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Lecture

'The Industrial Archaeology of Britain's Post-War Technological Renaissance

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The Rolt Memorial Lecture 2008
'Dan Dare's Lair' — The Industrial Archaeology of Britain's Post-War Technological Renaissance

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The theme of the 2008 Association for Industrial Archaeology conference seminar was 'Modern military matters'.[1] Modern military sites have much in common with large industrial sites. They are places of employment for many hundreds of people, incorporate complex technologies, and are also creators of new landscapes and communities. This paper explores the places created and used to develop and manufacture many of the products that were portrayed as representing the rebirth of post-war Britain as a major industrial power. Many of the new industries were based on technologies developed in the Second World War, including radar, jet and rocket engines, and military and civil atomic power. Politically, the World Wars had left a legacy of heavy government involvement in scientific research establishments and the state as the main customer for their products. In the post-war decades, this relationship was strengthened as the development of high-tech weaponry was seen as one means of countering the growing threat from the Soviet Union and her allies.

Introduction

Throughout the industrial age obsolescent industries have existed alongside the innovative. During the post-war decades when Tom Rolt was at his most prolific, writing on waterways, railways, and the great figures of 19th-century engineering, this contrast between the old and new industries was most marked. He saw the early engineers working with nature for the benefit of mankind and their creations, such as waterways, adding to the beauty of landscape. He, however, held particularly trenchant views on their successors, on their arrogant disregard for nature and remodelling of the landscape for the benefit of machines. These beliefs permeated many of his books and were most forcefully argued in his philosophical essays on the failing of modernity, the rise of the state, and in particular the threat to the survival of mankind posed by the atomic bomb collected together in *The Clouded Mirror*.[2]

Glancing through many early industrial archaeology books and journals a reader might also come away with an image of the 1950s and 1960s as decades of industry in terminal decline, a land of silted-up canals, weed-covered railway lines, derelict textile mills and scrap yards full of steam engines. However, there is a contrary picture of the early post-war decades, of a Britain typified by dynamic industrial renewal, underpinned by optimism and faith in a brighter industrial and social future that could be delivered by scientific and technological progress. At a time of national uncertainty brought about by the withdrawal from Empire and the perceived threats posed by the Soviet Union and her allies, beyond their practical benefits the development and exploitation of new technologies were also seen as a source of national security, pride and prestige.

If we wish to analyse post-war British industry, the production of a myriad of high-tech defence products and civilian spin-offs may be seen to dominate the new industries of the era. Their products were often high in value, manufactured in small production runs, specified by and supplied to a single customer — the government. To many, they were not only manufacturing the most up-to-date technology they also offered a futuristic vision. This was most famously visualised by the *Eagle* comic, with cutaway drawings that kept its readers informed of contemporary scientific developments, while Dan Dare's adventures presented a world set in the 1990s of space travel and the space age Venusian city of Mekonta. Imagery that has recently been used by the Science Museum in its display on post-war technology, *Dan Dare & the Birth of Hi-Tech Britain*, while the Victoria and Albert Museum explored the period's wider cultural contributions in an exhibition *Cold War Modern: Design 1945–1989*.[3] This paper will explore some of the scientific research centres and associated manufacturing plants that were at the heart of this vision — places that are not only monuments to British science and technology, but were also places of work for tens of thousands of people, and creators of new settlements and landscapes.

Industry and War

A feature of the 19th century was how ostensibly commercial technologies were quickly adopted by the military. Steam power and iron revolutionised naval design, heavy engineering combined with the explosive

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products of the emerging chemical industry vastly increased the firepower of navies and armies. The spread of the railway network also greatly increased speed in which armies might be mobilised. All these developments led to a far more complex relationship between states and private industry as each nation's steel manufacturers and engineering firms also competed amongst themselves, aided by relatively small government research laboratories. At the end of the century the invention of the internal combustion engine and wireless were to transform warfare during the 20th century.

