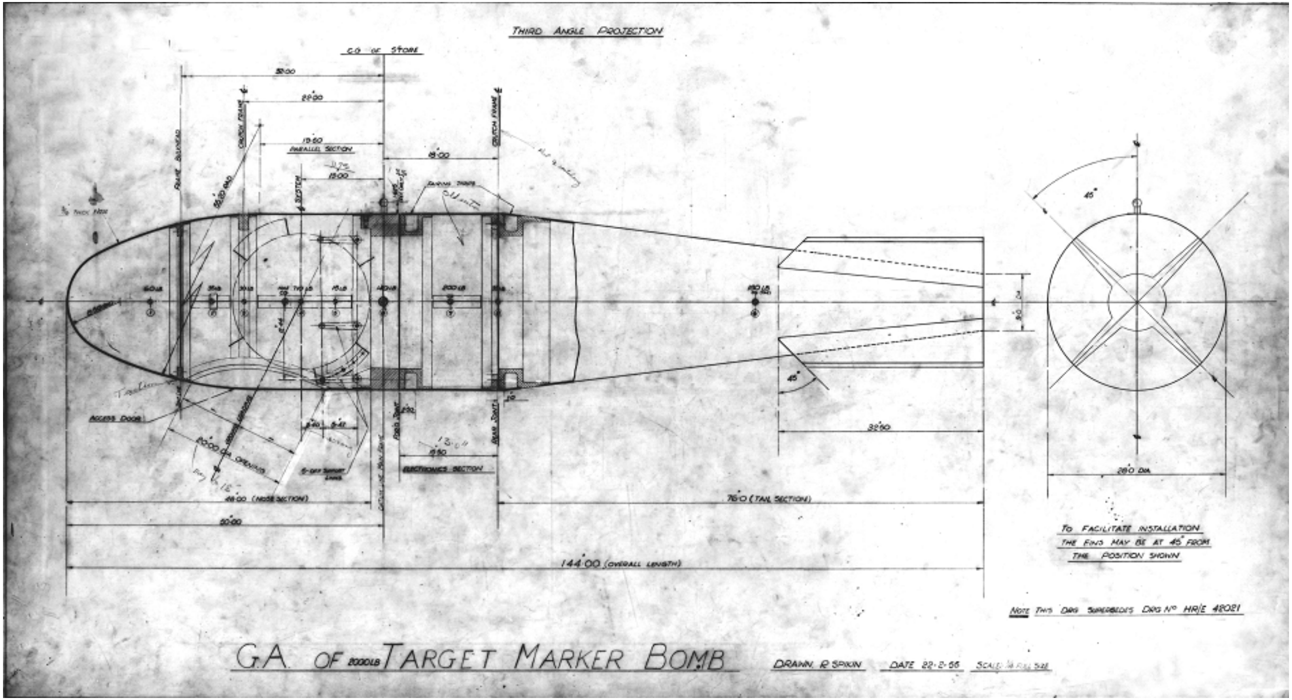
Early production Javelin with external fuel tanks, illustrating the restricted space available for carriage of an externally mounted bomb on a centreline station.

Pilgrim, an old hand in research work involving the effects of blast.[24] The 'promising research' was led by R F Johnston. The Atomic Energy Authority, which ran the atomic weapon sites under the title Weapons Group from 1954 until 1972, took out a secret patent on the main idea. The main advantage was that for a given yield, warheads would be smaller and lighter than the BLUE DANUBE type. The MoD, RAF, Royal Navy and the warhead project itself began referring to a new 'tactical' atomic weapon.

In February 1953, a report by the UK Chiefs of Staff introduced a complication. Amongst other things, it stated that, 'Our R&D programme should be directed to the provision of […] a small free falling bomb weighing not more than 3,000 pounds (1350 kg) with [a specified limit on diameter]'. It would be carried in (*sic*) RAF Javelin all-weather night fighters. For a while, the new bomb carried the nickname JAVELIN. Although the CoS Report had used the preposition 'in', the Gloster Javelin had not been designed to have a strike capability and it did not have an internal weapons bay. The type was troubled by having a short range and, not long after its inception, drop tanks became a standard feature. These took the form of two long elliptical bulges capable of holding 250 gallons of fuel, mounted side-by side under the aircraft centre section. Inevitably, they were christened 'bosom' tanks.

Fitting the RED BEARD weapon between the tanks placed a limit on diameter and, like BLUE DANUBE, it would have to have telescopic fins which would extend as soon as it cleared the immediate vicinity of the aircraft. A further restriction on the size of the weapon came from the possibility that the maximum ground clearance normally available might be reduced if an urgent need to carry out an atomic strike arose involving aircraft undergoing maintenance with deflated oleos and low tyre pressures. The combined reduction in ground clearance meant that rotating the aircraft beyond 12º on take-off might remove the bomb from the aircraft by contact with the tarmac, so the diameter had to be kept to a minimum. This driver for reducing warhead diameter served another purpose. A capable and relatively small fission device was an essential pre-requisite for the UK thermonuclear warhead development programme which began in 1954.

Meanwhile, in November 1953, the BLUE DANUBE weapon officially entered service with the RAF, despite the fact that the first of the three types of V-bombers, specially designed to deliver this large weapon, would not be in squadron service for several more years. Although having the hallmarks of a political decision, it is fair to point out that William Penney, Director of the Atomic Weapons Research Establishment (AWRE) from August 1954, justified it on the grounds of needing to give key RAF personnel the experience of handling nuclear weapons. The officers and men involved belonged to the Bomber Command Armament School (BCAS) based at RAF Wittering. Humphrey Wynn, author of the Official History of the airborne British deterrent, noted that, if necessary, the Avro Lincoln would have been used to deliver BLUE DANUBE weapons to the targets before the V-bombers became available.[25] The Valiant entered RAF service in 1955 and trials with inert BLUE DANUBE bombs began. Teams from the Bomber Command Armament School took part in the assembly of a BLUE DANUBE nuclear weapon for the 1956 BUFFALO Trial at Maralinga[26] and the experimental thermonuclear devices for 1957-58 GRAPPLE Trials based at



Recognisable RED BEARD bomb shape.

The September 1956, BUFFALO A1 test of the prototype RED BEARD warhead. The yield was 16 kilotons.

Christmas Island in the mid-Pacific.

By early 1955, the design of the RED BEARD bomb was well advanced. This much can be deduced from drawings showing the incremental advance of the warhead and of the bomb shape itself, the latter being the responsibility of the Royal Aircraft Establishment at Farnborough. This was a process that involved both establishments until they could jointly agree that neither needed to make further changes substantial enough to require significant alteration to the design of the warhead or ballistic shape.

The drawing on page 19, dated February 1955, shows the result of what, in more modern times, is referred to as the 'integration phase' – matching the warhead with delivery vehicle. Prototype RED BEARD warheads were tested twice in 1956 at the Maralinga test site in Australia. Ten other live nuclear tests of various nuclear devices also took place on Australian territory at three main locations, including five more at Maralinga. Mostly these tests were related to the development of fission devices including two that were even smaller than RED BEARD.

The nine remaining atmospheric shots out of the UK total of twenty-one took place at locations on or near Christmas Island for the 1957-58 GRAPPLE series. Seven of these were of prototype warheads for the UK thermonuclear warhead project and all were dropped in BLUE DANUBE casings from Valiants, by now a well understood combination. The remaining two were fired hung from a series of barrage balloons linked together.

RED BEARD entered service with RAF in 1960 and later with the Royal Navy and about 170 were built in various versions. All were taken out of the stockpile in 1972.

The other half of the RED BEARD Story – the British Hydrogen Bomb

As noted earlier, the considerable effort in developing the reduced diameter of the RED BEARD warhead made it small enough for use in thermonuclear devices. Documents from 1953 onwards make reference to RED BEARD as a trigger for a thermonuclear device. The political decision for this new stage in the British nuclear weapon programme was finally made on 26 July 1954 by the Churchill Cabinet.[27] Like the United States, when President Truman called for the development of thermonuclear bombs, Britain was years away from being able to test any form of H-bomb. The physics of such warheads were very complex and the principles were as yet unknown in the UK. Work on the mechanics of thermonuclear reactions at AWRE began in April 1954 and by the middle of 1956, enough was known to be able to design the first experimental test devices.

In November 1954, Sir William Penney had divided the work into two different approaches, describing them in vague terms. The first he termed the 'Type A spherical hydrogen bomb' and the second, the 'Type B cylindrical hydrogen bomb'. The Type A was a boosted fission device and Penney described it as, 'an extension of existing principles', implying that it was an easier concept to master and therefore might have an earlier in-service date. As for the Type B, Penney stated that, 'Not much was known about this type of warhead'.[28]

Continuity in the story so far

Being able to guarantee the performance of BLUE DANUBE's implosion system, which used the same layout as the American designed Trinity device, now that it had a big hole through it for loading the fissile core, led to experiments at Foulness. These led, in turn, to the technology needed for the RED BEARD warhead and a new small nuclear bomb for the Royal Air Force and the Royal Navy. The restriction placed on its diameter for the Javelin project made it suitable as a trigger for the British Type B cylindrical hydrogen bomb used in four GRAPPLE shots. Modified RED BEARD technology was used on a different trigger for another of the GRAPPLE shots.

But what of the Type A spherical hydrogen bomb? This also used modified RED BEARD technology. Type A seemed a good idea at the time, but the underlying principle was found to be incapable of delivering the high yields originally thought possible. In fact two nuclear tests, based on BLUE DANUBE warheads, showed the difficulties of making it work at all! So the Type A spherical hydrogen bomb, GREEN BAMBOO, was cancelled in 1957 just before the start of the first GRAPPLE Trial in May 1957. The resources invested in GREEN BAMBOO were not wasted. At fairly short notice, in the previous August, AWRE had been requested to provide a megaton yield warhead capability by the end of 1957. The dilemma for AWRE being that the Type B cylindrical hydrogen bomb would be nowhere near to completing development by then. Following the first GRAPPLE Trial in May 1957, discussion at Aldermaston suggested the use of one of the test devices to satisfy the megaton yield requirement. But it was concluded that the only warhead option that could be provided in time was some form of pure fission device. The Type A GREEN BAMBOO design was modified by removing the thermonuclear element and the result, after much tinkering, became the pure fission megaton yield GREEN GRASS warhead.

To say the least, it was problematic.[29]

The short service life of GREEN GRASS

There was not enough uranium-235 for the planned stockpile at a yield of one megaton. So the yield was reduced to about 400 kilotons in order to eke out stocks of uranium-235 across the stockpile. To substantiate the claim that megaton yield weapons were being provided to the Royal Air Force, yields in the range 400 kilotons upwards were officially described as being ‘in the megaton range’. The first GREEN GRASS warhead was delivered to RAF Wittering, in components, at the end of February 1958. The only way of achieving even this, already delayed, in-Service date was to continue its development for Service use *after* entry into RAF service. This was

YELLOW SUN Mk 1 and a Victor.

legitimised with a set of rules that would have to be rigidly observed in order to ensure complete safety. Some of these rules were relaxed as development proceeded to completion.

One rule that remained firm throughout the service life of GREEN GRASS was the method of ensuring nuclear safety. A half-ton of steel ball bearings was poured into the hollow interior of the warhead in order to spoil the implosion should an accidental firing of a detonator or high explosive charge occur. The balls would be removed at the last possible moment before an operational take-off when the weapon already loaded. At that time, an operational requirement existed for nuclear weapons to be ready for use at 15 minutes notice and the procedure for de-balling a GREEN GRASS warhead certainly took longer than that. Plans to carry out the procedure in flight to the target were made and prototype hardware was produced but incorporation into the weapon was not authorised before the weapon had been withdrawn from service following the 1962 Cuban Missile Crisis.

In terms of the Continuity theme therefore, GREEN BAMBOO lived on as GREEN GRASS. Indeed it was externally identical. This meant that it could easily be fitted into the hefty YELLOW SUN bomb casing, originally developed for GREEN BAMBOO.

The first few, however, were delivered in BLUE DANUBE casings – a combination known as VIOLET CLUB – development of the YELLOW SUN casing having been somewhat delayed. When it did become available, GREEN GRASS warheads in the handful of

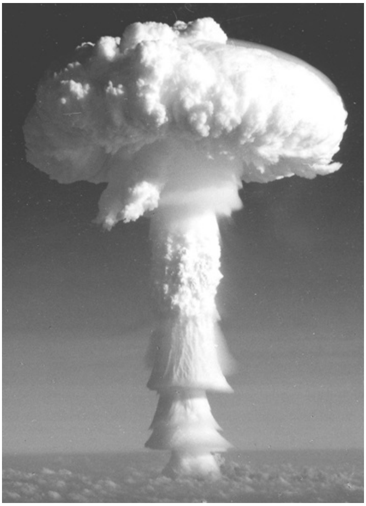
VIOLET CLUBs were removed, brought up to the latest modification standard, and installed in YELLOW SUN casings to produce the YELLOW SUN Mk 1. Some 37 were constructed.

GREEN GRASS is usually referred to in the documentation as the interim megaton warhead. The word ‘interim’ laid stress on the intention to replace these warheads, when a megaton yield thermonuclear device eventually became available. The attraction of thermonuclear warheads was two-fold – they were capable of very high yields and in doing so offered economy in the use of the expensive fissile materials required.

Watershed

In October 1957, the Soviet Union launched the first ever artificial Earth satellite. This was a big psychological shock to the collective American psyche because the United States had been so sure that *it* would be first to achieve that goal. But, more important than hurt pride, was the palpable fact that a sizeable item of Soviet rocketry was now encircling the world passing freely over American territory at regular intervals. This was seen as a powerful demonstration of Soviet military capability. The British Prime Minister, Harold Macmillan, egged on by his advisors, made an approach to President Eisenhower, appealing for more co-operation on developing things like nuclear weapons in order to do something jointly about ‘these Russians’. Eisenhower took the hint and set in train a process in Congress ultimately intended to modify the 1946 McMahon Act, the legislation which had, in effect, stopped the American and British collaboration on nuclear warhead design during the wartime Manhattan Project. The way had been prepared by some relaxation of its provisions over the years in the interest of both countries.

The United States then crafted a wider diplomatic package which invited the two other nuclear powers to join in with them in a halt to atmospheric nuclear testing beginning in October 1958. This would, amongst other desired effects, help to assuage the widespread unrest which had developed over possible genetic damage due to radioactive fall-out. But a halt in testing would more or less stop further development of British nuclear warheads. The way past that difficulty was an agreement in principle to exchange information on the design of nuclear warheads to be governed by a bi-lateral agreement between



FLAGPOLE explosion.

the two nations. In August 1958, amendments to the 1946 McMahon Act were signed into American Law facilitating the Bilateral Agreement between the two governments.[30]

Early in September, a Valiant dropped a prototype UK thermos-nuclear device called FLAGPOLE off the shore of Christmas Island. It performed according to design expectations with a yield of 1·2 megatons. It was the nearest Britain ever got to a practical thermonuclear deterrent weapon. Although successful, it would have needed at least one more nuclear test with a different trigger. After testing stopped in October, this was not possible for the foreseeable future. In addition, FLAGPOLE would have also needed 'weaponising' – the lengthy process of engineering the design for service use in order to ensure that it would remain safe under all circumstances during a long stay in the stockpile and being subjected to the occasional rough handling and extremes of temperature, pressure and humidity. In other words, the British development of thermonuclear warheads was frozen in time. So how was this problem to be solved?

The initial technical exchanges under the new US/UK agreement took place in mid-September. The British had previously intended to use the more advanced American experience to short-cut the final stage of their own development and testing. During the September Exchange, it became obvious that this intention had changed into the idea that since UK design ideas were on a par with those of the US, the UK would obtain complete sets of drawings for two fully developed and weaponised American warheads with the intention of producing them in the UK. The two designs were the megaton thermonuclear Mk 28 warhead – which was built in Britain under the code-name RED SNOW – and a version of the kiloton boosted fission Mk 44 warhead intended for production in the UK as TONY.[31]

Except for RED BEARD and YELLOW SUN Mk 1 with the

GREEN GRASS interim megaton fission warhead, all British warhead designs were abandoned. The RED SNOW warhead was installed in the YELLOW SUN bomb casing to make YELLOW SUN Mk 2 and was also used in the large BLUE STEEL rocket powered stand-off bomb. It would also have been used by the BLUE STREAK ballistic missile, in development from 1953 onwards, to replace the V-bombers around 1965 to counter the deployment of Soviet surface-to-air missiles. BLUE STREAK was cancelled as a weapon in 1960 and a number of American Skybolt air-launched ballistic missiles were ordered in its place. Two were to be carried by the Mk 2 Vulcans. A British delivery vehicle for the deterrent had been partially replaced by an American weapon.

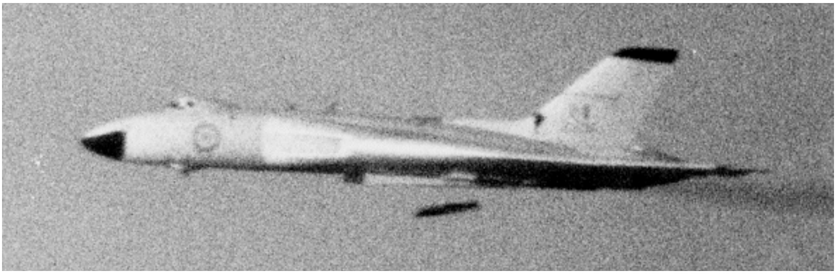
In December 1962, the Skybolt programme was cancelled by the Kennedy Administration. The diplomatic fuss was exploited and the result was a good deal on the submarine based Polaris missile. In 1969, the UK deterrent role was formally handed over by the Royal Air Force to the Royal Navy.

Continuities again

Work for UK equivalent of the US Skybolt warhead forms a major component of the Continuity argument after the 1958 warhead design information exchanges began with the United States under the Mutual Defense Agreement.

The original American trigger for the Skybolt warhead could not be built as designed for the equivalent British KLAXON Skybolt thermonuclear warhead for regulatory reasons. These centred on Ordnance Board and AWRE Safety Committee objections to several features of the American warhead design including the type of high explosive formulation used. Changing to an acceptable UK composition had several serious ramifications. Modifications to overcome the problem were proposed which included the use of a novel UK idea. An earlier version had been tested in the final UK GRAPPLE test series, GRAPPLE-Z. When revealed at the September 1958 Technical Exchange, it was new to US colleagues who asked for full details.

By 1961, the UK Chiefs of Staff were judged unlikely to accept the extent to which a successful US design of trigger had been modified without a live test and live nuclear tests were not possible because of



Trial release of a WE177B from a Vulcan.

the 1958 moratorium. The Soviet Union came to the rescue, with impeccable timing – they unilaterally broke the moratorium and re-started live nuclear testing in August 1961. The United States hastily carried out two underground tests, providing an opportunity for Britain to negotiate the use of the Nevada Test Site. The advanced UK technique for the UK version of Skybolt warhead trigger could be tested after all. This test was called PAMPAS and was successfully fired on 1 March 1 1962, the first of an eventual total of twenty-four British underground tests carried out at Nevada, the last one in 1991.

While Polaris had been acquired as a result of the sudden cancellation of Skybolt in December 1962, the system would not enter service with the Royal Navy until June 1968 and, in the meantime, the RAF's older nuclear weapons would begin to be withdrawn from the stockpile. A capability gap was perceived by planners unless development of the high yield version of the new WE177 gravity bomb, which was already on the stocks, could be hastened.

Additional, so-called, minor trials (defined as non-nuclear) were carried out at Maralinga in 1963 to finesse theory on nuclear warhead safety. Although originally concerned with RED SNOW, the UK-built version of US Mk 28 warhead, other tests were related to the UK's KLAXON Skybolt warhead trigger called KATIE. With the ending of Skybolt, KATIE became an off-the shelf trigger for two versions of the new WE177 free-fall weapon. A third version made do with KATIE only.

The high yield WE177B gravity bomb entered RAF Service in 1966 and served as an interim deterrent weapon with the Vulcan until the advent of Polaris in June 1968. The much reduced yield WE177A followed in 1969 with both the Royal Air Force and the Royal Navy.

Trial release of a retarded WE177 from a Tornado.

A third version with an intermediate yield came along in 1971.

All three versions were capable of being used in the laydown mode of delivery at high speed and low level. This required the deployment of a parachute system to slow the weapon down, reducing the shock to its systems on impact. It also needed the development of both nuclear warheads and bomb shape to be robust enough to withstand the shock of contact with a hard surface. This was a particular challenge for both AWRE and the former Royal Aircraft Establishment.

The WE177 bomb served to the 1990s, making it the longest serving UK nuclear weapon. It was taken out of service after the Cold War ended and the last one was dismantled in 1998.

The WE177's successor, the Future Theatre Nuclear Weapon (FTNW), was cancelled in 1993. It was to have been a short range ballistic missile powered by a solid propellant rocket motor. The Clinton Administration had cancelled both the American delivery vehicle and the warhead designs that would have served as the basis for a British equivalent. As the warhead was closely tailored to the delivery vehicle, it would have taken some years, starting from scratch, for the UK to develop both vehicle and warhead and would have been very expensive. Under the circumstances, a UK developed delivery vehicle was simply not a realistic option.

Conclusions

The development of each warhead for Royal Air Force nuclear weapons cannot be seen in isolation from its predecessor or successor design. This continuity typically shows expediency in fiscal, political, scientific and technical terms. As such, it represents a very pragmatic British approach to the nuclear warhead business and the foreign and defence policies which underpin it.

The UK is a successful nuclear weapon state on the basis of a mere

45 tests – a total shared only with China. This very different way of developing nuclear warheads has supported the repeated renewal of the 1958 Mutual Defence Agreement between the United States and the United Kingdom, making it a very valuable foreign policy asset for the United Kingdom.

Note

Sadly, we have to record that Kate, died on 20 June 2015.

Notes:

[1] Arnold, Lorna with Pyne, Katherine; *Britain and the H-Bomb* (Macmillan, London, 23001).

[2] Frisch was an Austrian and the nephew of Lise Meitner, a distinguished scientist in exile in Sweden at this time. Both collaborated on interpreting results from experiments carried out by Meitner's former colleagues Otto Hahn and Fritz Strassman in 1938 to confirm the discovery of nuclear fission. The original Frisch-Peierls Memorandum may be accessed at Kew as AB1/210.

[3] The complete text of the Einstein letter of 2 August 1939 can be seen at http://upload.wikimedia.org/wikipedia/commons/b/bf/Einstein-Roosevelt-letter.png.

[4] Implying a smaller range of possible targets.

[5] Presumably 'defence'.

[6] The meaning of MAUD is unclear. Some sources state that it was an acronym for 'Military Application of Uranium Detonation', although this is not spelled out in the Committee's Reports. Another, rather convoluted, explanation is that it was a random term derived from a reference to an individual (Maud Ray, an English governess) in a contemporary personal telegram from Lise Meitner (an Austrian-born Jewess working in the field of nuclear fission who had taken refuge in Sweden in 1938) to the Chairman of the Committee, Sir George Thompson, conveying a message relating to Niels Bohr, who was still in Denmark at the time. **Ed**

[7] TNA AB1/328. The type of nuclear warhead envisaged by the MAUD Report (Part I, p1) emerged in August 1945 as the weapon that destroyed Hiroshima.

[8] Zimmerman, David, *A Most Secret Exchange* (Alan Sutton Publishing; Stroud; 1996) p188.

[9] Understandably, the United States wanted to keep the unfolding secrets of such a powerful weapon for itself, despite the initial impetus being provided by Britain. Similarly, Britain itself had delayed replying to an initial offer of co-operation from the United States, toying with the idea of going it alone for similar reasons. Enormous sums of money were being authorised for the American Bomb Project, known from August 1942 as the Manhattan Project, reinforcing the idea that the country that put up the money should get the benefit. Britain simply did not have resources on that scale in addition to its other wartime commitments.

[10] TNA AB1/376. Meeting on Diffusion Project held at Kellex Offices, New York, Wednesday, 15 September 1943.

[11] *Ibid*. Rudolf Peierls, note 'Possible Arrangements for Collaboration on Theoretical Problems' dated 6 October 1943.
[12] Szasz, Ferenc Morton; *British Scientists and the Manhattan Project* (Macmillan; London; 1992) Appx III, p148.
[13] TNA CAB130/2. Minutes, GEN 75, 18 December 1945.
[14] Named after the Senator who guided the legislation through Congress, Brien McMahon.
[15] TNA CAB30/1. GEN 163 Committee, 1st meeting, Confidential Annex, minute 1, 'Research in Atomic Weapons', 8 January 1947.
[16] The writer is greatly indebted to Professor, (now Lord) Peter Hennessy, for use of this anecdote from his book, *Cabinet* (Basil Blackwell; Oxford; 1988) p127.
[17] Gowing, Margaret; *Independence and Deterrence, Vol 2* (HMSO, 1974) p443.
[18] A common practice on all nuclear tests.
[19] Hoddeson, Lillian *et al*; *Critical Assembly – A Technical History of Los Alamos during the Oppenheimer Years, 1943-1945* (New York, 1993) p333.
[20] TNA AB1/201. The Frisch-Peierls Memorandum.
[21] Most of the scientists involved thought that a test would not be necessary; there was high degree of confidence that it would work.
[22] Apart from security aspects, assigning a code-word provided a sense of progress with even the most rudimentary ideas.
[23] The remoteness of Foulness was a common requirement for atomic sites in the early years because, even if an accidental detonation did not result in a (reduced) nuclear yield, approximately two tons of high explosive in the implosion system could still do a lot of damage.
[24] See, for example, Lorna Arnold's *Britain and the H-bomb* (Palgrave, Basingstoke, 2001) p72.
[25] Considerable numbers of inert BLUE DANUBE weapon trial drops were carried out using Lincoln bombers at various altitudes and speeds so the aircrew experience for what would could have only been operationally marginal missions already existed. See Humphrey Wynn's *The RAF Strategic Nuclear Deterrent Forces* (HMSO, 1994), p88.
[26] The third BUFFALO test, code-named KITE, was a live test of a near operational standard BLUE DANUBE, complete with In Flight Loading (IFL) of the plutonium core.
[27] On the third attempt. See TNA CAB 195/12/4. Conclusions of Cabinet Committee Meeting CC(54)53 of 26 July 1954.
[28] References appearing in the documentation to RED BEARD as a trigger for thermonuclear bombs only applied to Penney's Type B cylindrical hydrogen bomb.
[29] Seemingly endless files in the National Archives reflect the issues from the Service perspective.
[30] See Cmnd Paper 9336 for the general terms of the 1958 Mutual Defense Agreement.
[31] On the verge of entering production, it was cancelled in August 1962.

BLUE STEEL – THE V-FORCE'S STAND-OFF BOMB

Air Cdre Norman Bonnor

Norman Bonnor graduated from Cranwell as a navigator in 1960. Initial tours on Victors with Nos 15 and 100 Sqns were followed by the Spec N course in 1967, prior to an exchange posting in Canada. Subsequent appointments were concerned with R&D and project management. Command of RAF Waddington led to his last appointment as Deputy Commander of the NATO AEW Force. After leaving the RAF he joined The University of Nottingham in 1994 as a lecturer and postgraduate course director until his final retirement in 2012.

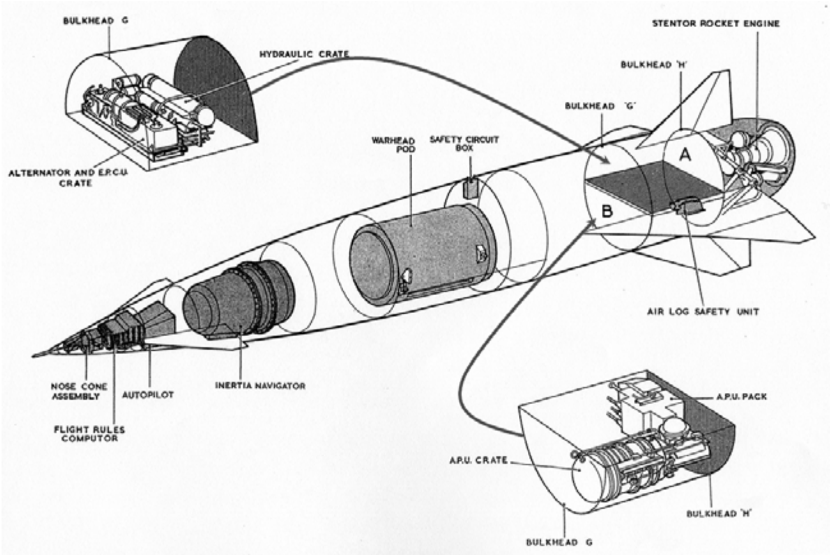
The prototypes of the Valiant, Vulcan and Victor first flew in 1951 and '52; however, before production versions entered service, the primary threat to these new aircraft was recognised as being the development of Soviet Surface-to-Air Missiles (SAM) for point defence of major city targets with a kill capability out to an expected range of at least 20 nm. Delivering BLUE DANUBE (and later YELLOW SUN) ballistic, nuclear weapons meant closing to within 7 nm of the target and thus made high flying bombers vulnerable, despite the use of jamming against the SAM radars and the tactic of weaving on an attack from a range of 40 nm in an attempt to disrupt the prediction system used by the beam-riding missiles.

After the demise of BLUE BOAR (an H2S/TV guided glide bomb) in 1953, early design studies for a powered stand-off weapon were started by the Bomb Group of the Air Experimental Section at the Royal Aircraft Establishment (RAE), Farnborough. A four-man scientific mission was sent to investigate progress on large guided weapons in the USA. The findings of their report were considered by the Air Warfare Committee of the Aeronautical Research Council and had a major influence on the drafting of OR1132, which was first issued in 1954. However, Sir Arnold Hall – the Director of the RAE at the time – felt such a project would take up too much of Farnborough's limited resources and that further design work should be undertaken by industry. The then Conservative Government decided that a new missile should be developed with high priority so, while alternative bids were considered, there was no competitive tendering. The Avro Weapons Research Division (AWRD) was formed at Woodford in September 1954 to design and develop the missile under a substantial Ministry of Supply (MoS) 'start-up' contract. AWRD's Chief Engineer, R H Francis, was recruited from the RAE where he had been in charge of the establishment's involvement in BLUE DANUBE and had been a member of the scientific mission to the USA.

OR1132 required that the missile be capable of carriage and launch from all V-aircraft types and be integrated with the aircrafts' navigation systems. The range requirement was to be between 100 and 150 nm when launched from 50,000 ft and its accuracy 500 yards at 150 nm using autonomous inertial navigation guidance. It was to have a low radar cross-section to reduce the risk of detection, and low drag to attain speeds of at least Mach 2·5. In this first issue of OR1132, the warhead was to be the GREEN GRASS boosted-fission package similar to that used in YELLOW SUN Mk 1. Finally, the missile was required to be capable of further development.

Development started with an extensive wind tunnel programme using a variety of scale models to measure lift, drag, and control and stability characteristics at subsonic, transonic and supersonic speeds. Un-powered 1/8th scale models were launched at the Aberporth range to test aerodynamics. Initially these were ground launched using a Mayfly rocket booster and, later, much larger models were dropped from a Valiant. In August 1955, AWRD submitted a brochure to the Air Ministry and the Ministry of Supply entitled 'WRB 1 – A weapon to OR1132'. The document proposed a baseline model of a missile to be in service by 1960 – version 48/35 (ie 48 inches in diameter and 35 feet long) propelled by a rocket motor – and a programme for further development to counter future improvements in Soviet air defences. This basic version, later designated as W100, had a wing span of 13 feet, limited by the geometry of the carrying aircraft, and was expected to weigh around 16,000 lb.

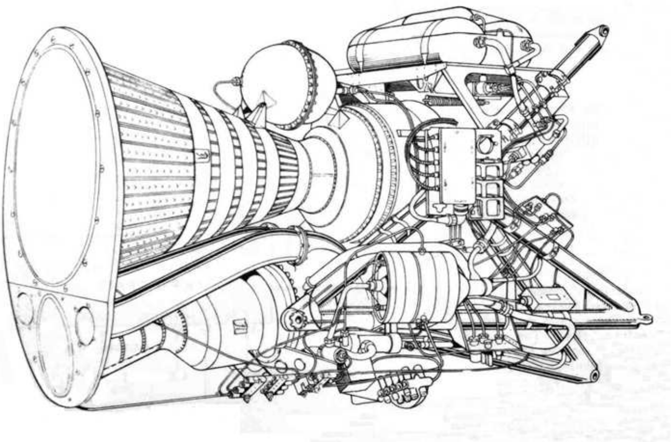
Early design decisions included the use of: a stainless steel outer skin, because of kinetic heating at supersonic speeds; a double skin to reduce temperature transfer to internal component systems; a canard configuration for a more favourable movement of the centre of pressure across the speed range; a larger bottom fin, as this would



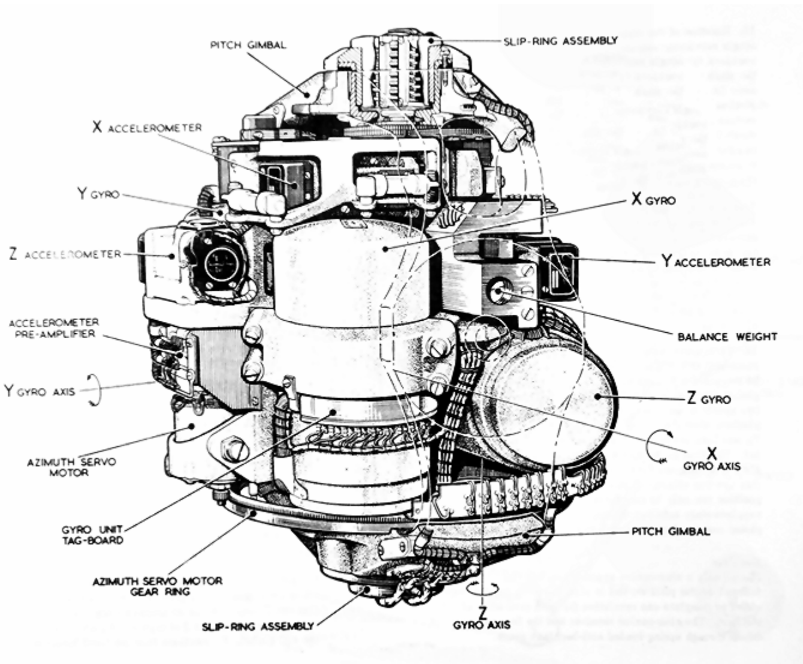
The distribution of the main components of the Air-to-Surface Guided Weapon (ASGW), 16,000 lb, HC No 1 aka *BLUE STEEL.*

have more effect during a high incidence climb; constant attitude cruise for best stability; and the use of pitot pressure and flight time to select the control parameters in the Flight Rules Computer throughout the missile's trajectory. Another advantage of the canard layout was that the wing structure was towards the rear of the fuselage and thus not at the maximum body diameter.

