THE *BLUE STREAK* WEAPON[1]

Roy Dommett[2]

Ballistic Missile Pre-History

The United Kingdom's involvement with ballistic missiles started with the V-weapons campaign in the Second World War. Once hardware had started to become available during the war, late in 1944, the Royal Aircraft Establishment (RAE) had supported Duncan Sandys'[3] Intelligence Committee on interpreting the German rockets. This material included the *Wasserfall* development *V2* that landed in Sweden of which recovered parts were flown back, the *V2* impact that the Polish resistance hid and parts of which were also flown back, captured handling gear from sites in Normandy, as well as the recovered parts of missiles once

[1] This paper grew out of various short contributions made at the annual British Rocketry Oral History Project (BROHP) Conferences at Charterhouse School, which were collated for a TV interview for a Channel Four programme to be broadcast in 2004. It was substantially re-edited for a lecture at the Tullie Museum, Carlisle, in support of their *Blue Streak* Project. It was then further updated and submitted for publication and in a further revised form, after peer review, presented at Charterhouse 2004. It is derived from personal involvement. It does not draw on other publications or the surviving material in TNA/PRO, and concentrates on the aspects with limited treatment elsewhere. But it does reflect the technical understanding generated through working on later UK ballistic systems. It is, however, still only an interim statement of the perceived background to the project.

[2] Roy Dommett is a retired engineer who worked all his career at RAE Farnborough on nuclear delivery systems, from *Blue Streak* to *Trident* (the US Navy's ICBM, a solid propellant MIRVed missile by Lockheed Missile and Space Company, now deployed in British Vanguard-class giant submarines). Particularly involved with the early re-entry system designs and the flight trials, Roy Dommett followed George Hicks at RAE on the *Polaris* Improvements programme. From 1982 he was Chief Scientist for Special Weapons Department and then a Principal Consultant on Ballistic Missiles for DERA, receiving the Royal Aeronautical Society Silver Medal and a CBE.

[3] Rt. Hon. Duncan Sandys, PC, (Lord Duncan-Sandys, 1908-87), Conservative politician. First Secretary to War Office, 1941-43; Chairman of War Cabinet Committee for Defence against German flying bombs and rockets, 1943-45; Minister of Supply, 1951-54; Minister of Defence, 1957-59; Minister of Aviation, 1959-60; Secretary of State for Commonwealth Relations, 1960-64.

attacks had started on the United Kingdom. The RAE answered the key questions for the Government of the likely maximum range and the warhead type and weight and produced reports for the *Big Ben* Committee[4] which supported the *Bodyline*[5] and then *Crossbow*[6] counter-strike operations. The maximum performance of *V2* was predicted accurately by Nonweiller,[7] the control and guidance system was reconstructed, and the improvements being adopted by the Germans were being followed. Soon after the war, the UK launched three *V2*s from Germany with the help of experienced Germans in *Operation Backfire*[8] and the whole experiment was written up in several volumes as no such complete German documentation existed. These and the RAE wartime reports and photographs can be found in the Imperial War Museum (IWM) and some in the FAST collection in the library of their museum at Farnborough. No one who worked on the *V2* material at RAE appeared to survive to work on *Blue Streak*,[9] but some of the Germans who came to RAE after the war did.

Following the war, an enormous amount of documentation on the *V2* was found in Germany and shipped to the UK. We had the Herman Goering Institute in our occupation zone and a small fleet of ex-German air-transports were used to carry papers and hardware to Farnborough. It is now hard to tell what the RAE made of all the material - there was a very large number of glass photograph negatives of German hardware in the RAE archives from 1944 to the end of 1946, which implied a potentially large influence on the design of future UK aircraft and guided weapons sub-systems. In the early days of the *Blue Streak* studies, a set of *V2* documents was kept in Q134 building at RAE. For some reason they could not be copied, borrowed, or referenced in reports, and work

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4 *Big Ben* Committee: a wartime Intelligence Committee on German V-weapons.

5 *Bodyline*: wartime counter-strike operations against V-weapons sites.

6 *Crossbow:* wartime counter-strike operations against V-weapons sites.

7 Professor Terence R. F. Nonweiler, Scientific Officer, RAE, 1944-50; Scientific Officer, Scientific Advisers' Department, Air Ministry, 1950-51; Senior Lecturer in Aerodynamics, College of Aerodynamics, Cranfield, 1951-57; Consultant to Admiralty 1951 and Ministry of Aviation 1959.

8 *Operation Backfire*: immediate post-war UK exercise to launch three *V2* rockets from Germany towards Heligoland.

9 *Blue Streak*: a UK-developed fixed site ballistic missile (FSBM) for delivery of UK-developed nuclear weapons, with an air-frame built by de Havillands with Rolls Royce engines which were first fired in 1959. It was cancelled in April 1960 and was later offered to ELDO as a satellite launcher.

with them had to be done in the room in which they were stored. As far as is known, all that material has now been lost. Even the Intelligence community in London passed its collection, a crate load, to a national museum and it appears to have disappeared without trace. Those who worked with the German reports remembered how advanced they were, covering many things that have not been mentioned in the open literature[10] about the *V2* since, such as the error budgets, which have been found important in the design of modern systems. Our Bert Longden[11] found one small mistake in their analysis of gyroscope errors.

There had been some official UK interest in ballistic missiles immediately after the Second World War. The concept had a name, Menace, although no evidence of serious studies has been found. The long trials range at Woomera[12] had been planned with missiles of up to 800nm maximum range in mind, this being the assessed capability of the next generation of missiles building on the *V2* experience. However, even after the establishment of the Iron Curtain[13] and the heavy arming of the Eastern bloc, this was not a militarily very useful range from the UK. The technical problems of the early surface-to-air guided weapons (SAGW), most not solved by the Germans, were such that the UK decided in 1948 to leave early ballistic system research to the United States, presumably for the duration of the 1945-51 Labour Government. At least one UK paper study showed that the required missile would be huge and quite outside then current experience.

There was some practical work that had been done since the war, and the Rocket Propulsion Establishment (RPE) at Westcott near

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[10] The author suspects that this was because it was neither understood nor appreciated by historians.

[11] Bert Longden, radio guidance expert in Guided Weapons Department, RAE in the 1950s.

[12] Woomera village and missile test range 350 miles into the interior of Australia.

[13] In 1946 Winston Churchill gave a speech in Fulton, Missouri, in which he stated that, ‘From Stettin in the Baltic to Trieste in the Adriatic an iron curtain has descended across the Continent. Behind that line lie all the capitals of the ancient states of Central and Eastern Europe. … these famous cities and the populations around them lie in what I must call the Soviet sphere, and all are subject, in one form or another, not only to Soviet influence but to a very high and in some cases increasing measure of control from Moscow.’

Aylesbury,[14] started to develop a series of liquid propellant rocket motors of increasing size: the *Alpha, Beta, Gamma*, and *Delta*. These were used respectively for the Vickers[15] transonic models by Barnes Wallis,[16] to develop the rocket engines for manned interceptors, for *Black Knight*[17] and *Blue Steel*,[18] and finally the *Delta* was a potential step towards an engine cluster for a large ballistic missile. German technology solutions were apparent in the designs of all early rocket engines, but there were improvements being made to injectors and to the cooling systems for the chambers and nozzles. The US introduced the concept of gimbals to swivel the engines instead of putting vanes into the exhaust, as had the German designs, to control the thrust direction. By using liquid propellants that could be pumped, the US also conceived the idea of thin tank walls which could act as the main structure when they were stabilised by internal pressurisation.