In characterising the industrial contribution to the two world wars, the Great War has been regarded as the 'chemist's war'. An assured supply of explosives was often reliant on ingenious solutions for the supply of scarce raw materials and was crucial to the belligerents' war efforts,[4] while the Second World War was considered to be the 'scientists' war', where radar played a vital role in detecting hostile aircraft and communications technology was able to coordinate scarce defensive fighters to best effect. Radar was also quickly developed for gun laying, directing searchlights and later to aid bombing missions. At sea, radar and sonar enabled the detection of submarines. In the air, jet engines offered the potential for greater speed and rocket engines the prospect of unstoppable missiles. Scientific vigour was also brought to the waging of war through operational research, the analysis of weapons, tactics and strategy.[5] Famously, at Bletchley Park, Buckinghamshire, code-breaking led to the development of a programmable electro-mechanical computer and information handling organised in a factory-like manner. In the space of a few years atomic technology was developed from a scientific theory to a fearsome weapon. Science and an advanced industrial base had not won the war, but for the western allies had probably shortened its duration, and left a great expectation that science could solve the country's post-war problems.[6]

At the end of the war Britain was left virtually bankrupt and with a huge overseas military commitment. In Eastern Europe, the growing menace from the Soviet bloc was both numerical and technical. High-tech weaponry was seen as critical to meeting these threats and as a means of reducing the number of service personnel, who might be better employed to rebuild the country's industry and the export trade. In many emerging fields British scientists and engineers were pre-eminent, including jet engines, radar and to a lesser extent in rocketry and the exploitation of the atom. If they wished to master the new forces that had been unleashed, investigations needed to move from the laboratory bench into large capital-intensive research facilities; the era of Big Science had arrived. In a period when a computer was generally still a person with a slide rule, mechanical calculator, or punch card machine, in many cases physical replication and modelling were the only practical methods of understanding these forces.

AVIATION

In the decades following the Wright brothers' 1903 achievement of powered flight, the single most important factor in aircraft development was the pursuit of greater speed. In the Second World War, as internal combustion power plants reached their almost ultimate forms in aero-engines, such as the Rolls-Royce Merlin, the invention of the jet engine opened up new opportunities. Speed offered the possibilities for a new generation of unarmed jet bombers, flying extremely high and fast to avoid air defences. This in turn presented defence systems with new problems, reaction times were greatly reduced, decision-making and communications needed to be able to react far more quickly, interceptor aircraft and missiles were also required that would be able to match the speed and altitude of the bombers.

To understand the dynamics of high-speed flight increasingly sophisticated ground testing equipment was required. The most important aviation test facility was the wind tunnel, which was used to understand aerodynamic forces by blowing air at very high speed past a static test piece. In origin, they are a relatively old technology; the first had been constructed in 1871 at Penn's Engineering Works, Greenwich.[7] By the end of the Second World War they were still generally restricted to government centres at the National Physical Laboratory, Teddington and the Royal Aircraft Establishment, Farnborough, as well as a handful of leading manufacturers.

Ever increasing aircraft performance placed new challenges on aircraft designers in understanding the best aerodynamic shapes for travelling and manoeuvring at high speed, and developing new materials to resist high temperatures. Early wind tunnels were often wooden, exceptionally might cost tens of thousands of pounds and were rated at a few hundred horsepower. The advent of high-flying jets required wind tunnels that could run at far higher speeds to simulate transonic and supersonic speeds to investigate the problems of stability, control and structural integrity.[8] Instead of wood they were now formed from steel pressure vessels, using up to 100,000 horsepower and costing millions of pounds, and were superb engineering feats in their own right. Within the tunnels the working test sections were relatively small, but required a huge complex to blow, compress, evacuate, cool and dry the air. In 1950, the English Electric Company installed the country's first transonic wind tunnel at their

Warton works, Lancashire, followed later by at least eight other manufacturers, and around five universities and colleges,[9] while at the government establishment at Farnborough the wartime high-speed tunnel was converted to operate in the transonic range.

National Aeronautical Establishment, Bedford

A large proportion of Farnborough's resources were taken up with answering questions about aircraft entering service and already in use. It was recognised before the end of the war that, to develop the aviation industry to its full potential, a new independent aeronautical establishment was required to push aviation technology to its limits.[10] As the allied armies advanced into Germany, special technical units were tasked with securing defence research establishments. In their wake came British experts who were amazed by the quality of often well-camouflaged aeronautical institutes, and a contemporary account speaks of a 'pilgrimage' by staff from the Royal Aircraft Establishment, industry and universities.[11] In the immediate aftermath of the war these visits also secured a bonanza of experimental equipment for Britain's research institutes from wind tunnels to calculating machines, and as importantly provided a vision of what a modern research institute might comprise.