The main MoS contract with AWRD was signed on 4 May 1956. Development of several vital components was assigned to sub-contractors including: Armstrong Siddeley, Elliott Bros, EMI and Hunting Engineering. An early development concern was related to fabrication of the missile skin using stainless steel; the metal was difficult to drill as the heat produced made the steel harder. Other concerns were the volatility and corrosive nature of the High Test Peroxide (HTP) to be used by the rocket motor, and the widely varying environmental conditions the missile would experience. The missile, its fuel and electronic components would need to cope with the normal range of climatic conditions when inert on the ground, the very low temperatures during prolonged aircraft carriage at altitude and the high temperatures generated after launch in supersonic flight;



Above the Stentor rocket motor and, below, the 'stable table' at the heart of the INS – essentially three pairs of gyros and accelerometers fixed at 90º to each other to establish the platform's X, Y and Z axes.



the temperature range could be -60°C during high altitude carriage to +300°C in flight at Mach 3.

As development continued in the late 1950s, other problems needed to be solved relating to the transfer of supplies from the aircraft to the missile systems at release, the stability and transient manoeuvres at release and engine start, and the possibility of vibrations and resonance during flight at high Mach Numbers. A wide variety of components ranging from accelerometers to hydraulic valves were under development. A major decision was the choice of the Armstrong Siddeley, RB 9/2, Stentor rocket motor with an expected thrust of 26,000 lb. By this stage, the overall system and aerodynamic design was substantially frozen, so the next step was the release of full scale, light alloy, unpowered models to check separation characteristics.

While there was strong political pressure for BLUE STEEL to succeed, there were many teething problems which caused delays in development, but this was hardly surprising as rapid changes were taking place in technology in the 1950s. The three gyros in the Inertial Navigation System were unreliable and had to be replaced by Kearfott gyros, the only American component used in the production missiles. Fifteen 2/5th scale, powered models and fifty full-sized missiles were built for development and proving trials at Woomera in Australia, and three modified Valiants were assigned for use by the contractors' team which formed at Woodford in July 1957. A major change was made in January 1959, when the original GREEN GRASS warhead was replaced by the RED SNOW physics package similar to that used in YELLOW SUN Mk 2. Apart from issues associated with the safe carriage and reliable fusing of the warhead, there was concern over the possibility that the warhead would fail to detonate on impact if the airburst barometric fusing failed. A complex test rig was constructed at A&AEE Boscombe Down primarily to check fuel flows to the rocket motor in manoeuvring flight but also to check warhead detonation if dropped as a ballistic shape.

In October 1959, Harold Watkinson succeeded Duncan Sandys as Secretary of State for Defence and immediately recognised the need to rationalise future plans for the UK's deterrent forces. Political opinion had turned against the BLUE STREAK MRBM because of its escalating cost and its limitations as a 'first strike', rather than

A BLUE STEEL round being launched over Woomera from Victor XL161 of No 4 JSTU.

'retaliatory', weapon. Despite reassurances from AWRD, Watkinson became convinced that design and development work on BLUE STEEL Mk 2 was a primary reason for the delays in development of the Mk 1 version. In April 1960, both the Mk 2 version of BLUE STEEL and the MRBM BLUE STREAK were cancelled in favour of BLUE STEEL Mk 1 and Skybolt.

The first powered launch at Woomera of a full-sized missile occurred on 22 February 1961; fourteen further launches were attempted in 1961, but the majority failed. Many of the failures were caused by the Missile Power Supply System. No 4 Joint Services Trials Unit (JSTU), which had also formed at Avro Woodford in 1957, moved to join the contractors' team at RAAF Edinburgh Field in December 1959; however, they had little to do until Vulcan XH539 arrived on 23 June 1961 later joined by Victor XL161. Their first attempt at a missile launch failed on 23 March 1962. One trial, involving XL161 on 17 August, nearly ended in disaster when the aircraft stalled and entered a spin from which recovery was finally made by deploying the brake-chute; investigation showed the problem

BLUE STEEL entered service, albeit with a strictly limited capability, with No 617 Sqn in October 1962.

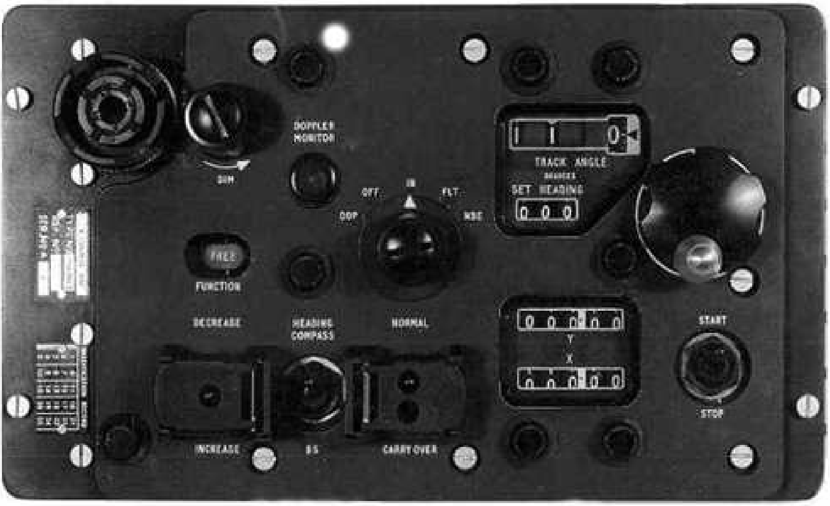
had been caused by different airspeed indications in the cockpit, and the pilots had believed the wrong one.

A total of fifteen launches were attempted in 1962, of which only about half were successful; despite this, BLUE STEEL entered service with 617 Squadron at Scampton in October 1962. However, the deployment was regarded as 'for emergency use only' because the Ordnance Board had yet to agree to the use of HTP-loaded missiles with a warhead in place. A further eleven high level trials launches were made at Woomera in 1963, most of which were successful and the restrictions on operational use were removed. By the end of 1963, two more Vulcan units, Nos 27 and 83 Sqns, had formed at Scampton together with Nos 139 and 100 Sqns at Wittering flying Victors. In total, forty Vulcan and Victor Mk 2 aircraft were modified to carry and use the fifty-three operational BLUE STEEL missiles, plus sixteen training rounds, that were delivered to the RAF.

The V-Force changed tactics to low level penetration of Soviet defences starting with the Mk 1 aircraft in 1963 and followed by the Mk 2s in 1965; to meet this change, a new contract was signed with Avro to produce the W200 version of the missile with a low level launch capability. The main change required was to the missile's Flight Rules Computer; fortunately, the original design was flexible enough to allow this change by modification of the W100 version. The first low level trial launch was made at Woomera on 26 November 1963, fifteen more low level launches followed before the JSTU closed down at the end of 1964.

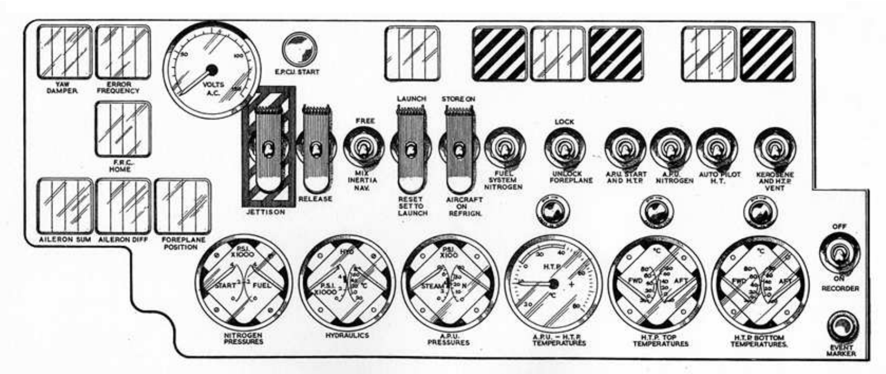
The aircraft conversion for BLUE STEEL included introduction of the Ground Position Indicator (GPI) Mk 6, probably the most accurate analogue aircraft computer ever built. It was the key component for integration of the aircraft system with the Inertial Navigation System (INS) of the missile. The aircraft could make use of the outputs of the INS until the missile was launched. At last, we had an accurate source of true heading once the INS was aligned, but here was the rub – the deterrent role of the V-Force involved rapid reaction using the 4-minute warning from the Ballistic Missile Early Warning System at Fylingdales on the North York Moors, hence no time for a conventional 15 to 20 minute INS ground alignment. Airborne alignments had to be used; this was long before the very accurate Global Positioning System (GPS) and the rapid in-motion alignments of Ring Laser Gyro INS now taken for granted by today's aircrew.

As well as the GPI Mk 6, some of the other equipment fitted in the cockpit for the carriage and operation of the missile were: the Blue Steel Control Panel (BSCP), the Inertial Navigator Control Unit (INCU) and the Inertial Navigator Monitoring Unit (INMU) which was not a normal piece of military avionics. It looked more like a fancy multi-meter about 10" × 8" inset in the Nav Plotter's chart-table (central in the rear cockpit) with a Perspex cover so that it could be read without disturbing the chart and plotting instruments in use. This meter had a variety of scales with different readouts selected by a multi-function switch. While the INCU and INMU were purely associated with the control and functioning of the missile’s INS, the BSCP controlled and provided indications of most other functional aspects of the missile’s operation, including: the refrigeration system; fuel tank pressurisation; starting the auxiliary power unit (APU); and launching or jettisoning the missile. It also included many indicators relating to the position of the ailerons, foreplane and lower fin, nitrogen and hydraulic pressures and, one of its primary uses, monitoring of the temperatures in the HTP tanks of the missile. This was crucial to safety as any contamination of HTP (a super-oxidant) would make it boil and become a major hazard, particularly with a nuclear warhead nearby! As a result, the Quick Reaction Alert (QRA) aircraft had to be visited by the alert crews at regular intervals throughout the day and night to confirm that all was well, particularly when an aircraft/missile combination first came on state. The crew chief and other ground crew were not permitted to enter the cockpit of the QRA aircraft once the live weapon was loaded, scramble checks



Above, the INCU, below, the INMU two, of the four units, which permitted the Nav Plotter to interface with the Missile.

Above, the GPI Mk 6, which, along with the INMU and INCU, was common to both Victor and Vulcan, but the Blue Steel Control Panels were bespoke – this one (below) is Panel CAG as fitted in the Victor; the equivalent Panel 94 in the Vulcan was significantly different.



were complete, targeting materials in place and the aircraft declared ready to Bomber Command.

If I remember correctly, each operational missile on the station had to be flown once every six months to meet Bomber/Strike Command goals. When we flew with these so-called 'wet' missiles (without warheads of course) rather than training rounds, HTP temperatures were one of the items checked and logged every 30 minutes throughout the sortie. Should the HTP temperatures start to rise while airborne, the crew would divert immediately to the nearest 'Blue Steel Diversion' airfield to offload the HTP into large tanks of water buried in the ground close to the ORP. There were several of these specially equipped airfields around the country apart from the main bases at Scampton and Wittering. The co-pilot and Nav Radar formed the offload crew who donned plastic suits after landing and connected hoses to the missile (this offload kit was kept in the visual bomb-aiming position); the offload procedure was very awkward with hard rubber gloves on and a face mask that kept steaming up! We had to practise this procedure regularly as a part of our six-monthly training requirements.

Although BLUE STEEL could be regarded as a 'fire and forget' weapon with autonomous guidance, a lot of work had to be completed by the 'Nav Team' before launch. After a scramble take-off, which the first aircraft, using a simultaneous 'combustor' start of all four engines, could achieve within 50 seconds (I don't know of any fighter aircraft that can achieve such a time today), the alignment of the INS was completed by the Nav Team using the GPI Mk 6, the NBS and the INCU and INMU in what can only be called a 'mandraulic' manner; ie each step was separately initiated, carefully monitored and required a large number of switch selections. During the alignment process, the INMU meter was used to monitor various parameters including: gyro temperatures and rotation speeds, torqueing motor currents on the gimbal rings, etc. A so-called 'LEDEX' pole switch and indicator on the INCU was used to activate INS alignment using a numbering system so, for example, LEDEX 1 turned on the gyro heaters, LEDEX 2 locked the gimbals to the missile frame (hopefully reasonably level), LEDEX 3 spun the gyros up to speed, and so on. In other words, the Nav Plotter manually selected each step of the alignment process (checking the indications as he did so); this process was totally automated for ground alignments of later INS used in aircraft such as the Phantom, Jaguar, Harrier, Tornado and now the Typhoon.

The final LEDEX position put the INS into a mode where GREEN SATIN Doppler velocities (N/S & E/W) were compared with the IN velocity outputs, and the differences used to torque the INS stable

Transporting the missile required a purpose-built vehicle – the AEC Mandator. On reaching the dispersal, as here, the missile was moved onto a transfer trolley, a notably uncooperative piece of kit which, along with its eight-ton load, had to be positioned precisely beneath the aircraft using its four hydraulic jacks and independently steerable wheels – with the hydraulic power being provided manually. It was hard work, and difficult enough with a Vulcan, even more so under a very low-slung Victor. 'Now thrive the armourers'.

platform and its levelling gyros. The assumption was that the Doppler velocities were correct, and that if the IN velocities were the same then the platform must be at right-angles to the local earth gravity vector. The INS was initially aligned in azimuth using the aircraft's gyro-magnetic compass reading corrected for variation, and then continually corrected throughout the sortie using a Fix Monitored Azimuth (FMA) technique.

FMA involved the Nav Radar using the H2S radar [either with the Plan Position Indicator (PPI) or the Rapid Processing Unit (RPU)] to fix the GPI Mk 6 as accurately as possible and then letting it run using IN heading for 150-200 nm (about 20 minutes' flight) in a reasonably straight line, when he fixed again. The assumption was that any across track error found was caused by IN azimuth gyro error, and this was torqued out automatically by accepting the fix on the GPI Mk 6 with other settings that represented the track and distance between the fixes. The GPI Mk 6 was removed from the Victor Mk 2 and replaced with the old GPI Mk 4 when the aircraft were converted to the tanker role in 1968. Later, they were equipped with a Litton 211 Omega Navigation System and, during the Falklands war, with an AC Delco Carousel INS.

The FMA process, and clamping the IN velocities to GREEN SATIN values, continued throughout the sortie or until missile launch. In the final preparations for launch, the last position fix was taken on a Release Point Fix (RPF). The RPF was the basis for defining the target position. Distances (N/S and E/W in minutes and decimal minutes of latitude and longitude) between the RPF and the target (or more correctly the position of the airburst height above the target) were set on the GPI Mk 6 and transmitted to the missile during the pre-launch checks so that the missile guidance and autopilot would know the target position very accurately. As the launch point was approached, the Nav Radar used the RPF to make the last corrections and, once these were accepted, the Nav Plotter selected the missile INS to ‘FREE’. At this stage, it was running as a space-stabilised system based on the RPF with no further GREEN SATIN or FMA updates. Of course, interspersed with the above, there were other final actions to perform to launch the missile including: unfolding the bottom fin at the rear of the missile, arming the warhead, withdrawing the motorized locking pin on the missile release unit, pressurizing the kerosene and High Test Peroxide (HTP) tanks, starting the missile APU, etc.

The Nav Plotter activated the final launch switch, and the missile would hopefully fall away under gravity. To prevent the rocket motor firing too close to the launch aircraft, a 100-foot lanyard remained attached to the missile and, when this separation distance was reached, a pin was extracted that enabled the kerosene fuel and HTP to flow onto a silver catalyst screen in the Stentor rocket motor. Ignition was almost instantaneous and a thrust of 24,000 lb was now pushing a missile weighing 16,000 lb. You have to remember that BLUE STEEL was a pretty ‘slick’ aerodynamic shape and, at launch, the canard foreplane was set at 15º nose-up, the maximum angle. So, as it fell away, it stayed pretty well under the aircraft and rapidly pointed its nose up until the motor fired when a 1·5:1 thrust-to-weight ratio rapidly accelerated it to Mach 2·5 in a steep climb, hopefully without colliding with the launching aircraft!

During training attacks at the UK's five Radar Bomb Scoring Units (RBSU), guidance accuracy and crew performance was assessed by simulating missile launch and allowing the INS to run free while the aircraft performed a manoeuvre designed to emulate the same effects on missile's guidance as the high Mach No flight profile would impose after a real launch. By 1965, the Victor Mk 2 had been fitted with a side-scan radar capability and the RPU. When this was in use, the H2S scanner was locked at 90 degrees to aircraft track (port or starboard) and radar video diverted from the normal PPI display to a low afterglow CRT in the RPU across which photographic paper was drawn at a speed proportional to the groundspeed of the aircraft. The exposed image was developed by passing the paper over two slots through which developing and fixing chemicals were sucked. Although it sounds hazardous to employ hot and corrosive chemicals in a pressurised aircraft cabin, the system was successful in that the radar image produced was much sharper and with a much wider spectral range than the normal high afterglow PPI; of course, it also produced a permanent image which allowed the Nav Radar time to study the returns more carefully before making any updates. The RPU was only fitted to the Victor Mk 2; I believe this small scale introduction was really aimed at developing the technique for the ill-fated TSR2 in which an RPU-based side-scan radar was to be the primary fixing aid.

My first involvement with the missile was soon after completing the Operational Conversion Course on the Victor Mk 2 Training Flight in July 1964 when our crew attended No 27 Blue Steel Course at the Bomber Command Bombing School, Lindholme. We were soon flying eight or more sorties a month with either a 'training' or a 'wet' missile and began working our way through the six-monthly crew classification programme, we achieved 'Select' status in July 1965. At this date, some cracks that could cause structural weakness started to appear in the Victor fatigue specimen; this gave serious cause for concern, particularly after the metal fatigue problems experienced a few years earlier by the Valiant. Although the specimen was many cycles and hours ahead of even the highest flown aircraft, caution was undoubtedly the sensible option.

Our training targets were dramatically changed from one based

A BLUE-STEEL-armed Victor of the Wittering Wing.

primarily on hours and sorties to new definitions based strictly on training value. We were allowed no more than four sorties a month, and each one had to be packed with high value training. The senior staff at Wittering thought this would lead to a drop in morale among the crews, but far from it. We no longer flew without a missile, or had to carry unserviceabilities; we also had priority on range bookings over our colleagues in No 1 Group flying the Vulcan; each sortie became a challenge to get best training value. A typical flight profile would include climbing out to the North Sea, starting an 800 mile high level navigation stage, possibly including fighter affiliation with Lightnings from Coningsby or Leuchars, descending to join a low level route over Scotland ending in a simulated BLUE STEEL attack at a Radar Bomb Scoring Unit over Newcastle or East Anglia which included a test of the AEO's reaction time to jam the RBSU as it attempted to lock-on to the aircraft at the start of the attack. If fuel permitted, a second attack would be made over Glasgow or Manchester before recovering for no more than a couple of ILS or GCA practice approaches at Wittering.

One of the limiting factors for making best use of a training sortie was the time it took in the air to start-up and align the missile INS.

The Standard Operating Procedure (SOP) was to take-off, climb out and not attempt to start up the missile until straight and level at 45,000 ft. One day, we were looking at an aircraft on a dispersal with a missile loaded, when our co-pilot, said ‘We align that missile when we are in level flight, but the missile isn’t!’ What he meant was that to fit BLUE STEEL on the Victor, unlike the Vulcan, it was hung in a 10º nose down attitude. ‘Why don’t we align it in the climb when it’s closer to level?’ The Nav Team, being typically dismissive of what co-pilots say, replied as one, “Cos the SOP says you do it at height!”

But he had started us thinking; we could save up to 20 minutes by starting the alignment immediately after take-off. So we got out our course notes again and then went to see the missile technicians. We soon realised that the SOP had been written during the trials programme in Australia and nobody had considered revising it since the system had entered operational service. In the INS Bay, we persuaded the technicians to let us experiment with an INS on a test bench and found that we could easily complete the initial stages of the start-up and alignment process in less than five minutes. Just to be sure, we contacted Dr Roberts at the RAE who had been deeply involved in the design of the navigation and guidance system. When we explained our thoughts about aligning the INS in about five minutes during the climb, he said he couldn’t see any reason why not. Of course, we kept all this ‘under our hats’, but it soon became rather obvious that we were completing many more practice attacks than any other crew on the station. First it was the Wing Weapons staff who questioned us, but we easily sold them a story, but then ‘the Boss’, Wg Cdr John Herrington, wanted to know what we were up to, so we came clean. He said we could keep going, but we had to let the other 100 Squadron crews in on the plot; however, ‘Don’t tell 139 Squadron!’ That didn’t work for long; No 139 Sqn were soon completing twice as many practice attacks as us, so the Station Commander, Gp Capt Lawrence, had to know. He said it was OK, ‘But don’t tell anyone on those flatirons at Scampton!’

After three years of BLUE STEEL operations, the AOCinC Bomber Command was concerned to prove the capability of the missile in front-line squadron use. Operation FRESNO was initiated to launch four missiles at the RAE’s Aberporth Range where the missiles could be tracked in flight by kine-theodolites and AN/FPS-16 radars.

The first was made by my crew on 27 May 1966 and achieved an accuracy of 410 yards over a range of 25 miles; the second, again from a Victor on 26 August 1966 achieved 580 yards over 50 miles. Vulcans from Scampton launched the final two on 31 May and 7 July 1967; the first achieved 1,055 yards at a range of 43 miles but was launched at an angle off of 65 degrees; the second achieved 515 yards over 30 miles.

As stated earlier, the Mk 2 version of BLUE STEEL – designed for much longer range using ramjet propulsion – had been abandoned in 1960 in favour of the US Skybolt missile; however, the US Government cancelled the Skybolt project in December 1962 leading to crisis meetings between the UK and US Government which culminated in the Nassau Agreement to provide submarine-launched Polaris missiles as the future UK nuclear deterrent. The first patrol of a Resolution Class submarine equipped with Polaris occurred in June 1968. The Victors at Wittering were withdrawn for conversion to tankers at the end of 1968. The last BLUE STEEL sortie was flown by a 617 Squadron Vulcan on 21 December 1969.

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BLOODHOUND

Richard Vernon

Richard Vernon served in the RAF 1983-2014 as an air defence system electronic technician. Much of his career was associated with aspects of the Air Surveillance and Control System (ACAS), including an initial four-year stint on Bloodhound at West Raynham, working with Soviet equipment at the Spadeadam EW Range and an Op TELIC deployment in Saudi Arabia. Since 2001 he has been an active member of the Bloodhound Missile Preservation Group which restores associated equipment, including the Bloodhound Mk 2 Launch Control Post Argus 700 Computer and display systems at RAF Cosford.

Introduction

The main focus of this presentation will be to describe the Bloodhound surface-to-air missile system from a technical and operational stand point. I will highlight the significant differences between, and briefly cover the deployment of, the two versions that entered service with the RAF. Unfortunately time constants will not allow me to cover in any detail the many twists and turns that took place during the development and deployment planning for either system.

Bloodhound Mk 1 Development and Deployment Planning

The development of Bloodhound started early in 1949 when the Bristol Aeroplane Company and Ferranti were offered a contract from the Ministry of Supply (MoS) to design a surface-to-air guided weapon (SAGW) to meet a naval requirement that would eventually materialise as Sea Slug.[1] The Ministry had hoped that the resulting missile could also be upgraded to meet a longer range requirement for an Army SAGW codenamed RED HEATHEN. Under the MoS codename of RED DUSTER, full scale development of a ramjet-powered missile using pulsed semi-active radar homing (SARH) started in 1951 to meet the Army requirement. The weapon's configuration was finalised in late 1952, detailed design of the wings and the ramjet engines having been heavily influenced by information provided by the USA.[2] Full prototype development was delayed until late 1955 due to lack of suitable boost motors, after which a prototype missile called eXpermental Red Duster (XRD) was flown and found to be incapable of meeting the altitude requirements. This resulted in the design of a lighter weight XRD2 airframe which became the basis of the production missile. Both prototype designs were used in the service acceptance firing trials at Woomera which were completed in April 1960.[3]

The RAF's involvement with RED DUSTER, and other Army-originated air defence guided weapon projects, started with the transfer of sponsorship to the Air Ministry in September 1953.[4] The Air Staff had serious reservations about the operational effectiveness of the programmes it had inherited due to their lack of resistance to ECM, non-existent low level capability and short impact range. The Air Staff's initial recommendation was for these weapons to be used only in limited numbers for service trials.[5] Subsequently, the Air Staff selected the RED DUSTER to be a Stage 1 SAGW due to the development potential of its ramjet propulsion for a longer range weapon[6] and by mid-1955, the plan was to establish a full scale trials station to provide service experience as a lead-in to a more advanced Stage 2 missile.[7] However by July 1956, the programme had expanded to become the trials station plus six operational sites located near the coast to create a defensive barrier from the Humber to the Thames. The intention was that these additional sites would later be used for an interim 'Stage 1¾' system.[8]

The majority of the radar equipment required for these deployments was on order by late 1956, along with 800 missiles. But the original barrier plan was dropped in June 1957 in line with a new policy laid down in that year's Defence White Paper. Bloodhound, as it was now named,[9] was now to provide point defence for the deterrent bases using all of the equipment already on order.[10]

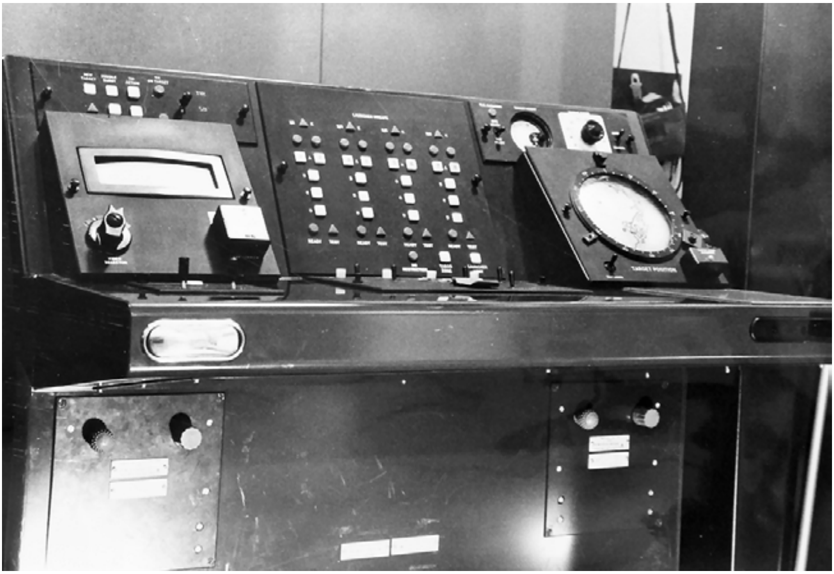
Bloodhound Mk 1 weapon system described

When Bloodhound Mk 1 became operational between 1960 and 1961, the system was integrated into the existing UK air defence control and reporting system. The missile squadrons were grouped into wings based on geographic location. Each wing headquarters was equipped with a 140 nm range Type 82 3D Tactical Control Radar

A Valiant of No 214 Sqn being towed past the No 242 Sqn's site at Marham shows the layout of a typical Bloodhound Mk 1 Fire Unit. The building above the tractor is the LCP of Fire Unit 8 with its 'A' section to the left and 'B' section to the right. The building to the right of the LCP is Fire Unit 8's Work Services Building with the 'B' Section Type 83 Radar above the rear fuselage of the Valiant. The missiles and launchers of Fire Unit 9's 'A' Section are to the right of the photograph.

(TCR) and a Tactical Control Centre (TCC) with an Operations Room equipped with an advanced analogue Data Handling System (DHS). Targets were allocated to each wing via an inter-station marker on a radar picture from the comprehensive GCI Station via a microwave video link. Once the target had been entered as a track into the DHS it was semi-automatically updated using the positional and height data from the TCR.[11] When a target entered the radar acquisition range of a missile squadron, its positional data and fire control orders were passed to one of the sections on the squadron via a digital data link over GPO landlines.

The basic fighting unit of the Bloodhound Mk 1 system was the Fire Unit and each operational squadron had two of them. The heart of the fire unit was the Launch Control Post (LCP) under the command of a Launch Control Officer. The LCP was a building that was



The missile operator's console within a Bloodhound Mark 1 Launch Control Post permitted him to control eight missiles and a TIR.

physically and electronically separated into two sections, each of which controlled one Target Illumination Radar (TIR) and eight launchers and included the equipment required to prepare, aim and fire the missiles. Each section was controlled from a console manned by an Aerospace Systems Operator.

On alert from the TCC, the operators ran up the missiles, while the transfer of target data from the TCC automatically aligned the TIR scanner and launchers of the selected section on the required bearing and positioned the TIR scanner in elevation. The launcher supported the missile at a 45° angle and could be steered 200° either side of a central datum. It supplied the missile with hydraulic oil and cooling air which was provided to the launcher from a pallet-mounted Launcher Plant Assembly (LPA) located next to the launcher pad. Adjacent to the LCP was the Works Services Building (WSB), which contained an air compressor supplying air to the LPAs. The WSB also contained the fire unit's stand-by electrical generators.

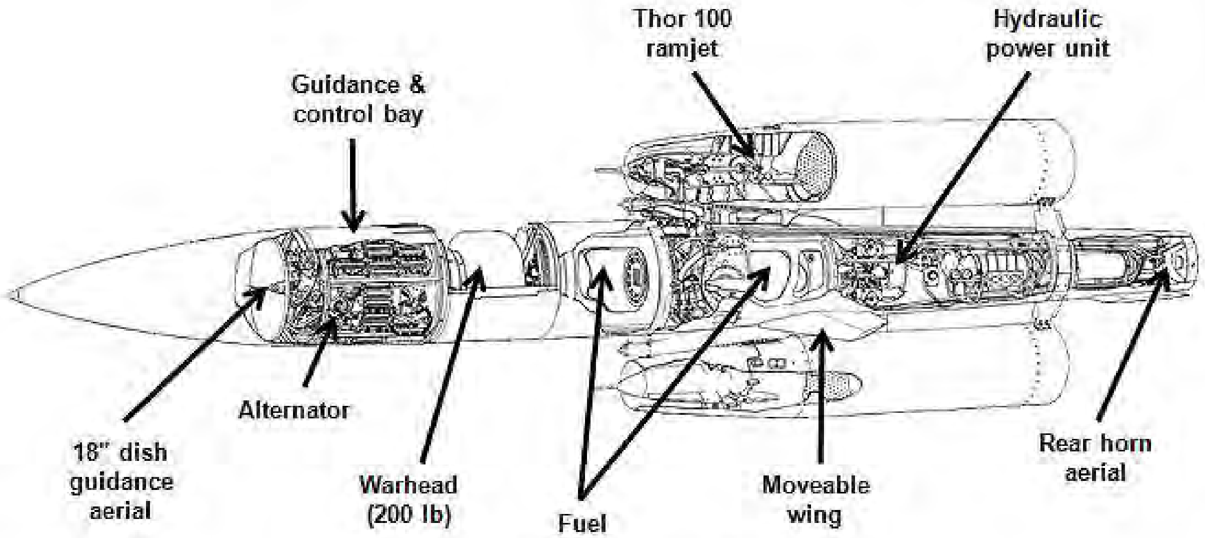
The Type 83 Target Illumining Radar consisted of an antenna trailer and display cabin. It was a two-channel pulsed radar fitted with an S Band acquisition and an X Band tracking and illumination transmitter/receiver combination using a common parabolic reflector and horn assembly. The antenna was steerable in elevation and azimuth. There were two other aerials mounted above the main beam reflector on the Type 83. The first provided a signal used to tune the missiles' guidance receivers to the TIR's X Band frequency and lock them to its pulse repetition frequency (PRF). The second aerial provided a broadcast reference signal for missiles in flight.

Once the TIR was tracking the target, precise target data was fed into the LCP which steered the launchers and missile dish on to the target and set a range gate in the missile's guidance system to pick up the target echo. As soon as a missile had locked onto the target echo, its guidance and dish control systems were released to track the target. The missile could be fired as soon as the target signal strength was strong enough for the guidance system to hold lock during boost and the target was within the missile's fuel range. A salvo of up to four missiles could be fired with a two-second delay between each launch.[12] For the engagement of jamming targets, the range gate system was disabled and the missiles could then home on the jamming signal.

The Missile

The missile was a twin-ramjet powered monoplane with moving wing control and fixed tail surfaces. The airframe consisted of a magnesium alloy inner structure with a light alloy skin and a glass fibre radome. Four Gosling rocket boost motors propelled the missile to Mach 1·8 in 2·8 seconds.[13] By that time its two Thor 100-Series ramjets were producing their full thrust and the boost motors separated from the missile.[14] The missile continued to accelerate until it reached Mach 2·2 when a Mach Number Control unit maintained that velocity. The ramjets used standard Avtur held in two separate bag fuel tanks which were pressurised with air from auxiliary air intakes. These intakes also supplied ram air that powered the turbines of a fuel turbo-pump and a second turbo-pump that provided pressure for the missile's hydraulic systems. The hydraulic system powered the missile's wing actuators, the actuators for the radar dish and a motor alternator which provided the missile's electrical power.

The missile's electronics used thermionic valve technology,



Bloodhound Mk 1 – salient features

	Missile only	Missile plus boost motor
Length	22.2 ft	25.01 ft
Span	9.29 ft	N/A
Height	4.77 ft	6.13 ft
Body diameter	21.5 ins	N/A
Weight	2,085 lb fuelled	4,222 lb

plus a small number of transistors. The guidance system was fitted with a twin-channel radar receiver which was locked to the TIR broadcast signal via an aerial in the tail. The tail signal also generated a sliding range gate which was positioned at the expected time of reception of the target echo signal. The target signal was picked up on an 18-inch diameter parabolic dish under the radome and the target/dish sight line was derived from an amplitude modulation imposed on to the signal by a conical scan of the dish's dipole. This modulation was extracted in the forward guidance receiver and used to drive the dish actuators in order to keep track of the target. These signals were also used to generate the steering commands needed to allow the missile to fly a proportional navigation intercept course using a twist and steer method of control whereby the wings rolled the missile and then pitched the nose up. The pitch demand was limited to an acceleration rate of 9g.