Air Staff Background

The value of delivery systems (bombers) flying higher and faster had been recognised by the Air Staff before the Second World War. The lower loss rate of the Lancasters and then the Mosquitos during the war was attributed to their higher operational ceilings. A new generation of multi-engined super-bombers was schemed during the war by the major aircaft companies, the so called ‘stratospheric bombers’, which were not then manufactured because of the perceived adequacy in the circumstances of the existing four-engined planes. But the Air Staff continued to look forward in various ways, e.g. in 1942 the RAE had set up a Tailless Aircraft Committee to exploit American National Advisory Committee for Aeronautics (NACA) laminar flow airfoils and UK jet

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[14] Westcott: the site of the former RAE out-station, then an independent R&D establishment, near Aylesbury, which became the Rocket Propulsion Establishment, PERME and then Royal Ordnance.

[15] Vickers: originally Vickers, Sons and Maxim, an armaments firm that built the First World War Vickers Vimy twin-engined bi-plane. The firm later became Vickers Armstrong that built the Valiant V-bomber.

[16] Sir Barnes Wallis, Chief of Aeronautical Research and Development, British Aircraft Corporation, Weybridge, 1945-71.

[17] *Black Knight*: a re-entry test vehicle managed by RAE and designed and built by Saunders-Roe.

[18] *Blue Steel*: an RAE conceived and AVRO designed and built Mach 3 cruise missile deployed in the 1960s, carried and launched by V-bombers with a stand-off range of 100 nm.

propulsion for a bomber, which study had as much influence on early V-bomber proposals as did the later access to the German aerodynamic advances. In parallel, there was a Supersonic Committee considering how to reach 1000mph, which was leading to the Miles M52. But immediately after the war, what the UK could really afford was limited and there were many cancellations.

The Korean War started in 1950[19] and in January 1951 the Labour Government announced a three-year rearmament programme.[20] There were concerns over the continued lack of an effective UK strike capability, studies in industry were initiated and prototype manufacture started of sub-sonic radar-controlled short-range bombardment-expendable bombers to specification Operational Requirement (OR) 1097/UB109 of December 1950, called *Red Rapier*[21] from early 1952 by Bristols[22] (type 182) and Vickers (type 725/SP2). Boulton Paul,[23] had also been asked to bid. The concept had been studied since September 1945 by the Expendable Bomber Working Party which reported in September 1950. It envisaged a missile capable of carrying 10 x 500lb bombs, 400nm at 500 knots and 45kft altitude with an accuracy of 250 yards that could be in service by 1958-62. It could only be used against static targets and the accuracy was not practical, so aircraft with stand-off

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[19] The 1950-53 Korean War was the first ‘hot’ war of the Cold War, fought between the United States, Britain and others under the auspices of the United Nations which backed South Korea, and the People’s Republic of China and Eastern bloc countries led by the Soviet Union, which backed North Korea.

[20] In August 1950, the UK government agreed to spend £3,400 million on defence over four years; this was increased in 1951 to £4,700 million to be spent over the next three years. The Treasury feared that this would precipitate a balance of payments deficit of nearly £600 million and did not preclude the possibility of national bankruptcy; see Michael Carver, *Tightrope Walking: British Defence Policy since 1945* (London: Hutchinson/Random, 1992), p21; see also C. J. Bartlett, *The Long Retreat: a short history of British Defence Policy, 1945-70* (Basingstoke: Macmillan, 1972).

[21] *Red Rapier*: medium-range guided missile design being built by Vickers and Bristols.

[22] Bristols: Bristol Airplane Company, which started in 1910 and built the Anglo-French Bristol Zodiac bi-plane. The firm later became the Filton Division of British Aircraft Corporation (BAC).

[23] Boulton Paul: originally Boulton & Paul, becoming involved in airplane construction during the First World War; the Company later became Boulton Paul.

weapons were considered to be more effective.[24] Both the Americans and Russians had been pursuing such cruise concepts. Churchill's post-war government of October 1951 found itself engaged in the reduction of this unsustainable defence programme drawn up by Labour, first by stretching it out and then by finding economies through cancellations and cut backs.[25]

The Cold War engagements between Western bloc spy-planes and the growing Soviet defences was a constant stimulus to aircraft developments on both sides. Between 1946 and 1956 up to 50 Western bloc aircraft were lost on surveillance missions. The Soviet MIG interceptor family ran to progressively higher performances from the MIG 15 onwards. But this experience and the assessments of the growth of Soviet defences made in 1952[26] showed that the high flying V-bombers, still to go into service, with their free fall *Blue Danube*[27] nuclear bombs, or the winged TV-guided glide bomb *Blue Boar*,[28] would be too vulnerable by 1960 to remain a credible deterrent.

At the end of 1952 the Air Staff started to plan for the next generation of weapon systems to succeed the V-bombers in ten years time. The obvious choice was between a manned supersonic aircraft to fly high, at about Mach 3, or an unmanned ballistic missile. The current perceived defence systems were limited to engaging targets at about Mach 2. Mach 3 appeared to be too fast for interception by any future systems working from an autonomous site. Either alternative required major technological developments that were certain to be exceedingly

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24 T. Buttler, *British Secret Projects, Jet Bombers since 1949*, (Hersham, Midland Publishing, 2003).

25 Alan Macmillan, 'British Atomic Strategy', in John Baylis and Alan Macmillan (eds) *The Foundations of British Nuclear Strategy* (Aberystwyth: International Politics Research Papers No.12-Aberystwyth, 1992), p.52; see also C. J. Bartlett, *The Long Retreat*.

26 The 1952 Global Strategy Paper assessed Britain's vulnerabilities and defence capabilities, see Christopher Staerck and Gillian Staerck, 'The Realities behind Britain's Global Defence Strategy' in Wolfram Kaiser and Gillian Staerck (eds) *British Foreign Policy 1955-64: Contracting Options* (London: Macmillan, 2000), pp.35-36.

27 *Blue Danube*: Britain's first in-service nuclear weapon containing a Mk I warhead: it was a free-fall bomb that could only be carried by the V-bombers.

28 *Blue Boar*: a family of TV-guided un-powered glide bombs, interchangeable with conventional free-fall bombs from 1,000 to 10,000 lbs, and with a special version to carry the Mk I nuclear warhead. The design was initiated by Barnes Wallis immediately post-war and developed by Vickers.

costly and time-consuming, but was seen as an inevitable insurance against the threat of nuclear war. A cheaper substitute was a fast, but not supersonic, low-flying aircraft just large enough to carry a rocket-propelled stand-off nuclear warheaded missile. This route led to OR344, tendered to by AVRO,[29] Bristol, Handley-Page,[30] Shorts[31] and Vickers-Armstrong, but which was cancelled early in 1954.