The site chosen for Britain's new National Aeronautical Establishment was to the north of Bedford at Thurleigh, and for a time it housed some of the world's most advanced aviation research equipment (Figure 1). Its transonic wind tunnel had an 8ft square working section that allowed more detailed models to be tested, pressures within the tunnel could be varied, and its 80,000 HP main drive allowed speeds of up to Mach 2.7.[12] To power this and four other wind tunnels the site's powerhouse accommodated two 20Mw gas-turbines — to put that into perspective, a small town requires about 5 Mw.[13] In 1952, a number of leading manufacturers combined to form the Aircraft Research Association and in Bedford built at a cost of £1½ million a 9ft by 8ft transonic wind tunnel, and a number of smaller facilities.[14]

National Gas Turbine Establishment, Pyestock

Prior to the end of the Second World War there were few dedicated aero-engine test stands; some were tested in wind tunnels, and in some quarters there was pride in what had been achieved despite the lack of facilities.[15] During the war, to develop Frank Whittle's jet engine designs his Power Jet Company and the RAE's gas turbine experts were brought together in Power Jets (Research and Development) Limited, and in 1946 were reformed as the National Gas Turbine Establishment.[16] At this point its headquarters was a few miles from Farnborough at Pyestock, while its test facilities remained at the new purpose-built jet engine factory at Whetstone, Leicestershire. In 1948, the test facilities were concentrated at Pyestock and from 1950 construction began of what was to become the world's second largest engine test facility (Figure 2). Its work was critical in proving and validating engine designs, the

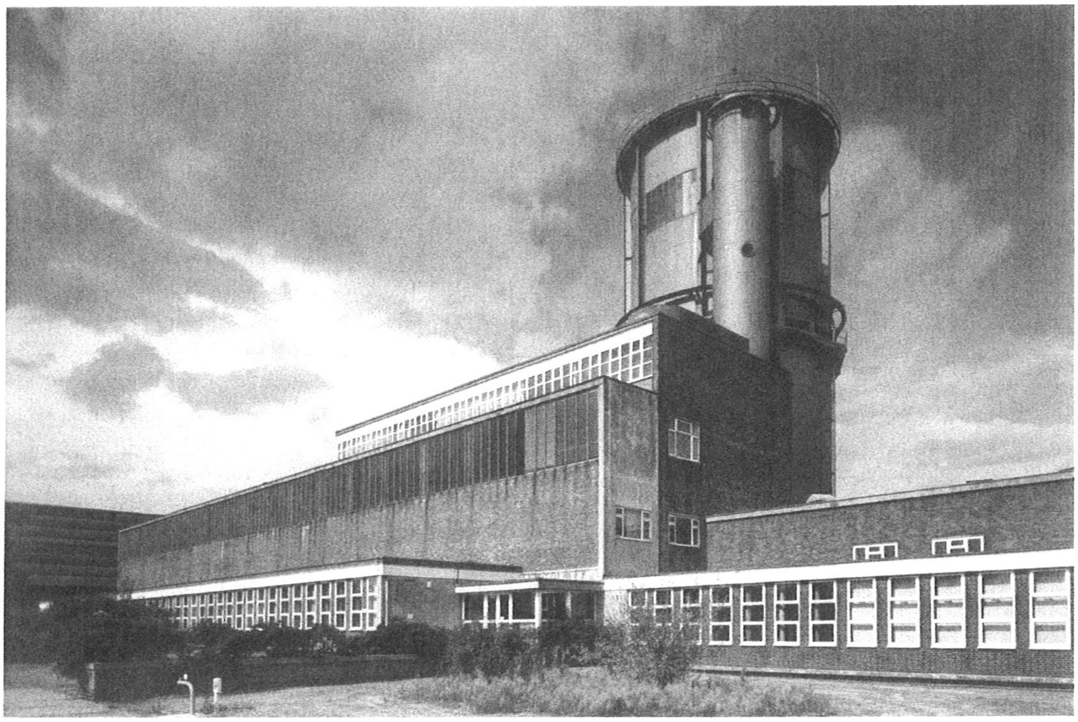


Figure 1. National Aeronautical Establishment, Thurleigh, Bedfordshire, Vertical Spinning Tunnel. In this facility aircraft spinning characteristics were investigated using free-flying models in an upward air stream (AA051298 © English Heritage).