The missile was fitted with a continuous wave radar proximity fuse which produced a narrow fan beam pattern 70° from the missile's centreline. On detection of a target, the fuse sent a firing signal to a warhead initiator, which had been activated by the acceleration of the missile in the boost phase, to link the detonators to the warhead. The blast warhead contained 200 lb of high explosive and had a lethal effective range of 100 ft. The missile's propulsion range was dependant on target altitude. The maximum powered range of the missile against a Mach 0·9 target at the system's minimum altitude of 10,000 feet was 15 nm. A Mach 0·9 target at the missile's maximum altitude of 60,000 feet gave a maximum propulsion range of 28 nm with a nominal impact range of 19 nm. The system's minimum range was 5 nm.

The Bloodhound Mk 1 in Royal Air Force service

The first Bloodhound Mk 1 unit, No 264 Sqn, was formed at North Coates in December 1958 using the trials equipment that was already *in situ*; it was primarily a trials and training unit and had very short operational role only towards the end of the unit's life.[15] The operational Air Defence Missile (ADM) squadrons formed between April 1959[16] and October 1960[17] and were allocated to one of four Wings (*see tables on page 55*). The wing HQs also controlled support elements providing centralised second line maintenance facilities

Sqn	Location	Formed	Fire Unit No	Combat Capable	ADM /SAM Wing	Non Operational	Disbanded	Remarks
264	North Coates	1 Dec 58	1 - 3	Oct 61	148	31 Aug 62	30 Nov 62	Role was trials and training, though the squadron did 28 days of QRA in May 1962. Fire Unit 3 cleared in 1960 for Type 87 Radar trials
141	Dunholme Lodge	1 Apr 59	4 & 5	Nov 61	148	31 Dec 63	31 Mar 64	Initial role was satellite trials site for North Coates
263	Watton	1 Jun 59	6 & 7	Nov 60	24	31 Mar 63	30 Jun 63	1st fully operational missile in UK loaded on a Launcher at Watton on 20 Nov 60
242	Marham	1 Oct 59	8 & 9	Jan 61	24	30 Jun 64	30 Sep 64	
266	Rattlesden	1 Dec 59	10 & 11	Jan 61	24	31 Mar 64	30 Jun 64	First squadron to be fully combat capable
62	Woolfox Lodge	1 Feb 60	12 & 13	Jun 61	151	30 Jun 64	30 Sep 64	
222	Woodhall Spa	1 May 60	16 & 17	Nov 61	148	31 Mar 64	30 Jun 64	
257	Warboys	1 Jul 60	14 & 15	May 61	151	30 Sep 63	31 Dec 63	Only 30 launchers until Apr 62
247	Carnby	1 Jul 60	20 & 21	Oct 61	21	30 Sep 63	31 Dec 63	
112	Breighton	1 Aug 60	18 & 19	Sep 61	21	31 Dec 63	31 Mar 64	
94	Misson	1 Oct 60	22 & 23	Sep 61	21	30 Mar 63	30 Jun 63	

Deployment of Bloodhound Mk 1 squadrons (above) and the evolution of the wing structure (below).

Wing	Location	Formed	Controlling MRS	Operational Capability	TCR/TCC Non Operational	Designated SAM Servicing Wing	Disbanded	Squadrons supported as SAM Servicing Wing
148	North Coates	12 May 60	Patrington / Boulmer	12 May 60	30 Dec 62	1 Feb 63	30 May 64	Nos 222, 141, 112 & 247
24	Watton	1 Apr 59	Bawdsey	27 Mar 61	30 Dec 62	1 Feb 63	31 Mar 64	Nos 263, 242 & 266
151	North Luffenham	1 Oct 59	Bawdsey	12-10-61	30 Dec 62	1 Feb 63	30 Sep 64	Nos 62, 257, 242, 266 & 222
21	Lindholme / Church Fenton	1 Apr 60	Patrington / Boulmer	1 Feb 62	30 Dec 62	1 Feb 63	31 Aug 63	Nos 94, 112 & 247

for the equipment used by the squadrons. The Bloodhound Mk 1 force defended nine Class A airfields, twenty Thor IRBM sites, three V-Force dispersal airfields and three USAF SAC bases. The first squadron to become operational was No 263 (ADM) Sqn at Watton in November 1960.[18] The Bloodhound Mk 1 weapon system was officially redesignated as a surface-to-air missile (SAM) in June 1961.[19] A total of 440 missiles was allotted to the squadrons, with the remainder to be used in further service trials or as replacements for rounds fired at Aberporth by the operational units.

Each squadron had missile servicing facilities which included fuelling and arming areas which supported an average strength of 40 missiles. The establishment of a missile squadron did not allow permanent '24/7' watch cover, but the force did instigate 24-hour manning for exercises, normally using technical personnel as operators. Between May 1962 and March 1964, the ten operational squadrons held a QRA commitment with each one having at least one section at 10 minutes' readiness at all times.[20]

Practice firings of Mk 1 missiles at Aberporth began in July 1959 and were completed in November 1963, 183 missiles having been fired at a variety of targets.[21] The overall success rate of the service firings was around 38%.[22]

In early 1963 the TCCs were shut down and direct control of the missile squadrons was assumed by the Master Radar Stations (MRS). The principal reason for this was a series of modifications embodied on the fire units during 1962 which had given the TIRs a sector search capability.[23] This allowed the modified fire unit to use target data passed by voice to put the radars on target.[24] At the same time the technical support elements of the missile wings had become SAM Servicing Wings and these continued to maintain the squadrons until they closed down at staged intervals between 1963 and 1964.[25] The first Bloodhound Mk 1 unit to disband was No 264 Sqn at North Coates who cleared the site to allow Bloodhound Mk 2 ground trials to commence.[26] The rest of the Mk 1 force had originally been planned to remain operational until late 1965, as the replacement Mk 2 was brought into service. However, in June 1963 the drawdown of the force was accelerated and by June 1964 the last squadron had ceased operations.

The planned successor to Bloodhound, BLUE ENVOY, was cancelled in 1957.

Bloodhound Mk 2 Development and Deployment Planning

The replacement originally envisaged for Bloodhound Mk 1 was the ‘Stage 1¾’ SAGW, BLUE ENVOY. It was to have been a Mach 3 ramjet-powered weapon with a 100 nm range, armed with either an HE or a nuclear warhead. Development of the weapon by the Bristol Aeroplne Company and Ferranti had started in late 1955. BLUE ENVOY, which would have looked like a cross between a Bloodhound and a Saab Draken, was to have used a mid-course guidance system with terminal Continuous Wave (CW) SARH. However, in April 1957 the programme was cancelled on financial grounds.[27] That left Thunderbird Mk 2, for the Army, as the only advanced land-based SAGW still under development in the UK and planning for the replacement of Bloodhound Mk 1 was now based on that weapon.[28] In the fallout from the cancellation of BLUE ENVOY the Bristol/Ferranti team proposed a ‘Super Bloodhound’ with a new airframe and ramjet engines which could be fitted with either a Command Guidance (CG) system with a nuclear warhead or a CW SARH system with an HE warhead. The RAF showed great interest in these proposals and initial development of both versions was approved in October 1958;[29] however the CG Bloodhound Mk 3, as it was known, was cancelled in April 1960.

In that same month development of a CW Bloodhound Mk 2 was approved as a deployable system for the defence of overseas bases where the manned bomber was more likely to be the primary air threat, although the system was also to have a secondary UK air defence role.[30] The main problems encountered in the development of Bloodhound Mk 2 were to do with its ground radar, rather than with the missile itself, but they delayed achievement of an Initial Operational Capability, originally planned for late 1962, until late 1965. Service evaluation firing trials at Woomera were completed in April 1965.[31]

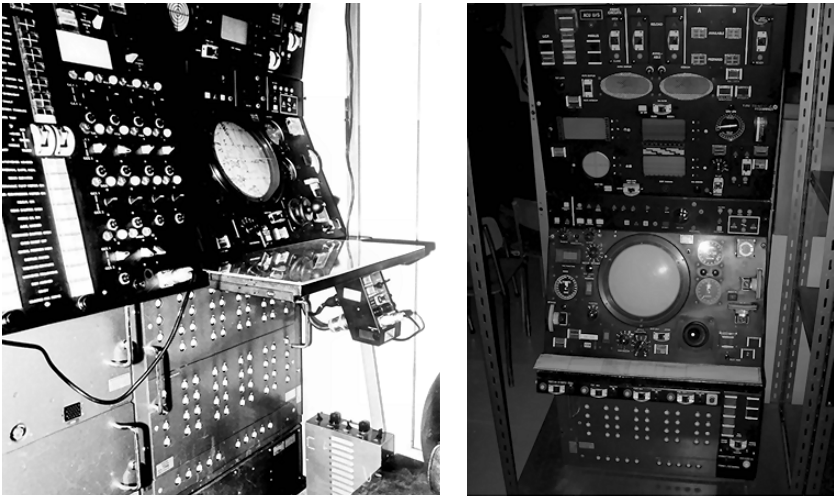
The Bloodhound Mk 2 Missile Section

The basic fighting unit of the Bloodhound Mk 2 system was the Missile Section; this consisted of a Launch Control Post, a Target Illumining Radar, up to eight launchers and various items for electrical power generation and distribution. All of the equipment, bar the larger radar, was air transportable.

The core of a Missile Section was the Launch Control Post, an air-transportable cabin approximately 20 feet long, containing all of the equipment needed to interface between the TIR, the launchers, the external data link systems and the units required for missile preparation and firing. All of these systems were transistorised and were, in most cases, controlled by a Ferranti ARGUS 200 digital computer.[32] A computer was essential for the operation of the system, as it made the many calculations required to prepare the missiles before launch and to control them in flight.

The LCP was occupied by an Engagement Controller[33] and a Technical Supervisor[34] who controlled the activities of the section. Digital data link and voice communications systems allowed target data to be fed into the system automatically or manually by the Engagement Controller, who could also select targets using the TIR's sector search capabilities.[35] In addition to controlling the firing of the missiles, the Engagement Controller would monitor the effects of ECM on the missile using visual displays, or the aural presentations of target and ECM signals. He also had limited control of the guidance systems of missiles in flight.

The Bloodhound Mk 2 TIR used frequency modulated continuous wave (FMCW) which was very resistant to ECM, including chaff, and



Left – the joint station in a Bloodhound Mk 2 LCP shared by the Technical Supervisor (nearest) and the Engagement Controller. Right – the Engagement Controller's displays.

greatly reduced the effects of ground clutter.[36] As a result the minimum intercept altitude of a Bloodhound Mk 2 was 150 ft.

Two different TIRs could be used with the system. The Type 86 was fully transportable, being fitted on a road trailer and weighing 10 tons; it had an effective maximum range of 90-100 nm. The other radar was the Type 87, which weighed around 50 tons. It could be moved if required, but relocation was a major task. It had a longer range than the Type 86 due to its bigger aerials and could track a target at up to 150 nm. The Type 87 was fitted with a large number of duplicated systems to allow maximum availability of the equipment.[37]

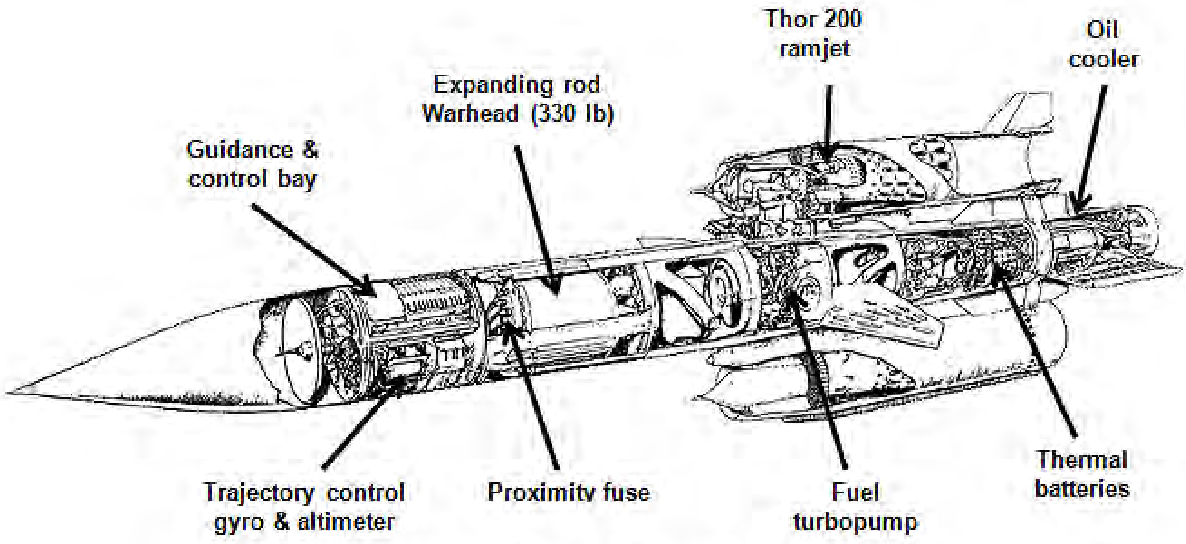
Both radars were fitted with an In-Flight Reference (IFR) aerial to provide a reference signal and a command link to missiles in flight. They were also fitted with a Jamming Assessment Aerial system which simulated the guidance system within the missile and provided information about the effects of target ECM on the missile to the Engagement Controller's jamming displays. Other aerials on the radar allowed the preparation of the missile's guidance system via a stalk aerial at the rear of the missile launchers.

The radars transmitted a signal at about 8,000 MHz (H/I Band) with a power output of 2kW. Both radars could independently search large volumes of airspace and had a selection of scan patterns available to allow them to locate targets when information from external sources was unavailable. The missile launcher was designed for fixed sites but, with outriggers fitted and portable blast mats, it could also be deployed for use on any suitably cleared ground. All of the services required for the launcher and missile were provided by packs fitted on the launcher structure. The only external connections required were signal and power cables. The launcher elevated the missile to an angle of 34° and missile loading was carried out by a purpose-built side-loading fork lift truck fitted with a beam attachment which lifted the missile via a lug on the boost yoke and a handling ring around the rear of the warhead bay.

The Missile

The construction of the Mk 2's airframe was very similar to that of the Mk 1 except that most components were 'beefed up' to deal with the missile's higher speed and longer flight time. The main change on the Mk 2 was the longer forward half of the missile airframe. To counter the aerodynamic effects of the longer airframe, the missile had enlarged canted tailplanes and yaw stabilisers fitted to the ramjets. The improved Gosling 15 boost motors fitted to the Mk 2 burned for 3·8 seconds and propelled the missile to Mach 2·2 before separation. The Thor 200-Series ramjets and revised fuel control system provided better reliability over all altitude ranges up to a maximum speed of Mach 2·7 with a fuel capacity of 55 gallons. The hydraulic system was very similar to that in the Mk 1 missile in operation, bar the removal of the alternator and the addition of an oil cooler to improve the hydraulic system's thermal efficiency. A thermal battery provided electric power for the missile's electronics systems which were mostly transistorised.

The guidance system employed two channels with the rear channel receiving the IFR signal via a tail aerial, keeping the missile locked to the TIR while, as with the Mk 1, the forward dish aerial produced conical scan information via a rotating off-set dipole. The rear channel also extracted the command link data from the TIR's IFR signal. The forward channel consisted of a Doppler tracking system fitted with swept search, memory and frequency modulation (coherency)



Bloodhound Mk 2 – salient features

	Missile only	Missile plus boost motor
Length	25.46 ft	28.26 ft
Span	9.29 ft	N/A
Height	5.78ft	6.2 ft
Body diameter	21.5 ins-	N/A
Weight	2,700 lb fuelled	5,400 lb

checking systems. The tracking function could not hold lock during the acceleration of the boost phase after launch, so the LCP computer predicated the target's Doppler frequency and the angle that the dish had to be set at in order to see the target on boost separation. The missile's tracking system memory was primed with the predicted Doppler frequency and the dish angle was also set just before launch. The missile would search either side of the frequency in its memory for the target signal at boost separation and on detection of a target Doppler signal matching the frequency modulation of its TIR, it would lock on and track the target echo's Doppler signal. The memory was updated with the target's Doppler frequency at regular intervals by the Engagement Controller (EC) via the command link. This allowed the guidance system to try to reacquire the target automatically if its echo signal lock was lost. The EC could also command the missile to break lock and hold off the re-acquisition of Doppler tracking lock if required.

The missile's dish and wing control systems were very similar to the Mk 1 in basic operation, although the maximum pitch demand had been reduced to 7·5g. The major change in the Mk 2 was the addition of programmed trajectories which allowed the missile to climb and cruise at high altitude on one of three pre-set profiles selected by the LCP computer before launch while following a proportional navigation course in azimuth. [38] This gave the missile a maximum propulsion range of 100 nm, although the nominal maximum intercept range was 75 nm for a best case engagement. Approximately 25 seconds before impact, the LCP computer initiated a terminal homing command which allowed the missile to use full proportional navigation to complete the intercept. The missile was fitted with an EMI pulsed range-gated proximity fuse,[39] a revised safety and arming unit and a large continuous rod warhead.[40] Detonation of the warhead produced an expanding hoop of connected steel rods 180 feet across before the rods broke apart.

The Bloodhound Mk 2 in Royal Air Force Service

The original Bloodhound Mk 2 deployment was five squadrons with three distinct operational roles: a training and trials squadron with two fixed and one deployable section in the UK; two 'standard' squadrons for base defence with four fixed sections each in Malaysia

SQN	LOCATION	ROLE	FIXED SECTIONS	MOBILE SECTIONS	FORMED	COMBAT CAPABLE	DISBANDED	REMARKS
25	North Coates	Training and trials (Deployable from 1969)	2 (0)	1 (4)	Dec 63	Feb 69	To Germany 1970-71	T87 radar to storage 1968. T86 from 65 Sqn 1968
65	Seletar	Composite	3	3 (0)	Feb 64	Dec 65	Mar 70 (Non Op from late 1968)	3 T86 sections to UK 1967. T87 sections to Singapore
112	Woodhall Spa	Standard	3 (2)	0	Dec 64	Jan 66	To Cyprus Oct 67 (Non Op from May 67)	One section to Aberporth 1967
33	Butterworth	Standard	4	0	Mar 65	Jan 66	Jan 70 (Non Op from late 1968)	Equipment to UK and storage
41	West Raynham	Composite (Deployable only from 1969)	3 (0)	3	Sep 65	May 67	Jul 70	T87 sections removed 1969. T86 sections to 25 Sqn

Bloodhound Mk 2 deployment 1963-70 (above) and 1971-83
(Numbers in brackets show number of sections issued to squadron on disbandment or relocation if different from initial issue.)

SQN	LOCATION	Flight	Type 87 SECTION	Type 86 SECTION	FORMED / ON SITE	COMBAT CAPABLE	DISBANDED/ RELOCATED	REMARKS
25	Bruggen	A Flt	0	2	Jan 71	Jan 71	Jan 83	To UK
25	Wildenrath	B Flt	0	2	Jan 71	Jan 71	Mar 83	To UK
25	Laarbruch	C Flt	0	2	Apr 70	Jun 70	Oct 81	To 85 Sqn in UK
112	Epispoki	N/A	2	0	Oct 67	Dec 67	Aug 69	To Paramali West
112	Paramali West	N/A	3	0	Mar 69	Aug 69	Mar 75	Disbanded – Equipment to UK
85	West Raynham	A Flt	2 + 1	0	Dec 75	Mar 76	N/A	2+1 T87 Eng Section became operational in 1982
85	North Coates	B Flt	3	0	Dec 75	Mar 77	N/A	
85	Bawdsey	C Flt	2	0	Oct 79	Oct 80	N/A	Formed at W Raynham Jun 77 pre-move to Bawdsey
85	West Raynham	D Flt		2	Jan 81	Dec 82	N/A	
85	Wattisham	E Flt		2	Oct 81	Dec 82	May 83	Ex 25 'C' Flt. Returned to 25 Sqn in 1983

Bloodhound Mk 2s of No 65 Sqn at Seletar.

Cyprus; and two 'composite' squadrons, one in Singapore and one in the UK each having three fixed and three deployable sections. A fixed site section was equipped with a Type 87 TIR and eight launchers, while the mobile sections were equipped with a Type 86 TIR and four launchers.

Additional equipment was used for technical training and at the missile firing range at Aberporth. The total number of Mk 2 missiles ordered was 357.[41] All squadrons were issued with enough rounds for a complete launcher load and a 100% reload. The remaining missiles were held in reserve for trials and as replacements for squadron practice firings at Aberporth.[42] All of the Mk 2 squadrons were equipped with an Engagement Controller simulator and missile servicing facilities.[43]

No 25 Sqn was the first to form, with the training and trials role, at North Coates. Due to the Indonesian Confrontation, FEAF's Bloodhound Mk 2 squadrons had the highest priority when the system

SQN	LOCATION	Flight	Type 87 SECTIONS	Type 86 SECTIONS	FORMED / ON SITE	COMBAT CAPABLE	DISBANDED/ RELOCATED	REMARKS
25	Barkston Heath	A Flt	0	2	Mar 83	Jan 84	Sep 89	To 85 Sqn
25	Wyton	B Flt	0	2	Jan 83	Jan 84	Sep 89	To 85 Sqn
25	Wattisham	C Flt	0	2	May 83	May 83	Sep 89	From 85 / To 85 Sqn
85	West Raynham	A Flt	3(0)	0(4)	Oct 67	Dec 76	Jul 91	System out of service
85	North Coates	B Flt	3(0)	0(3)	Dec 75	Mar 77	Apr 90	System drawdown
85	Bawdsey	C Flt	2(0)	0(2)	Oct 79	Oct 80	May 90	System drawdown
85	West Raynham	D Flt	0	2	Jan 81	Dec 82	Sep 89	One section to 85 Sqn A Flt
85	Barkston Heath	D Flt	0	2	Oct 89	Oct 89	Jun 90	From 25 Sqn. Drawdown
85	Wyton	F Flt	0	2	Oct 89	Oct 89	Jul 90	From 25 Sqn. Drawdown
85	Wattisham	E Flt	0	2	Oct 89	Oct 89	Jul 91	From 25 Sqn. System out of service

Bloodhound Mk 2 Deployment 1983-91

(Numbers in brackets show number of specific radar type issued to squadron on disbandment or relocation.)

entered service, with No 65 Sqn being formed at Seletar and No 33 Sqn at Butterworth. For a number of reasons, the system's deployment to Cyprus was delayed until October 1967 and, pending a decision, the nominated unit, No 112 Sqn, operated from Woodhall Spa with its missile and launcher establishment being shared with those of No 25 Sqn.[44] The last Mk 2 unit to form was No 41 Sqn at West Raynham.

The fully-armed, fixed-site sections of Nos 112 and 41 Sqns formed part of the Air Defence of the UK between 4 January 1966 and 30 June 1969. All of the fixed-site Type 87 sections in the UK had been stood down and their equipment put into storage by the end of 1969.[45]

The first deployment of a Bloodhound Mk 2 mobile section was carried out by No 65 Sqn in early 1966 when a single Type 86 section was moved to Borneo by air and sea during the Indonesian Confrontation.[46] No 41 Sqn's mobile sections carried out a number of training and trial deployments within the UK moving by air and road.[47] No 41 Sqn also mounted more ambitious exercise deployments, involving air and sea movement, to destinations within NEAF – Libya, Malta and Cyprus.[48] The Libya deployment was notable for being the first to be carried out solely by air movement. As a result of the Six Day War, which broke out while the section was at El Adem, it was moved from there to Cyprus where it remained until No 112 Sqn became operational in late 1967. In 1968 No 25 Sqn also took on a mobile commitment, with sections equipped with ex-FEAF Type 86 radars, and it too carried out exercise deployments to Cyprus and Malta.

The rundown of SAM defences in FEAF, as a result of the political decision to withdraw from east of Suez, began in May 1967 when the mobile sections of No 65 Sqn returned to the UK, the fixed site Type 87 sections at Seletar being sold to the Singapore government in 1969. No 33 Sqn at Butterworth was disbanded and the majority of its equipment was put into storage on its return to the UK. No 112 Sqn, after the initial deployment of two sections to Episkopi in late 1967, moved to a permanent site at Paramali West during 1969 and received a third section in 1971.[49] The SAM defences in Cyprus were stood down in mid-1975 and the equipment was returned to UK.

The plans for the post-1969 Bloodhound force in the UK were for two squadrons with six deployable sections to be based at West Raynham and additionally tasked for overseas contingency plans.[50] However, the adoption of NATO's 'flexible response' policy in 1968 resulted in a requirement for low level SAM coverage of the RAF bases in Germany to meet SACEUR's Programme for the Physical Protection (PPP) of airfields.[51] No 25 Sqn was selected to provide low level air defence of the clutch airfields with six sections being deployed between 1970 and 1971, a two-section flight being stationed at each of Brüggen, Laarbruch and Wildenrath.[52]

All remaining Bloodhound assets in the UK were concentrated at West Raynham in 1971 where, as the Bloodhound Support Unit (BHSU), they provided back-up for the squadrons based in Germany and Cyprus. Missile servicing was not carried out in Germany, hence regular missile rotations were carried out by air between Germany and the UK until the last flight of No 25 Sqn returned to the UK in 1983. The BHSU had a trials section from 1972 onwards which had an emergency operational capability.[53]

The LCPs were upgraded in the 1980s with introduction of the Argus 700 computer and a display suite with four 20 inch monitors.

The return of operational Bloodhound sections for UK Air Defence from late 1975 was to provide the low level SAM cover required to meet a SACEUR pre-condition for access to NATO common infrastructure funding for the construction of Hardened Aircraft Shelters (HAS).[54] The initial aim of the deployment was to provide an area defence Low level Missile Engagement Zone (LOMEZ) down to the system's minimum altitude that covered a number of RAF and USAF airfields with three missile flights of No 85 Sqn being based at West Raynham, North Coates and Bawdsey.[55] No 25 Sqn returned to the UK from West Germany between 1981 and 1983 to deepen the coverage of the LOMEZ, with a flight moving to Wattisham in October 1981 with the rest of the squadron following in early 1983 with flights forming at Barkston Heath and Wyton, where the squadron HQ was located.[56]

The intended Out of Service Date (OSD) of the Bloodhound Mk 2 system was 1985. This was extended to 1992 by the acquisition of surplus British Army[57] and Swedish Air Force versions of the Type 86 radar, along with 66 Swedish missiles and launcher spares.[58] The Type 86 radar replaced all of the Type 87s during the late 1980s, while new computer and display systems[59] were fitted to the LCPs along with a computerised command and control system which networked the whole force and included simulation functions.[60] In 1989, the two squadrons were amalgamated into a single squadron with the No 25 Sqn nameplate going back to a flying squadron. The fall of the Berlin Wall saw a rapid draw down of No 85 Sqn with four flights being disbanded during 1990. The intention was to extend the OSD of the remaining two flights until 1995 when a replacement was expected to be in service. However, on 1 July 1991, the remaining sections at West Raynham and Wattisham were stood down and No 85 Sqn disbanded in the middle of that month.

Eighty-seven RAF Bloodhound Mk 2s had been fired from Aberporth between June 1966 and November 1986 with a success rate of around 70%.[61] The system's main weaknesses being poor target discrimination against aircraft in close formation and poor homing accuracy against low level targets over water.[62]

Bloodhound Replacement

Studies for a replacement for Bloodhound were carried out in the late 1970s. These concluded that there was no low cost, off-the-shelf system that could meet the operational requirements.[63] A request for proposals was issued in the early 1990s, but by 1993, the end of the Cold War, a lack of funding and the removal of the mandated provision of Ground-Based Air Defence for SACEUR's UK airfields made a replacement redundant.[64]

Notes:

1 TNA AVIA 54/1225 'Design, 1949-1955'. The original specification given to the Bristol/Ferranti Team called for a weapon with an maximum impact range of at least 30,000 yd (15 nm) with an engagement envelope of as close to sea level as possible up to 50,000 ft. The missile was to be capable of intercepting B-29 type bombers and fighter-bomber aircraft.

2 *Ibid*. In the autumn of 1950, a combined RAE/Bristol team visited US companies and research institutes working on the ramjet-powered weapons which were part of the US Navy's Bumblebee and USAF's Bomarc projects. The basic 16-inch ramjet design that evolved into the Thor 100-Series ramjet was designed and first ground tested by a combined Boeing and Bristol Engines team in Seattle during 1951 after the two companies had signed a technical agreement earlier in the year.

[3] TNA AIR 29/2703 'No 8 JSTU ORB Jan 56-May 60'. Service acceptance trials at Woomera by No 8 Joint Service Trials Unit began in April 1958 and had been completed by November 1959 with the exception of warhead trials which were carried out in April/May 1960. Eighty-six missiles had been fired with a 46% success rate.

[4] TNA AIR 2/15114 'SAGW: transfer from Army to RAF control 1952-54' and TNA AVIA 54/1789 'Surface-to-air guided weapons for use in air defence of UK: consideration 1953-58.' Early in 1953 the Chiefs of Staff Committee directed that the Air Ministry should assume responsibility for all UK-based SAGW. The current projects were covered by OR1124 – Bristol/Ferranti's RED DUSTER and English Electric's RED SHOES missiles, OR2095 – the YELLOW RIVER Target Illumining Radar (TIR) and OR2094 – the ORANGE YEOMAN Tactical Control Radar.

[5] TNA AIR 20/7780 'SAGW Stage 1 Production'. This recommendation was approved by the Chiefs of Staff Committee in July 1954.

[6] *Ibid*. Correspondence between DCAS and CGWL in July 1954.

[7] Buttler, Tony and Gibson, Chris; *British Secret Projects Supersonics, Ramjets and Missiles* (Midland Publishing, Hinckley, 2007) pp52-53, TNA AVIA 13/1236 'Long range surface to air GW system for air defence of United Kingdom 1954-56'. OR1137 for a Stage 2 missile called for a minimum propulsion range of 100 nm with a minimum impact range on a Mach 2 target at 75,000 ft of 40 nm, but all work on it was cancelled in 1957.

[8] TNA AIR 20/7780 'Surface to air guided weapons requirement and production 1953-56', AIR 20/12314 'Deployment of Stage 1 SAGW 1957' and AVIA 54/2190 'SAGW acceptance trials programme: policy 1953-56'. Two interim weapons were proposed by the MoS in mid-1955 to overcome the limitations of the Stage 1 weapons as regards ECM and their low level capability. The Stage 1½ system was RED SHOES with CW SARH for the Army, while the Stage 1¾ weapon was to be a long range development of RED DUSTER with mid-course guidance and terminal CW SARH.

[9] The system was officially named Bloodhound in November 1956 which was Bristol's and the MoS's preferred name; Fighter Command had wanted it to be named after a snake.

[10] TNA AIR 20/7780. North Coates was to have had six fire units with twelve TIRs and 96 Launchers. The six operational coastal sites were to have had three fire units with six TIRs and 48 launchers. All sites were to have a Tactical Control Radar.

[11] TNA AIR 10/7488 'SD 773 Vol 1 Stage 1 SAGW system: trials station general information'. The Tactical Control Centre had a Track Allocator for each squadron who, in liaison with the GCI station's Chief Controller SAGW and the wing's Chief Controller, started tracks on the DHS and allocated them to one of their subordinate Weapon Control Teams (WCT). Each WCT was tied to a fire unit and was led by a Target Selection Officer (TSO). The other members of the WCT were two trackers and a height operator; a team could control up to eight tracks. A monitoring group within the TCC could track up to sixteen friendly aircraft within the wing's area of operation. The Chief Controller, Track Allocators and Target Selection Officers were all equipped with twin-scope consoles that displayed the pictures from both the

remote GCI radar and their own TCR. The TCR PPI displays included synthetic data in the form of track number or track identity and the operations room had an automatic tote displaying track information and engagement status.

[12] *Ibid*. The recommended salvo size was two missiles for a semi-active engagement and three for a passive one.

[13] TNA AIR 10/7419 'SD751, Vols 1 & 6, Book 2, Cover 2, 'BLOODHOUND: missile, including boost rocket motor 1959-60'. The nominal thrust of each Gosling 1 boost motor was 23,000 lb at 15° C, though the actual thrust output and burn time was dependant on the ambient temperature of the 315 lb charge of cordite propellant.

[14] *Ibid*. The nominal thrust of each ramjet was 5,000 lb at Mach 2 and 10,000 feet. Each engine was lit by six flares which were fired 2 seconds before launch and burned for 10 seconds. When exhausted they fell away and normally landed some 8,000 ft from the launcher.

[15] TNA AIR 26/608 'No 148 (SAM Servicing) Wing ORB 1960-64', AIR 27/2852/5 'No 264 Sqn ORB 1956-60' and AIR 27/3119 'No 264 Sqn ORB 1961-62'.

[16] TNA AIR 27/2819/1 'No 141 Sqn ORB 1956-60'. The first operational unit, No 141 Sqn, was initially formed at Dunholme Lodge to act as a remote satellite trials site for North Coates to test the digital data link system.

[17] TNA AIR 27/2843 'No 222 Sqn ORB 1960'. No 222 Sqn at Woodhall Spa was the last missile squadron to become operational.

[18] TNA AIR 27/2852/4 'No 263 Sqn ORB 1956-63'. The first fully-armed live operational missile to be loaded at an operational squadron was on Fire Unit 7 at Watton on 18 November 1960.

[19] TNA AIR 72/82. AMO N493 of 21 June 1961 directed that, to comply with NATO nomenclature, the term Surface-to-Air Missile (SAM) was to replace both SAGW and ADM.

[20] The nominal establishment of a missile squadron was around eight officers, eighteen SNCOs and 100 airmen. From May 1962, the QRA commitment required each squadron to have one section at 10 minutes' readiness, the other half of the fire unit at 30 minutes' and the other fire unit at 2 hours'. This was changed in April 1963 to one fire unit on each squadron to be at 10 minutes' readiness for three weeks in an eight-week period on a rotational basis with a 30-minute readiness state for the complete squadron during normal working hours and 2 hours' readiness at any other time. No 264 Sqn at North Coates also started QRA on 1 May 1962, however their '24/7' commitment was reduced to 6 hours' notice 28 days later.

[21] TNA AIR 2/16403 'Bloodhound Mk 1 service firing trials'. Targets included: foil-covered parachutes dropped from a Canberra at high altitude (the normal target for squadron practice shoots); Meteor and Jindivik drones; a balloon-carried metal sphere and piloted Canberras using ECM equipment – the latter procedure, not surprisingly, going by the name of FORTITUDE.

[22] TNA AIR 2/16403 and AIR 28/1672 'RAF Aberporth ORB 1962-65'. Of the 62% failure rate, 48% were failures of the missile, 1·5% system failures and 12·5% range

equipment failures or a second missile being aborted during a salvo trial due to failure of the first missile (which happened on 7 out of 8 twin missile ripple firings).