The West had to take risks to check the reality of the 'bomber' and then the 'missile gaps' proclaimed by the Soviet leadership. The US produced the purpose-built Lockheed U2, starting the project in 1954, and used operationally for over-flying from 1956-1960; it was immune for that period because of its 75,000 ft cruising altitude, which was well above that achievable by an aircraft to a conventional military specification. What to choose out of the various future mission possibilities available to the UK with our limited resources was not too obvious. OR330 for a Mach 2.7 reconnaissance aircraft, for which the AVRO 730 was chosen, was cancelled in 1957. Instead, in November 1956, the Supersonic Transport Aircraft Committee began to meet at Farnborough under the chairmanship of Morien Morgan.[32] The US started to look at a high supersonic U2 follow-on later in 1954, but there were considerable difficulties, and a configuration was not settled on until 1959, with a first flight in 1962 of the A12 capable of cruising at Mach 3.2 at 85,000 ft or higher. Key senior UK ministers and their advisers had access to the intelligence from such sensor platforms and would have been aware of the difficulties and the costs involved, and would have understood that this was not a credible route for the UK. However what was being done at that time for the ballistic option and who supported it in the UK is not yet clear. The author wonders whether it might have been Duncan Sandys himself who promoted it, arising from

[29] AVRO: A. V. Roe Aircraft Company, founded in 1910. A.V. Roe sold out in 1928 and bought S. E. Saunders.

[30] Handley Page Aircraft Company, founded in 1909; the company specialised in building bombers, including the Victor V-bomber

[31] Short Brothers Aircraft Company, Belfast; one of the earliest airplane companies, it specialised in building aircraft for the Royal Navy.

[32] Sir Morien Morgan, Head of Aeroflight Section, RAE, 1946-48; Head of Guided Weapons Department, RAE, 1948-53; Deputy Director, RAE, 1954-59; Scientific Adviser to the Air Ministry, 1959-60; Deputy Controller (R&D), Min. Tech. 1960-63; Controller of Guided Weapons and Electronics, Min. Tech. 1961-69; Director of RAE, 1969-72.

his wartime experience at Aberporth[33] with solid propellant rockets and then with the V-weapons intelligence.

The Start

The Minister, Duncan Sandys, had publicly announced a UK interest in ballistic missiles during a visit to Australia in 1953. The first Controller of Guided Weapons and Electronics (CGWL), Steuart Mitchell,[34] tasked RAE to examine their potential, starting in November 1953. The managing directors of the firms that were likely to be involved were briefed at a meeting at the Royal Military College, Shrivenham, late in 1953. The potential booster contractors, English Electric and de Havilland Aircraft, both produced schemes as private ventures before any formal contracts were placed, to begin to understand the issues involved. The late Charles 'Mark' Martin, of Hawker Siddeley Dynamics, had such an outline drawing looking like an enlarged *V2* without fins. The actual booster characteristics were defined in outline by RAE before the contracts were placed in the UK, as was common then in new development areas, because of the companies' relative inexperience. This was the equivalent of the modern pre-feasibility stage. An agreement to share research was signed with the US in Spring 1954.[35] The terms and limitations of this UK/US Agreement have not been seen recently, but presumably determined the path of the UK/US cooperation. The main UK contractors were chosen by Controller Aircraft (CA) without any tender action as the choice was so limited. The lead contractor was de Havilland Propellers because of the firm's extensive systems experience with guided weapons. Any systems studies on effectiveness were in those days done by the RAF themselves, very simplistic by modern standards, although the establishments formed their own independent views. The Air Ministry Requirement that appeared was for a maximum range initially of 1,000 to 1,500nm, then for 1,750 to 2,000nm, but finally with a need for a stretch potential to 2,500nm. An early version of the RAF Requirement also considered deployment of *Blue Streak* in North Africa. The Australians even considered that it

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[33] Aberporth: the guided weapon test range in Cardigan Bay, Wales, from which guided weapons were launched over the Irish Sea.

[34] Sir Steuart Mitchell, Controller of Guided Weapons and Electronics, Ministry of Supply, 1951-56; Controller of Royal Ordnance Factories, 1956-59; Controller of Guided Weapons and Electronics, Ministry of Aviation, 1959-62.

[35] US/UK Agreement to share R&D on anti-ballistic missiles as well as on *Blue Streak*, 1954.

could defend them because, before the 1958 Anglo-American Agreement for Cooperation on the Use of Atomic Energy for Mutual Defence Purposes, there were signs of the UK's nuclear force becoming a Commonwealth one in conjunction with Canada and Australia.[36]

By early 1954, RAE staff had already written preliminary papers on the major issues, covering simplified hypersonic aerodynamics, re-entry trajectories and angular motion, attempts at estimating likely aerodynamic heating levels, and the choice of booster structural materials. The author is not aware that the UK did any work on guidance and control specifically for large missiles, but all the theoretical work on more conventional ones carried over. The work in each area had grown out of related work with other weapons, but the lesson was that it could not easily be read across: the numbers had to be reworked. Very quickly the RAE set up four internal panels to plan and progress research activity: Guidance and Control, Aerodynamics, Materials and Test Vehicle. In due course, de Havillands set up seven panels covering Design, Propulsion, Control, Guidance, Trials, Re-entry and the Underground Launcher.

English Electric was eased out. They had major aircraft projects in hand. English Electric had the first shock tube in the UK that could measure aerodynamic heating. The company was initially tasked with the promising, but initially alternative, ablative heat shield re-entry head design, but soon faded out of the scene, although this was eventually the preferred design solution. De Havillands had just come through the Comet[37] episode. None of the early RAE or de Havilland panel minutes have been traced in private or heritage collections, nor have the semi-annual reports complied by G. Pardoe for de Havillands with their many photographs, of which copies were sent to the US Mutual Weapons Office in Paris. EADS Astrium has at least one of the progress film reports.[38] RAE provided monthly technical progress reports to London, except when a de Havilland semi-annual report was due.

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[36] See Wayne Reynolds, ‘Whatever happened to the Fourth British Empire? The Cold War, Empire Defence and the USA, 1943-57’ in Michael F. Hopkins, Michael D. Kandiah and Gillian Staerck (eds) *Cold War Britain 1945-64: New Perspectives* (London: Palgrave, 2003), pp.127-140.

[37] Comet: the first jet-propelled airliner into service, built by de Havilland Aircraft Co.

[38] European Aeronautic Defence and Space Company (EADS) Astrium specialises in space science and technology

The US Linkage

There were three areas of contact with the US which influenced the *Blue Streak* design. The first was with Convair[39] on their evolving ideas for the *Atlas* vehicle.[40] *Blue Streak* could not be a copy as the UK performance requirements were different, and the design had to be worked through again from scratch. De Havilland Aircraft staff said that their first visit to the USA was very useful. After that there was little to learn and, naturally, Convair and the United States Air Force (USAF) were not interested in exchanges or in the UK's improvements, having their own agendas. De Havillands thought that the Convair detail design was not all that wonderful and could be significantly bettered.