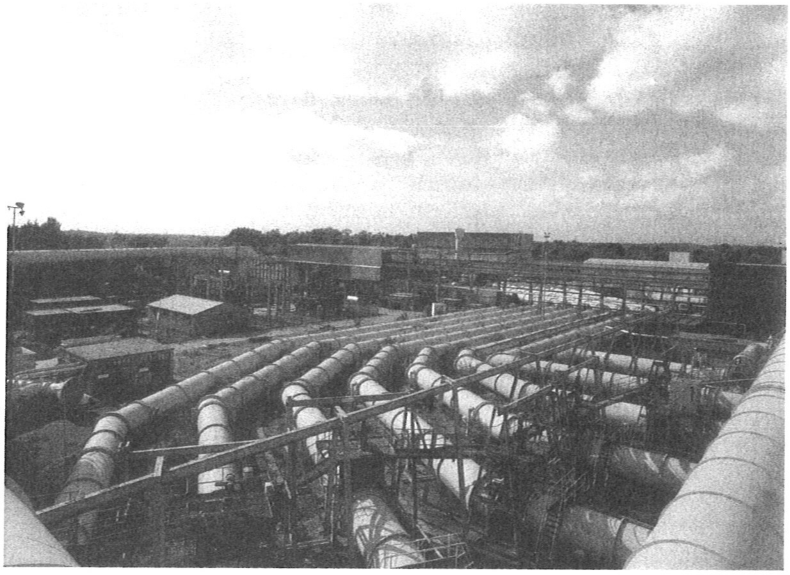
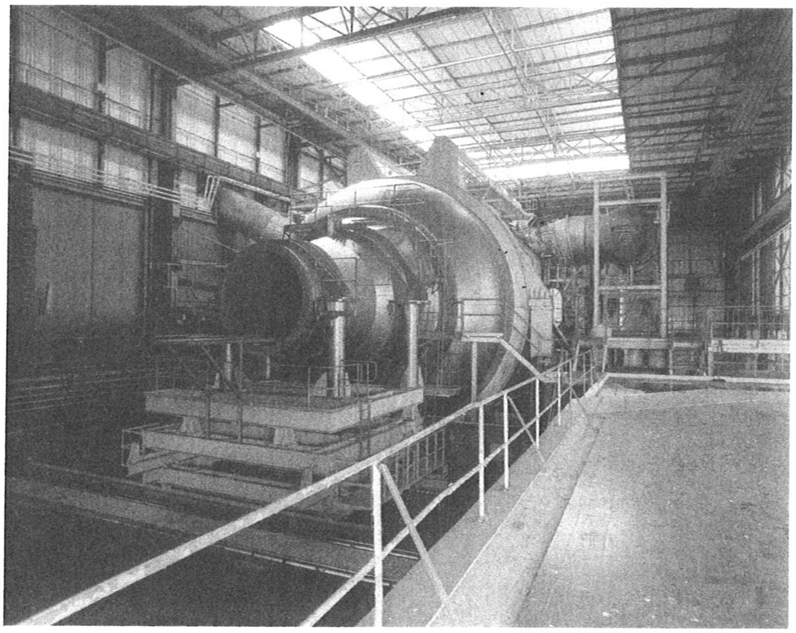


Figure 2. National Gas Turbine Establishment, Pyestock, Hampshire. View showing the pipes leading from the air house, to the left is Cell 3 West, to its rear No. 10 Exhauster and to the right Cell 4 (DP070612 © English Heritage).