[23] TNA AIR 2/17787 ‘Bloodhound Mk 1: deployment timescales 1960-62’. The, so called, Phase 2 modification programme was instigated at the request of HQ Fighter Command in 1961 and included modifications to the LCPs, radars and missiles to allow the fire units to work independently from the TCCs. The Type 82 radar at North Coates was used for Bloodhound Mk 2 trials until the late 1960s while the other three were re-roled as Air Traffic Control radars in 1966.

[24] AIR 27/2938 ‘No 62 Sqn ORB 1961-64’. The procedure involved the Master Radar Station passing the target’s position and altitude to the Launch Control Officer who would then convert this data into a range, bearing and elevation angle to permit alignment of the TIR.

[25] TNA AIR 26/610 ‘No 21 (SAM Servicing) Wing ORB 1960-63’, AIR 26/608 ‘No 148 (SAM Servicing) Wing ORB 1960-64’, AIR 26/606 ‘No 24 (ADM) Wing ORB 1960-63’ and AIR 26/611 ‘No 151 (SAM Servicing) Wing ORB 1959-64’.

[26] TNA AIR 26/608, AIR 27/3119 ‘No 264 Sqn ORB 1961-62’ and AIR 29/3193 ‘No 17 JSTU ORB 1960-65’. No 17 Joint Service Trials unit started Bloodhound Mk 2 ground equipment trials in 1960.

[27] Buttler and Gibson, *op cit*, pp57-59, TNA AVIA 13/1236, ‘Long range surface to air GW system: for air defence of United Kingdom, 1954-56’ and *Bristol Ramjets, Part 4* by Roy Hawkins (Rolls Royce Historical Trust – draft copy provided by the author in 2004). BLUE ENVOY, to OR1146, was to have had a range of at least 100 nm and altitude coverage from sea level to 80,000 ft. A series of test vehicles was flown to test the boost motors and aerodynamics and a 9/10 scale ramjet was tested at Patchway. Development of the ramjet continued post-cancellation to provide an engine for BLUE STEEL Mk 2 until that project was also cancelled.

[28] TNA AIR 20/12314 ‘Deployment of Stage 1 SAGW’. The cancellation of BLUE ENVOY resulted in the ordering of 150 Thunderbird Mk 1s in July 1957 to allow the RAF to gain experience with the English Electric weapon before ordering the Mk 2 version but the cost escalated and, after it had become apparent that there were major differences between the two missiles, the order was cancelled in 1958.

[29] TNA AVIA 65/1547 ‘Air defence of UK 1958-60’.

[30] TNA AIR 20/10554 ‘Air defence: Bloodhound Mk 2 SAGW; future policy 1958-63’. OR1169, covering Bloodhound Mk 2, was reissued in August 1960 to stress the system’s role in overseas base defence.

[31] TNA AIR 29/3188 ‘No 15 JSTU ORB 1960-65’. Between December 1963 and April 1965 56 missiles were fired with a 46% success rate.

[32] Bloodhound Museum, Menzingen, Switzerland: AP 118X-0202-1 ‘Ferranti Argus 200 Computer General and Technical Information’. The computer had a 1Kb ferrite core store and 4Kb of programmable memory which was a number of trays looking rather like an oversized cribbage board onto which the programming was entered by inserting ferrite pins into the holes.

[33] Normally an officer from the General Duties or Fighter Control Branches.

[34] Normally a SNCO Ground Radar Technician.

[35] TNA AIR 27/3069 'No 41 Sqn ORB 1965-70', AIR 27/3313 'No 33 Sqn ORB 1966-75 and AIR 27/3353 'No 112 Sqn ORB 1972-75'. Bloodhound Mk 2 could be interfaced with the GL-161 Tinsmith Data Handling System which was deployed overseas at Western Hills in Malaysia and at Cape Gata on Cyprus. Both of the Bloodhound squadrons in those theatres could receive digital target data directly into the LCP computer. In the UK No 41 Sqn also used this capability in trials with the GL-161 equipped TPS-34 radar of No 1 Air Control Centre at Wattisham.

[36] 'Bloodhound – Last and First', a joint lecture given by David J Farrar and Mike A Nedham at the Bristol Aero Collection on 12 October 1993. The system used by Bloodhound Mk 2 was proposed to Ferranti in April 1949 by R J Lees at TRE Malvern. However, it required very frequency-stable and low noise, high power transmitter valves to work and at that time such devices did not exist. Ferranti's work on the RED DUSTER programme led to useable valves that could just do the task in combination with additional noise cancellation equipment.

[37] The two radars used on Bloodhound Mk 2, although built by different firms, used the same transmitter valves. The Type 86 was built by Ferranti as INDIGO CORKSCREW and had the export name of Firelight. It was originally intended for use with Thunderbird Mk 2 where it had the Army designation of AD-10. The Type 87 was developed by the British Thomson Huston division of AEI as BLUE ANCHOR which was to have been the guidance radar for BLUE ENVOY and the target tracker for Bloodhound Mk 3. It was exported under the name of Scorpion.

[38] RAF Air Defence Radar Museum (ADRM): SD 747. The missile could fly four trajectories: full terminal homing from boost separation; 15° climb until receipt of a terminal homing command; 30° climb to 40,000 feet and cruise at that altitude until receipt of a terminal homing command and 45° climb to 55,000 feet and cruise at that altitude until receipt of a terminal homing command. The terminal homing command was generated by the computer.

[39] RAF Museum, Cosford: AP 118C-0201-01. The introduction of a pulsed radar fuse, with ECCM facilities, was intended to increase the ECM effort that the target had to employ in order to jam either the missile or the fuse. It also prevented the warhead from functioning if the missile miss distance exceeded its maximum effective range.

[40] *Ibid*. The Safety and Arming Unit was located just under the missile's warhead bay and was fitted with arming status visual indicators that could be inspected via windows in the missile's skin. The warhead consisted of 365 steel rods arranged around a 77 lb shaped charge to form the cylindrical shockwave. The missile's warhead bay skins were lined with rubber sheets to ensure that the density of the airframe that the rods had to break through was equal around the whole circumference of the warhead bay.

[41] TNA DEFE 7/1338: 'RAF production programme for guided weapons: BLOODHOUND 1958-63'.

[42] *Ibid*. Fifty-seven missiles were allocated for this purpose.

[43] These facilities included two Missile Overall Test Equipments, a Fuelling and

Fuel System Test area, an Explosive Fitting Area and a Launcher Pack Repair Bay. A Task Control and Ops Room allowed autonomous operation of the squadron to be coordinated; the mobile sections had radio relay equipment for deployment proposes.

[44] DEFE 4/196/12 'Minutes of Chiefs of Staff Committee Meeting No 12 of 1966; Air Defence of Cyprus – Bloodhound 2'. The principal reason for the delay was to see whether the 1966 Defence Review was going to delete the requirement.

[45] TNA AIR 27/3069 'No 41 Sqn ORB 1966-70' and AIR 27/3044 'No 25 Sqn ORB 1966-73'.

[46] TNA AIR 27/3098 'No 65 Sqn ORB 1966-72'.

[47] TNA AIR 27/3069. The first road deployment made by No 41 Sqn was to Rattlesden in March 1967 and the last to Aberporth in May 1970 where Missile Section 5 became the only operational missile section in the history of the RAF Bloodhound force to actually fire a missile. The routine training firings conducted by all units were carried out using Aberporth's own on-site facilities

[48] *Ibid*. The first complete air movement of a missile section, Exercise LONG HOOK, took place in May 1967. The airlift involved fifteen Argosy and six Beverley movements. It was recorded by a BAC film unit who later released a film of the deployment called *Bloodhound In The Desert*.

[49] TNA AIR 27/3147 'No 112 Sqn ORB 1966-71'. During the period that Bloodhounds were on Cyprus, they were repainted in light stone camouflage. Although the squadron was famous for painting shark's teeth on its aeroplanes, only a modified ex-R&D trial round, re-roled as a display and loading training missile, had the famous teeth on it.

[50] TNA DEFE 5/183/68l 'Chiefs of Staff Committee Memo No 68 of 1969'.

[51] *Ibid*.

[52] TNA AIR 27/3069. The squadron had to provide up to three mobile sections for UK national requirements.

[53] TNA AIR 29/4180 'Bloodhound Support Unit: RAF West Raynham 1971-75'; RAF ADRM 'SD 747 1972/1974' and AIR 27/3457 'No 85 Sqn ORB 1976-80'. The Trials Section had direct communication links to the Master Radar Station at Patrington until 1973 and then to Neatishead, permitting it to participate in air defence exercises.

[54] TNA DEFE 71/10 'Improvements to UK land/air defence, general 1973-74', DEFE 24/1292 'Air defence: airfield survival measures; provision of hardened shelters for operational aircraft on UK airfields, 1975-76'. Both of these files contain correspondence between the MOD and SHAPE, proposing the use of Bloodhound to provide area defence (instead of a point defence system) to meet SACEUR's PPP requirement, in order to secure NATO common infrastructure funding.

[55] Within the LOMEZ a missile section could engage any fast low-level target or any aircraft emitting any form of ECM detected within a defined sector. This did not require the endorsement of the Sector Operation Centre at Neatishead, authority to fire having been delegated to the squadron operations room. The system was not fitted with IFF, so any friendly aircraft not following the correct MEZ procedure was subject to engagement.

[56] TNA AIR 27/3663 'No 25 Sqn ORB 1983-84'.

[57] TNA DEFE 71/207 'New equipment: Bloodhound missile, deployment, 1977-80' and AIR 27/3457. Eight Army AD-10 radars were transferred to the RAF.

[58] TNA DEFE 71/207, AIR 27/3457, AIR 27/3590 'No 85 (SAM) Squadron ORB 1980-83' and AIR 27/3687 'No 85 (SAM) Squadron ORB 1983-84'. Nine ex-Swedish radars and 66 missiles were transferred to the UK and modified to RAF standard at West Raynham.

[59] RAF Museum, Cosford: AP 118B-0212-10A1. The new Ferranti Argus 700 computer and display system included a simulator facility with an instructor's position at the Engagement Controller's and Technical Supervisor's consoles. The new computer had a 1Mb memory and a 128 Mb hard drive (which was the size of a shoe box).

[60] RAF ADRM: AP 118B-0212-1B2, Chapter 17. All of the squadron and flight operations rooms were interlinked to the LCPs with a primary Sqn Ops Room (SOR) at No 85 Sqn and a secondary SOR at No 25 Sqn. During this period a Bloodhound Force organisation was set up under the command of the Station Commander at West Raynham.

[61] TNA AIR 28/1710 'RAF Aberporth ORB 1966-70', AIR 28/1933 'RAF Aberporth ORB 1971-75', AIR 28/2166 RAF Aberporth ORB 1976-80', AIR 28/2325 'RAF Aberporth ORB 1981-82' and AIR 29/4179 'Bloodhound Firing Unit: Aberporth ORB 1971-74'.

[62] TNA DEFE 58/86 'A statistical survey of Bloodhound Mk 2 live firings 1966 to 1976' and AIR 28/2325. The low level over water issue was caused by the missile locking on to a reflection of the target echo on a calm sea and splashing down in front of the target. The major system weaknesses are described in a report about the removal of a dedicated Bloodhound firing section at Aberporth.

[63] TNA DEFE 71/207. A replacement study was carried out while the system's OSD was scheduled for 1985. The only weapons under development or production that were considered were Patriot and Sea Dart. Patriot was rejected on grounds of cost, lack of range and a single battery's inability to provide 360° cover. Sea Dart Mk 1 was rejected due to concerns about its ECCM capability, along with the fact that a new radar and fire control system would be required to make the equipment deployable and work at low level over land. The recommendation was that a collaborative European replacement be examined with either an Anglo-Franco-German system or a land based Anglo-French EUROSAM development of Sea Dart. The fall-back option was a British only Sea Dart Mk 2 as a joint RN/RAF system which, although not having the ECCM issues, would still require a new radar and fire control system. A lack of French interest resulted in the first option being killed at birth, while Sea Dart Mk 2 was cancelled in the 1980 defence review.

[64] Gething, Michael; *Sky Guardians, Britain's Air Defence 1918-1993* (Arms and Armour, London, 1993) p208. Three systems were considered: a mix of Patriot and Rapier Field Standard C; the AdSAM system using ground-launched AMRAAM and the EUROSAM SAMP/T. The 1993 Defence White Paper noted that there was no near term requirement for a replacement.

MORNING DISCUSSION

Richard Bateson. Mention was made of RED SHOES. In 1947 the Ministry of Supply set up a Guided Weapons Progress Group that reported to Sir Ben Lockspeiser, then the Chief Scientist. A little later a Guided Weapons Advisory Board was created and this had a small offshoot called the Anti-V2 Sub-Committee, chaired in 1952 by Prof J L M Morrison. In November that year English Electric submitted a proposal for a practical defence against a V2-type missiles using RED SHOES missiles and a special guidance system. They reckoned that four launching sites could defend London. The Advisory Board was also involved with an expendable bomber working party. Could anyone speak about that?[1]

Richard Vernon. I haven't really attempted to investigate the work done by English Electric at Luton or Stevenage on RED SHOES – or on Thunderbird, which it became – because it wasn't an RAF weapon. The RAF's involvement with RED SHOES only arose because we inherited it, along with Bloodhound, when the Army lost its responsibility for UK Air Defence in 1953. The RAF wanted to cancel Thunderbird, but it survived because the Army wanted it for deployment in the field. When BLUE ENVOY was cancelled, the RAF did consider acquiring Thunderbird for a time, and it actually placed a provisional order for 150 Mk 1s. But when it became apparent that the Army was aiming for the Mk 2, which was considerably different, the order was cancelled because the Mk 1s would have provided little training value. It is perhaps worth pointing out that, so far as I am aware, the Army only bought 200 Thunderbirds, whereas the RAF actually *fired* 183 Bloodhound Mk 1s.

Wg Cdr Andrew Brookes. Can anyone shed any light on Project E weapons? Why did we get them? Was it because we couldn't develop our own fast enough, or were American weapons perhaps better than ours?

Kate Pyne. I think the basic idea was simply to make up the numbers as quickly as possible, although they were not under independent British control, of course. As to whether one weapon is better than another, that would depend on the criteria you apply. I think that the first US warheads to be supplied would have been the W28s associated with Thor, which was also the one that we Anglicised at Aldermaston to become RED SNOW for BLUE STEEL, BLUE STREAK and YELLOW SUN. But it is difficult to say whether they were 'better'.

It was quite problematic to make them in this country because of differences in specifications. The classic example of this is that the sole UK defence contractor tasked with making the casing for the warhead itself could not replicate the American design. In order to design one that could be manufactured here, our scientists got a second lease of life – they had all been expecting to lose their jobs as a result of the decision to build American weapons!

In the event the warhead casing that the contractor was able to make turned out to be 5 cm larger in diameter than the original so it wouldn't fit within the American bomb casing. The Treasury declined to underwrite the cost of a new British bomb so RED SNOW had to go into the existing YELLOW SUN casing. There was a knock-on effect to this, as you could get only one such weapon into a V-bomber rather than up to, perhaps, four of the American-style Mk 28s. That created some problems with target coverage once the V-bombers had been assigned to NATO. The upshot of all that is that there was a body of opinion that said that it hadn't really been such a good idea to adopt American designs after all. How that bears on the question of whether they are 'better', however, is moot.

Air Cdre Norman Bonnor. The YELLOW SUN casing had been designed, of course, to accommodate the much larger GREEN BAMBOO warhead and all of the aerodynamic work and ballistic trials had been carried out on that tailor-made shape. When we switched to the much smaller RED SNOW for YS2 it permitted us to retain the original, albeit now unnecessarily large, casing because it meant that all the ballistic and performance data would remain valid. All that was necessary was to add a lump of concrete to maintain the original weight. Starting again with a redesign of the casing would have imposed a significant delay on entry into service.

Pyne. We have a sectioned YELLOW SUN Mk 2 in the museum at Aldermaston and it is remarkable to see just how much empty space there is within the casing.

Air Chf Mshl Sir Michael Alcock. The first two presentations took me way back to my youth. Indeed, in May 1960 I was preparing XL190 for Norman to fire his BLUE STEEL into Cardigan Bay. But my question concerns the fuel that was chosen for that rocket. HTP was enormously volatile – I wonder who signed off on its safety and that of the nuclear warheads. I recall it being a nightmare, especially on QRA when, on one occasion, one of the aircraft – in the middle of the night, of course, and with a live warhead and a fuelled missile on board – managed to drop both of its underwing tanks! Not a happy evening. Would it have been the Ordnance Board? Or AWRE? Who would have been the responsible authority?

Bonnor. I'm pretty sure that it would have been the Ordnance Board who had overall responsibility for safety – they certainly kept on imposing restrictions. But HTP was selected because it was considered to be less hazardous than the alternative, which would have been hydrazine, which the Americans were using in some of their missiles. The RAE had sent a team across to the States to see what the Americans were doing and they were horrified by some of the safety issues associated with rocket fuel that they observed.

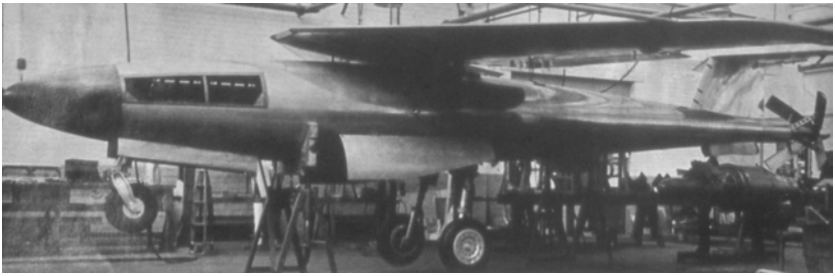
Payne. In fact, you didn't have many options at that time. If you wanted a rocket motor of a given power, there wasn't a great deal of choice when it came to oxidants, and the big advantage of HTP was that, unlike, for instance, liquid oxygen, it was storable. So, while there were a number of constraints, you could fuel-up a missile and it could then stand on QRA for a relatively long period.

Alcock. That may be so, but it didn't inspire a lot of confidence among the engineers who had to deal with it! (*Laughter*)

Bonnor. In this context it is interesting to note that BLUE STEEL Mk 2 was to have been a ramjet that would have gone three or far times as far as the Mk 1. That would have been fine for a high level launch because it would probably have been going fast enough to fire up the ramjets but I'm not sure whether that would have been the case at low level – but the missile had been cancelled before that could become a problem.

Vernon. I believe that the ramjet engines were to have been the same as for BLUE ENVOY and that the Mk 2 BLUE STEEL was intended to have two solid fuel booster motors to get it up to speed.

Pyne. That was also factor in the decision to use stainless steel in the construction of BLUE STEEL. It wasn't really necessary for the Mk 1 but would have been for the Mk 2, and the use of stainless steel contributed to delays in the development of the airframe as it is not an easy material to work with. I can vouch for that personally from the time I spent repairing and riveting the engine exhaust trunking on Bristol Britannias!



Bristol's Type 182R recoverable BLUE RAPIER prototype.

[1] The question relating to the expendable bomber elicited no response at the time but it would have been OR1097 which sought a small, turbojet-powered, pilotless aircraft which could be catapult/ramp-launched in large numbers (annual production at rates of between 5,000 and 50,000 were discussed) in a campaign rather like that of the V-1 in 1944. The idea was refined to become Specification UB109. Proposals submitted by Vickers and Bristol both resulted in hardware. In contrast to the low-level V-1, the Vickers Type 725 RED RAPIER would have flown at 50,000 ft and M0·83 to deliver a 5,000 lb warload over a range of up to 400 miles. One-third scale models were dropped from a Boeing Washington at Woomera and several full scale prototypes were approaching completion when the project was cancelled in 1954. This work is described at some length by John Forbat in *The Secret World of Vickers Guided Weapons* (The History Press, Stroud, 2010 Edn). Similarly detailed information on Bristol's Type 182 BLUE RAPIER is less readily available but it would have had a similar performance. Production aircraft were to have been made of a plastic material, like that used to manufacture drop tanks, but a full-scale metal prototype, with an undercarriage to permit its recovery, was almost complete when it too was cancelled. **Ed**

SHORT RANGE AIR DEFENCE – TIGERCAT

Wg Cdr Martin Hooker

Martin Hooker was commissioned in 1969, his early tours being spent at Wattisham, Cranwell and Gütersloh. In 1985 he became OC 26 Sqn at Laarbruch, which involved time in the Falklands. Subsequent staff appointments included stints at High Wycombe, in Hong Kong and at the MOD (during DESERT STORM) before commanding a multi-national UN monitoring team in Cambodia. In 1997 he became Head of the RAF NBC Branch before filling NATO appointments at Norfolk VA and Ramstein. Since leaving the Service in 2005 he has been Regimental Secretary to the RAF Regiment and Editor of its Journal, Centurion.

While the RAF Regt's historical focus is invariably on its infantry capability – its very formation was vested firmly in ground-based air defence (or GBAD) from the outset. From the earliest pre-RAF Regt ground gunner roles, including defending London along the *Luftwaffe's* 'Bomb Alley' approach through Kent, anti-aircraft artillery (AAA) was in our DNA.

From the more modest and limited-range machine guns, we converted rapidly onto the heavier ordnance and until the mid-1970s, the 40mm Bofors gun – in all its variations – was the Regt mainstay. While it was not the most effective weapon in the role, it was the world's first GBAD to bring down a jet fighter – an Me262 – in Holland in late-November 1944.

Switch now to the early 1960s. AVM Edouard Grundy had been in post for barely a year as Commandant General RAF Regt before being promoted to air marshal on his appointment as Controller Guided Weapons and Electronics (CGWL). He kicked off the surface-to-air guided weapons (SAGW) debate for the Regt, almost as soon as he took office in 1962. His intent was that the Regt should have its hands on all RAF SAGW (including Bloodhound and even, for a time, the solid-fuelled Thunderbird) and the new low-level tactical weapons then on the drawing-board, principally the General Dynamics MIM-46 Mauler.

Left – the General Dynamics MIM-46 Mauler; right – Shorts Seacat on HMS Cavalier *(D73).*

Mauler was a self-propelled, anti-aircraft missile system designed in the late 1950s to satisfy a US Army defence requirement for a system to combat low-flying, high-performance tactical aircraft and short-range ballistic missiles. Based on the ubiquitous M113 chassis, Mauler carried search and attack radars, fire control computers and nine missiles in a highly mobile platform. It was an ambitious design for its era but ran into intractable problems during development; it was eventually cancelled by the US Army in November 1965, leaving the RAF without a future system in the pipeline.

Born of Seacat

In parallel with Mauler, Short Bros of Belfast had been fielding the successful ship-borne Seacat point-defence missile system and had identified the commercial potential for a land-based version. Tigercat was thus born as a private development using the Seacat GWS20 missile.

However, efforts to generate commercial sales – particularly in the global market and on the back of the undoubted Seacat sales success – were frustrated by the Company's inability to quote a UK Armed Forces user and so three systems were 'allocated' to the MOD in 1966 and duly assigned to the RAF Regt to take into service. No 48 Sqn RAF Regt, based at RAF Catterick, reconfigured as a Tigercat squadron in mid-1967 and highly successful firing trials by the Regt took place in November that year. Thus, the RAF became the world's first air force with a missile for its local air defence.

The Missile

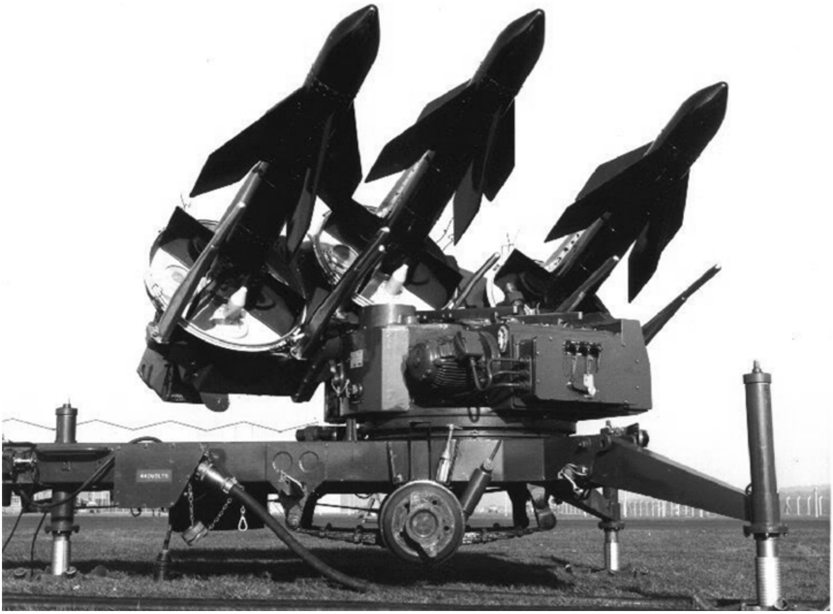
The GWS20 was a small subsonic missile powered by a two-stage solid fuel rocket motor. It was steered in flight by four swept, cruciform wings and was stabilised by four small tail fins that also housed tracking flares. For handling and mounting on the launcher, the missile was covered by a rigid fibreglass casing. Within the casing the actual missile was covered by a thin, hermetically-sealing rubberised membrane that protected the missile from moisture and the elements, and through which the missile could fire.

Ordered for the RAF Regt and the Imperial Iranian Air Force, the weapon system was mounted on two-wheeled trailers towed by LWB Land Rovers. One trailer comprised the three-round launcher while the other was the Fire Control and Launch system, known as the Director, with its optical sight and control gear. The Operator sat in a 4-foot diameter ‘bin’ which could be slewed rapidly within a 280-degree arc in the direction of an incoming target. Once the operator was on the right azimuth, he then searched in elevation until he saw the target, when he could then unlock his sight and commence tracking. When he judged the aircraft to be in range – effectively when the aircraft filled the relevant graticules in the naval-type binocular sight – he physically triggered the missile launch.

After what seemed an age, but effectively just over a second while the thermal batteries and electro-hydraulic pumps and gyros fired up, the boost motor ignited and punched the 150 lb missile off the beam. Even after all these years, I still remember it as a fairly lumbering affair! After the initial boost phase, the second stage ignited and took the missile to its target, coasting in the final stages of flight until the luckless aircraft entered (hopefully) the IR proximity-fuse zone of about 30 metres.

Command & Control

Guided by Command Line-Of-Sight (CLOS) via a UHF radio-link, commands were transmitted by a remote operator using a thumb-operated joystick, with both the missile and target in the binocular sight. His left hand controller featured the firing trigger while the right hand operated the joystick control. The operator's biggest challenge



Shorts Tigercat.

was to hold the missile on the aircraft target and not to confuse that with what he was trying to guide! When we found a good operator, we tended to flog him to death with any visits or firing demonstrations!

I joined Tigercat in March 1970, ostensibly because the postings officer noted that I had been a computer programmer and operator before joining the RAF and Tigercat had an analogue computer, albeit a mechanical one built more like a huge Swiss watch with lots of brass wheels and whirring cogs! We fired annually at the Aberporth Range near Carmarthen and the system’s limitations became fairly obvious to the users.

The limitations

First – as intimated in the earlier reference to Seacat – Tigercat was a short-range, point defence weapon, designed to engage radially-approaching targets attacking ships. As such, its slow speed (880 fps) did not pose a problem in that the attacking aircraft would literally fly into the missile, whereupon its quite large, 37 lb TNT RDX expanding-rod, proximity-fused warhead would do the rest with quite spectacular results. Only Bloodhound and the Army's Thunderbird had a bigger warhead in the UK missile inventory at that time (and probably since).

Secondly, with the missile itself largely influenced by WW II technology terms (lots of plumbing-like copper pipes, first-generation thermal batteries and expansion tanks), its fibreglass wings were never designed to withstand any meaningful g-force and therefore the system's ability to engage any form of crossing target was severely limited.

Thirdly, the Tigercat system, as fielded, was a daylight/fair-weather optical system that relied on a gun-style Warning and Reporting (W&R) ring, which introduced all manner of human-interface and environmental obstacles to a timely and accurate engagement.

Warning & Reporting

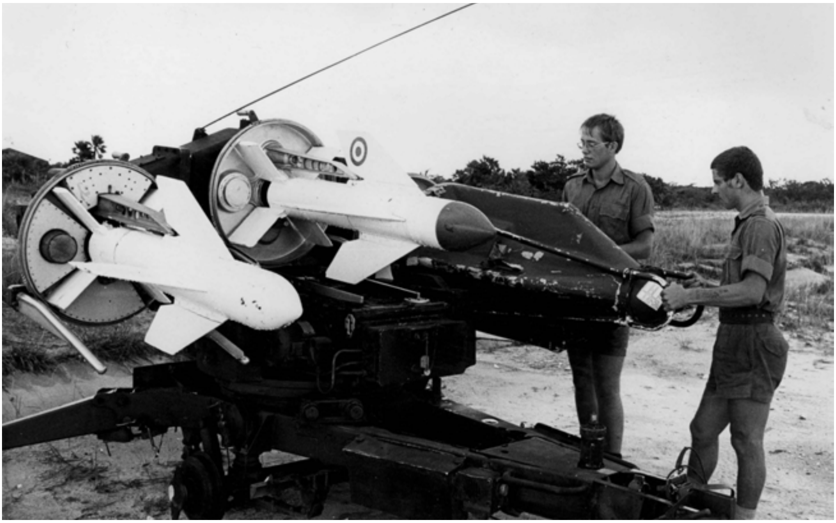
Without adequate low-level (ie electronic sensor) early warning, the manpower-intensive W&R screen – comprising twelve remote observation posts – could rarely provide sufficient notice of attack and the system's limitations could not overcome those factors.

As such, with only three systems to cover an airhead, there were only so many places to position the fire units before their maximum range was either before the point of weapon release, or their coverage was inadequate, which would allow attacking aircraft to penetrate the defended area. There was, therefore, a certain inevitability that some attacking aircraft – if not all – would have a significant crossing component and if the alerting system proved in any way lacking, system engagements were likely to be ineffective.

The squadron's war-role was at RAF Gütersloh and the systems were helicoptered onto elevated blast bunds to give them some line-of-sight advantage over the surrounding woodlands, a factor that also frustrated the ATC radars and any low-level, early warning potential that they provided.

Central American Sojourn

In late-January 1972, as Guatemala rattled its sabres over the minnow-like British Honduras, I carried out the initial deployment reconnaissance of Airport Camp in preparation for No 48 Sqn's deployment there a week later. The mangrove swamps, secondary



Tigercat in the field – Belize.

jungle and frequently impassable tracks meant that the W&R screen was spread over a 70-mile ring, which made alerting very challenging.

I hired a Cessna 180 aircraft to test the W&R capability; however, the pilot – ex-WW II *Luftwaffe* – was well-versed in hedge-hopping and crop-spraying and I don't recall us being reported by any of the OPs. Fortunately, the media images of the Tigercat systems deployed on the airport, the off-shore RN and Buccaneer presence and, later, the high-profile deployment of Harriers provided a suitable deterrent to further Guatemalan aggression and the system was never tested operationally – at least by us.

The system was to return to the then independent nation of Belize in 1978-79 when Guatemalan invasion threats re-occurred, but, by the end of the 1970s, Tigercat was viewed as increasingly obsolescent and Rapier was already well established in service.

Tigercat Postscript

As a postscript, the Nigerian Defence Force sent a team of their soldiers to Catterick in 1979 to train on Tigercat before taking possession of the Regt's missiles under a personal 'fence-mending' initiative of the then Prime Minister, Jim Callaghan, but their Government defaulted on the procurement terms and the three systems

Tigercat firing.

were disposed of elsewhere. Also, the Imperial Iranian Air Force's systems were eventually, by a circuitous route, probably through Jordon, sold on to the UN sanctions-bound South African Air Force, which operated some 54 fire units under the system name of HILDA. They were eventually withdrawn from service in 1993.

Finally, in 1982, my Tigercat expertise was re-examined as the Task Force prepared to deploy south to the Falklands. Argentina – which already used Seacat extensively – had also taken on Tigercat with systems deployed by their Marines around Goose Green and Stanley airport and the UK's Intelligence staffs were gathering 'enemy weapons' data. Subsequent analysis of Argentinean engagements seems to indicate that at least one Harrier was badly damaged by a Tigercat missile over Stanley, although this is difficult to validate beyond an islander's account of some local power generation equipment being damaged by the Tigercat missile's fragmentation when a Harrier was engaged overhead.

And so the RAF's first experience with short-range surface to air guided weapons ended. It had provided a stop-gap solution for the more demanding defence of our deployed locations but had also given the Regt a valuable foot-in-the-door for the acquisition of the next generation of guided weapon – Rapier.

SHORT RANGE AIR DEFENCE – RAPIER

Wg Cdr Simon Openshaw

Having joined the RAF Regiment in 1995, Simon Openshaw spent four tours specialising in GBAD, with No 37 Sqn RAF Regt at Brüggen and, as a QWI, with Nos 2623 Sqn RAuxAF Regt and 16 Sqn RAF Regt, before filling a staff appointment in the RAF GBAD Force HQ. In 2004 he joined the RAF Regiment Training Wing before completing a six-month stint in Liberia with a UN peacekeeping force, followed by appointments at High Wycombe and Marham. Operational deployments have included service in Kuwait and at Kandahar and Gioia del Colle. Promoted to wing commander in 2011, he is currently stationed at Honington as OC 20 Wg RAF Regt.

Development

Rapier began development in 1961 as a private venture by the British Aircraft Corporation known as PROJECT SIGHTLINE. When Mauler ran into problems in 1963, the MoD started funding the project, and it was developed as Rapier. The system entered operational service first with the RAF Regt in 1974; No 63 Sqn RAF Regt was the first, six others following, based in the UK and Germany.

Later came No 6 Wg RAF Regt, funded by the US DOD and tasked with protecting USAF bases in the UK. This comprised three more squadrons, all UK-based. At its peak between 1983 and 1992 the whole Force numbered ten squadrons and was the largest specialisation within the RAF Regt. Rapier also entered service with the British Army.

Field Standards 'A' & 'B'

The original Rapier – Field Standard 'A' (FSA) – took the form of a two-wheeled launcher, an optical tracker unit and generator. The launcher consisted of a large dustbin-shaped unit with the surveillance radar dish and IFF system under a radome, two missiles mounted on each side, the guidance computer and radar electronics at the bottom, and a parabolic antenna for sending guidance commands to the missiles on the front.