In the second, Rolls Royce had been chosen to produce the large rocket engines, although the company had no previous relevant experience, and they arranged a licence with North American Aviation (NAA) ahead of the UK placing a contract with Rolls. They bought and made a few copies of the NAA motor which were test fired singly at Westcott, and then produced significantly improved versions, which can be seen at the Rolls Royce Heritage Centre at Derby. A comparable new UK engine would have been at least two to three years longer in reaching the same degree of maturity. The NAA motor was a direct descendent of the *V2* motor, via the US-developed versions for the cancelled *Navaho* cruise missile booster[41] and for the US Army's *Redstone* ballistic missile.[42]

The third area was the inertial system instruments for which Sperry UK was the leading UK manufacturer. As a UK subsidiary of the US holding company, Sperry UK had access to US developments, but usually at one generation behind. Sperry had produced a prototype of the inertial navigation (IN) system by the time of the *Blue Streak* cancellation in 1960 and one exists in the Guided Weapon collection at

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[39] Convair: the Convair Astronautics Division of what later became General Dynamics Corporation, San Diego, California.

[40] *Atlas*: a US intercontinental range ballistic missile conceived by Convair and deployed in small numbers in the USA in the late 1960s.

[41] *Navaho*: a US cruise missile with a large solid propellant booster stage and a liquid propellant sustainer, which was extensively tested but not deployed.

[42] *Redstone*: a short-range US Army ballistic missile, developed at Redstone Arsenal; it was deployed for a while in Europe as the *Jupiter-C* vehicle used in early space attempts (a ballistic test vehicle for *Jupiter* using Redstone components for its first stage).

the Royal Military College, Shrivenham. However it would not have been used for early development flights as these could and were done with a simpler pre-programmed autopilot. The IN system developed later for the European Launcher Development Organisation (ELDO) missions was different.

It was not all helpful information from the USA. For example, the RAE investigated the UK-available version of the stainless steel that Convair said it was using for the tanks; it was not suitable, and RAE had to find an alternative.

In 1954 it was thought that the US and the UK would mutually benefit from co-operation. Seeing what had been achieved already was expected to give the UK confidence in that it would be known that it could be done. The US work was tapped by sending what were in those days called senior staffed ‘missions’. Travel was by ship or slow piston-engined aircraft. The first mission was exposed to a great deal about the *Redstone* ballistic missile and the *Viking* sounding rocket,[43] but the *Atlas* Inter-Continental Ballistic Missile (ICBM) work was still in its early stages, and had not flown. The *Atlas* concept of three engines, two of which were dropped during flight, was not appropriate to the UK. *Atlas* was to be guided by radar beams as the later study of possible Inertial Navigation systems at Massachusetts Institute of Technology (MIT) had not begun. Bert Longden quickly discovered that, theoretically, guiding by three radar beams would not be very accurate over the flight ranges of interest to the UK because of the errors introduced by the normal minor imperfections of the atmosphere through which the beams passed. The system would have been very vulnerable to counter-battery fire with its three above-ground radars. The only US blueprints obtained appear to have been of the NAA rocket engine. Access to US data on aerodynamic heating from 1957 was limited to simple shapes which had no relation to the in-service re-entry vehicle proposals by the US companies AVCO and GE.[44]

Although the *Atlas* design was built on earlier studies by Convair, for their X-planes,[45] it had undergone a major re-work with the promise of a

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[43] *Viking*: a US sounding rocket which was the first development from the *V2* missile.

[44] AVCO and GE (General Electric): US aerospace companies involved in re-entry vehicle and decoy design.

[45] X-planes: US National Advisory Committee for Aeronautics (NACA/NASA experimental aircraft and missile series), see J. Miller, *The X-Planes: X-1 to X-45* (Hinckley, Leicester: Midland Publishing, 2001).

much lighter nuclear warhead. Its development started not greatly ahead of *Blue Streak*, although the ability of the US to accelerate its programme eventually left the UK behind.

That the US input was rather limited is not surprising. Firstly, competent engineers only needed hints on how to proceed; secondly, data exchange was mostly via these missions, so that it was mainly notes that were gained, as requests for reports often took ages to get through the US system and would arrive too late to have any impact. The best flow was via Wing Commander Pinkerton at the British Embassy, Washington, who was allowed into the Pentagon Library to read and trace diagrams from relevant reports, but not to borrow nor have them photocopied! The value of the exchanges was the meeting of senior people from both sides and the swapping of views on trends and possibilities.

The *Blue Streak* structure was specific to UK needs and can only be considered as in the same general family of ideas as *Atlas*. The tankage was unusual for the UK in that it was thin and required to be pressurised at all times to hold its shape, but this was not greatly outside the experience of pressurised aircraft and, of course, was similar in size to the *Comet* fuselage. But it did require special procedures for handling - as was found when moving one survivor from Liverpool to Leicester, and is to be faced at East Fortune[46] in the proposal to move their *Blue Streak* to another site. The Inertial Navigation system did not draw on proposed US in-service components. The motor was significantly improved, in terms of design, reliability, thrust level and light-up and shut-down characteristics. The rest was all of UK design.

Need for Progress

Where the UK was lacking in experience was in launch stand design, whether above or below ground, in storing and handling large quantities of liquid propellants, and in the sheer physical scale of flight trials. Worst of all was the ignorance of design procedures for the re-entry vehicle, and this was not helped by the initial uncertainty about the warhead design that was to be carried. It had been hoped by 1955 that the UK missile would be a single-stage, single-engined vehicle, about the size of what turned out to be the US *Thor*.[47] But this would have needed a

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[46] East Fortune: a historic airfield, now the site of the Aerospace Collection of the National Museum of Scotland, which holds a comprehensive collection of UK rockets.

[47] *Thor*: a US intermediate range ballistic missile (1,500nm) built by Douglas and deployed in eastern England from 1958-63.

warhead of only about 2,500lb. The RAE had provided calculations for many combinations of engines and stages to enable a choice of configuration to be made, although the prime interest was in simplicity. A *Blue Streak* and a *Thor* can be compared at the National Space Centre at Leicester.

The Atomic Weapons Research Establishment (AWRE) was approached early in 1954 by RAE. At that time the UK Mk 1 A-bomb in the *Blue Danube* casing weighed over 10,000lb, for a yield of less than 20 kT; therefore, some at RAE and AWRE thought that to send such a weight as 2,000nm would need a nuclear-powered rocket and Dr. L. Shephard at the Atomic Energy Research Establishment (AERE), Harwell, was consulted. Advances in nuclear device design, which was under Service pressure to produce something that could be delivered by smaller aircraft than the V-bombers, were reducing the diameter of devices and hence their weight. Eventually this led to what became known as *Red Beard*.[48] But a single-stage[49] warhead needed a reasonable accuracy of delivery to be meaningful. Dr John Corner[50] of AWRE thought that a boosted[51] *Red Beard* of order 50 kT yield would be possible but an accuracy of better than one mile must be achieved.

During 1954 the Government decided to pursue the H-bomb, solving the poor accuracy problem. *Red Beard*, an A-bomb, was about 2,000lb, but *Yellow Sun*,[52] the first H-bomb, looked like being about 7,000lb. These were the total bomb weights not just the warheads, but with a re-entry shell and the other sub-systems added in they were not unreasonable guides. AWRE thought that a realistic warhead could be provided in the 1960s at 4,500lb with a future possibility of 2,500lb. But

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[48] *Red Beard*: the second UK tactical nuclear warhead design produced and introduced into service.