Figure 3. National Gas Turbine Establishment, Pyestock, Hampshire, Cell 4. In the 1960s, to assist in the development of engines for Concorde this cell was used to simulate flight conditions at Mach 2 at 60,000ft (DP070613 © English Heritage).

development of new materials, endurance trials and safety tests, such as the threats from icing. In operation the test cells were similar to a wind tunnel. The test engine was held in a static position while air was blown into it at great speed to simulate flight conditions; within the test cell temperature and pressure might also be varied. The statistics surrounding the establishment's operation are staggering: in total there was ¼ million horsepower available, the air house was equipped with eight compressors and blast furnace blowers, and the site had cooling water stored in eight one million gallon tanks. So veracious was its appetite for power that Battersea power station needed an advanced warning before it went on line. The supersonic Cell 4 completed in 1965, used up to 80Mw of power and was for a time a unique facility and was involved in the development of Concorde's Rolls Royce Olympus engines (Figure 3). During its 50 years of service the establishment contributed to the development of virtually all of Britain's military and civil, air and maritime gas turbine engines, and more widely to noise reduction studies, turbine blade and compressor technology.



ROCKETRY

In addition to the jet engine, rocket technology also offered speed and a futuristic vision of space travel, but its immediate development was given a boost by Cold War imperatives. At the end of the war Britain's attempts at producing guided weapons were at a rudimentary stage, while the capture of a bewildering variety of German missiles revealed the possibilities of this technology.

With the potential of nuclear-armed Soviet jet bombers, the development of guided weapons and missiles was given the same national priority as the atomic weapons programme.[17] This was reflected in the creation in 1946, at an anticipated cost of £2,000,000, of the Guided Projectile Establishment on a disused airfield at Westcott, Buckinghamshire (Figure 4).[18] Initially, the focus of its work was the development of liquid propellant engines, an area where Britain had little experience. Captured hardware and research notes were evaluated and more practical knowledge acquired through the employment of a number of German scientists, engineers and technicians. Amongst their number, Walter Reidel was one of the most experienced. While at Westcott he produced a valuable account of his earlier work, including sketches of test facilities at Kummersdorf and Peenemunde.[19] In particular, their knowledge of the oxidants hydrogen peroxide and red fuming nitric acid was to influence the future course of British rocket engine design.[20] At Kummersdorf, to the south of Berlin, Stand II, which was built in 1932 and used by Wernher von Braun to complete his doctorate, exhibits many of the features common to later liquid propellant test stands. These include the separation of the fuel and oxidant bays, an adjacent control and monitoring room with direct observation, and water to dowse the stand during firing. German ideas were also evident in the design of post-war British test stands, at Farnborough, Westcott and Waltham Abbey. At the latter site the use of wall rails for mounting test equipment is a feature that may be directly linked back to some of the 1930s stands at Kummersdorf. At Westcott, a fatal accident in November 1948 led to a redesign of their test stands generally to remove any direct line of sight observations.[21]

British scientists and engineers were far more confident in the use of solid propellant rocket motors, and from the 1930s, principally at Fort Halstead, Kent, had developed unrotated projectiles, which had been put to a variety of uses. In service use solid propellant motors had many advantages, they were generally more robust, less hazardous to handle and were almost instantly available for firing. If this technology was to be used for a new generation of larger missiles, new techniques were required to fill very large diameter motors. In 1950, a new solids section was added at Westcott incorporating best design practice from the Royal Ordnance Factories; its function was both to develop new techniques and to undertake small production runs. In common with other filling factories, casings were generally manufactured elsewhere and brought to Westcott for filling. In the example of the Raven motor for the Skylark sounding rocket, a casing was brought into the filling section and lined with an inhibitor sheath to bond the propellant to the case. In the filling section a pug mill, similar to ones used in the china clay industry, was used to fill the casing with a ton of propellant, which was then firmly pressed into place by a large horizontal press. Finally, it might be X-rayed to check for hairline cracks that might affect its burning characteristics. Test stands associated with solid propellants are generally simpler in form, as they do not require the complex plumbing to handle hazardous liquids and the disposal of unburnt fuel (Figure 5).