Rapier Field Standard A. (Nirazul)

The missile contained a solid-fuelled rocket motor and a small, 1·4 kg, warhead with an impact fuse. Engagement time to the maximum effective range was about 15 seconds. The small warhead was designed to disrupt the missile after it had penetrated the aircraft skin to maximise its effect.

The search radar was of the pulse-Doppler type with a range of about 13 km. The optical tracker unit had a stationary lower section with the operator's controls and a rotating upper section with the tracking optics and a separate missile tracking system using a television camera optimised for the IR band.

The whole system, along with its crew, was delivered by two LWB Land Rovers. RAF Regt squadrons had eight fire units each. In 1979 the Field Standard 'B' version of Rapier saw the Blindfire tracking radar introduced into service. This important upgrade gave the system a night and all-weather capability, and the ability to guide a missile to the target automatically. Later upgrades through the B1 and B1(M) – or 'modified' – standard introduced a variety of new features. Some were as a result of lessons from the Falklands war: the ability to engage targets below the original -5º maximum depression angle; and

The Blindfire radar unit introduced with Field Standard B.

the addition of a 'pointing stick' facility, which permitted manual acquisition of a target that the radars had not detected. The search radar was upgraded, which included the ability to mute the signal in case of an anti-radiation missile attack.

To explain, very briefly, how the system worked: upon surveillance radar detection, the optical tracking system would be slewed automatically to the target's bearing and the operator would then search for the target in elevation. The tracker radar would do likewise. When the target was found the operator could engage manually using the optical tracker, or automatically using the radar tracker.

For a manual engagement he used a joystick to keep the target centred in the telescope. Once a steady track was established the missile was fired. The TV camera on the tracker was tuned to track the four flares on the missile's tail. For a radar engagement the target and missile would both be tracked by the radar.

The difference between the line-of-sight of the target and missile was calculated by the computer in the base of the launcher. Constant guidance updates were sent to the missile through the transmitter on the launcher platform. Thus the missile would automatically fly to line-of-sight, be that optical or radar.

Given the previous types of SHORAD (Short Range Air Defence) systems used, the original Rapier FSA impressed the users from the outset. It was quick into action, pretty reliable, if treated respectfully, and very accurate. It was developed with the intent of directly hitting its target, thus reducing the size of the warhead required and eliminating the need for a proximity fuse. It was referred to as a 'hit-ile' – as opposed to a 'miss-ile'.

The system enjoyed the confidence of the user and its performance

Rapier Field Standard B firing in the Falklands.

at such exercises as RED FLAG – where a FSB1(M) system detected and tracked a USAF F-117 Nighthawk successfully at maximum radar range – demonstrated its prowess.

As a footnote to the FSB standard system, Rapier's performance in the Falklands has drawn much comment. The RAF Regt squadron and the RA battery were both delivered to the Islands in a chaotic fashion which resulted in their not being sited properly. Furthermore, the Army battery lacked its Blindfire radars. Thus, although official records reflect around seventeen Argentinean aircraft having been engaged successfully by Rapier, the true figure is more likely to have been just one. However, it was primarily a deployment problem, not one of system capabilities.

Field Standard 'C'

Development of what was to become the definitive version of Rapier began in the late 1980s, and Field Standard 'C' (FSC) entered service with the RAF and British Army in 1996. The new system was conceived to keep British SHORAD capability ahead of the developing late Cold War threat. Defence cuts reduced the original planned buy of some 250 Fire Units to 57, from which the Army and RAF maintained an operational fleet of 24 Fire Units each. In RAF service, these equipped a reduced Rapier Force of four regular and one reserve squadron.

Unlike the previous evolutionary changes, FSC was a ground-up re-design, although it used the same principles of operation. The headline figures for overall performance were broadly similar to earlier versions, the surveillance radar having a 16 km range, with the

Rapier Field Standard C.

missile effective out to 8 km and an altitude of 10,000 ft. However, the level of performance and reliability with which this was achieved were step-changes from the previous marks. The whole system utilised 1990's generation technology: until the advent of the Typhoon, Rapier FSC and the Harrier GR7 were the most advanced weapon platforms in RAF service.

FSC took the form of three identical trailer chassis, known as Common Trailer Bases – CTBs. These were the launcher, the surveillance radar and the tracking radar. Each was towed by a standard 4-ton truck with a custom load bed, each providing carriage for 15 missiles, fire unit ancillaries and the detachment's personal kit and equipment.

The launcher now mounted eight missiles and incorporated the optical tracking system and a missile command link transmitter. The two operator control units and the 'pointing stick' were also attached to the launcher. As the control units were divorced from the optics, FSC enabled the operators to be under cover or dug in to the ground for protection. The thermal tracker (the same as fitted to the Harrier GR7 and Tornado GR4) was capable of tracking both target and missile by day or night, and could also be used for passive surveillance. It is worth noting that with no other optical system, aircraft recognition training for operators had to be based on thermal signatures alone.

The surveillance radar was a pulse-Doppler system operating in the J Band. It could now resolve targets in three dimensions, reducing acquisition time by the system's trackers amongst other benefits. The radar incorporated a number of active and passive features to counter ECM and the ARM threat, and an IFF system. Using all of this information, its computer would perform an automatic threat assessment on any targets detected, and present them for engagement in priority order.

The tracking radar provided very high resolution tracking of both target and missile. Operating in the F Band, it utilised frequency agility and digital signal processing techniques to counter ECM, and also had a 'track on jam' facility. The tracking radar had its own missile command link transmitter.

The Rapier missile itself was upgraded, with a Mark 2 version entering service alongside FSC. Kinematic performance was enhanced, compared to the Mark 1, and the electronics were now fully digital. The Mark 2 was produced in two sub-variants: the Mark 2A retained the Mark 1's impact fuse and shaped charge warhead. However the 2B introduced probably the most significant missile upgrade, fielding a laser proximity fuse matched to a blast-fragmentation warhead. This was in order to ensure lethality against very small and manoeuvring targets, and finally turned Rapier from a 'hittile' to a 'missile'.

The principles of an engagement were the same as previous generations, and the operators had a choice between radar or thermal trackers to guide the engagement either automatically or manually. The ace up FSC's sleeve was that these two tracking methods could be used simultaneously against two targets, although it was not possible to fire two missiles at the same target.

FSC was a further step change in performance from the previous versions, and as users we had a high degree of confidence in it. Reliability was excellent, and even after a three-day road and sea

FSC firing at the Hebrides Range.

move to the Hebrides for a Missile Practice Camp there was still an expectation that the equipment would be fully serviceable when deployed on the firing point.

Roles, Tactics and Employment

Throughout its life, Rapier was employed in four basic tasks: defence of routes, areas, vital points or airfields. Route defence was seldom practised, at least in the RAF Rapier Force. Area defence would typically be used to cover a large troop concentration area or similar. VP defence might be employed around an important asset such as a bridge or HQ. An airfield, with its size and attendant requirements to allow friendly aircraft to operate, was treated as a different task.

While the Army tended to concentrate on the first three of these roles, the RAF Rapier Force concentrated heavily on airfield defence. Given the need to keep friendly aircraft safe in the same airspace, this was also the hardest of the tasks to conduct.

Our tactics were based on four principles: all-round defence; defence in depth; mutual support; and engagement before line of weapon release. This last principle is worth highlighting; Rapier was intended to be an air *defence*, not an air *revenge*, weapon, and so we made every effort to engage before aircraft released their ordnance. This did not apply when the ordnance itself was the target – a cruise missile for example.

A typical squadron deployment would run something like this:

1. The squadron would establish two CPs – a main and alternative. For an airfield defence task the CPs would normally be co-located with Flying Ops and closely linked to ATC in order to conform to local Base Defence Zone (BDZ) airspace control measures, with safe lanes corresponding to runways opened and closed for friendly movements.

2. Fire Unit sites all needed selecting and surveying before they could be occupied. The two Flight Commanders (junior RAF Regt officers) and their flight sergeants would be tasked with the actual reconnaissance. Once a site was identified the recce officer would survey it. This included measuring the angle and distance to the radar horizon through 360 degrees. The idea was to reconnoitre multiple sites and use the coverage information from this measurement to select the best ones for occupation.

3. When this had been done, the Fire Units would deploy. The target time from arrival to the Fire Unit being ready to engage was around 30 minutes for Field Standard ‘A’ or 40 minutes for Field Standards ‘B’ and ‘C’. This was, however, heavily dependent upon the ease of access to the site. Each detachment comprised eight men: a SNCO in command, two JNCOs and five gunners. The three NCOs were all qualified as Tactical Controllers and the gunners as operators; the kit was operated by one of each at any one time.

4. The squadron CP would link in to the theatre air-defence command and control network. This was normally by voice only, but if you were lucky the squadron might have access to a Recognized Air Picture display. Early warning and tactical orders would be passed to the CP, who fought the squadron by turning them into orders useable by the Fire Units. These were passed by radio and each Fire Unit then fought its own individual battle, reporting back actions after the fact.

5. Not to be forgotten in all of this were the squadron’s engineers. They had workshops established at the unit’s B Echelon location, and would deploy repair teams to Fire Unit sites to conduct routine maintenance, or in response to specific faults. The Engineering Controller would sit in the main CP to co-ordinate all this activity

No 63 Sqn RAF Regt at San Carlos, June 1982.

in close conjunction with the tactical situation.

Operational History

Over its service life with the RAF, Rapier was deployed on operations on several occasions and for protracted periods. In common with its air defence contemporaries – the Lightning, Phantom and Tornado F3 – the missile was never fired in anger, much to the chagrin of the units involved!

The first operational deployment was in the late 1970s, when the threat posed by Guatemala to Belize prompted a deployment to protect Belize airport and its detachment of RAF Harriers. This task lasted until 1991.

After Belize, the next test was the 1982 Falklands war (Op CORPORATE). The initial Task Force deployment had included an Army Rapier battery (T Battery) which was aligned to 3 Commando Brigade. However No 63 Sqn RAF Regt at Gütersloh was ordered to accompany 5 Infantry Brigade, the next wave of reinforcements. Having been warned for operations on 7 May 1982, the squadron embarked on the QEII at Southampton just five days later, a remarkable feat considering the huge logistical challenges involved.

The squadron arrived at San Carlos with no clear orders and in piecemeal fashion over the period 1-3 June and took over responsibility for defending the anchorage and nearby Harrier FOB from T Battery, who had moved forward to defend Bluff Cove. Despite the chaos, all eight Fire Units were in action by the end of 3 June. By this stage of the war the tempo of air attacks against the San Carlos area had reduced, and only one further raid was experienced. Unfortunately, none of the Fire Units managed to maintain track long enough to engage.

After the Argentineans surrendered, No 63 Sqn was tasked with defending the airfield at Port Stanley. Despite the surrender on the islands, it was considered that Argentine forces on the mainland might still want to carry on the fight, so this was still very much an operational deployment. The squadron became operational in its new location on 3 July. On 11 September 1982, they handed over to No 37 Sqn RAF Regt, returning to RAF Gütersloh after four months of operations conducted in the most austere of circumstances and often amid the thick fog of war.

It is unlikely that, at the time, anyone on the Rapier Force predicted that the final squadron *roulement* would be 24 years away. However, maintaining a continuous deterrent presence in the Falklands (first at Stanley, and later moving to the purpose-built military airfield and base complex at Mount Pleasant in 1986) became the Force's over-riding operational commitment, maintained regardless of other activity, including subsequent operations in the Middle East.

The Iraqi invasion of Kuwait in 1990 prompted the next operational deployment. With a large scale RAF contribution to the allied effort, airfield defence was naturally seen as a high priority. Nos 20, 26 and 66 Sqns were deployed to the Gulf. No 20 Sqn went to Bahrain to protect Muharraq airfield, going to the lengths of building a causeway into the sea to ensure the optimum siting for all their Fire Units. No 26 Sqn protected Tabuk in Saudi Arabia with No 66 Sqn at Dhahran. As with the Falklands war, the enemy did not oblige with any air attacks.

Rapier returned to the Middle East on two more occasions. In 2001, we deployed to Ali Al Salem air base in Kuwait in the immediate aftermath of the '9-11' attacks. At that time Ali Al Salem was home to the Tornado detachment providing the UK's contribution to the policing of the southern No-Fly Zone over Iraq. The Iraqi Air Force had become increasingly active and the attacks in the US provided the catalyst for the deployment. This was done in extremely

No 16 Sqn RAF Regt at Ali Al Salem, 2001.

short timescales, with No 15 Sqn embarking a half-squadron-sized detachment on two of the RAF's then brand-new C-17s on 16 September 2001.

The deployment lasted for seven months. RAF Rapier was not long absent from Ali Al Salem before No 16 Sqn re-deployed in February 2003 as part of Op TELIC – the invasion of Iraq. Initially, this merely re-established the previous defensive posture at Ali Al Salem. However, as the invasion progressed, the Iraqis began firing *Silkworm* anti-ship cruise missiles into Kuwait. In response to this the squadron was deployed forward into Iraq to create a defensive screen. However, by the time the required airspace co-ordination measures were in place the *Silkworm* firings had ceased, and the squadron returned to Ali Al Salem having not had the opportunity to engage the enemy.

Withdrawal from RAF Service

Op TELIC was the RAF Rapier Force's high point, as later in 2003 the Ministry of Defence began the 'Medium Term Workstrand' process. It was decided that GBAD needed rationalizing. A Joint GBAD HQ was to be formed, under RAF command, to bring greater co-ordination. However, the critical decision was that there was no longer a requirement to field both the Army and RAF Rapier FSC forces: one or the other would go.

In the RAF Rapier Force, we were quietly confident the decision

Rapiers of 16 Regt RA deployed at Blackheath for the 2012 Olympics.

would go our way. We had the operational pedigree of recent deployments in Iraq and Kuwait and the maintenance of the continuous presence in the Falklands. By contrast the Army had never deployed Rapier FSC on any kind of operation. We also had a rigorous and formalised STANEVAL system and were part of the NATO TACEVAL process, neither of which applied to the Army. We also maintained a far more active exercise programme. Our trump card was our cost – the RAF Rapier Force had fewer people than its Army equivalent and was cheaper.

But it was not to be: in a classic case of winning the battle but losing the war, it was clearly the RAF's turn to take a hit and the decision was made that the RAF Rapier Force would disband. The final ignominy in our eyes was that the Army was not deemed competent enough to take on the role immediately, so there would be a two-year transitional period to allow them to come up to scratch! The RAF Rapier Force was wound up in 2006.

Rapier continues in Army service, remaining in the Falkland Islands and deploying to protect the London Olympics in 2012. It is due out of service by the end of this decade, likely to be replaced by a land-based version of the Common Anti-Air Modular Missile system due to be fitted to the Navy's Type 23 and Type 26 frigates. Under current assumptions, this will be an Army-fielded system, so the RAF's association with ground-based missiles appears to have ended for good.

Finally: The Nearly Had . . .

Fairly on in Gulf War I, the threat from Iraqi ballistic missiles became very real and to counter it the RAF proposed the acquisition

FSC engaging aircraft in the field.

of the Patriot missile system from the US. The project was evaluated; No 6 Wg RAF Regt was designated as the prospective user and my team carried out the necessary operational, training and support studies in the light of which the MOD approved the acquisition. In theatre, the US declined – on operational security grounds – to confirm where their own Patriot theatre umbrella would extend, or whether UK assets would be covered by it. Nevertheless, the UK Treasury, in all its infinite wisdom, decided that we could be protected, withdrew the funding and the project died instantly.

Finally, probably through commercial-political pressure, we were invited to evaluate Starstreak, a modern High-Velocity Missile system that flew at Mach 3+. While it was carefully evaluated, we found no practical use for such a short-range weapon in RAF SHORAD terms and it was not pursued.

MARTEL and SEA EAGLE

Air Cdre David Wilby

David Wilby joined the RAF via Cranwell and trained as a navigator. His flying experience was associated with the Canberra, Buccaneer, including a stint with the RN, and Tornado. He commanded RAF Finningley and held NATO posts during the Balkans crisis. Other senior appointments included Director of Intelligence Operations in London and Chief of SHAPE's Special Weapons Branch. On leaving the RAF in 2000 he spent the next twelve years working in a variety of capacities, first with BAE Systems and later with Selex Galileo within the Finmeccanica Group.

INTRODUCTION

In days of old, battles at sea generally required closure until the enemy was sighted and salvoes were exchanged when within weapons range. As maritime warfare became more advanced and technology enabled the development of more capabilities, ship attacks also became possible from above and below the surface. As these threats evolved, there was a similar thrust to counter them by improving ship defensive systems which made major fighting vessels extremely difficult targets. In turn, to counter this threat, the Blackburn Buccaneer strike/attack fighter-bomber was designed to long toss a nuclear weapon at a *Sverdlov* cruiser from 4 miles at very low level

A Sverdlov-*class cruiser of the 1950s, the threat that the Buccaneer was specifically intended to counter.*

and at very high subsonic speed; this attack profile gave it a reasonable chance of staying outside the ship's defences and also escaping the subsequent detonation. Before escalation to that draconian level, however, conventional attacks were planned with six to eight aircraft, each delivering sticks of 1,000 lb bombs, using co-ordinated manoeuvres that would confuse, degrade and saturate the target's defensive systems.

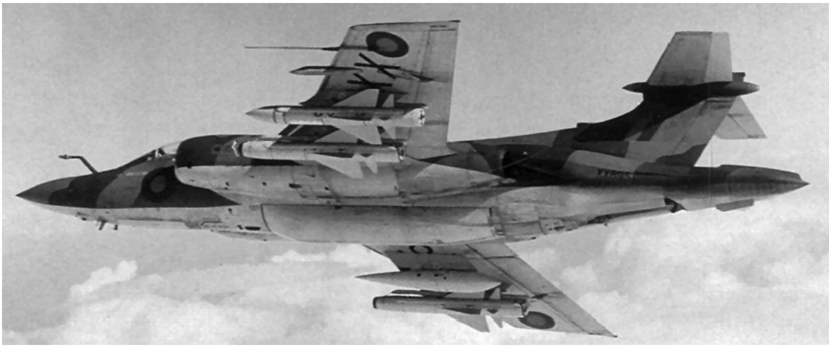
As Soviet maritime capability intensified, ships like the *Kresta 2* and *Kara* emerged. These very capable platforms had been provided with a comprehensive mix of early warning radars, electronic warfare and anti-aircraft missile and gun systems, forcing us to develop stand-off missiles that would keep attacking crews outside the missile engagement zone but still able to drive home a successful attack.

AIM

This paper will address the development of the MARTEL and Sea Eagle missile systems and tactics that were developed to counter the emerging Soviet maritime threat in the 1970s and beyond.

MARTEL

An Anglo-French collaboration, between Hawker Siddeley Dynamics (which later became British Aerospace Dynamics Group) and Engins Matra,[1] which started in 1964, led to the development of MARTEL – the Missile Anti-Radar Television – which, as its name implies came in two versions.



A Buccaneer with an anti-radar MARTEL (nearest) and a TV MARTEL under its port wing and, to starboard, the digital link pod and a second TV MARTEL

The AS 37 MARTEL

Firing Trials	Feb 70 to Jul 73
Into Service	Oct 74 (RAF); Oct 75 (RN)
Type	Anti-Radar Missile (ARM)
Wingspan	3ft 11in
Length	13ft 9in (longer radome)
Diameter	16in
Weight	1,179 lb
Speed	M 1·3plus
Range	80-15 Hi-Lo level
Propulsion	Two-stage solid propellant rocket motors (2·4s boost, 22·2s sustain)
Guidance	Passive Radar Homing System
Warhead	330 lb Proximity-Fused with delayed impact high-explosive blast fragmentation

The Anti-Radar Missile (ARM) – AS 37

The Buccaneer could carry four ARM MARTELSs on the underwing pylons or, if range was critical, two with two underwing fuel tanks. To compensate for the weight of the missiles, the wing-fold hydraulic jacks had to be improved and the undercarriage strengthened to allow for a heavyweight landing, as unlaunched missiles were too expensive to jettison. The missile had four main sections: the sensor head; the guidance package; the warhead and the rocket motor. These were all connected by an umbilical strake on each side of the body of the missile, with the wings and guidance fins attached towards the rear. The missile selection panel was in the rear cockpit, along with a visual display. This provided indications of signal reception and missile lock-on, and could be used for homing or to take bearings using an azimuth gauge. There was also a most useful attention-getter audio note fed into the intercom which accompanied signal reception and lock. It was also possible to manually lock and fine tune the received frequency signal.

The ARM had two passive sensor options optimised to detect long range early warning radars, one operating in C band and the other in E/F band, and either or both of these could be fitted before flight to meet target requirements. The receiver heads were extremely sensitive and thus able to detect the target's early warning radar transmissions long before it would be able to 'see' the incoming aircraft. Each head could have a specific target frequency pre-set before launch, which, with the missile head sweeping in azimuth, extended the field of view. Alternatively, when target frequencies were unknown, the navigator could search through the whole band available and wait for a lock-on to occur; this option gave a more limited field of view as the missile head was locked to the missile fore-aft axis.

From operational studies and training, we knew most of the electromagnetic signatures of the likely enemy or friendly radars in play. With practice, a twitch on the dials or a flicker of the lock-on green light would give a very early indication of imminent acquisition. The sensitivity of the system gave us 'radar range advantage', in that the crew could detect the target's transmissions before its outgoing pulses had enough energy to return to the shipborne receiver. Using this feature, the aircraft could descend 'under the radar lobe' and remain undetected until crossing the radar horizon.

The ARM could be launched from high or low level and specifications advised that launch from 80 nm should be possible at height. I was fortunate to be attached to No 22 Joint Service Trials Unit (JSTU) at Boscombe Down to fire the in-service proving trials at Biscarosse Range in France. Flying from Cazeaux, with Flt Lts Peter Warren, from 12 Squadron, and Colin Cruickshanks, a test pilot from 'A' Squadron at the A&AEE,[2] we fired three missiles in September 1974. All three were launched over the sea, from about 19 nm at 200 ft, at an inland target-set of radar heads. At launch, the missile had an impressive departure as the rocket motor ignited and propelled the ARM on its parabolic trajectory to around 15,000ft before turning

Photographed circa 1984, the Admiral Yumashev, *a* Kresta 2-*class cruiser, bristling with radar, guns and guided weapons.*

over and approaching the target in a near vertical supersonic dive. The results were hugely impressive with airbursts occurring as advertised and missile impact a few metres from the radar heads.

Operational Trials

The introduction of more complex multi-beam technology on the latest Soviet radars gave cause for concern. Thus, in April 1975, I was detached from No 237 OCU to No 12 Sqn at Honington to carry out some extremely covert operational trials against a *Kresta 2*. This involved political clearance from the highest levels, empty pockets, no flight plans, radio silence and no electronic emissions. That included Doppler, so to navigate we had to revert to a manual air plot and 'dead reckoning'. We flew three sorties, each of 5-6 hours' duration, supported by a dedicated Victor tanker, which we picked up overhead its base at RAF Marham. After it had topped up our tanks to full over the Shetlands, the Victor travelled no further north and waited for our return for another refuel to get us home.

On the first sortie, with Flt Lt Mike Kelly, we were purposely given no target location, save that our *Kresta* should be well north towards the Greenland-Iceland-UK Gap. With the target radar frequency pre-set, and using well-practised search techniques, we were able to demonstrate our ability to detect and roughly plot the target's position from long range – and certainly outside its detection range – while maintaining both radio and electronic silence, ie while observing Emission Control (EMCON). This enabled us to stay undetected at height and, by flying on a tangential track, to construct a fairly precise 'running three-position line fix' of the ship's location. Initial detection ranges at height became remarkably predictable and on later sorties, when we were allowed to close with the target, were proven to be accurate.

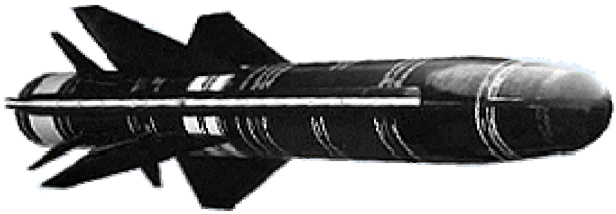
On the second sortie, flying with the Squadron Commander, Wg Cdr Graham Smart, and again under strict EMCON, we were briefed to home in and identify the target. This we did, under a 200-foot cloud base and with very little forward visibility. The noises coming from our electronic warning systems as we steamed in at around 550 kt were positively Wagnerian, as they reflected a total lock-on from all of the *Kresta's* defensive systems. The language coming from the front cockpit was quite entertaining! We closed to within a few hundred yards on the port side and, after identifying our foe, pulled up into a steep climb to break cloud at around 30,000 feet on the return track.

On the last sortie, with Flt Lt Dave Ray, and in better weather, we were briefed to close with the target and take photographs, which we did, just off Jan Mayen Island. On this beautiful day, after our attack, it was somewhat galling to see a Royal Navy frigate in the tattle-tale position, just a few miles away, keeping close watch on the entire proceedings!

But we had convincingly demonstrated the Buccaneer's ability to detect and locate a major specific threat, a capability that had hitherto been in some doubt.

The TV Missile (TVM) – AJ 168

The Buccaneer could carry up to three TVMs with a data link pod on the remaining wing station. The TVM was very similar in appearance to the ARM save for a flattish nose 'faceplate' which allowed the camera to see ahead, an impact delayed fuse to allow for hull penetration before explosion and a rearward-facing transmitting



The AJ 168 MARTEL

Firing Trials	Feb 70 to Jul 73
Into Service	Oct 74 (RAF); Oct 75 (RN)
Type	Anti-Ship Missile (TVM)
Wingspan	3ft 11in
Length	12ft 9in
Diameter	16in
Weight	1,265lb
Speed	M 0·75
Range	12 miles
Propulsion	Two-stage solid propellant rocket motors (2·4s boost, 22·2s sustain)
Guidance	Manual control from launch aircraft via TV imagery and data link pod
Warhead	330 lb Semi-Armour Piercing (SAM) with delayed impact fuse

system which formed the data link with the aircraft. The pod was fitted facing rearward and the receiving dish could be parked to either port or starboard to enable the aircraft to fire the missiles and then turn away in a prescribed manoeuvre which would optimise maintenance of the data link during the turn. Because salt spray at low level over the sea would cloud the vidicon faceplate in transit, it was protected by a rubber cap which was removed prior to launch by an inflatable bladder.

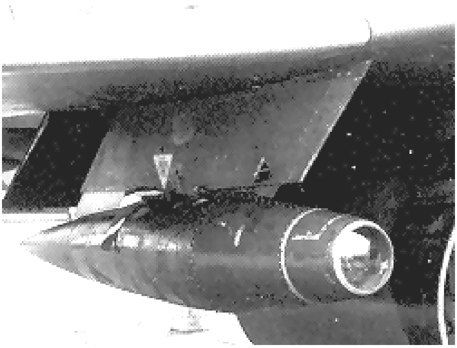
The conditions in the Buccaneer's rear cockpit, which had always been regarded as an ergonomic slum by its occupants, was degraded even further by the introduction of the missile control panel, a pedestal-mounted TV screen between the navigator's legs and a small side-stick controller on the right hand bank of rear seat switches. Squeezing in and out of the seat whilst wearing an immersion suit and all the necessary survival equipment and then having to put up with such cramped leg room makes even Ryanair seem luxurious.

Once the target had been selected by the navigator on his BLUE PARROT radar, the crew would home towards it at low level until the launch range, which was about 10 nm. At that point, the pilot would fire the missile, which would leave the aircraft and climb straight ahead to around 1,200-1,500 ft where it would cruise at about M0·75. Remaining at low level, the pilot then carried out a 60º/70º banked 4g turn through 120º onto the outbound track so that it was now tail-on to the missile, permitting the rearward facing pod to establish the data link – this was a fairly demanding manoeuvre at 100 ft and 500 kt, requiring a lot of concentration and practice.

During the mid-phase of the attack, while the missile was cruising inbound, the navigator could pan the camera in its nose from side to side and/or vertically to search for the target and/or to keep the missile below the weather. TV picture quality was hardly 'high definition' but, eventually, the target would begin to appear on his screen through the haze and, at the appropriate point, he would select 'Terminal Phase'. This gave him full control of the missile, permitting him to capture the aiming point by using the cross hairs that were driven by his side-stick controller. He would then track this point as smoothly as possible until impact. Picture quality improved as the missile neared the target and scoring a hit was never a problem! It is important to stress that at missile impact, the controlling aircraft would be some 15 nm away at very low level and well clear of the ship's defensive engagement zone.

Operational Employment

As in most ship strike scenarios, attack formations and tactics would be optimised to surprise, saturate and confuse the target defences. In an ideal world, we would have seamless tactical support and direction from a Nimrod, or a variety of other NATO maritime and airborne early warning agencies, updating us with current target information. However, if this deluxe targeting service was unavailable, we had to plan based on the last known information and be prepared to use dead reckoning and 'sniff out' the target using our



The TVAT.

own sensors.

Since the 1970s there have been a number of strategic systems that should be capable of locating, identifying and tracking major maritime targets, but in the event of war against a sophisticated opponent, these may not always be available for a variety of operational or meteorological reasons. Furthermore, targeting support aircraft may be prevented from staying on station if within range of enemy fighter cover.

Those of us who have been at the point of the spear, leading multi-aircraft attack formations with dated and rapidly decaying intelligence, at high speed, on critical fuel margins and in the extremely demanding weather conditions that can prevail in the northern Atlantic, will remember only too well the intense pressure involved in endeavouring to locate and positively identify the *correct* target. Tactics were practised constantly by day and by night and in all weathers to increase and maintain crews' confidence and efficiency.

The operation of both missile systems, including the TVM's target capture and terminal guidance procedures, were practised and tested in ground simulators to keep crews current. There was also an airborne TV trainer – the TVAT – essentially a TV camera slung under the wing. This allowed crews to simulate the launch procedure but then to continue towards the target, following the missile's flight profile, with the TV picture being fed to the navigator's display. Very prominent in this training were two wonderful characters, now sadly departed, Sqn Ldrs Jim Boyd and Paddy O'Shea, who had been the lead navigator on the JSTU.

There was also an airborne ARM trainer – the ARAM – which was, in effect, a radar seeker head on a dummy missile body fitted with a data recorder. This provided excellent training with operational applications and with the bonus of a comprehensive post-sortie intelligence analysis.

Attack formations could be adapted to suit the target and prevailing operational circumstances. For large targets, six aircraft would be employed – two ARM carriers, each with at least two missiles covering both radar band options, and each leading a pair of TVM firers. The ARM aircraft would search for and identify the target and then launch their missiles to suppress the defences, thus permitting the TVMs to be launched into a degraded hostile environment. While inbound, the TVM aircraft would execute programmed, and well-rehearsed, manoeuvres to confuse the defences before turning towards the target for the final run-in, launch and turn onto their escape tracks.

The TVM was tested in several successful in-service exercises, like MYSTICO, when it was fired against some of the Royal Navy's more senior vessels, until they sank, which was the case with HMS *Whirlwind* after Sqn Ldr Mick Whybro's first hit; similar results were obtained against target rafts in Cardigan Bay. The TVM remained in service until it was replaced by Sea Eagle in 1984. The ARM continued as the primary defence suppression weapon until the Buccaneer was withdrawn from service in 1994.

During the Falklands campaign in 1982 MARTEL was considered for operational use on both the Buccaneer and, as a special operational modification, on the Vulcan for attacks against an Argentinian radar near Port Stanley airfield. In the event, however, because of concerns over carriage, drag and fuel consumption, and possible collateral damage in the target area, the Vulcan actually used the smaller and well-proven American Shrike missile.

SEA EAGLE

As ship defences continued to improve and their associated engagement zones grew larger, TVM attacks became increasingly vulnerable. As a result, a new operational requirement was raised to replace the MARTEL system. The missile of choice, initially known as P3T, was developed by BAe Dynamics at Stevenage and Hatfield. I was posted to Operational Requirements in 1979 and took up a post in OR52 as the desk officer to see P3T through its development. I arrived three weeks before the project went before the Operational Requirements Committee for endorsement and I stayed with the programme until it entered flying trials in 1981. It was a fascinating assignment and I was privileged to attend the project meetings at Stevenage and watch the system evolve at first hand. One of my last

Sea Eagle (P3T)

Contractor	BAe Dynamics
Into Service	1984 (RAF)
Type	Anti-Ship Missile
Wingspan	3ft 11in
Length	13ft 7in
Diameter	16in
Weight	1,320 lb
Speed	Mach 0·85 (560 kt, 645 mph)
Range	60 miles
Propulsion	Microturbo TRI-60 turbojet 787 lb static thrust
Guidance	Active Radar Homing System
Warhead	505 lb Semi-Armour Piercing (SAM), impact delay-fused penetrating blast fragmentation

tasks was to staff its in-service name as Sea Eagle, which we thought most appropriate.

Missile Operation

Sea Eagle was similar in size to MARTEL and came in five main sections: seeker; guidance package; missile control systems; warhead; propulsion, in this case provided by a Microturbo TRI-60 jet engine, and fuel; and, finally, the control surfaces. As before, the interconnectivity was provided by umbilical strakes. Four cruciform wings, fitted to the fuel section, provided lift and aerodynamic stability.

However, this was a launch and leave missile and, after the relevant target data had been transferred to its inertial guidance system and it had been released, it became autonomous. Pre-launch, the navigator could select from several available targeting options – designated, nearest, furthest, left, right or largest. The Buccaneer could carry up to four missiles and the Sea Harrier and Tornado could each carry two. In all cases, the missiles could be set for a single, ripple or multiple launch.

On release, ram-air would fire up the missile's engine which comprised a three-stage axial flow compressor, a straight through annular combustion chamber and a single stage turbine. It was a relatively simple system, that had been extensively tested and had proved to be highly reliable, and it gave Sea Eagle a high subsonic cruising speed with a low infrared and smoke free signature. Once in flight, the missile would use its inertial system to follow a programmed launch trajectory and its radar altimeter to take it down to skim the waves at around 10 feet. As soon as the aircraft had released all of its planned missiles, the crew was clear to disengage.

When the missile reached the target area, it carried out a short pop-up and transmitted high frequency radar pulses in a narrow and powerful beam that provided early target acquisition and target discrimination. Sea Eagle also had state-of-the-art electronic counter-counter measures (ECCM) equipment that was programmed to deal with many of the known electronic counter measures (ECM) options that the targets might be able to employ to deceive or seduce the missile.

After lock-on, the missile was programmed to decrease its sea skimming height to ensure an impact close to the waterline. The warhead was designed to penetrate a ship's hull and then explode within the vessel to cause maximum damage to its fighting systems. With a very low radar cross-section and infrared signature and a sea skimming profile, Sea Eagle was a challenging target for any of the then current defensive surface-to-air systems.