[49] The first UK nuclear atomic warheads were single high explosive-driven implosion devices. Later devices used one to drive another stage, achieving compression by focusing the X-ray pressure from the first. Thus, the first part became known as the first stage, or primary, and the next stage as the second stage or secondary. For convenience they were often referred to as ‘Tom’ and ‘Dick’ respectively.

[50] Dr. John Corner, physicist and specialist in nuclear device performance at AWRE 1950s-70s.

[51] The first nuclear devices incorporated a neutron-producing material which helped initiate the reactions. In later designs this could be boosted by small thermonuclear reactions.

[52] *Yellow Sun*: the first UK thermonuclear warhead to go into service with UK-designed two-stage nuclear device.

at decision time, CGWL in London felt forced to accept the higher weight and hence the implications of needing a two-engined missile. It was thought at that time that the problems of simultaneous light-up and shut-down would add 18 months to the development time. The Germans had developed radar-controlled ballistic systems and had been heading towards a mixed radar and inertial system for optimum impact accuracy. But what they had not done was to develop multiple-thrust chamber missiles or multi-stage liquid propellant systems, with their associated issues of simultaneity of light-up and shut-down and of ignition whilst in free fall, although they had such plans.

Remember that, at the time of the Government's decision to develop an H-bomb, AWRE did not know how to design or make one. The 1957 *Grapple*[53] series of trials at Christmas Island proved a UK warhead concept but even those were of a size and shape that was difficult to fit within the current ideas of acceptable re-entry body shapes compatible with the existing missile design. Project co-ordination was difficult: nuclear matters had special security caveats, and very few people outside of Aldermaston had the necessary security clearances.

The RAE team was basically one division within Guided Weapons (GW) Department under D. 'Joe' Lyons[54] with support from other Departments. Those were the days when the aircraft industry relied on the RAE for many things: wind tunnel testing, prediction method developments, structural strength tests, material evaluation, instrument choices - really all those areas requiring some research and development beyond the commercial state-of-the-art. Also the establishment had to find paths through the newer topics: guidance, control and navigation, vulnerability to nuclear effects, and how to design a silo. Much of this was decided before main-frame computers became available: it was the days of 20-inch slide rules, rooms of women using mechanical and electrical desk computers, and of analogue computers. Quite important was the use of the very large TRIDAC[55] analogue computer at RAE: a three-dimensional analogue of a generic total guided weapon system, which could be used to verify the design of the control and guidance

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[53] *Grapple*: thermonuclear trials at Christmas Island in the Pacific in 1957.

[54] D. Lyons, Superintendent of Ballistic Missile Division, Guided Weapons Department, RAE, 1954-60; Head of Weapons Department until 1967, then Director of Road Research Establishment, Crowthorne, Berks.

[55] TRIDAC: a three-dimensional analogue computer built at RAE, Farnborough, to tackle complex guidance and control problems and able to incorporate real system hardware.

systems throughout flight, from moving up out of the silo to engine shut-down.

The work on arming and fuzing, which was done for all nuclear systems by RAE after *Blue Danube*, was confined to Armaments Department in a remote part of RAE, and all the documents were TOP SECRET. The 1958 Agreement for exchanges on warhead design with the USA followed the successful UK proving of a megaton warhead after only three shots, much faster than the USA or USSR. An anglicised warhead was chosen, *Red Snow;*[56] it was intended that it should be mounted in a capsule which could be fitted within the re-entry vehicles and also into other weapons such as the *Yellow Sun II*[57] free-fall bomb and the stand-off weapon *Blue Steel*. This capsule was designed and produced by a part of Hunting Percival.[58] The design incorporated impact fuzes for ground bursts and as a back-up for air burst settings which had to allow for first contact being the sides of buildings or trees. Tests had been planned on the rocket sled at Pendine.[59]

The Re-entry Vehicle Problem

The first problem was estimating the flow characteristics immediately over the heat shield for various shapes of body; the second was finding a formula which conservatively predicted the aerodynamic heating produced by the hot gases in the boundary layer; the third was calculating the heat then conducted into the heat shield structure and the internal components; and fourth the behaviour of its materials at elevated temperatures. The first required new developments in what is now called computational fluid-dynamics as realistic bodies had to have blunt noses. The RAE expert was Dr. K. Mangler.[60] Heat transfer formulae were developed and eventually appeared as an industry standard in Reports &

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[56] *Red Snow*: a UK megaton nuclear warhead developed from a US design, following the exchanges under the 1958 Agreement; it was intended to be carried in *Blue Streak, Yellow Sun II* and *Blue Steel.*

[57] *Yellow Sun II*: the replacement for *Yellow Sun*, using the same ballistic case, but including the *Red Snow* warhead.

[58] Hunting Percival: the name of the Percival Aircraft Company when taken over by the Huntings Group, which later became Hunting Engineering.

[59] Pendine: an Army-administered test range in Wales near Tenby; sands once used for land speed record attempts.

[60] Dr. K. Mangler, a German aerodynamicist in Aerodynamics Department, RAE, who made many important advances in techniques for predicting flow fields.

Memoranda (R&M) of the Aeronautical Research Council.[61] These were validated by flights of various shapes to a Mach Number of 4 at Aberporth, by analysis of US measurements from their *Trailblazer* programme[62] using the Lockheed X-17, a three-stage solid propellant vehicle of the second half of 1956, from careful wind tunnel tests in the UK, and eventually from satisfactory flights in the *Black Knight* programme. The heat conduction side was tackled at first using a special purpose analogue computer designed by Harold Robinson,[63] then main-frame computers became available. We found ways of comparing the performance of different heat shield materials. With metals there appeared to be a maximum amount of heat that could be absorbed before the surface started to melt, defining the limiting performance of the so-called 'heat sink solution'. What happened when the material was near the melting temperature was very important, as materials could flow and heavily distort. The solution finally sought was one in which the surface ablated, dumping the absorbed energy back into the wake.

Professor Lovell[64] of Jodrell Bank approached us hoping that his radar observations of meteorite re-entries would be of help, but we concluded that when we understood re-entry then we could help him!

The UK worked with the US *Jupiter*[65] team and shared in the *Jupiter-C*[66] flight of an ablative body down the Atlantic Missile Range.[67]

There was an evolution of re-entry body shape - the best drawing of a missile in flight is that in the Officer's Mess at Spadeadam.[68] It would

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[61] Published by HMSO.

[62] *Trailblazer*: NASA X programme multi-stage solid-propellant rocket.

[63] Harold Robinson, an ex-Portsmouth Dockyard apprentice, who became leader of the *Black Knight* team at RAE, Superintendent of Launcher Division, Space Department and eventually Deputy Director of RAE.

[64] Professor A.C. Bernard Lovell, Director of Jodrell Bank Experimental Station, Cheshire (now Nuffield Radio-Astronomy Laboratories), 1951-81.

[65] *Jupiter*: a US Army ICBM deployed in small numbers in Italy and Turkey at the same time as *Thor* in England.

[66] *Jupiter-C*: a ballistic test vehicle for *Jupiter*, using *Redstone* components for its first stage.

[67] Atlantic Missile Range: a US over-ocean rocket test range which extends from Cape Canaveral/Kennedy in Florida, USA to Ascension Island in the South Atlantic.