In addition to perfecting new extrusion techniques, another plant was set up in a wartime factory at Summerfield, Kidderminster, to manufacture cast double base rocket motors. In this technique an explosive-based casting powder was mixed with desensitised nitroglycerine. One advantage of this technique was that they were able to manufacture very complex internal charge shapes, which allowed the ratio of the burning surface to the mass of the propellant to be carefully controlled. Some of the factory's wartime buildings were adapted, but new specialised structures were also needed. The 40ft tall casting house enabled casings to be held in a vertical position, and after a spell in the curing house returned for the extraction of the internal former. An interesting feature of this building is the use of protective Chilworth mounds, corrugated iron covered mounds first used in the 19th century at Chilworth gunpowder works.[22] In addition to the government establishments most of the leading aircraft manufacturers were also involved in missile and guided weapons work. Projects included the development of large surface-to-air missiles that would result in Bloodhound, Thunderbird and Seaslug, air-to-air missiles, such as Skyflash, Firestreak and Redtop, and smaller anti-tank missiles for the army. This 1950s enthusiasm for rockets and missiles culminated in Duncan Sandy's 1957 White Paper that envisaged manned aircraft as a thing of the past.

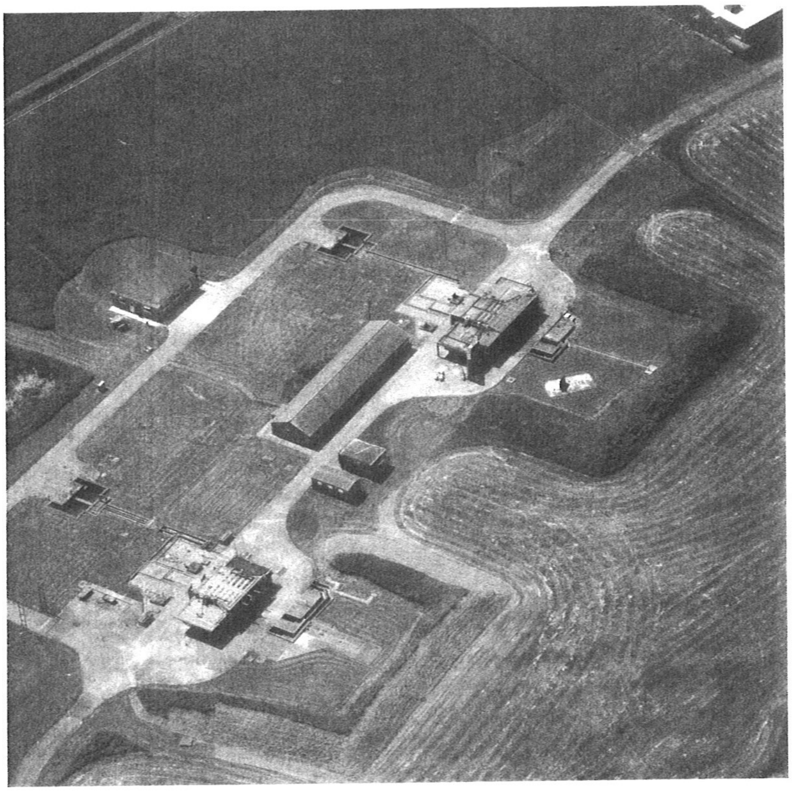


Figure 4. Rocket Propulsion Establishment, Westcott, Buckinghamshire. Test stands C and D constructed in 1947 for experiments with liquid propellant engines. Note the conduits that were placed to carry away unspent fuel (15034/008 © Crown Copyright. NMR).

In 1954, the decision was taken to develop Britain's most ambitious rocket programme, which would eventually become known as Blue Streak. By the grim logic of nuclear deterrent stratagem, it was determined that a missile with a range of 1,500 miles (2,413km) could threaten Moscow and enough of the Soviet population to be an effective deterrent.[23] To increase its range would cost more, lead to more technical complications and delay its entry into service. As we have seen most of the post-war British missile programmes were relatively small scale and the development of long-range missiles was beyond the experience of most British scientists and engineers. Many other critical issues also needed to be resolved, including the method of launch and the mass of the warhead.

The close collaboration of government research establishments, the services, industry and universities was regarded by contemporary observers as one of greatest strengths of the British defence industry.[24] The Blue Streak project is a good illustration of how a complex project was organised, where cutting-edge technology was combined with complex administrative procedures, and where