Operational Employment

Between December 1984 and September 1986, as one element of an Avionics Update Programme to Air Staff Requirement 1012, some twenty Buccaneers were provided with a Sea Eagle capability. No 208 Sqn had become fully operational with the new missile before the end of 1986 and they were followed by No 12 Sqn during 1988. Designed to attack very high value targets, deploying comprehensive arrays of defensive weapons backed up by sophisticated ECM capabilities, Sea Eagle had to be a pretty smart missile. Nevertheless, from extensive mathematical modelling by our intelligence and operational analysis

A Buccaneer toting four Sea Eagles.

organisations, we had understood from the outset that we would need to employ large salvoes of missiles in order to guarantee success against such well defended targets.

Ideally, maritime targeting support agencies and aircraft would be able to provide the most recent and reliable target data. Air-to-air refuelling (AAR) was vital to cover targets at long range and planning a fully integrated maritime support package was always a complex procedure. In the Buccaneer era, when ARM was still an option, additional aircraft could be employed to help detect and pinpoint the correct target passively and then launch their ARMs for defence suppression. For Sea Eagle, a two-pronged attack by two sections, each of three aircraft, launching a total of twenty-four missiles would give the best results against a large Surface Attack Group (SAG). Aiming at the centre of the SAG would provide the optimum distribution of hits, given the expected spectrum spread due to system variances, wind and relative target dispositions. Attacks were planned to surprise, confuse and saturate the target defences with missile launch taking place at around 45 nm.

The introduction of Sea Eagle also heralded the return of night conventional maritime attacks which had been side lined due to a lack of suitable weapons in the early 1980s. As the Soviet fleets had little organic 'Red Air' with an effective night capability, the pendulum

A Tornado GR 1B of No 617 Sqn armed with a pair of Sea Eagles.

swung in our favour as long as the targets remained beyond the range of shore-based fighters. Although attack heights increased a little to compensate for the additional difficulties of operating in the dark, crews practised hard and soon regained their confidence and proficiency in night operations. In the winter of 1987-88 night flying for 208 Squadron was increased dramatically. This was not very popular with the wives, but it did allow the first night Sea Eagle six-ship attack formation to be flown on 17 February 1988.

On this sortie, using AAR and Nimrod Targeting Support, an attack against one of the Royal Navy's frigates well to the north west of the Hebrides was carried out very successfully. Completely radio and radar silent for the two-hour plus sortie, the attack element leads, simulating the launched missiles, managed to overfly the target at a 9 second interval. The Buccaneer's capabilities improved further once its recently installed inertial navigation system had settled down after some initial teething problems.[3]

Sea Eagle continued to arm the Buccaneer until that aircraft's retirement on 31 March 1994. The missile was then taken over by the Tornado GR 1Bs of Nos 12 and 617 Sqns who maintained the RAF's anti-shipping capability, enhanced by a more modern and capable navigation system. Sadly, in the late 1990s, defence cuts and a perceived weakened threat, led the MOD to dispense with the RAF's maritime attack role.

Apart from domestic use, Sea Eagle was successfully exported to India, where it was used to arm the Sea Harrier, Jaguar, Il-38 *May*, Tu-142 *Bear* and Sea King. It has also seen service on Saudi Arabia's Tornados and with Chile on the ENAER A36-M (a licence-built CASA C-101). Variants with a rocket booster pack were developed for launch from helicopters and surface platforms.

Of interest, as you might imagine, such a clever missile would not be cheap. During its development and production the numbers of missiles to be procured became a very sensitive subject; all operational studies pointed to an initial requirement for more than 2,000 rounds to meet current and perceived contingencies. But, as defence cuts were enforced, I spent much of my time re-evaluating the threat against the requirement with all agencies – primarily the Treasury – until the final fractional numbers were eventually procured. This reduction in numbers drove up the cost of individual missiles very significantly which, when considering the overall investment in project development and production, had made it an expensive, albeit effective, solution. Fortunately, the Berlin Wall came down and the threat evaporated – for a while.

NATO ASSM

During my time in Operational Requirements as the Sea Eagle desk officer, I also became part of Project Group 16. This was a NATO weapons group tasked with procuring an Advanced Supersonic Anti-Shipping Missile (ASSM). It was a very interesting scheme, a hybrid, reflecting the capabilities of all the then current and projected anti-ship missiles – but this one would have been on steroids. It would have sea skimmed at M2·5, corkscrewed for the final run-in and had an advanced seeker with a comprehensive ECCM suite – and, at the time, the seeker was already on the industrial test bench. Dual mode seekers, combining radar and imaging infra-red options were tabled as were advanced warhead and fusing options. This fascinating project saw me travelling around Europe and introduced me to the problems involved in working in an international NATO forum. Suffice to say that, after everyone had culled as much intelligence and expertise from the discussions and research as they could, the project was cancelled – a great shame, as I think that it could have been a world beater and it could have been used as a vehicle for many other applications.

ON REFLECTION

During the development of Sea Eagle, there was a sustained US campaign to try to persuade us that the McDonnell Douglas Harpoon was a better option. In my opinion, it was not, but better funding and increasing advances in cruise missile technology and navigation did lead to the very successful Tomahawk series of missiles. During the development of MARTEL and Sea Eagle, and several other missiles, British engineers and designers have devised some innovative solutions, evidence of their considerable technical expertise in the field of guided weapons, and shown that the UK's aerospace industry is capable of producing a successful product. More recent weapons like Storm Shadow, Meteor and Brimstone underscore this claim. It is a shame that we could not have found greater harmony within NATO and thus the will to invest funding jointly to produce a more receptive and larger and more economic market.

The poor state of the UK's economy, and the Defence Budget in particular, was influential in the withdrawal of the RAF's maritime capabilities. However, there can be little doubt that, as an influential island nation, the UK will always face a significant maritime threat. As such, we should always maintain and equip comprehensive forces to protect our coast lines, off-shore oil installations and our access to the vital sea lanes that carry our supporting lifelines and our export links to the rest of the world. Moreover, we need to counter any air, sub-surface or surface threat to our strategic assets. Once lost, current expertise and experience in this demanding role will take much time to reacquire.

Notes:

[1] Both now elements of MBDA (Matra, BAe Dynamics, Alenia), Europe's major guided weapons manufacturer, who assisted with the provision of video material used when presenting this paper at Hendon.

[2] As an air commodore Colin eventually became the Commandant at Boscombe Down; but sadly he died in 2014.

[3] My thanks to Wg Cdr Brian 'Boots' Mahaffey, OC 208 Sqn at the time, for this insight.

THOR AND THE RAF – POLITICS AND OPERATIONS

John Boyes

John Boyes has had a lifelong interest in military aviation – particularly Cold War missiles and nuclear issues – and the political backdrop of the early post-war era. He originally intended to join the RAF but was advised that chartered accountancy was a better bet. Having qualified, he spent his working life in the motor industry while serving for seventeen years in the Territorial Army Media Operations Group. He is currently Chairman of the Pen and Sword Club – a tri-Service group for those with defence media interests – Financial Controller of the Bomber Command Association and has been Treasurer of this Society since 2001.

The subject of the RAF's Thor missiles has already been given excellent coverage by Wg Cdr Colin Cummings in his presentation as part of the Society's seminar on the RAF and nuclear weapons held in April 2001, and available in Journal 26. I do not intend merely to cover the same ground again but rather instead to examine some of the political and operational issues that covered the four years when the missiles took their place beside the V-bombers as part of the UK's strategic deterrent. We start, however, somewhat earlier in the final phase of the Second World War.

At 7.28am on 8 September 1944 a new era of war witnessed its destructive opening. From a launch site near the Belgian town of Houffalize in the Ardennes, the German Army opened its ballistic missile offensive, Operation *Regenwurm*, against Allied city targets in Western Europe. Although the launch was successful, the missile never reached its target, in this case Paris, apparently breaking up when it re-entered the atmosphere. Greater success followed some three hours later when a second V-2 landed in the Parisian suburb of Maisons-Alfort. Some thirty people who were killed or injured in this attack have no specific memorial but they were the first victims of the ballistic missile age.

That same evening, at 6.34pm, London experienced its first attack when an explosion in Staveley Road, Chiswick destroyed eleven

A V-2 being prepared for launch from Cuxhaven in October 1945 as part of Operation BACKFIRE.

houses, killed three people and injured nineteen. Until the advancing Allied armies placed England beyond the reach of the German V-2 batteries, the population of south-eastern England was to experience directly the devastating effect of ballistic missile bombardment which left over 7,000 civilians dead. The V-1 flying bombs added a further 19,000 casualties.

There were no realistic countermeasures to this new weapon other than to locate the V-2s on their mobile launchers before they took off. But despite concerted efforts to locate and destroy them *in situ*, no operational V-2 was ever detected on its launch pad. Perhaps therefore it was not surprising that there was a keen interest to understand the operational aspects of this new weapon and Britain initially led post-war experiments when they set up Operation BACKFIRE. This used captured German artillery troops to launch three V-2s from the Krupp gunnery ranges at Cuxhaven. The purpose was to understand the complex launch process and to document this process fully by way of film and a five-part report. But this early British enthusiasm was to wane in a post-war world in which Britain found itself near to bankruptcy and involved in the complex negotiations to divest itself of its empire.

On the other side of the Atlantic, however, the US Army had gathered up a team of German rocket scientists headed by General Walter Dornberger and the pre-eminent expertise of Wernher von

Wernher von Braun, shortly after being taken into custody in Bavaria by the Americans; the plaster cast was a consequence of a recent car crash.

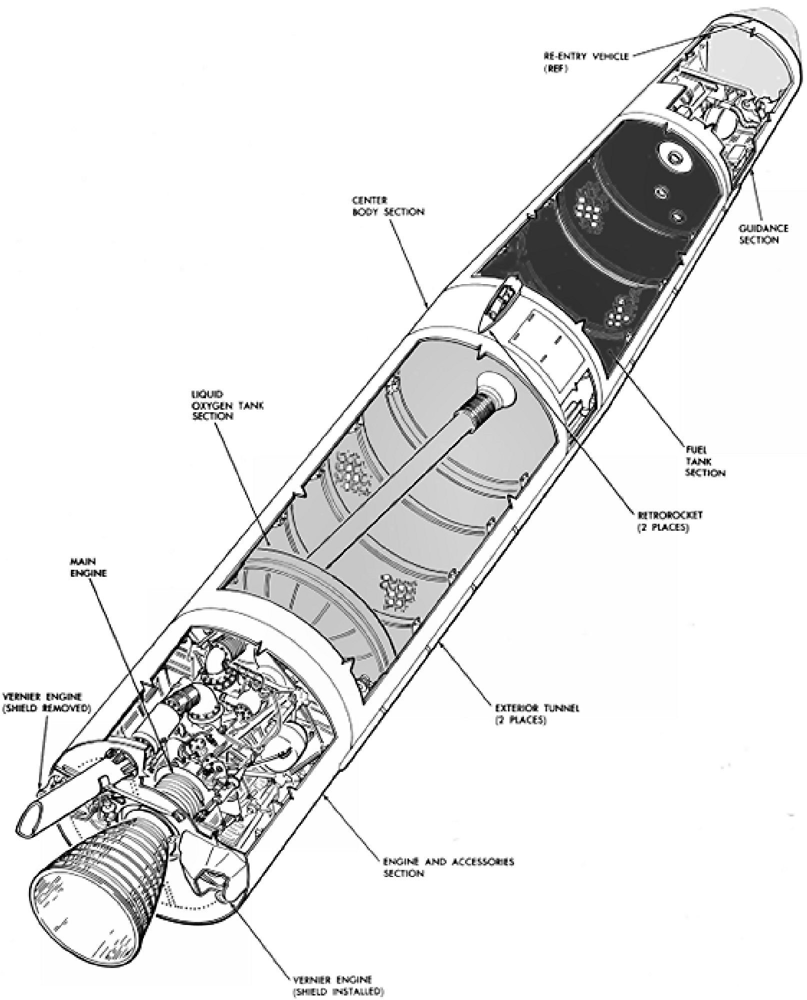
Braun who was later to take Americans to the Moon. This was despite the fact that Britain had wanted to detain the two Germans and charge them with war crimes. They set to work at the White Sands Proving Ground in New Mexico launching captured V-2s.

The US Army Air Force metamorphosed into the United States Air Force in September 1947 and was preoccupied with creating a coherent strategic force through Strategic Air Command and its fleet of new jet-powered bombers. Recognising, however, that the day of the manned bomber would eventually pass as enemy air defences became ever more effective, low key discussions on ballistic missiles had continued and by 1952 had evolved into a contract with Convair to build a full blown Intercontinental Ballistic Missile (ICBM) which would be called Atlas, a complex project that it was estimated might take ten years to bring to fruition. But a wary eye was kept on the Army's progress. Von Brauns' team was developing the Redstone missile and seemed keen to secure the middle ground of the battlefield or even beyond.

In 1954 General Bernard Schriever was put in charge of the Air Force's newly formed Ballistic Missile Division. He was one of the few men to stand up to SAC's General Curtis LeMay – and survive. Whilst conscious of what the Army's aspirations were, he believed that with limited resources available the ICBM program should not be diluted by a shorter range, 1,500 nm weapon that would, in any case, have to be based in client countries within range of Soviet targets. One lasting problem at this stage was the size and weight of thermonuclear weapons which complicated any thoughts of mounting them on missiles, but there were assurances that this problem would soon be overcome as lighter warheads became available. With these thoughts in mind, approaches were made to Britain to see if, with US support, a British Medium or Intermediate Range Ballistic Missile (M or IRBM) could be developed. However, a visit by the US Aircraft Industries Association determined that the UK had insufficient resources, particularly in respect of computer power. The most suitable computer that the delegation found was the one that ran the stock control for Lyons Tea Shops. Nonetheless, it was agreed that a British MRBM would go ahead with US support. This support was later to evaporate as the Americans saw the project as an unnecessary diversion from more useful projects.

Increasing uncertainty as to what the Soviets might be doing, and a lack of decision as to whether the air force or the army, which was developing its own Jupiter IRBM, would be given the IRBM role, sparked a conflict which was to see a bitter internecine confrontation between the two services. Schriever reluctantly supported an air force IRBM programme and the contract was duly placed with the Douglas Aircraft Company in December 1955. Due to a misunderstanding at the tender process, the missile had no name but Joe Rowland of the Glen L Martin Aircraft Corporation came to the rescue. When Martin tendered for the ICBM contract their Titan design was adopted. Thor had been their alternative name and as this was no longer needed, Rowland offered it to Douglas.

Thor was 65 feet long, eight feet wide and, fully fuelled, weighed in at around 110,000 lb. Fuels used were a fairly conservative RP-1 kerosene and liquid oxygen. But the Rocketdyne MB-3 engine was a fearsome and impossibly-powerful unit, whose thrust-to-weight ratio was about 70:1, and had a working life of about 3 minutes. Inertial guidance was by way of an AC Spark Plug Achiever unit which had already proved itself in the Mace and Regulus 2 missiles. The warhead was a 1·44 kiloton thermonuclear device delivered in a Mk 2 re-entry vehicle. From the start the decision was made to build the missile under the concurrency concept, unlike the US Army’s Jupiter which was developed under more conventional lines. Concurrency meant that all aspects of the development programme, manufacture, testing, infrastructure and training ran in parallel with no prototypes being developed first. All missiles and their associated equipment was built



The internal structure of a production-model Thor.

on production jigs to productions standards from the outset. This was a risky, and at times inefficient, way of doing things but was considered essential to minimise the time taken to field an operational missile. Another parameter was that the missile was not to be a scaled-down Atlas as any problems with the larger missile would risk duplication in the smaller one. The one compromise was the use of the same engine in both Thor and Jupiter and when a flaw was discovered in the turbopump, both missiles were, for a time, affected.

The new technology of the missile age required a new order of skill particularly in the machining tolerances required for the inertial guidance system. Aero-engine machinists, accustomed to working at 1,000th's of an inch, were now required to work to a micron. The traditional machinists began to crack up with the stress of what they were attempting to do. So Douglas recruited 16-year old schoolgirls who didn't know what a micron was, showed them what to do and they just did it.

The first Thor, essentially built to basic production standards, was delivered to the USAF's Eastern Test range at Cape Canaveral in October 1956, a mere ten months after the signing of the contract. Unfortunately, technical problems delayed the initial launch until 25 January 1957 but this attempt ended in an ignominious failure when the missile exploded on the launch pad. Such failures were typical of the early days, as technology had been pressed to the limit and sometimes beyond it. It was not until October 1957 that a success could be claimed when the ninth Thor, albeit stripped of all but the bare essentials, flew downrange a distance of 2,350 nm.

Unofficial discussions had taken place behind the scenes to explore the UK's willingness to accept US missiles on British soil and these were advanced in July 1956 when US Secretary of the Air Force, Donald Quarles, visited the UK and in the ensuing discussions, raised the question at an official level. However, whatever harmony may have existed at this stage disintegrated when Britain and France invaded the Suez Canal Zone in October. The US was furious that Britain had not given advanced warning of its actions and this resulted in an all-time low in relationships between the two countries. Russia threatened nuclear retaliation, the first time they had done this, and while they were at it, took the opportunity to suppress the Hungarian uprising. The resulting humiliation cost Prime Minister Anthony Eden his job, leaving his successor, Harold Macmillan, to repair the damage.

Macmillan had been a wartime colleague of President Eisenhower in North Africa and the two friends met at a conference in Bermuda in March 1957. This led to the provisional agreement by which Britain would be supplied with IRBMs for use by British forces, the type not at this stage specified. But by this time progress on the Atlas ICBM was encouraging and some still felt that the shorter range missile may not be needed. The initial discussions had sparked an idea of an attractive *quid pro quo* trade-off for the possible acquisition of advanced US fighter aircraft for the RAF. The Gloster Javelin was proving troublesome and US financial support for 177 aircraft, which were to have been provided under an offshore purchase agreement, had been withdrawn. The alternative that was initially considered was Convair’s F-106B two-seater, but Convair was under considerable pressure to complete its contracts for the USAF, let alone anyone else. Attention then turned elsewhere in North America, to the Avro Canada CF-105 Arrow. Despite some promising discussions with the Air Ministry both proposals came to nought, indeed the Arrow suffered a fate not dissimilar to that of the TSR-2 when it was summarily cancelled in 1960.

Just before the Bermuda Conference, Duncan Sandys had presented to parliament his White Paper ‘Defence: Outline of Future Policy’. The future, as he saw it, lay in missiles, both offensive and defensive and the agreement on the supply of IRBMs fitted the bill perfectly as it would give Britain some initial experience before BLUE STREAK entered service in the mid-1960s. Notwithstanding all this preamble, one further event was needed to seal the deal absolutely and for this we have to look east. On 7 October, from a site deep inside Kazakhstan, the Soviet Union launched the world’s first artificial satellite, Sputnik 1. Despite some prior intelligence of the event, America was paralysed by the tiny bleeping sphere. This was no time to consider cancelling defence arrangements. IRBMs *would* come to Britain.

The project gathered considerable momentum thereafter with the Americans wanting to deploy the first units during 1958. Parliament was not told officially until February 1958 with the publication of the Thor Agreement, somewhat vaguely titled ‘Supply of Ballistic Missiles by the United States to the United Kingdom’, which did not at this stage even confirm that it was Thor rather than Jupiter that would be supplied.

The American concept envisaged two large bases with sixty missiles each, but the RAF wanted more widely dispersed sites in order to increase the number of Soviet warheads needed to neutralise the force. After much discussion, the deployment was agreed – sixty missiles would be dispersed across twenty sites, organised as four wings, each of which would administer five sites identified by squadron number plates. It was initially proposed that the first two sites, would be US-manned, but would eventually be handed over to the RAF, along with the others, when trained British crews became available. Clearly the Americans had chosen to overlook the fact that it had been agreed in Bermuda that the missiles would be 'for British forces'. Furthermore, with an emergent nuclear disarmament lobby playing an increasingly prominent role at the time, American involvement on such a scale was too politically sensitive for the British, who were already having to justify a considerable US presence.

But where to put the missiles? There were, on the face of it, plenty of options – left over bases from the Second World War. Surveys were undertaken in relative secrecy and an initial plan drawn up. Radar scatter in the Yorkshire Dales was considered to be a potential hazard and potential sites in North Yorkshire were replaced by a group based on North Luffenham, although the Polebrook site was only approved after the Duke of Gloucester, who lived nearby, raised no objections. Feltwell, with its close proximity to the US base at Lakenheath, was selected as the first site and it became, in effect, the prototype for the other nineteen

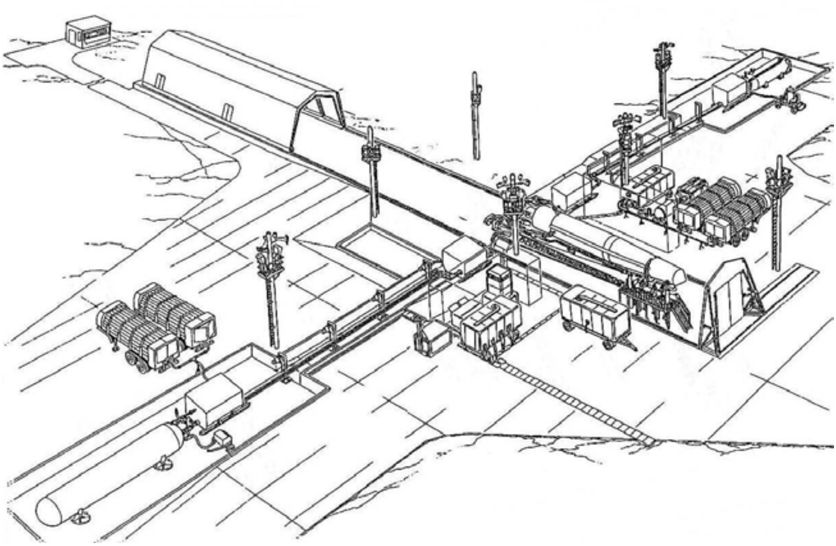
By midsummer 1958 the first group of American contractor personnel were crossing the Atlantic to start commissioning the bases. Contracts had been placed with British civil engineering firms to build the basic infrastructure at the twenty sites and thereafter the American technicians were to take over and install the equipment. Most of this was flown across the Atlantic from California on the so-called 'Thor Hauls' using C-124 Globemasters later joined by C-133 Cargo-masters. One of the design parameters for Thor was that it had to be able to fit inside these aircraft. Because of the need to air lift many of the components, it has been believed by some that Thor was envisaged as a mobile weapon, much like the German V-2s, but this was never the case. The Launch Emplacements were sturdy, permanent structures and, although much of the equipment was mounted on wheeled chassis, this was only to assist in its air transportability.

A Thor project office was set up in the Air Ministry and Rowland Hall who, after serving in the Royal Navy had studied architecture and civil engineering before joining the Air Ministry's Directorate of Works, set about drawing up the site plans. The US 7th Air Division handled the American aspects of the project in the UK and their Colonel Woodruff T Sullivan occupied an adjacent room, his main function being administration and sanctioning what the RAF was achieving. One day he came into Hall's office and, having decided that the project needed a name, asked Hall if he had any ideas. On the wall of the office was a calendar with a scantily clad female of a genre that was much in vogue at the time. Her name was 'Emily'. Colonel Sullivan asked to borrow the calendar and that is how Project Emily – the deployment of Thor missiles to the UK – got its name. It had nothing to do with the entirely separate Project 'E' under which the US made nuclear weapons available to the RAF.

Initially it was decided that, in order to alleviate accommodation problems, only single American men and women would be seconded to the project, but the required skills often lay with married individuals and families therefore had to be accommodated. Many were housed in caravans – or trailers in American parlance. Locals soon became accustomed to a signpost to 'Santa Monica in the Wolds'. Most adapted well to the English way of life, enjoying a game of darts in the local pub whilst eating jugged hare washed down with warm beer but there were inevitably some labour problems.

Nevertheless some lasting friendships were forged and when the Americans returned home a number were accompanied by English wives – the so-called 'Feltwell Wives Club'. Most of the Americans were in their twenties and had been accustomed to working long hours, including weekends, on the project back in California. Every Friday a progress meeting took place in the Air Ministry. This started mid-morning after coffee, broke for lunch and concluded mid-afternoon with tea and biscuits. Frustrated by what he saw as a lack of progress, one of the Douglas staff suggested that everyone might meet again the following day to move things forward. An incredulous RAF officer informed him, somewhat firmly, that 'we're not at war you know' as he headed for his staff car and his weekend.

Like the missile themselves, there were upgrades to the launch complexes and, without the advantages of computer communications,

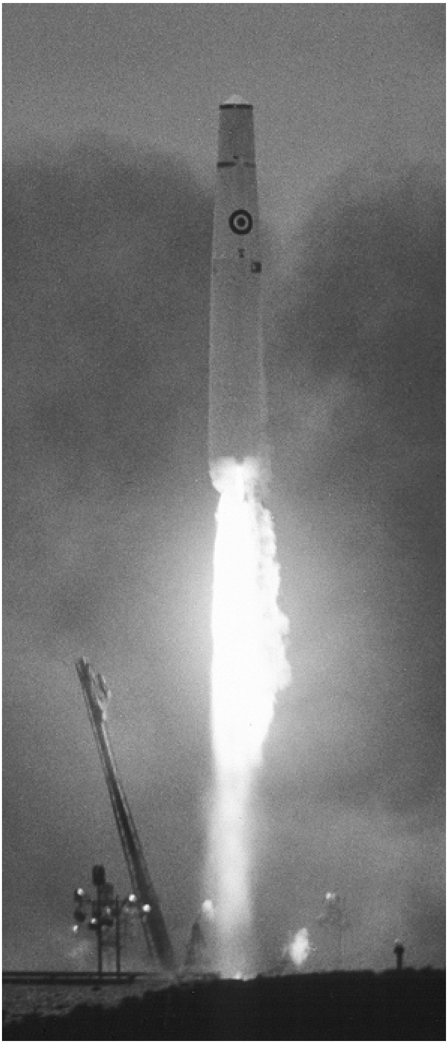


The layout of an operational Thor emplacement. There were sixty of these in the UK, grouped in clusters of three, most of them on airfields that had been abandoned since shortly after WW II.

disseminating upgrades to all twenty sites was complicated and not always fully reported. An inter-site taxi was provided in the form of a Dragon Rapide. Nonetheless what was achieved by the joint efforts of two air forces and a variety of contractors was a remarkable tribute to Anglo-American co-operation. By the beginning of 1960 all twenty sites were fully operational and all had been assigned their squadron identities with the COs ranked as squadron leaders.

Each site had three launch emplacements, solid structures protected by two 'L'-shaped blast walls, but most of the equipment was contained in trailers. Two tanks contained the fuel and liquid oxygen. A separate area was a hardstanding for the launch control trailers. In a separate compound were the two US-controlled buildings, one for warhead storage and one for the pyrotechnics used on the missile. Three shifts covered each twenty-four hour period under the command of a flight lieutenant Launch Control Officer.

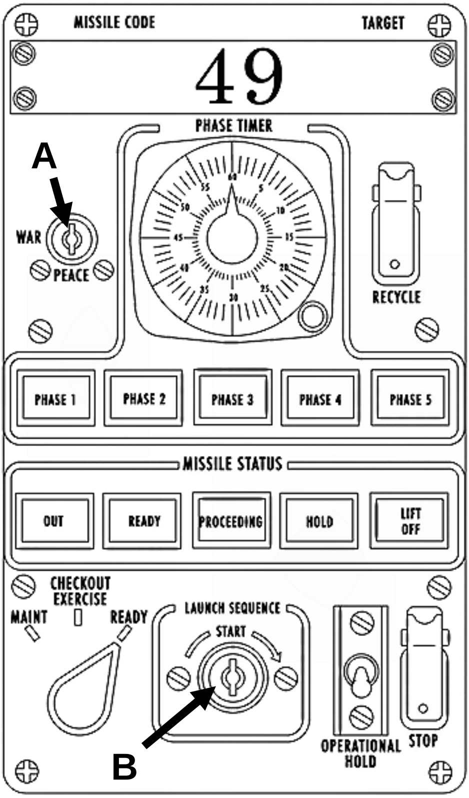
While construction of the bases had been taking place, training of the launch crews was underway at various locations in America. Some 1,200 RAF personnel acquired the skills to look after and launch the



In all, the RAF participated in the launch of twenty-one Project Emily Thors from Vandenberg, the last five (of which this is the first, on 20 June 1961) being handled exclusively by RAF personnel.

missiles and a select number of those undertook live launches from Vandenberg Air Force Base. The first of a series of nine Integrated Weapons System Tests was, suitably enough, codenamed LIONS ROAR and took place on 16 April 1959. A further series of twelve Combat Training Launches (CTL) tested launch crews' proficiency under mock combat conditions. From CTL-4, onwards missiles from the RAF's inventory were flown back to Vandenberg to assess how well they had withstood the rigours of the British climate and repetitive count-downs. An encouraging level of accuracy in reaching the target was demonstrated by these launches.

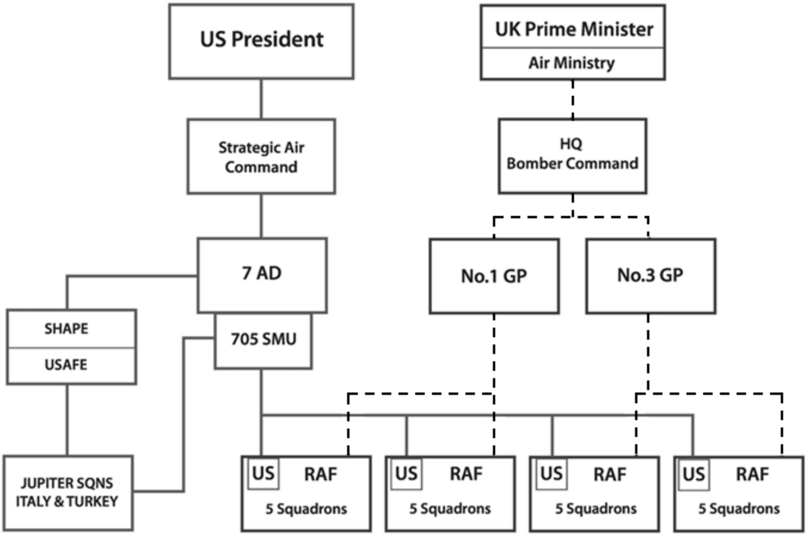
The first RAF Thor was flown into Lakenheath, without ceremony, on 29 August 1958, but its arrival at Feltwell was shown to the press on 19 September. Well known investigative journalist Chapman Pincher had somewhat pre-empted this ten days earlier with his *Daily Express* scoop, 'No 1 Rocket Site – First Picture' showing a photograph taken from outside the fence. He was, however, wrong in



The Launch Control Panel, with the USAF- and RAF-controlled keys slots marked A and B respectively.

his claim that the warheads were there as well. From the start, there had been pressure from the US to declare the missiles operational, a move resisted by both the Air Ministry and the Chiefs of Staff, partly because there was still resistance to the project and partly because the five-year support agreement did not actually start until the missile was considered to be operational by both parties. The British contended, with some justification, that at this stage it was not, if for no other reason that there were no warheads in the UK. The warheads presented problems because US and British safety standards were different and the reception and onward movement of the warheads to the bases required considerable safety planning, not least because the UK was not immune to the terrorist threat from across the Irish Sea. In fact the Feltwell Wing was not declared operational until July 1959 with the fourth, at North Luffenham, just slipping in by the end of the year.

Protection, for both nations, against a rogue unilateral decision to launch was provided by a dual-key arrangement. The RAF key started the countdown but only the US key – held by a USAF Authentication Officer, could arm the warhead when he turned the setting from ‘Peace’ to ‘War’. However, as the accompanying illustration shows, both key slots were on the same panel, so one person could turn both



The complexity of the international chain of command involved in authenticating the dual-key release of a nuclear-armed Thor.

keys – or, indeed, just use a screwdriver. Furthermore, the dual key arrangement involved a complex and lengthy chain of command in the event of a launch order being given. Would it have worked in the short time that was possibly available?

By 1960 the first Atlas and Titan ICBMs were operational which meant that, from a US perspective, Thor was arguably redundant. But there was another factor. Alongside the ballistic missile version another Thor variant had been successfully launching a series of satellites declared to the public as the DISCOVERER research programme. They were, in fact, part of the secret Project CORONA, the first generation of reconnaissance satellites and an increasingly valuable intelligence asset once the high-flying U-2 had become vulnerable to surface-to-air missiles – the Gary Powers incident of May 1960.

The USAF needed more launch vehicles and attention turned to the 64 missiles in the UK. The US Defense Secretary, Robert McNamara, had informed Peter Thorneycroft that the Thor agreement would not be extended beyond its fifth anniversary – 31 October 1964. However, this was too long for the Americans to wait and behind the scenes negotiations took place to bring the matter to a close much earlier. The first of the RAF's Thors was repatriated on 9 October 1962, just as the US was becoming concerned about what was going on in Cuba.

The ensuing Cuban Missile Crisis has been well covered in the Society's Journal No 42, but suffice to say that fifty-nine, and for a brief period, all sixty Thors were at fifteen minutes' readiness to launch – very much the routine situation on the sites in any case. It would appear that some squadrons brought the countdown to T minus 8. In his post-crisis analysis Air Mshl Cross, AOCinC Bomber Command, was generous in his praise of Thor and the ease with which the squadrons transitioned to a high alert status. How many would actually have lifted off successfully and how many of those would have reached their target is debatable but by then confidence was high, based on the Vandenberg launches – and there is every reason to suppose that, if called upon, Thor would have performed well. By April 1963 all of the missiles had been returned to the US and were put to use in a variety of air force programmes, including live nuclear tests from Johnston Island in the Pacific. One remains at Vandenberg preserved as a national historic landmark. And Thor's descendants are still used as launch vehicles to this day.

The missile did have its weaknesses: above ground it was dangerously vulnerable; the chain of command was complex; once launched it could not be recalled and it fought an unequal battle against the manned aircraft lobby. In the final analysis it had both supporters and detractors on both sides of the Atlantic as these comments show.