[68] Spadeadam: a remote RAE base in Cumbria, inland from Carlisle.

have been long and thin and not at all like the simple cap seen on the initial F1-3 ELDO flights at Woomera.[69]

If *Blue Streak* had continued it would have been quite capable of being developed for carrying Multiple Independent Re-entry Vehicles (MIRV), probably exploiting the smaller *WE177*[70] warhead components. The quality of the design was shown in its ELDO guise with its rather successful launch record. It had stretch potential, the motors could have developed a higher maximum thrust, as well as be throttleable. It also could have switched later on to UK storable propellants. But that would require some re-work and development of the engine and, of course, re-organisation within the silo. Such propellants were researched, and paid off in the small liquid propellant motors used later on the payload of *Chevaline*[71] and safely carried in submarines.

The details of the engineering of the booster, the design cases, as well as the supporting test facilities, are covered in a book written by the late Charles Martin, published by the British Interplanetary Society in September 2004. The size and quality of the facilities in the UK was determined by the Ministry requirement to handle the through-put of a few hundred missiles.

Deterrence and Silos

In reaching a view on the necessary strength of the proposed *Blue Streak* weapon as a credible second strike nuclear deterrent system, pragmatic considerations, such as, how many missiles could be produced in the time-scale postulated, how much fissile material could be supplied for the warheads, and how great a total expense of resources could be tolerated, had to be taken into account. Equally important was the essentially political judgement of the extent of damage the UK force needed to be able to threaten to inflict on the enemy for him to be deterred from initiating offensive action against the UK. Part of these considerations also included the need to be able to penetrate possible

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[69] F1-3 ELDO flights: flights of the single-stage *Blue Streak* at Woomera to demonstrate fitness for basis of EUROPA satellite booster.

[70] *WE 177*: a free-fall nuclear bomb.

[71] *Chevaline*: the name of the Improved Front End built to modify the UK *Polaris* system in response to Soviet ABM developments, known initially at KH793 until 1974. *Polaris* was the US Navy's submarine-carried ICBM, which went through radical redesigns as the A1, A2 and A3, and was bought by the UK under the Agreement made at Nassau in December 1962 between UK Prime Minister Harold Macmillan and US President John F. Kennedy.

enemy defence, and the need to protect the *Blue Streak* force against attack before launch.

Aircraft would be very vulnerable even when dispersed, as it was thought possible for an attacker to use multi-megaton warheads each of which might clear several airfields of parked aircraft. Suitable submarines and solid propellant motors had not been developed. Above-ground missile launchers as used for *Atlas* and *Thor* were at least as vulnerable as aircraft. Thus the UK intended to go for silo basing, if research and development (R&D) showed it was feasible.

The method proposed to protect *Blue Streak* when deployed was by siting in underground silos. The silos were supposed to survive a one-megaton ground burst 1,000 yards away, because it would then be outside the plastic deformation volume of ground, and, although shaken, would have been tilted by only a very small angle. The working specification for the silo suggested that it need only take a brief time to recalibrate for a launch, but another source has suggested that it might in practice be up to a day, which would have been quite unacceptable operationally. Estimates of earth movement and the shocks to be expected were based partly on data from the UK in-atmosphere nuclear tests at Maralinga in Australia,[72] but depended on the underlying rock type.

Approval to go for silos was dependent on satisfactory research on their feasibility, although if they had not been possible, then it could have killed the project, unless lifting the missile to the surface for its launch did not appear to leave it vulnerable for too long. A working model of such a scheme exists in the Science Museum reserve collection at Wroughton, near Swindon.[73]

The silos are described in the book on Cold War archaeology by English Heritage.[74] They would have required a massive total amount of concrete as 64 were intended, just as the UK was building up the capability of producing sufficient concrete for the motorways. One-sixth

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[72] Maralinga: the test site in central Australia used by the UK for early in-atmosphere nuclear weapons tests.

[73] Wroughton: the out-station of the Science Museum south of Swindon, used to store large exhibits and work on restorations, which is occasionally opened to the public.

[74] Wayne Cocroft and Roger Thomas, *Cold War: Building for Nuclear Confrontation*, (Swindon: English Heritage, 1989).

scale model tests at Westcott under Barry Ricketson[75] showed that a satisfactory configuration was possible and the sixth-scale silo, built on its side, is still there in segments. There were three problems: the first was the noise generated in the confined space. We were already aware of acoustic fatigue from experience with the Saunders-Roe[76] rocket-propelled aircraft - panels would fall out near the engine exhaust. RAE ran tests at Pyestock[77] using an Avon jet engine[78] which had its exhaust made additionally noisy, at nearly 200db. We found that the *Blue Streak* structure had to be specially manufactured to survive. It also meant that an improved *Thor* offered by Douglas,[79] with higher thrust and a lighter re-entry vehicle which could reach 2,000nm, was not an option without completely changing its method of manufacture. There is an interesting display on the UK *Thors* in the Northants & Carpetbaggers Aviation Museums[80] next to a *Thor* site near Kettering. Work was done on incorporating a thick acoustic liner but by cancellation it seemed to be going to be unnecessary. The second problem was the lid: a ground detonation just over 1,000 yards away would scatter debris all over it, and this would have to be cleared. Steam jets were proposed. The third problem at that time was thought to be the effects of nuclear radiations from the near ground burst.

Liquid oxygen is rather cold, boils off easily, and needs to be stored very carefully. It could not be kept for long in the missile without topping up. It was possible to load it fairly quickly: *Thor* could do so in under ten minutes. It was expected that it could be done somewhat faster and a full-scale experimental rig was being built at Spadeadam at cancellation to iron out any difficulties. However LOX needs to be

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[75] Barry Ricketson, leader of team designing and model testing *Blue Streak* silo configuration, RAE Westcott, 1956-60.

[76] Saunders-Roe: the aerospace company on the Isle of Wight, one-third owned by de Havillands from 1956, and then absorbed by Westlands in 1959, becoming British Hovercraft Corporation in 1966. Originally it had been the firm of S. E. Saunders, that built flying boats, before becoming involved with A. V. Roe and John Lord in 1928 to become Saunders-Roe (Saro Aviation).

[77] Pyestock: RAF Pyestock, sited next to RAE, Farnborough, formerly the independent National Gas Turbine Establishment (NGTE), and now part of Qinetiq.

[78] Avon: a jet engine produced by Rolls Royce.

[79] Douglas: the American aerospace firm McDonnell Douglas.

[80] Northants. Aviation Museum incorporates the Carpetbaggers Museum, near Kettering.

handled in equipment that has cooled down sufficiently, and how to do it and how long it would take to do this was uncertain still at cancellation. The need for ultra-rapid loading was probably a misunderstanding, unless it was intended to appear to be able to attempt to launch whilst under warning before the first incoming warheads had arrived. But it was, and probably still is, impractical for anyone to launch a raid with missiles travelling different ranges over a spread of flight times to arrive near simultaneously, and this realistic variation was not allowed for in the RAF's pre-cancellation evaluations.

It is hard to see how anyone could ‘prove’ that silos would be satisfactory under attack as a demonstration would be unacceptable. This of course is the problem with an ABM defence, the first offensive detonation could bring the whole system down. The main issue with the silos was not engineering feasibility but where to place them. It was initially proposed to base *Blue Streak* on the *Thor* sites in silos. The prototype, to be called *K1*, would have been at Duxford, but trial borings showed a problem. The author understood it was to do with the water table, but the vulnerability studies wanted the silo surrounded by wet ground to reduce nuclear effects. The next proposal was for the prototype, now to be called *K11*, to be at Upavon in Wiltshire, but the author does not think that the RAF had agreed to this by the time of the cancellation. However plans were going ahead for simulated silos at Spadeadam and at Woomera. Siting the silos was a major problem for the Home Office as it was national policy not to have major towns in the prevailing down-wind direction from nuclear sites. There was a severe requirement on the ground not being geologically faulted as well. Because sites placed along the North Downs were, therefore, not attractive, there was a limited examination of other possible basings, such as being mobile or off-shore, none of which appeared desirable, especially as by then the whole concept was losing its attractions under advice from the USA. *Blue Streak* would have been a little large to have been rail-mobile, although it might have helped avoid having the Beeching branch-line closures![81] The experience of the Army's GW Regiment was that the Campaign for Nuclear Disarmament (CND) followed them around announcing their presence, and mobile systems, when with warheads, would have been desirable terrorist targets.

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[81] In March 1963, in his Report entitled ‘The Re-shaping of the British Railways’, Dr. Richard Beeching proposed cutting the railway network by a third, closing 2,000 stations and 5,000 miles of track.

There were a number of clever engineering solutions found for *Blue Streak*. A simple scheme for turning over the re-entry body to re-orientate it and spin stabilise it facing the defence sensors was proposed by A ‘Ken’ Weaver[82] and G ‘Stan’ Green,[83] and demonstrated on *Black Knight*. The booster's vernier motors, to be used to fine-tune the cut-off condition, were replaced by a much lighter, small solid-propellant motor, the *Guillemot*,[84] attached to the re-entry vehicle, whose thrust could be terminated at the correct state vector. Propellant sloshing in the booster was controlled by baffles. Impact fuzes for the re-entry bodies were developed to deal with hitting trees or the sides of buildings before reaching the ground.

RI

The Radiation Interaction (RI) was apparently an effect, a project and an access caveat, depending on whose records are accessed. The UK had considered many possible adverse nuclear effects in the mid-1950s. One was a consequence of the capture of neutrons by fissile material and the changed isotopes short-term radioactive decays releasing more neutrons. Thus, if it was attempted to detonate the device within minutes of an exposure, it could have an excess of neutrons, and would be a fizzle, in effect achieving a system kill of the device. The RAE seriously considered incorporating a parachute to slow the fall of the re-entry vehicle to increase the time available for recovery. Briefly, about 1957, it was thought of as a potential exploitable defence mechanism. Perhaps this is the key issue that influenced Duncan Sandys’ 1957 Defence White paper which switched attention from manned to missile systems. It was promptly discussed with the US, who did not indicate whether they had thought of it. Access to information on its existence was very limited at the time, which is why it had been largely forgotten until its recent access by historians. The RAE considered the implications to re-entry vehicle

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[82] A. ‘Ken’ Weaver, mathematician, head of Aerodynamics Section, RAE Guided Weapons (GW) Department, who went on to be a Professor of Mathematics at the Royal Military College, Shrivenham

[83] G. ‘Stan’ Green, an ex-Hawkers Aircraft employee who made break-throughs in understanding the dynamics of re-entering vehicles; he worked in Guided Weapons and Space Departments, RAE, 1954-60, and later modelled the start-up processes of the EUROPA rocket engines.

[84] Guillemot: a small cigarette-burning solid propellant rocket motor, with thrust termination designed for use on *Blue Streak* re-entry vehicle.

design of neutron shielding - it proved to be quite impractical, requiring about a foot of heavy material.

Orange Herald was sensitive, but three design innovations were tested by AWRE in 1958 and were particularly robust in staged weapons.

In the meantime a new requirement for a UK ABM with a nuclear warhead had been produced specifying a generous 400ft miss distance!

The Path to Cancellation

The biggest problem was the perceived urgency. *Blue Streak* was required by the earliest date that the V-bombers could be obsolete because of developing anti-aircraft defences. This was a recipe for overruns on time and cost. Involvement with the US in every aspect was needed in order to speed up the UK acquisition of the capability, with little regard for its potential long-term adverse effects. Speeding up increased facilities and staffing. The expectation of handling a few hundred missiles meant that everything had to be very substantial.

The Soviet launch of *Sputnik*[85] came as a great surprise to Western intelligence agencies, causing them to bring forward by several years their estimate of the date by which the Soviets might acquire operational ICBMs. The US was able to give its ballistic missile programmes greater priority by greatly increasing funding and hence resources. This option was not available to the UK, although we did speed up as much as possible with a tighter, riskier schedule. The US *Thor* programme exploited what had already been done for *Atlas*, and by being so conservative it could be rushed through; but, as far as the author knows, nothing about *Thor* influenced *Blue Streak*, although we would probably have tapped the operational experience of the RAF if *Blue Streak* had gone into service.

A major issue was that, consequent on the change in intelligence assessments, requirements for deterrence had changed. From *Blue Streak* being a potentially invulnerable system, the Soviets had developed an apparent first strike capability and were doing the R&D for a defence system which might use nuclear warheads - to mirror-image UK and US thinking. They were not well behind as was thought at the start. Thus *Blue Streak* front-end details had to be changed. The re-entry vehicle was to be much more advanced and penaid research was underway. All the issues of hardening electronics had been recognised - fortunately the available technology of the day was robust, as techniques for analysis

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[85] *Sputnik I*: a Soviet satellite launched on 4 October 1957, ahead of the US *Vanguard I* satellite, which was not launched until 4 March 1958.

and test of advanced semi-conductor components were up to a decade away.

No matter what the urgency, in the UK it took time to build the large facilities needed at RAE, Stevenage, Hatfield, Luton,[86] Spadeadam and Woomera, and left an impression of slowness of progress for a while. After cancellation, the large tower at Luton was toppled where it stood and is now under the corporation rubbish tip.

The RAF final assessment *of Blue Streak* assumed a high accuracy for Russian missiles in the 1970s and considered that up to six would be targeted onto each silo. Many thought that these assumptions were quite unrealistic. Even the Soviets might have hesitated to drop 300 megatons of ground bursts anywhere in the world. The RAF had studied *Skybolt*[87] as a replacement for *Blue Steel,* then compared *Blue Streak* with *Skybolt.*

Cancellation

From 1958 it became clear that, in its present form, *Blue Streak* could only be an interim weapon and its potential window of credibility was shrinking because of the advances elsewhere. The Treasury began to drag its feet as soon as it became obvious that it would have a limited life, whilst the costs were rising due to the accelerated programme and the consequential greater facility demands. The Treasury rightly sees its role as minimising nugatory expenditure.

Although the neutron flux effect, called RI, was a serious hiccup about 1957, there were solutions, as there are to all the technical problems. The US continued with silo-based systems because it had the real estate, but the gradual demonstration of large solid propellants of high performance showed that they could be air or submarine carried, and that these were going to be the long-term, relatively invulnerable, solution. *Blue Streak* was probably continued until a credible alternative existed, as having no deterrent by the late 1960s was not a politically acceptable option.