> 'The Thor program in the UK was entirely political; there was no military requirement for it and the RAF had never wanted it.' *General Curtis LeMay*

> 'The Thors [*have*] not only been a military success, but perhaps even more important, it has demonstrated how two nations with similar beliefs can work together. British and American people are not war-like. They believe in justice and in peace. The Thor has been the guardian and the symbol of our intention to defend that peace.' *Air Marshal Sir Kenneth Cross.*

AIR-TO-AIR MISSILES – THE FIRST 30 YEARS

Wg Cdr Andrew Lister-Tomlinson

Andrew joined the RAF in 1972 and, having trained as a navigator, spent his first three tours on Phantoms with No 892 NAS, No 19 Sqn and No 228 OCU before moving on to the Tornado with No 229 OCU and the Operational Evaluation Unit. He was subsequently involved in the further development of the Tornado F3, trials work, lecturing at Cranwell and a tour with the Air Warfare Centre at Waddington. His final appointment, prior to retirement in 2009, was as the UK Operational Test & Evaluation Director for the F-35 programme.

The Provision of Missile Trials Facilities

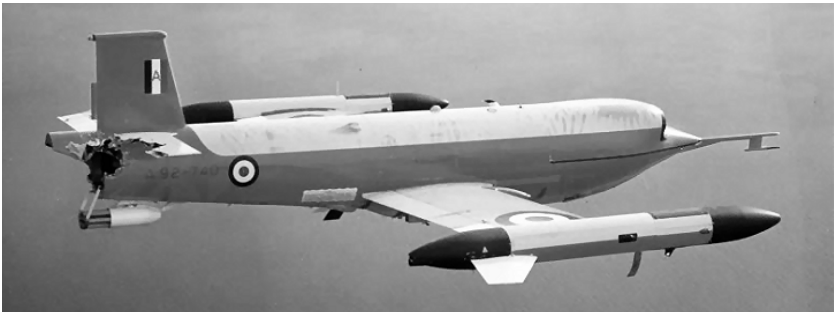
Aberporth Range. By the 1950s, it was clear that dedicated facilities would be required in order to test and develop the forthcoming first-generation missiles, both air-to-air and surface-to-air. The site selected was a pre-existing gunnery range at Aberporth which had been established in 1939 at an Army camp that had been set up at Pennar Uchaf Farm in the 1930s within which the range head was established. In 1940 a grass airfield was laid out and the Projectile Development Establishment moved to Aberporth from Fort Halstead to continue its experimental work. While the airfield was initially used quite extensively in support of the weapons range's work in Cardigan Bay, military activity conducted from there declined after the war. While it continued to handle occasional movements, the airfield was reduced to a care and maintenance basis until 1951 when responsibility for its operation was transferred to the Royal Aircraft Establishment (RAE), with a hard-surface runway being provided in 1955.

By 1954 a new Operations Room had been built at the range head and, with Llanbedr providing facilities for the operation of pilotless target drones, trials of increasing complexity were being carried out on the Range. By the early 1960s sophisticated tracking radars had been provided, along with more comprehensive telemetry to support the development of increasingly complex missile projects.

The first target drones were Fairey Firefly U8s. this one, WM890, was 'lost on operations' on 1 November 1957. (R A Scholefield)

Llanbedr Airfield. Llanbedr airfield opened in 1941 and until 1958 its primary function was the provision of towed target facilities and, during the war, the hosting of squadrons detached for armament practice camps. From 1954 onwards Shorts had begun to operate pilotless target drones from Llanbedr under contract to the RAE. The first of these were Firefly U8s, converted from T7 airframes. Since it lacked adequate performance, the Firefly began to be supplemented by Meteor U15s converted from surplus F4s. The first example was delivered in January 1957 but it was July 1958 before pilotless flights began. From 1960 onwards the Meteor U15s were joined by U16s, which was a similar conversion based on the F8.

This early drone work had represented a somewhat makeshift approach, however; what was really needed was a purpose-built target and one was already under development, as the Jindivik,[1] to Specification E.7/48 that had been issued to the Australian Government as early as March 1948. An upgraded version, to Specification U.22/49, flew in 1953 and the first batch of a production model, the Mk 102, was ordered in 1955 but it was June 1960 before the first flight was made in the UK. Many more would be delivered and Jindiviks were still flying from Llanbedr when the airfield closed more than forty years later. Jindivik was not the only pilotless target used by the UK; others included the Chukar and Shelduck, but the most impressive to be operated from Llanbedr and elsewhere was the Beech AQM-37 Stiletto supersonic (Mach 2+ and well above 60,000 ft) drone that was air-launched from Canberras.



A Jindivik following an engagement with a Sidewinder training round that had ignored the towed flare and gone for the jet pipe instead.

Meanwhile, in 1992, having operated as an RAE Detachment for many years, during which it had also been a designated V-Force dispersal airfield, the facility was renamed the Test & Evaluation Establishment, Llanbedr, but only three years later it became the Defence Test & Evaluation Organisation, Llanbedr. It was latterly the Defence Evaluation and Research Agency (DERA), Llanbedr but DERA was largely privatised in 2001, with the major part becoming QinetiQ plc, and trial operations from Llanbedr ceased in October 2004.

The Missiles

Fireflash

Development of air-to-air missiles (AAM) started towards the end of WW II with renewed interest in the West at the beginning of the Cold War as the Soviet manned bomber threat intensified. The original British requirement was for a ‘tail-chase’ missile with a warhead large enough to ensure a high kill probability and with sufficient range to permit the launching fighter to remain outside the range of the target’s guns. In May 1949 the Fairey Aviation Company at Heston was contracted by the Ministry of Supply to develop a beam-rider missile, initially code-named BLUE SKY, which would eventually become Fireflash.

Fireflash materialised as an unpowered dart, which was boosted at launch by a pair of solid-fuel rocket motors. The motors had slightly offset thrust lines which caused the missile to rotate during the powered phase, cancelling out any asymmetric difference in thrust between the motors and providing a degree of spin stabilisation. On

A Fireflash trial round mounted on a Meteor NF11.

burn-out, after 1-2 seconds and at Mach 2+, the spent motor cases were explosively separated, leaving the dart to decelerate while coasting towards its target. At the same time, the missile's four fins, which were indexed at 45º to the cruciform wings and worked as interconnected opposed pairs, were unlocked. The launching aircraft had a conical scan radar and the pilot was required to keep his gunsight trained on the target throughout the engagement, the bore-sighted axis of the rotating transmitted radar signal representing a 'beam'. The dart had a receiver, tuned to the fighter's radar transmissions, in its tail. If the received signals fluctuated in amplitude the missile was not 'on the beam' and its guidance system was able to sense the error and use the control surfaces to reduce this to zero, a steady null signal indicating that it was now 'riding the beam'.

While Faireys were the lead contractor for BLUE SKY/Fireflash, any project of an advanced nature is a major undertaking which may involve extensive industrial collaboration. In this case, for instance, Faireys, acknowledged the assistance it had received from Gloster, Armstrong Whitworth, Hawker, Air Service Training, Vickers Supermarine, Plessey and E K Cole along with the Ministry of Supply's technical establishments – the RAE Farnborough and Westcott, the RRE at Malvern and ARDE at Fort Halstead.

A Fireflash-armed Swift F7 of the Valley-based Guided Weapons Development Squadron.

Beginning in 1951, while the rocket motors were being tested at Larkhill, initial flight tests were conducted by Faireys using Meteors operating from Cranfield to drop inert missiles over the Wash ranges to certify safe separation and jettison characteristics. With that phase complete, the trials team relocated to Valley in 1952 to commence live firings over the Aberporth Range. To handle Ministry of Supply acceptance trials No 6 JSTU was formed in the summer of 1954 and by January 1955 it too was operating from Valley. The first successful live firing, against a Firefly drone, was achieved by a missile launched from a Meteor NF11 on 21 June 1955. While many more missiles would be launched in the UK, some were also fired at Woomera.

In 1957, following the issue of a formal Release to Service for Fireflash, the Guided Weapons Development Squadron was established at Valley to conduct further practical trials in an RAF environment. Operating under the auspices of the Central Fighter Establishment, the unit was equipped with ten Swift F7s, the essential beam being generated by the conically-scanned, X-Band, Radar Ranging Mk 2, with which many successful firings were made. Some thought was given to deploying the Swift/Fireflash combination in the

A Firestreak being loaded onto a Javelin of No 25 Sqn.

bomber destroyer role but it was never a serious contender as it was soon to be eclipsed by the far more flexible and capable Firestreak AAM. Nevertheless, Fireflash had achieved the significant distinction of having been the first AAM to enter service with the RAF.

Firestreak

While much had been learned from the Fireflash programme, it was clear that beam-riding guidance had severe tactical limitations. The ideal would be a fire-and-forget missile and the first attempt at such a weapon was BLUE JAY, later named Firestreak. The project began in 1951 and was led by de Havilland Propellers. Firesteak had a conventional missile airframe with cruciform wings just aft of the mid-section and four moveable tail surfaces operating as two interconnected pairs. The most significant advances, compared to Fireflash, were an integral rocket motor and infrared (IR) guidance. The lead-tellurium seeker was protected by an eight-faceted arsenic tri-sulphide ‘pencil-nib’ nose and cooled by anhydrous ammonia to improve detection performance. There were two rows of triangular windows in bands around the forward fuselage behind which were the optical sensors for the proximity fuses. The 23 kg blast warhead was

RED TOP on a Lightning.

fitted at the rear of the missile, wrapped around the exhaust of the motor.

Live firings, from Venom NF2s, began in April 1953, eventually leading to a Firefly drone being destroyed on 5 (or 29?) September 1955. As with Fireflash, later trials were conducted at Woomera but, with the rundown of the Fireflash programme, in 1958, Valley's Guided Weapons Development Squadron had dispensed with its Swifts and, re-equipped with Javelin FAW7s. With these it began work on a similar three-year programme to introduce Firestreak into service.[2] Although it was confined to rear aspect attacks and was unable to cope with operations in cloud, Firestreak represented the state of the art and was an effective weapon for its day. It was the first AAM to enter operational service with the RAF and FAA, arming Javelins, Sea Vixens and Lightnings from 1958 until the latter were retired in 1988.

RED TOP

De Havilland Propellers (which was absorbed into the Hawker Siddeley Group in 1960) continued to develop its basic BLUE JAY concept and by 1956 it had begun work on a Mk 4 version. While originally conceived as an upgraded Firestreak, the eventual missile was so different that it was given a new code name – RED TOP. While it retained the same overall configuration as Firestreak, RED TOP had a more powerful motor, was faster, more manoeuvrable and, at 7+ miles, had almost twice the range of its predecessor. It also had a much heavier, 31 kg, warhead and an improved IR seeker which was said to be sensitive enough to be able to carry out a head-on attack against a supersonic target, although, as with all IR guidance systems, it was still unable to cope with cloud. Further improvements,

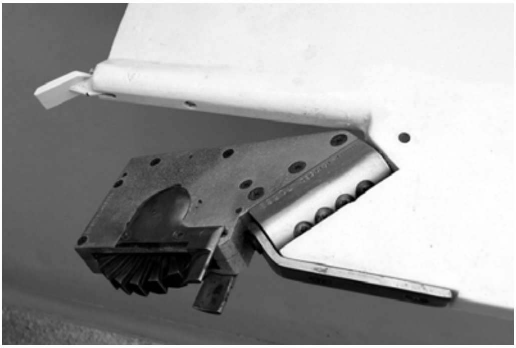
RED TOP on a Lightning.

including a true 'all aspect' IR capability, and a BLUE JAY Mk 5, which would have replaced IR guidance with semi-active radar homing, were not pursued. RED TOP entered service in 1964 and armed Sea Vixens and Lightnings until 1988 when the Lightning was withdrawn from service.

AIM-9B Sidewinder

The Sidewinder evolved from an investigation that began shortly after WW II at, what is today, the Naval Air Warfare Center Weapons Division at China Lake, into the feasibility of mounting a heat-seeking sensor on a 5-inch rocket to create an IR homing missile. The project eventually attracted US Navy funding in 1951 and two years later the missile was assigned the designation AAM-N-7. It entered service in 1956, by which time the Sidewinder had already demonstrated its superiority over its USAF-sponsored equivalent, the GAR-2 Falcon, and in 1955 the USAF was obliged to order large numbers of Sidewinders as the GAR-8. With the imposition of a joint-service designation system in 1962 all Sidewinders became AIM-9s. After a disappointing showing in Vietnam the USAF withdrew the AIM-4 Falcon in favour of the AIM-9.

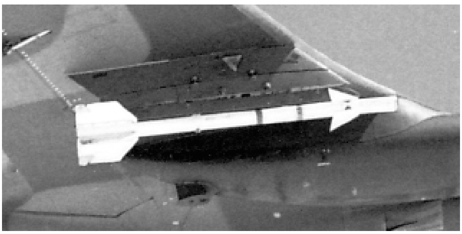
Sidewinder's seeker, which was housed in 2½" glass dome nose window, used an ingenious Cassegrain reflector in conjunction with a tilted secondary mirror. The secondary mirror rotated in unison with a reticle and projected its field of view through the reticle onto a filter/IR detector assembly. The effect was analogous to a conical scanning radar seeker. The AIM-9B employed an uncooled lead sulphide IR detector and was strictly a tail-chase weapon because its



The serrated disc is the Sidewinder's innovative 'rolleron'. Spun by the airflow (at Mach 2+) it became a de facto gyro and, if the missile began to rotate, the stabilised section of the fin was deflected (as here) and thus exerted an aerodynamic force to counter and cancel the spin.

seeker was not sensitive enough to detect anything cooler than a hot jet tailpipe. Four canard fins operated as two pairs of inter-connected control surf-aces to manoeuvre the missile. Unlike other contemporary missiles, Sidewinder did not employ active roll stab-ilisation (ie it did not use gyros and differential control inputs fed to the missile's fins). Instead, it used novel 'rollerons', slipstream-spun metal discs embedded in the trailing edge of each of its four fins. These acted as small gyros which prevented the missile from spinning (which would have disrupted the guidance system).

The UK first acquired Sidewinders, AIM-9Bs, in1958 to arm RN Scimitars. When the Scimitar was withdrawn from service its missiles were passed on to FAA Buccaneers which then found their way into the RAF when HMS *Ark Royal* was de-commissioned in 1978. While the AIM-9B was not withdrawn until 1992 its capabilities were relatively limited compared to later models of the Sidewinder which, so far as the UK was concerned, began with the AIM-9D which entered service in 1968 with the acquisition of the F-4 Phantom.



An AIM-9B Sidewinder on an RAF Buccaneer.

Sidewinder AIM-9D/G

The most important change in the second-generation Sidewinder, the US Navy-sponsored AIM-9D, was the use of a nitrogen cooling system for the lead sulphide IR detector element, coupled to a redesigned optical system. The new optics retained the tilted Cassegrain mirror arrangement, but was more compact and spun at 125 Hz, compared to the 70 Hz of the AIM-9B. The hemispherical glass nose was replaced by an ogival magnesium fluoride dome, providing better transparency to longer wavelength (ie lower temperature) IR emissions. The coolant, which was contained in a 6-litre bottle within the LAU-7 launcher, provided up to 2½ hrs of cooling time. The new seeker, which allowed a higher target tracking rate, and improvements to the fin actuator system, enhanced manoeuvrability, while a new rocket motor, a Hercules Mk 36, made the missile both faster and longer ranged (of the order of M2·5 and 18 km compared to the M1·7 and 5 km of the AIM-9B).

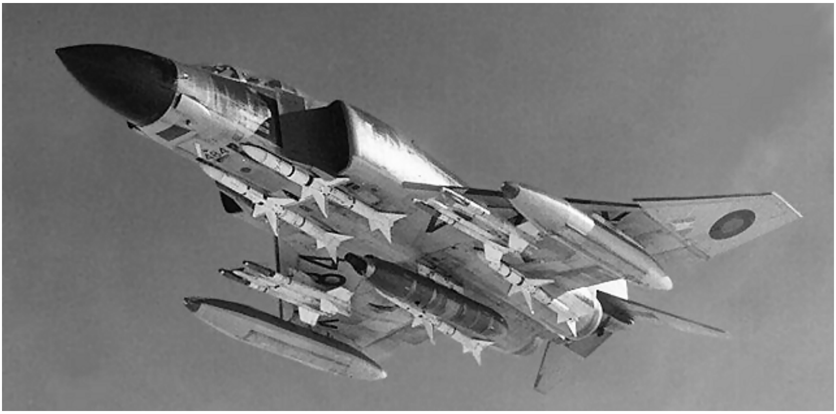
Changes were also introduced to fusing, with the options of IR or radio-frequency proximity fuses, which detonated a new continuous rod warhead. Continuous rod warheads were wrapped around the body of a missile in the form of a band of lengthwise rods welded together at alternate ends; on detonation the rods expand into a ring about the missile finally breaking up to create a circle of fragments about the axis of the weapon. These rods slice into the target on contact. All of these changes made the AIM-9D a far more capable missile, its much wider engagement envelope and enhanced performance and manoeuvrability conferring a much higher kill probability.

The AIM-9D was succeeded by the very similar AIM-9G variant, which featured the so-called Sidewinder Extended Acquisition Mode (SEAM), a facility which allowed for the missile optics to be slewed, with an additional search pattern to acquire targets, or slaving of the missile optics to angular radar information or a helmet sight direction. Or, to put it another way, it could be utilised 'off boresight'.

The RAF's Phantoms were adapted to carry the AIM-9G, and by the 1980s, Sidewinder was no longer restricted purely to the air defence role. During and/or following the Falklands campaign AIM-9Gs began to arm Harriers, Jaguars, Buccaneers and even Nimrods.

Sidewinder AIM-9L

The third generation Sidewinder, the AIM-9L, was produced in response to a joint USN/USAF requirement for a much improved



A Phantom FGR2 armed with four AIM-7E Sparrows and four AIM-9G Sidewinders plus a SUU-23 gun pod.

missile. This ‘Super Sidewinder’ featured a very sensitive argon-cooled indium antimonide IR detector and redesigned double-delta canard fins. The latter conferred a 35g manoeuvring capability, which made it virtually impossible for an engaged target to evade and, and perhaps most importantly, this Sidewinder was not restricted to a tail-chase – the AIM-9L was an all-aspect weapon. During the 1982 Falklands War, the first in which the AIM-9L was employed on a relatively large scale, the Sea Harrier was claimed to have achieved an 80% success rate, compared to the less than 20% that had been the ballpark for all earlier versions. From then on the AIM-9L became the universal weapon of choice for both air defence and self-defence.

Sparrow AIM-7E Sparrow III

The early versions of Sidewinder were optimised for close-in engagements and, especially in the air defence role, were generally complemented by a much longer-ranged weapon. In the case of the Phantom, this was the Raytheon Sparrow III. The result of a prolonged development programme that had begun in the early-1950s, the version acquired by the UK, the AIM-7E, had entered production in 1963. Sparrow featured semi-active radar guidance, which is to say that the launch aircraft used its radar to illuminate the target and the missile homed passively onto the reflected signals. This permitted engagements from any aspect up to and including head-on. While not as demanding as beam-riding employment, which was critically dependent upon the pilot aiming *precisely* at the target throughout the engagement, semi-active guidance was still somewhat tactically limiting as the target still had to be permanently illuminated throughout the missile's time of flight.

First operationally deployed by the US forces in Vietnam, Sparrow's performance was disappointing, not least because the lack of a reliable IFF facility often precluded launch at the long-ranges (of the order of 30 miles) that had been envisaged. Since it was, therefore, having to be used at relatively short range, the missile was adapted to make it more efficient under those circumstances, resulting in the AIM-7E2, the variant that armed the UK's original Phantoms. The AIM-7E2 missiles were subsequently updated to the AIM-7E3 standard that introduced improved reliability and enhanced fusing.

Hawker Siddeley Dynamics had been appointed as the UK Design Authority for the Sparrow and the company established a test and repair facility at their Lostock factory and, with its assistance, the AIM-7E3 remained in RAF service until the Phantom was retired in 1992.

Skyflash

Meanwhile, in the UK, the RAE, in conjunction with Hawker Siddeley and Marconi, had been working on a much more efficient homing device utilising a monopulse seeker. This involved the fighter employing a continuous wave, rather than a pulsed, transmission to illuminate the target while the seeker used multiple receivers to detect the phase difference between the reflected responses and converted these into steering signals. It was still a semi-active system but a far more effective and accurate one which could be made highly resistant to electronic counter measures.

A Tornado F3 armed with four, Sparrow-lookalike, Skyflash missiles

A Phantom FGR2 of No 29 Sqn armed with four late-model AIM-9L Sidewinders and four Skyflash missiles (all marked as drill rounds) plus a SUU-23 gun pod. While they may look little different from those in the picture on page 139, its upgraded weapons made this Phantom a much more formidable opponent.

As project XJ521, this seeker head was installed in what was basically an AIM-7E airframe with modified control surfaces, along with a very capable Thorn EMI active radar fuse and powered by a more powerful rocket motor (eventually a series of new motors over the life of the missile) to produce what eventually became the Skyflash. Retaining the Sparrow's all-aspect engagement capability, Skyflash began to enter service in the late 1970s to arm the Phantom and later the Tornado ADV. It proved to be a remarkably flexible missile which could be launched from as low as 250 feet to engage a target at high level, or from altitude to engage a target at low level.

21st Century Missiles

Sidewinder and Skyflash remained in RAF service well into the 21st Century but, while it does extend the timeframe of this paper beyond the scope of its title, it may be of interest to summarise their successors. The current range of AAMs available to the RAF are:

a. The AIM-120 Advanced Medium-Range Air-to-Air Missile – the AMRAAM. AMRAAM, which now arms the Typhoon, is a beyond visual range (BVR), fire and forget weapon with fully active guidance, which is to say that the missile has its own guidance radar and seeker.

b. The AIM-132 Advanced Short Range Air-to-Air Missile (ASRAAM). The replacement for Sidewinder for the Typhoon and Tornado GR4, ASRAAM uses imaging IR guidance, ie rather than merely locking-on to a heat source, the missile 'sees' an infrared image so that it can distinguish, for instance, between an aeroplane and a decoy flare, and it is said to be able to pull up to 50g.

c. Meteor, which is yet to enter service but will shortly be added to the Typhoon's weapon options, will be a very sophisticated, extremely manoeuvrable missile with fully active guidance, a much extended ('in excess of 100 km') BVR capability and a high degree of resistance to jamming.

[1] Jindivik is widely reported as being an Aboriginal term meaning 'the hunted one' but it is interesting to note that the following letter, from R West, the Town Clerk of Shepparton, Victoria, was published in Melbourne in the 1 April 1952 edition of *The Argus*. 'Referring to your report on the use of Australian aboriginal names at the Woomera rocket range, and the apparent lack of knowledge of the meaning of jindivik, I wish to say that in Brough Smythe's work "The Aborigines of Victoria"(*Melbourne: John Ferres, Govt. Printer; 1878*) the word (spelt jindivic) is given as meaning "burst asunder, destroy, vanish, &c." In Martin's "Place Names in Victoria" (*Sydney: NSW Bookstall Co: 1944*) the meaning is shown as "broken apart." Jindivick is the name of an agricultural district near Drouin, in Gippsland.' **Ed.**

[2] In 1959, to reflect its slightly different role, the Guided Weapons Development Squadron was reorganised as No 1 Guided Weapons Trials Squadron. Having completed its work on Firestreak by 1962, during which it had fired about 100 rounds, the primary function of the unit at Valley became the provision of training facilities so it was re-styled as the Fighter Command Missile Practice Camp until 1968 when it became the Strike Command Air-to-Air Missile Establishment. **Ed**

Apology

Unfortunately, owing to a technical problem, the afternoon discussion period on 1 April 2015 was not recorded.

Erratum

There is an error in the table on page 63 of Journal 61. The location for the final entry (Op CALAMANDER) should read Tengah, not Butterworth.

BOOK REVIEWS

Note that the prices given below are those quoted by the publishers. In most cases a better deal can be obtained by buying on-line.

The Bridge to Airpower – Logistics Support for Royal Flying Corps Operations on the Western Front 1914-18 by Peter Dye. Naval Institute Press; 2015. $39.95; £29.34 (Amazon)

Faced by my uncharacteristic diffidence in agreeing to review Peter Dye's scholarly work on the RFC's logistics system on the Western Front, the Editor of the Journal sent this book to me with the admonition: 'Read and be enlightened and amazed', a prophetic suggestion that encapsulates exactly my reaction. *The Bridge to Airpower* (sic) is not an easy read, yet it is one that confirms the deep knowledge and understanding of the subject of someone who is himself both a respected professional practitioner of the logistic disciplines and an historian of the First World War in the air. The book is clearly one of academic provenance and it is likely in my view to be valued more as a considerable source of reference material and specialist comment, rather than one readily to appeal to a lay readership.

Peter Dye's work sets everything in the context of the RFC's widely acknowledged contribution to the Army's success in the field, principally in artillery cooperation and reconnaissance, rather than the air fighting or bombing more popularly regarded as significant. Indeed, he suggests that air fighting was an 'enabler' of the dominant cooperation roles. He describes the evolution of the logistic and support organisation, almost from a blank sheet of paper, to become the comprehensive and complex structure of air parks and depots that ultimately supported a front line of 86 squadrons. Even when the Western Front had become bogged down in trench warfare, logistic mobility was regarded as a given. The importance of salvage and repair in sustaining an expanding front line is a constant theme running throughout the book; the integration of supply and repair was a vital ingredient in handling the conflicting effects of wastage, obsolescence and expansion. In the same way, a large investment in Motor Transport was at the heart of the system's ability to cope. I was intrigued to read of a squadron organisation in the field in 1914 almost identical to that of a mobile support helicopter squadron in Cold War Germany!

This book is densely written and is furnished with a plethora of references. As I read my way with some difficulty through the early pages, I spotted with some relief the remarks of Maurice Baring, Trenchard's invaluable assistant, who wrote in another context:

> 'I have written down all these technical details, not from any hope that the reader will keep them clear in his mind.'

I was thus reassured that it was possible for a non-specialist to keep head above water – and so it proved.

Throughout the book Peter Dye makes repeated reference to the achievements and influence of Brigadier-General Robert Brooke-Popham who headed the RFC's logistics branches throughout the War. Brooke-Popham's reputation has been tarnished – unfairly in the view of many – by his involvement in the failures of Far East Command in 1941-42. His name will not always be remembered with great affection by those who endured the many mind-numbing lectures delivered in the eponymous lecture theatre at the RAF Staff College in Bracknell. His mastery of air logistics at the Western Front, his adaptability and his flexible decision-making are writ large in every chapter. He was clearly a towering figure and one whom the author holds in high esteem.

Truth to tell, this 272-page book, with its 15 b/w plates and many tables and charts, offers a very detailed account of a complex subject but, with care to avoid immersion in detail, the reader is quickly aware of the nature of the woods visible beyond the trees. Dye's account of the evolution of the RFC's logistic system takes the reader systematically through the static phases of the Western Front battles, to describe the very different demands of mobile warfare in retreat, and in the final 'Hundred Days' Allied advances. With that change, came nimble, responsive and at times fundamental alteration of the established ways of supporting the squadrons, notably in redeploying near-static depots in short order in the face of the German threat. The institution of a 'push' system, to replace the established 'pull' methods of supply, bravely accepted reduced efficiency as the price for support of the operational task.

Peter Dye's final chapter draws together the experiences of the

RFC in the field and views the logistic organization that emerged 'through the prism of modern supply chain theory'. He concludes that:

> 'A variety of logistic techniques were pioneered that provide the basis for global supply chain logistic management.'

The achievement of the RFC logistic system was massive and, even allowing for a degree of professional pride on the part of the author of *The Bridge to Airpower*, can only be so regarded. From a standing start in 1914, resilient, responsive, innovative systems evolved to sustain an ever-expanding force in the face of high but variable wastage, erratic supply and rapid technological change. This book does full justice to that amazing achievement – and I am enlightened and amazed!

AVM Sandy Hunter

Phantom Boys edited by Richard Pike. Grub Street; 2015. £20.00.

Phantom Boys is another in the series from Grub Street Publishing, and is edited by Richard Pike of *Lightning Boys* pedigree. He is well qualified for these tasks having flown both types over the years. This new publication offers a refreshing change from previous 'Boys' books where the varied and entertaining contents from several authors are not constrained to 'there I was' stories from the cockpits of the mighty battlewagon which served the Royal Navy and Royal Air Force in several roles during its lengthy career. The format is similar to previous books in the series, embracing several chapters from different authors, but the composition styles and contents vary. Some are written in elegant prose, a scribing talent not universally attributed to fighter pilots (or navigators), touching on events and circumstances often far removed from the confines of the Phantom cockpit but all make thoroughly enjoyable reading. Described as a tough old bird by one of the contributors, the aircraft was loved and respected by those who flew it, in both ground attack and air defence roles, despite its quirky handling and unusual aerodynamics.

Although this sturdy, versatile and very capable beast did not feature in the RAF's long term procurement plans, the cancellation of the P1154 in 1965, together with the Royal Navy's determination to procure the Phantom for their aircraft carriers, provided an opportunity for the MoD to achieve some commonality for its future combat aircraft. Thus the multi-role Phantom arrived in the front line at Yeovilton with the Royal Navy in 1968 and with the RAF in 1969, serving as an air defence fighter at Leuchars and as a ground attack aircraft at Coningsby. It was to remain in the front line in Germany, the UK and the Falkland Islands until its withdrawal from service in November 1992.

It is a measure of the affection engendered and to the credit of the writers that the aircraft which entered service some forty-six years ago has stirred recollections of drama and tales from its twenty-three years of squadron service which have been recalled and brought together by the editor. These range from amusing accounts of life on the typical squadron to the inevitable engine problems, emergency situations, accidents and ejections (where a total of some fifty-five airframes and several lives were lost throughout its time in British uniform). While performing its designated duties as an air defender there are interesting accounts of QRA activities, including some Lightning and Tornado incidents which, although interesting, are peripheral to the main theme of the Phantom. The interception of Soviet long range bombers during prolonged missions over the North Sea are described and illustrated with personal photographs, many of which were previously unseen. Although QRA was a serious business, there is room for levity in the descriptions of manoeuvres designed to thwart the Soviet intruders' photographic reconnaissance efforts.

One chapter is devoted to the ambitious non-stop flights from the UK to Singapore as part of Exercise BERSATU PADU in 1970 which demonstrated Britain's ability to reinforce the Far East with its new multi-role fighter. The duration of these long sorties, up to fifteen hours from the take-off at Coningsby to landing at Tengah, boosted confidence in the Phantom's endurance and deployment capabilities but was a strain on the crews' physiological limits. Ceremonial flypasts were part of the Phantom's routine and included are tales of weather challenges, doubtful airmanship and successful appearances over Buckingham Palace although the flypast to mark the investiture of the Prince of Wales at Caernarvon Castle in 1969 in very poor weather does not feature. Disappointingly there are some other notable omissions where the reader would have welcomed an account of the infamous Sidewinder demolition of a Brüggen-based Jaguar during a Taceval in 1981. Neither are there are stories from Royal Navy operators although there are interesting accounts of life aboard ship from RAF men who served with the Fleet Air Arm on exchange duties where the novelty of deck landing and other ship courtesies are described vividly. Also absent are any accounts from the several exchange officers who flew with British units and many well-known Phantom operators seem not to have been invited to contribute. There are several submissions from the same authors but these criticisms may be overtaken by events as I understand that *Phantom Boys 2* is being prepared for publication.

That said, such shortcomings do not detract from the enjoyment of this book. *Phantom Boys* is a good read and very well illustrated by numerous coloured photographs in two sections, together with several black and white images, interspersed within the narrative. This volume and the other 'Boys' publications are timely, serving to record in an informal way recent history including the people, places, aircraft and events which were vital contributions to preserving the peace during the Cold War. It is recommended for general reading and as bookshelf 'musts' for the great Phantom Phraternity and I look forward to reading the next in line.

Gp Capt Jock Heron

Horizons – The History of the Air Cadets by Ray Kidd OBE**.** Pen & Sword; 2014. £35.00.

A survey of those members of the RAF Historical Society who have served in the armed forces would probably determine that the majority had had prior experience with the Air Training Corps (ATC) or the RAF Section of a school's Combined Cadet Force (CCF): together The Air Cadet Organisation. In the current RAF, there would probably be a majority of members who have also had a previous involvement with the cadet forces, although conversely, relatively few air cadets join the forces.

In 2016, the ATC will celebrate its 75th anniversary but, to an extent, this is a false beginning. In 1928 two former Royal Flying Corps men started a youth organisation devoted to the development of 'air minded' young men in Bournemouth but by that time, there was already an embryonic University Air Squadron organisation, formed in 1925. In truth, therefore, and in keeping with some of the more imaginative centenaries, being claimed; the air cadets are already 90 years old.

Aside from the mental gymnastics by which an organisation's age is determined, it is perhaps surprising that there has never been a widely available commercial history of the air cadets, although several writers have chipped away at small parts of the organisation. However, over many years and with an enormous amount of help, which he generously acknowledges, Wing Commander Ray Kidd has now produced a comprehensive and liberally illustrated hardback account of the air cadets and in a manner which has made the wait worthwhile.

In its 450 pages, Kidd covers almost every facet of the ATC and CCF (RAF) Sections in 23 chapters, each dealing with specific aspects of the air cadets, supported by 19 appendices and a fulsome index. I did not find this a book to be read from cover to cover, rather one to be browsed and 'dipped into' as the mood takes one. It is well worth its cover price for the pages of photographs, both colour and monochrome, alone. Unfortunately, it suffers from the same problem as any account dealing with an institution which is still with us and that is its currency. Although the book was completed two years ago and published in 2014, the dynamic nature of the Air Cadet Organisation is such that things are already moving on in several important areas. However, this should not dissuade one from acquiring a copy, as it covers the history of probably the best youth organisation in the UK, if not the world. As somebody who joined it in 1958 and, after full time service, returned to the ATC, where I still hold a uniformed appointment, I would say that – wouldn't I?

Wg Cdr Colin Cummings

Rapid Rundown by Simon Gifford. Fonthill; 2015. £25.00.

Sub-titled *RAF Operations in the Middle and Far East, 1945-1948*, this book is, I believe, the first to be specifically dedicated to providing an account of the very interesting early post-war years. It was a particularly challenging period because, rather than heralding an era of peace, the ending of WW II was followed by a backlash of instability. As a result the RAF (along with the other Services) found itself having to hold the fort in the Netherlands East Indies and Indo-China until the Dutch and French were able to re-assert their own imperial authority while at the same time handling the repatriation of

POWs and coping with, often increasingly violent, nationalist movements in India, Palestine and Malaya. None of this was made any easier by the rapid drawdown of resources due to the ending of Lend-Lease and mass demobilisation, problems with the latter even giving rise to industrial action. Drawing on the Operations Record Books of the units concerned and the log books and personal recollections of some of those involved (not all of them aircrew), Simon Gifford has provided a very useful account of the troubled years before the tide began to turn in 1948 when the Berlin Airlift brought the first real chill of the Cold War.