Two key reasons for cancellation were expressed effectively by the Chief of Bomber Command. His reasons were sound, and not a consequence of what was or was not being done on the project. Firstly, the collateral damage from a determined Soviet first strike against the

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[86] Hatfield and Stevenage: de Havilland Aircraft Co. sites for large *Blue Streak* test facilities; Luton: English Electric site used by Hunting Percival for a large *Blue Streak* test site.

[87] *Skybolt*: a US-designed and built air-carried ballistic missile with a range of 700 to 1000nm, intended to be carried by UK V-bombers, but cancelled in 1962.

deterrent would have been horrendous. The UK could hardly cope with the effects of one or two A-bombs, let alone megatons, no matter where they fell. Secondly, there was no credible command and control system in sight when under attack. Obtaining authority to launch would have been impractical in many circumstances. Despite the propaganda, there was actually UK chaos during the Cuban Missile Crisis.[88] The solution of an airborne control centre was eventually achieved by the US, but was probably beyond the UK's capability.

The Ministry had decided to cancel it sometime before it was announced but kept it a close secret. The first *Blue Streak*, intended for handling exercises at Woomera, was on its way and had reached Los Angeles, accompanied by two ‘babysitters’ whose task it was to made sure that the pressurisation never dropped. Some of us were rather upset, particularly because of the reasons being quoted in public, implying a less than successful development when the true issues were elsewhere. Oddly de Havillands had managed the flight trials of *Black Knight* at Woomera because it was intended to give them the experience in preparation for flying *Blue Streak*.

Exploitation

The RAE Director, Sir Arnold Hall,[89] asked Dr Desmond King-Hele[90] early in 1957 to estimate the potential for payload into low earth orbit of combining *Blue Streak* with *Black Knight*, the pairing becoming known as *Black Prince*. Serious study was authorised in 1958. It did not call heavily on existing resources as the issues were often with what sort of payload was desired. It quickly became clear that the *Black Knight* technology was adequate for an upper stage, but not in the existing form; a shorter, fatter vehicle was better. The first plan had an attempted launch of a *Blue Streak* with dummy upper stages as number 11, and then launches interspaced with regular weapon ones and live launches of the upper stages as a separate vehicle.

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[88] Cuban Missile Crisis, October 1962: a confrontation between the SU and the US, after the US obtained photographic evidence of in-progress installation of Soviet missiles on Cuba, only 90 miles off the coast of southern USA..

[89] Dr. Arnold Hall, Principal Scientific Officer, RAE, 1938-45, Zaharoff Professor of Aviation, University of London and Head of Department of Aeronautics, 1945-51; Director of RAE, 1951-55; Chairman of Hawker Siddeley Group, 1967-86.

[90] Dr. Desmond King-Hele, joined RAE in 1955; Deputy Chief Scientific Officer, Space Department, RAE, 1968-88.

At the weapon's cancellation a series of internal RAE panels were set up to progress the satellite launcher vehicle issues further, and out of these came the UK proposal that was discussed with the French. The French appeared to be more interested in acquiring UK technology. At that time, the payload capability into low earth orbit was compatible with many of the foreseen uses, such as telecom or telephone links. A number of reference missions were defined and explored. A difficulty was that no UK payloads could be financed without full Government support, which was not given.

UK studies for a three-man crew in orbit were done by several firms, for example Armstrong-Whitworth,[91] and for a while the RAF had an Air Staff Target, OR 9001, issued in April 1962, and held a conference on the possibility about August 1963. *Blue Streak* as it stood would have been too small, it probably needed a four-engined first stage to obtain adequate lift into orbit.

As part of a potential exploitation, development work on a liquid hydrogen/liquid oxygen engine went on at Westcott. It was hoped to fly it as an upper stage on *Black Knight*, giving it a limited satellite launch capability, and then extend it for upper stages for *Blue Streak*. This was one of several possible uses of *Black Knight*, others included an inertial navigation development vehicle, and a basis for launching hypersonic aircraft models.

Hindsight

Blue Streak has been widely criticised in hindsight, technically and managerially, partly because it was thought essentially dependent on US technology. The ELDO launches proved the soundness of the booster, the *Black Knight* programmes the validity of the UK re-entry vehicle design procedures, *Titan II*[92] showed the correctness of the silo design. The only component not proven was the penaids, which were only months away from testing on *Black Knight* at cancellation.

Regarding managerial, aspects, Professor Lighthill,[93] whilst Director of RAE, toured the US in 1962 to examine the state-of-the-art on project management. He wrote:

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[91] Armstrong-Whitworth: a UK aerospace firm that merged with Gloster in 1961 within the Hawker Siddeley Group and then, in 1963, all became Hawker Siddeley Aviation.

[92] *Titan II*: a US-designed and built two-stage ICBM, able to carry a many-megaton warhead and deployed in silos from which it could be launched directly.

[93] Professor M. James Lighthill, Director of RAE, 1959-1964.

> The biggest recent UK experiment along the lines now favoured in the USA was in respect of *Blue Streak*. A large RAE division, nominated as Co-ordinating R&D Authority, and supported by numerically far bigger teams scattered all over RAE, and by teams in several other R&D establishments, monitored and managed the technical development of that project. In this technical sphere, the experiment can be claimed to have produced excellent results. Financially, estimates rose by a large factor but none more than has been the standard experience with large projects all over the world. Politically, the project collapsed, but technical deficiencies were never adduced as reasons for this; indeed, *Blue Streak* is now seen to have been ahead of its time in several important respects.

One consequence of the *Blue Streak* experience appears to be the more formal method of having project phases which require reports, reviews and permissions to proceed to the next stages. These are no different from the way projects were run before, but now there is more visibility, and hopefully less rush. We recognise Pre-Feasibility, Feasibility, Project Definition, Development and Production phases, with formal cost estimates, programmes, facility requirements and specifications. But the most difficult and complex projects at the leading edge of technology always seem to be needed the quickest. It is not obvious in retrospect why the various weapon systems were required by particular dates. Costs are driven by external circumstances. Is it possible now to discover how far the imposed tight time-scales were responsible for the cost escalations? The media and academic studies misled themselves over *Blue Streak*. As always the key issues were sensitive and therefore not too apparent at the time to the outside world. Should the final reasons for cancellation have been foreseen sooner?

The issue of anglicisation of US designs is particularly misunderstood, especially with regard to nuclear warheads. The UK could not make exact copies: firstly the engineering culture is different; secondly, it has to be done in UK-available materials that were acceptable to the Ordnance Board, with UK-available processes. Moreover, as the UK is entirely responsible for performance and safety, it has to have a deep understanding of everything and have adequate computational tools. US ‘designs’ in principle save some time, but often the effort involved made it seem hardly worth it to those involved. A parallel example in the aircraft field was the Phantom,[94] where the UK changes produced the worst version of the outstanding aircraft design, and then there was the Canberra,[95] which had to be reworked before it could be manufactured in the USA.

[94] Phantom: a US fighter aircraft by McDonnell Douglas, fitted with Rolls Royce engine for the RAF.

[95] Canberra: the first RAF twin-engined jet bomber and reconnaissance aircraft, built by English Electric.