Sadly, the author has been badly let down by his publisher. The manuscript needed to be proof read by someone sufficiently familiar with the material to be able to spot errors of fact, of which there are a number. Most of these are oversights – I am quite sure that Gifford knows full well that SEAC's Liberator bomber squadrons were stationed in north-east India, but he wrote 'north-west' and never spotted the problem thereafter. Similarly, he wrote of: Don Muang airfield being in Indo-China, when he meant Saigon airfield; a ferry stage from Agra to Akyab, when he clearly meant Mingaladon to Akyab; No 298 Sqn being stationed at Jaipur, which should have been Raipur; an airfield SW of Calcutta being called Armada Road, which should have been Amarda Road. There a few more of these, but it can be difficult for a perpetrator to see his own mistakes – they need to be pointed out by another reader.

In this case, the problem has been compounded by numerous irritating grammatical errors – apostrophes are inserted (or not) somewhat indiscriminately; there is some confusion over the difference between 'practice' and 'practise' and terms are occasionally used inappropriately, eg one feathers a propeller (not an engine). Finally, there are several incomplete edits where an original passage has not been deleted; in one case this amounts to several residual lines, which is particularly unfortunate, as they contain a reference to Typhoons being flown in India which does not appear in the corrected text, but has nevertheless managed to appear in print. All of this provokes frequent double-takes which distracts from the narrative, which is a real shame, because the content is essentially sound.

The fault here does not really lie with the author. He has done his research competently and submitted his final draft. It is the publisher who is surely responsible for bringing it to market in a form that is fit for purpose. In this case, while the production values are good, it is difficult to understand how a publisher can have failed to see the many flaws in the syntax – did anyone actually read the manuscript?

All of that having been said, should you buy this book? Perhaps surprisingly in view of my criticism, yes, you should. *Rapid Rundown* is a worthwhile effort that sharpens the focus on an era that was full of interest and action but has received relatively little publicity in the past. While it does have its limitations, Gifford's book has filled that gap; moreover, he has illustrated his account with some 200 remarkable photographs. Probably drawn from the albums of veterans, most of these were new to this reviewer. Some, being of the 'ad hoc flight-line snapshot' variety, lack something in their composition but that is more than offset by their immediacy and novelty – and, bearing in mind the variable quality of the originals, they have been well reproduced.

My adverse observations notwithstanding, this one probably is worth adding to your bookshelf.

CGJ

Thor Ballistic Missile by John Boyes. Fonthill, 2015. £25.00

Subtitled *The United States and the United Kingdom in Partnership*, this book complements the same author's *Project Emily – Thor IRBM and the RAF* which was published in 2008. Although the two volumes tell, what is essentially, the same story, they do it from different perspectives. The first, a 160-page softback, summarised the evolution of post-war rocketry until the emergence of Thor in the mid-1950s and then provided (to quote the review that appeared in Journal 43) 'an account of the political negotiations that led to the decision to field the system in the UK, the practical problems involved in siting and deployment, and, once the rockets had been installed, an insight into the daily round of the men who spent five years, 1959-63, tending the sixty launch pads located on, mostly isolated, windswept airfields left over from WW II.' The second book, a 208-page hardback, has a more transatlantic feel and provides a great deal of information on activities at Vandenberg AFB, including the construction of the launch facilities and details, often amplified by contributions from participants, of all twenty-one RAF missiles actually fired from there.

There is, inevitably, a degree of overlap, but this is skilfully managed and kept to a minimum. For, instance, while both books deal with the construction of the launch emplacements in the UK, the second amplifies much of what appeared in the first and includes (albeit rather small) scale plans of the layout of each of the twenty squadron sites showing the relative locations of their three launch emplacements. The technical detail in the narrative is comprehensive but, as with the first book, Boyes exploits his extensive network of British and American veterans of the Thor programme, both service and civilian, to lighten the tone with frequent first-hand anecdotes.[1]

Rocketry bred its own jargon and a raft of short-lived, because of the brief life of Thor (in the RAF), acronyms that are unfamiliar, but there is a glossary and one soon becomes accustomed to them. The text is pretty much typo-free, although there are few slips of the pen, eg the Suez affair was Operation MUSKETEER (not MUSKATEER), the B-29 that dropped the second atom bomb was named *Bockscar* (not *Boxcar*) and I am pretty sure that surveying the sites in the UK would have involved astronomical (not astrological) observations. There appears to be a problem with the presentation of the tables on pages 155 and 157-9 where some entries should have been in bold or italics but this refinement seems to have been lost in the publication process. But none of this detracts significantly from the overall content.

Thor was undoubtedly a remarkable technical achievement. As a first generation long range bombardment missile it had its limitations, notably the vulnerability of its fixed above-ground launch pads and the complexity of its dual-nation release authentication procedures, but the fact that it was successfully deployed represented the strongest possible evidence of the West's political resolve. The RAF was always somewhat ambivalent towards Thor, and missiles in general, but, if never enthusiastic, it had come to respect the system by the time that it was withdrawn from service.

[1] Of purely incidental interest, one of these anecdotes tells of the dissatisfaction felt by RAF personnel obliged to wear the hairy blue battledress and embarrassingly awful KD provided by HMG in the 1950s. Folk involved in the first RAF participation in RED FLAG may recall that the poor quality of our tropical uniform was still an issue in 1977. **Ed**

Having spent many years studying Thor the author has resisted the temptation to oversell its capabilities and his book presents a very balanced account of its successes and its failures. While 2008's *Project Emily* told the Thor story well enough, this second book gilds that lily while also being able to stand alone as an account of the RAF's involvement with the system.

Recommended.

CGJ

A Goldstar Century by Ian Hall. Pen and Sword; 2015. £25.00.

As squadron histories go, No 31 Sqn has a lot going for it. It formed in late-1915 and its leading element had arrived in India just before the end of the year to become the first formed air unit to be established on the sub-continent. It remained in India between the wars as an Army Co-operation squadron flying Bristol Fighters and Wapitis. In 1939 the squadron was re-roled to transport, initially with Valentias followed by ex-commercial DC-2s and DC-3s and ultimately Dakotas. For a short period early in the war the squadron helped out in the Middle East but at the end of 1941 it was recalled to India to assist in the withdrawal from Burma and the subsequent campaign to drive out the Japanese. The first post-war year was spent in the Dutch East Indies followed by a short spell back in India before a five-year stint at Hendon providing an air taxi facility for the Air Ministry. In 1958 the squadron re-formed with Canberra PR7s in Germany, subsequently remaining there while working its way through Phantoms, Jaguars and Tornados until 2001 when it re-located to its present base at Marham.

So much for the bare bones but Ian Hall fleshes out the story and he does it better than most. Mind you, he has some good material to work with. Accounts of inter-war air policing are always full of interest especially, as in this case, when they involve the disastrous Quetta earthquake of 1935, which cost No 31 Sqn twenty-two lives. Spending the war in the transport role, with no guns and no bombs, one might have expected the story to become comparatively pedestrian, but that is far from being the case and it continues to be full of incident. The squadron soon became the premier transport unit in India and as such it was heavily involved in establishing the air re-supply techniques without which the re-taking of Burma may well have been so impractical as to have been impossible.

Operating from Java in, what was supposed to be, peacetime proved to be a particularly troubled interlude. Much of the flying was conducted in the pretty hostile environment created by resentful nationalist militias. Indeed the squadron sustained a disproportionate number of fatalities, including the notorious massacre of the crew and passengers of a crash-landed Dakota. It was much the same in the run-up to the partition of India with the squadron evacuating British nationals from Kashmir as it descended into violence ('No madam, there is no room for your piano').

The thirty-odd years that the squadron spent assigned to RAFG, with its endless succession of Cold War exercises, competitions, evaluations and QRA, will be more familiar ground to many members of this Society. This ended in the early 1990s, since when the squadron has played a full, indeed often a leading, part on active service in the Balkans and the Middle East. That said, these waters occasionally become a little muddied due to the RAF's recent tendency to respond to a crisis by cobbling together composite units which rather obscures the contributions being made by each of the squadrons embedded within the mix.

I have only two adverse observations to make. The book includes an appendix listing the aeroplanes allotted to the squadron by serial number, but with no other details – and the author even 'makes no claims as to the completeness of this list'. That is a valid choice, of course, but it will disappoint those purchasers who consider 'mini-biographies' of its individual aeroplanes to be an essential element of a unit history. My second problem is the illustrations – there are scores of them. Considering the circumstances under which they were taken, many appear to be of surprisingly high quality and they are full of interest, but they are *sooo* small! – most are no more than 3 inches across, often less. They really did deserve to have been given the full page width. So much for the pictures; what of the story-telling?

Some writers have a natural ability to string words together. It must be possible to analyse their syntax to determine exactly why their prose is easier to read than that of others but I am not persuaded that it would be a particularly productive exercise. It isn't a conscious thing; some folk simply are better writers than others and their work flows more comfortably. Ian Hall has this gift.

Unit histories are notoriously difficult to write because they tend to be repetitive. Each flight or fight is full of interest, of course, but there is often little to distinguish one from another and after a few pages the eyelids may begin to droop. The secret is to be selective. Considering the large numbers of sorties flown by, for instance, No 31 Sqn's Dakotas in 1944 or its Tornados on Operation TELIC in 2003, we are presented with first-hand accounts of only a relative handful, but I was left with a very clear impression of life on the squadron at the time. It is also necessary to lighten the tone with personal recollections focusing, in particular, and frequently, on aspects of squadron life other than flying and fighting. It is a balancing act and *A Goldstar Century* does it extremely well. The result has been to create an impression of 31 Squadron as a 'family' with continuity ensured by an active Association to which the author often refers and whose contribution he repeatedly acknowledges.

Recommended.

CGJ

Harrier Boys, Volume One by Bob Marston. Grub Street; 2015. £20.00.

The most recent 'Boys' book from Grub Street tackles the first generation Harrier and, as its sub-title says, it covers the '*Cold War through the Falklands, 1969-1990'*, although a small number of aircraft continued in service for a few months longer. A second volume is underway and it will cover the later 'all digital' machine which arrived in the front line in 1989. The author, Bob Marston, flew both generations of this pioneering aircraft and became one of the RAF's most experienced Harrier pilots. He has followed an interesting format by writing well-informed continuity paragraphs linking the chapters from his contributors, most of whom are well known characters from the small Bona Jet community.

The Foreword is written by Air Chief Marshal Sir Dick Johns, himself an experienced Harrier commander at squadron and Force level, whose lengthy experience in the aircraft and personal knowledge of the contributors qualify him to describe Harrier pilots as having a reputation hallmarked by neither reticence nor modesty. These are the men who have written their personal stories with flair and style. He goes on to say that their contributions to *Harrier Boys* are distinguished by the admission of mistakes and a pleasing addiction to truth. Illustrating that honesty, their personal stories are written with flair and, style describing adventures in and out of the cockpit.

The author describes the Harrier Force as a close knit community and the camaraderie is evident in the first-hand accounts beginning with the hugely ambitious 1969 Daily Mail Trans-Atlantic Air Race which took place just a few weeks after the Harrier's formal release to service. The operation was not without risk and I doubt that an Op Order for such an adventurous project would reach even a preliminary draft in the light of today's risk assessment culture. However the determination of the planners and participants ensured that the Harrier and its pilots found a place in aviation history with the presentation of the Harmon Trophy, an American award recognising the world's outstanding aviators. Graham Williams and Tom Lecky-Thompson found themselves in the company of Neil Armstrong, Buzz Aldrin and Michael Collins at the subsequent ceremony for the 1969 awards. The race and its aftermath form the basis for the opening chapter of this excellent book.

At the same time, the conversion of the four pilots of the Harrier Conversion Team was underway, followed by the conversion of No1 Squadron, the first front line unit, but events did not run smoothly. Sadly the nominated OC, a highly experienced wing commander, had died in a Hunter accident and his successor failed to master the unusual VSTOL handling techniques so it was the third nominee, Ken Hayr, later Air Mshl Sir Kenneth, who was given responsibility for the formation of the embryo Harrier Force's first squadron. He was the man for the hour and the subsequent adventurous spirit and character of the Harrier Force owe much to his effective leadership and resolve. Although these early years were marred further by the removal from command of the first two OCs from the second of the RAF Germany squadrons within the command chain other robust personalities arrived to ensure that after three years, despite the loss of twelve aircraft and several pilots, the Harrier Force was to become a formidable presence both in the UK and RAF Germany.

Fifty years ago the infant Harrier was seen by some as an interesting capability seeking a concept of operations but those who were responsible for the creation and development of the RAF Harrier

Force saw it come of age when called to the colours, well into its maturity. *Harrier Boys* contains personal accounts of the little jet's operational career in Belize and the Falklands where events highlight its unique versatility. Central American activities justify several short extracts but Operation CORPORATE is covered in greater detail by those of the 'Falklands Few'. One of the RAF pilots who served with the Royal Navy on the Sea Harrier describes ground attacks and air combat successes in graphic detail and Air Chief Marshal Sir Peter Squire, then OC 1 Squadron, gives a measured and lengthy account of GR3 operations from HMS *Hermes* and ashore from the temporary strip at Port San Carlos. After hostilities had ceased, he goes on to describe events at the badly damaged airfield at Port Stanley and the primitive conditions surrounding the reoccupation of this remote dependency. These are refreshingly frank diaries which will serve as authoritative records of the Harriers' contribution to the unique Falklands campaign.

Over many years, and well before its combat debut, lessons were learned during deployments 'off base' in support of operations on the NATO flanks and in Germany. Standard operating procedures and rules were invented and refined in unique flying environments. Living in rudimentary facilities was to become the norm and all ranks became familiar with the 12×12 tent, mud, the 'green worm' sleeping bag and field catering. These experiences were applied ashore in the Falklands after the invasion when there was an urgent need to provide Harriers and Sea Harriers with a forward operating site for fuel and, potentially, weapons replenishment. Operations from 'Syd's Strip' at Port San Carlos returned the concept of the Harrier to its formative years by providing rapid reaction to tasking from rudimentary deployed sites, but without any trees to provide cover. Syd Morris' account of his four week detachment as the Site Commander describes sortie rates far in excess of the plan during the final week of hostilities, taking advantage of the Harrier's flexibility and adaptability.

Adventurous spirit, drive and initiative, characteristics of the Harrier Force and its people, were not confined to the pilots and commanders but extended to the ground crew whose observations are contained in a lengthy chapter with amusing contributions along the lines of 'now it can be told'. More sombre is the short chapter about some of the losses, of aircraft and pilots, where lucky escapes are matched by the deaths of colleagues, some caused by technical failure and some, very regrettably, by errors of skill or judgement. Bird strikes, a normal operating hazard while flying at low level, technical failures both material and maintenance, combat losses and 'aircrew error' accounted for 73 first-generation GR Harriers being listed as Category 5, a sobering statistic.

A few minor errors were identified where there is an incorrect caption to the photograph on page 46 of XV792. Also wrong is the date of the fatal accident at Gütersloh where the six-inch rod connecting the aileron to the reaction control shutter fractured in the hover leading to the loss of control and the tragic death of the young first tourist who had joined 3 Squadron only weeks earlier. 14 October 1980, not 1981, is burned into my memory as I was the main witness from short finals while on my last sortie in a GR3. Also, the photograph opposite page 97 of the mass take off from Bad Lippspringe, led by the IV Squadron Boss, Bryan Baker, is credited to me but was not one of mine, although I did witness the launch as the Site Commander. Exceptionally well-illustrated, with many original photographs in colour and monochrome, this 192-page hardback is a worthy addition to the *Boys Books* series. It is thoroughly recommended, both as an authoritative historic record for the academic and, for Harrier men, a nostalgic canter through the pioneering years of the Bona Jet and its people.

Gp Capt Jock Heron

The Perfect Aerodrome – A History of RAF Chivenor 1932-1995 by David Watkins. Fonthill Media; 2015. £18.99.

Chivenor was always a popular Station, partly because it was located on the NW coast of Glorious Devon, partly due to the good weather factor, partly because the domestic and technical site was compact and everyone knew everyone, and partly because, for pilots in its later years, it was the gateway to a front-line tour on fast-jets. David Watkins presents a comprehensive account of Chivenor's 63 years in a book of 240 pages with 264 illustrations, 57 of them in colour. All photographs are well reproduced.

Chivenor's history had four phases: the early years as Barnstaple's aerodrome; the war years and the Battle of the Atlantic; the early post-war years as No 229 OCU training pilots on the Vampire then the Hunter; and, after a period of closure, the re-opening in 1980 as No 2 TWU training pilots on Hawks for the front-line fast jets. The book covers the entire period and is drawn up largely from operational records and newspapers, brought to life by frequent personal accounts by pilots and navigators of the time.

It all began when Sir Alan Cobham's touring Air Display flew from Heanton, a few miles West of Barnstaple, in May and September of 1933 and a flying club opened there soon after. The Mayor of Barnstaple officially opened the Barnstaple & North Devon Airport in 1934 and, for the next five years the flying club was busy and a commercial service operated regularly to Lundy Island and, occasionally, to Cardiff, Bristol and Weston-super-Mare. All civilian flying stopped at the outbreak of war.

Over the next six months, plans were made for a new airfield with three concrete runways half a mile to the West of Heanton and RAF Chivenor opened as a maritime training base in October 1940. No 3 (Coastal) Operational Training Unit began to train Anson and Beaufort crews. In May 1942, the Battle of the Atlantic had become a major concern and Chivenor transferred from No 17 (Training) Group to 19 Group. Nos 51 and 77 Sqns arrived with Whitleys and they were soon joined by 235 Squadron with Beaufighters to provide fighter support. The Whitleys gave way to Wellingtons from a number of different squadrons and these continued the maritime battle until the end of the war. During this time, Chivenor's Whitleys and Wellingtons claimed to have sunk twelve U-Boats and to have damaged a further eleven. The crews were awarded three DSOs, twenty-five DFCs, five DFMs and one AFC.

The immediate post-war years were marked by a miscellany of units coming and going whilst the future of the airfield was in doubt. During this period it was transferred to Fighter Command.

In March 1952, the pattern for the future was set when No 229 OCU arrived with Vampire FB5s and Meteor T7s and tactical training in the day-fighter role was provided. The main runway was lengthened and concrete was laid for aircraft parking areas. No 229 became the RAF's first swept-wing OCU when it received 22 Sabre F4s in 1954. The following year, the Sabres were replaced by 26 Hunter F1s. In time, these gave way to the Mks 4, 6, 7, 9 and 10.

Chivenor continued to train pilots for Hunter squadrons and also gave lead-in training for pilots destined for the Lightning, Jaguar, Phantom and Harrier until September 1974 when the unit moved to RAF Brawdy and became the Tactical Weapons Unit. The Station closed but for the resident Search and Rescue Flight which remained.

Six years later, in mid-1980 it re-opened as No 2 TWU equipped with the Hawk T1 and these remained until October 1995 when Chivenor closed as an RAF base and ownership passed to the Royal Marines.

Search and Rescue was a continuous feature of Chivenor's task from 1958, when 'A' Flight of 22 Squadron arrived with Sycamores, until 2015 when it disbanded and its Sea Kings departed. The era is covered in a separate, fairly short chapter.

Annexes cover U-Boat claims, flying accidents, Station Commanders and resident units.

The book provides a very good account of Chivenor from beginning to end and many of the illustrations are from personal records and thus have not been published before. It is a good book at a reasonable price. Just one gripe: it is a very useful reference book which includes many aircraft types, many units and a large number of people but there is no index. This is a pity.

Air Mshl Sir Roger Austin

Looking Down The Corridors – Allied Aerial Espionage Over East Germany and Berlin 1945 – 1990 by Kevin Wright and Peter Jefferies. The History Press; 2015. £18.99.

This book fills a gap in Cold War Intelligence History. There are at least four books on BRIXMIS and its American and French equivalents – the Allied Military Liaison Missions (AMLMs) that conducted diplomatically-enabled spying on the ground in East Germany. In the air, meanwhile, the same trio of Allies flew military transports converted for IMINT and SIGINT along the Berlin corridors, as well as assorted light aircraft within the Berlin Control Zone (BCZ).

While BRIXMIS was two-thirds bigger than the American MLM, the US air effort 'dwarfed British and French efforts', the authors note. A succession of US Air Force C-54s, C-97s, T-29s, C-130s and other types flew from Wiesbaden and Frankfurt almost every day. The

French specialized in SIGINT using the Noratlas until replaced by the Transall. The British settled on the Percival Pembroke in the mid-1950s, three camera-equipped aircraft serving as part of No 60 Sqn at Wildenrath. A Chipmunk flew around the BCZ from Gatow, with the observer using a variety of hand-held cameras.

All these aircraft were supposedly covert collectors, that would ‘hide in plain sight’ amidst the steady stream of Western civilian and military aircraft flying to and from Berlin. Sliding doors covered camera windows, and some antennas could be retracted. But the large radomes on some of the American aircraft were a giveaway. So also were the flight tracks, with frequent zig-zags within each corridor to cover targets of interest. The authors list no fewer than 88 of these in an Appendix – Soviet and East German airfields, barracks, training areas, and logistics bases.

At any rate, the Soviets weren’t fooled. The authors suggest that this elaborate game served to avoid ‘an open affront to their sensibilities’. But they also suggest that the other side did not appreciate how good were the Allied airborne sensors, and their exploitation by the PIs and other ground-based analysts. Since the Soviets often deployed their newest kit to East Germany, the intelligence take from these flights was rich indeed. Of particular interest to airmen: an early understanding of the SA-2 SAM, the first-ever view of the mobile SA-9 SAM, and a good analysis of the truck-mounted *Paint Box*, designed to jam terrain-following radars.

The authors assert that these flights provided ‘virtually the sole source of new (Soviet) equipment photography’ until the advent of satellite imagery in the mid-1960s (p171). That surely does a disservice to the valiant efforts of BRIXMIS and the other MLMs in East Germany, and the Western military attaches who also performed covert photography behind the Iron Curtain, as well as the pilots who flew U-2s over the USSR from 1956-60, and over Cuba from 1961 during the Soviet buildup there.

Other minor grumbles include an awkward handling in the narrative of unit chronologies, that would have been better expressed in tabular form; some editing errors that allow the introduction of acronyms without prior explanation. Fortunately, there is a Glossary. There is also a good selection of photographs, especially of those targets in the barracks and on the airfields of East Germany. The description of photographic interpretation equipment and procedures in Chapters 7 and 8 is particularly valuable. Recommended.

Chris Pocock

Defending the Motherland. The Soviet women who fought Hitler's Aces by Lyuba Vinogradova (with an Introduction by Antony Beevor). MacLehose Press; 2015. £20.00

In Soviet society – except in terms of their purely biological functions – little distinction was made between the roles of men and women. Hence women flew as combat aircrew in front line Red Air Force Regiments. They made excellent pilots and proved just as ruthless killers as the men. Although women served in male regiments three solely women's regiments were set up after a petition to Stalin by Marina Raskova, an aviatrix with a national reputation for record long distance flights and a big fan base. Only two examples of her participation as a navigator in such flights are cited, one of which is described in some detail and ended in failure. This was an attempted non-stop flight of 6,000 kilometres in a Tupolev ANT-37 piloted by two women Valentina Grizodubova and Kalina Osipenko. For propaganda purposes, both at home and abroad, the Soviets were eager to demonstrate that they were up to anything the decadent capitalists could do and aviation was an excellent vehicle for doing that. An organisation called *Osoaviakhin* existed one of who's remits was to train pilots for sporting purposes and as the starting point for reserve and regular military service. Men and women learned to fly in their spare time and *Osoaviakhin* had similarities to the mechanisms of the RAFVR. After the war Grizodubova, who had gone on to command a male bomber regiment during it, was critical of Raskova. She considered that she had been a poor navigator with little experience who had been 'recommended' – a euphemism for 'placed' – in her crew as a representative of the NKVD to keep an eye on things political.

Raskova had a sinister undertone. She had worked in an office in the *Lubyanka*, which housed the headquarters of the KGB, and had achieved the rank of Senior Lieutenant in the NKVD. The author implies that with her reputation as an aviatrix, which gave her access to the aeronautical elites in the USSR, Raskova may have been implicit in getting some of them placed under close supervision as actual or potential dissidents. She also suggests that Raskova's NKVD credentials may have helped when she went to Stalin in 1941 with a successful proposal to set up three women's regiments. Raskova is an important figure in this book yet there is something which seems paradoxical about her. We are told that she was a national heroine as a long distance flyer yet on several occasions in the text she is said to have little flying experience! One such occasion is when she was appointed as commander of one of the three regiments which she had proposed. The author does not help us with sorting out this paradox. However, the three women's regiments which were established were 586IAP, a Fighter Regiment; 588NBAP, a Night Bomber Regiment which later became the 46GNBAP, the Taman Guards Night Bomber Regiment (the Guards designation was a badge of honour awarded to Regiments which had performed outstandingly) and finally, 587BAP, a Bomber Regiment which became the 125GBAP, a Guards Bomber Regiment.[2]

586IAP flew Yakovlev fighters. Yak-1s appear in photographs here but as the war progressed women in fighter regiments must have flown all versions of the Yak fighter, the -7 the -9 and when it came on-stream in the late spring and early summer of 1944, the superb Yak-3 (Yak fighter numbers have little chronological significance; the -7 and the -9 were in action before the arrival of the -3). The author notes the prickly reputation of Yakovlev in some quarters and his closeness to Stalin. The same kind of criticism concerning relations with Stalin have been levelled elsewhere at Ilyushin. However, the quality of Yakovlev's fighters and Ilyushin's *Shturmoviks* suggests that Stalin had an eye for picking winners when it came to aircraft designers. 586IAP did not earn the Guards title and in September 1942, eight of its pilots were transferred to men's regiments in the Stalingrad theatre, four going to 437IAP and four to 434IAP. After spending a short period with a male commander it ceased to be a women only unit. As a general point, there is some evidence given of

[2] IAP – Fighter Aviation Regiment (literally *Istrebitel'niy Aviatsionniy Polk*), sometimes GIAP or GvIAP when afforded 'Guards' (*Gvardevskiy*) status.

BAP – Bomber Aviation Regiment (literally *Bombardirovotsniy Aviatsionniy Polk*), sometimes prefixed N (*Nochnoy*) for night and/or G or Gv if afforded Guards (*Gvardevskiy*) status. **Ed** male commanders of regiments being reluctant initially to send young women up into skies full of Bf109s and Fw190s. This may reflect anxieties about their reliability as wingmen or may be evidence of a residual chivalry which had not been expunged by exposure to Soviet ways of thinking.

Two women who had started in 586IAP became outstanding fighter pilots after leaving it. They were Lydia Litvyak (12 solo and 4 shared victories) and Katya Budenova (11 solo victories). They went first to 437IAP which was equipped with Lavochkins but the girls continued to fly Yaks. The next move was to the 9GIAP and finally to 296IAP which became 73GIAP. Both women were lost in action in the area near the river Mius on the Southern Front whilst escorting *Shturmoviks*. (*Schturmovik* is the type name for a heavily armoured ground attack aircraft but it became synonymous with the Il-2.)

Litvyak comes in for a lot of the author’s attention including both her beauty and her tendency to insubordination. She was an excellent fighter pilot and, as RAF history shows, fighter pilots do tend to be extroverts – think AAF types and their attitude to Regular rules and regulations at times! Budenova’s death was certified by the identification of her crashed aircraft and body but Litvyak’s death gave rise to the sort of mania which followed the death of Elvis Presley. There were conflicting eye-witness reports of her crash location over a fiercely fought battleground and her aircraft and body were not found. This provided an ideal recipe for all kinds of wild speculations. There were denials, reported sightings, tales of her capture by, or desertion to, the Germans and because she had at best been captured by the Germans the paranoid logic practised by the Soviets in such cases denied her the title of Hero of the Soviet Union. This paranoia could mean that anyone who had been captured or had tried to re-join their units after being stranded behind German lines risked being accused of treachery and exposed to examination by SMERSH, a sinister organisation (parodied in the James Bond films) set up to expose and denounce traitors. Sonya Ozerkova, a Po-2 pilot who became stranded behind German lines, faced a firing squad on returning to her Soviet compatriots and was only saved by a last minute intervention by her regiment’s Commissar. The injustice suffered by Litvyak was rectified in 1990 by Mikhail Gorbachev who awarded her the Honour posthumously.

588NBAP was equipped with Polikarpov Po-2 biplanes. They were two-seaters and carried a navigator. Their low speed and high manoeuvrability made them difficult targets for fast interceptors such as the Bf109. Nevertheless, losses were very high and many women pilots lost their lives as a result. The Po-2 was robust but constructed from wood and fabric and burned easily. In action they carried one or two 50 or 100 kg bombs who's value lay primarily in the night time havoc they played with German nerves and sleep patterns. It is part of the folklore that the Germans referred to their pilots as 'the Night Witches' and to the aircraft as 'Sewing Machines' because of the distinctive clatter of their five-cylinder engines. There are good accounts given here of 588NBAP missions including one in which they met fierce ground fire and attack by Bf109s aided by searchlights. The fact that the regiment was accorded Guards status shows the quality of its women pilots. It was also the only one of the original three women's regiments which remained exclusively so.

587BAP flew Petlyakov Pe-2s. The Pe-2 was an efficient twin engine tactical bomber which can be spoken of in the same breath as the Mosquito and the Ju88 although it was not so easy to fly having, for example, heavy controls at take-off and a high approach speed. Like the Ju88 it had a dive bombing capability making it a vital component of ground attack and air support over battlefields alongside *Shturmoviks*. The Soviets apparently referred to it as a heavy bomber. At one point the Pe-2 is described as a 'huge machine' whereas it had virtually the same span and length as a Mosquito. The Pe-2 is right up there with Yakovlev's fighters and the *Shturmovik* among the best aircraft flown by the Red Air Force. Ground attack support over battlefields was hairy stuff and women flying the Pe-2 took part in it alongside *Shturmoviks* which they also flew. Raskova chose to command 587BAP in spite of the fact that she is said here to have had little flying experience. She perished with her crew when she crashed en route to the Stalingrad sector having set off in in very bad weather conditions.

To sum up, the structure of this book consists of a montage of episodes featuring the women pilots and reveals things about them as people as well as their involvements in action. The foci are not exclusively on Raskova's three regiments. The women retained a good deal of their femininity even in the trying circumstances of the war and behaved much as they might have done in caring for their appearance and in relations with men. We can only infer more intimate matters from the information that Fascist condoms were superior to the Soviet variety. The author has done a good job in assembling her montage from a wide range of sources which are detailed in her chapter notes and bibliography. References to items of the Russian literature, both formal and informal will not be easily accessible to most of course. She has also found and interviewed veterans who have given first-hand accounts of their experiences. She tells us that she is not a historian and so her text lacks one or two features that historians might like to see. For example, the chronology is hard to follow at times, as her focus shifts, and there is a general lack of quantification, eg in terms of male/female compositions and of regimental strengths as the two years of her study, which included Stalingrad and Kursk, progressed. One cannot have everything and here we have a book which provides a good insight into an unfamiliar aspect of the terrible struggle against Nazi Germany in which our Soviet allies triumphed. I think it is not for Society Members' shelves as a work of reference but it is certainly worth reading.

Dr Tony Mansell

Hawker P.1103 and P.1121 – Camm's Last Fighter Projects by Paul Martell-Mead and Barrie Hygate. Blue Envoy Press; 2016. £11.95.

Hawker P.1103 and P.1121 is a 64-page, A4 softback which opens with an informative short chapter providing an insight into the autocratic, and thus somewhat dysfunctional, fashion in which Sir Sidney Camm presided over Hawker's design department in the 1950s. Despite this handicap, the fertile minds at Kingston produced a steady stream of proposals culminating in the P.1121 on which metal was actually cut before the project was abandoned.

While focusing on Hawker's design and development processes, Martell-Mead and Hygate set this in the context of the long-running saga of the attempts to provide the RAF with the right kind of fighter to counter the rapidly evolving manned bomber threat of the 1950s, beginning with rocket-powered responses to OR301, such as the Avro 720 and Saunders-Roe's SR177, and culminating in the massive 'ultimate interceptors' to OR329/F.155, like the Fairey Delta III and

Armstrong Whitworth's AW 169. The narrative covers the evolution of Hawker's solution to OR329, the P.1103, in some detail, but the eventual submission failed to conform to too many aspects of the F.155 specification and was eliminated from the competition. In the event, the OR329 interceptor project was cancelled in 1957 in any case but Camm and his team persevered, using the P.1103 as the basis for a private venture that became the P.1121 single-seat, multi-role strike fighter.

But by 1958 changes in defence policy meant that there was only one game in town – OR339, the Canberra replacement that would eventually materialise, via OR343, as the TSR2. Hawker's, unsolicited, response to OR339 was a progressive extrapolation of the P.1121, via the P.1123 and P.1125, to produce the P.1129, by which time it had morphed into a two-seat, twin-engined tactical bomber, a progression that is also covered by the book. Along the way, the authors note the introduction of the weapon system concept and Hawker's, ie Camm's, failure to commit wholeheartedly to it, perhaps a factor in the company's failure to secure an order for any of this series of projects.

As with earlier Blue Envoy publications, this one deals with a 'what if' aspect of British aviation, rather than RAF history *per se*, although there are, of course, frequent references to the influence of the Air Staff, and Operational Requirements in particular, and sundry named senior officers. Printed on gloss paper and lavishly illustrated with original Hawker artwork and general arrangement drawings with additional drawings by the authors, along with artists' impressions and computer generated images of 'what might have been' aeroplanes in service. There is also excellent photographic coverage of the surviving components of the half-built prototype P.1121 which now reside in the safe-keeping of the RAF Museum at Cosford.

If such projects interest you, this publication will both enlighten and entertain, and at a very reasonable price.

CGJ

ROYAL AIR FORCE HISTORICAL SOCIETY

The Royal Air Force has been in existence for more than ninety 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 interwar 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, Wg Cdr Colin Cummings, October House, Yelvertoft, NN6 6LF. Tel: 01788 822124.

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 British 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
2005	Wg Cdr S D Ellard MSc BSc CEng MRAeS MBCS
2007	Wg Cdr H Smyth DFC
2008	Wg Cdr B J Hunt MSc MBIFM MinstAM
2009	Gp Capt A J Byford MA MA
2010	Lt Col A M Roe YORKS
2011	Wg Cdr S J Chappell BSc
2012	Wg Cdr N A Tucker-Lowe DSO MA MCMI
2013	Sqn Ldr J S Doyle MA BA
2014	Gp Capt M R Johnson BSc MA MBA

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

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