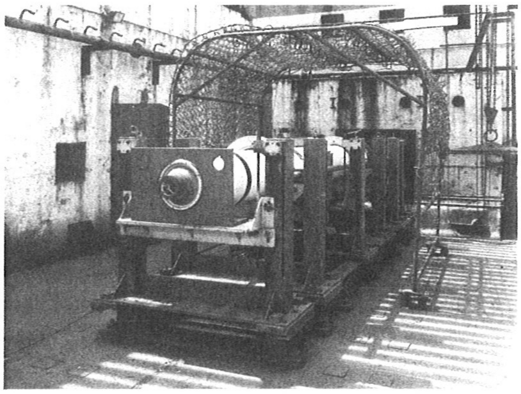


Figure 5. Rocket Propulsion Establishment, Westcott, Buckinghamshire. Solid propellant rocket test stand with a surplus Raven motor; this type of motor was used for the Skylark scientific sounding rocket (BB99/04751 © Crown Copyright. NMR).

the working cultures of numerous private sector and public organisations were reconciled to ensure success. The main contractor for the project was de Havilland Propellers, while Rolls Royce was responsible for its engines, and Sperry Gyroscope for the guidance systems. Although the basic design of the rocket was based on the United States Atlas series, complex technology transfer requires more than a copy to meet different materials and engineering standards, both of which could have unforeseen consequences on the performance of a system. Communications between the two countries was also still relatively slow and expensive, which also encouraged home grown British solutions to any snags that might occur.

De Havilland's main factories were in the South Midlands at Hatfield and Stevenage; the former was responsible for the fabrication of the main airframe, which was then taken to Stevenage for final assembly. For the project the existing factory was considerably modified, with the addition of a large assembly shop and office range. Trials facilities were also built at Hatfield to test fuel flows in the rocket and also a tower to investigate the launcher mechanism. Other tests were carried out at government establishments, including Westcott, where the P2 site was modified to carry out engine tests.

A location was also required for the full test firing of an assembled missile. Such a place needed to meet many selection criteria; one of the most important was remoteness, the missile was extremely noisy, and when fully loaded it contained over 80 tons of volatile propellants. The presence of stable bedrock for the test structures and access to large quantities of water for cooling the stands during firing were also crucial requirements. After a number of existing ranges were considered and dismissed 8,006 acres (3,240ha) of open moorland in the north of England, known as Spadeadam Waste, Cumbria, was selected. From 1956 over a period of three years, and at a cost of about £20 million, its landscape was transformed into one of the world's most advanced rocket research establishments (Figure 6). It was built and operated on behalf of the government by De Havilland, Rolls Royce and the British Oxygen Corporation, and its activities were divided into five main areas: administration and assembly, liquid gas manufacture, and separate test areas for components, engines and fully assembled missiles.

For final tests missiles were driven on pre-motorway trunk roads from Stevenage to Spadeadam. On arrival they were taken to the assembly building for a final check before test firing, after this the procedure was reversed and the missiles returned to Stevenage for further checks before they were packed for their sea voyage to the launch site at the Weapons Research Establishment, Woomera, Australia. If the project had continued it was proposed to build 60 missiles for the RAF, each of which would have been proof tested at Spadeadam prior being emplaced in underground silos. Once this launching method was decided on, another joint design team, with representatives from the Air Ministry, Ministry of Works and De Havilland Propellers, was drawn together to over see the development of the underground silo. Initial work using one-sixtieth and one-sixth scale models was carried out at Westcott, where a number of sections of the larger model survive. Full-size mock-ups were planned for Spadeadam and Woomera, but work at both sites never progressed beyond initial groundworks before the project was cancelled.[25] Although the system was not used in Britain, the research was passed to the United States and used to inform the design of the Titan missile silos that were operational until the 1980s. The significance of the Blue Streak silo work was as a historian of the Titan project commented was as 'the free world's first in-silo launch weapon concept'.[26]

In April 1960, the same month as the last British steam engine, *Evening Star*, was out-shopped from Swindon, Blue Streak as a missile project was cancelled. It was later adopted as the European Launcher Development Organisation's first stage, but in 1968 the United Kingdom government announced its intention to withdraw from the organisation. By the mid-1970s the facilities at Spadeadam had been dismantled.

The design of Blue Streak's warhead was the responsibility of the Atomic Weapons Research Establishment, and beyond its notional dimensions and mass few people on the rocket programme knew about its progress.[27] To support this research another smaller rocket was required to launch model warheads to investigate the best shapes and heat-resistant materials for their re-entry heads. Working closely with the Royal Aircraft Establishment, the Saunders Roe

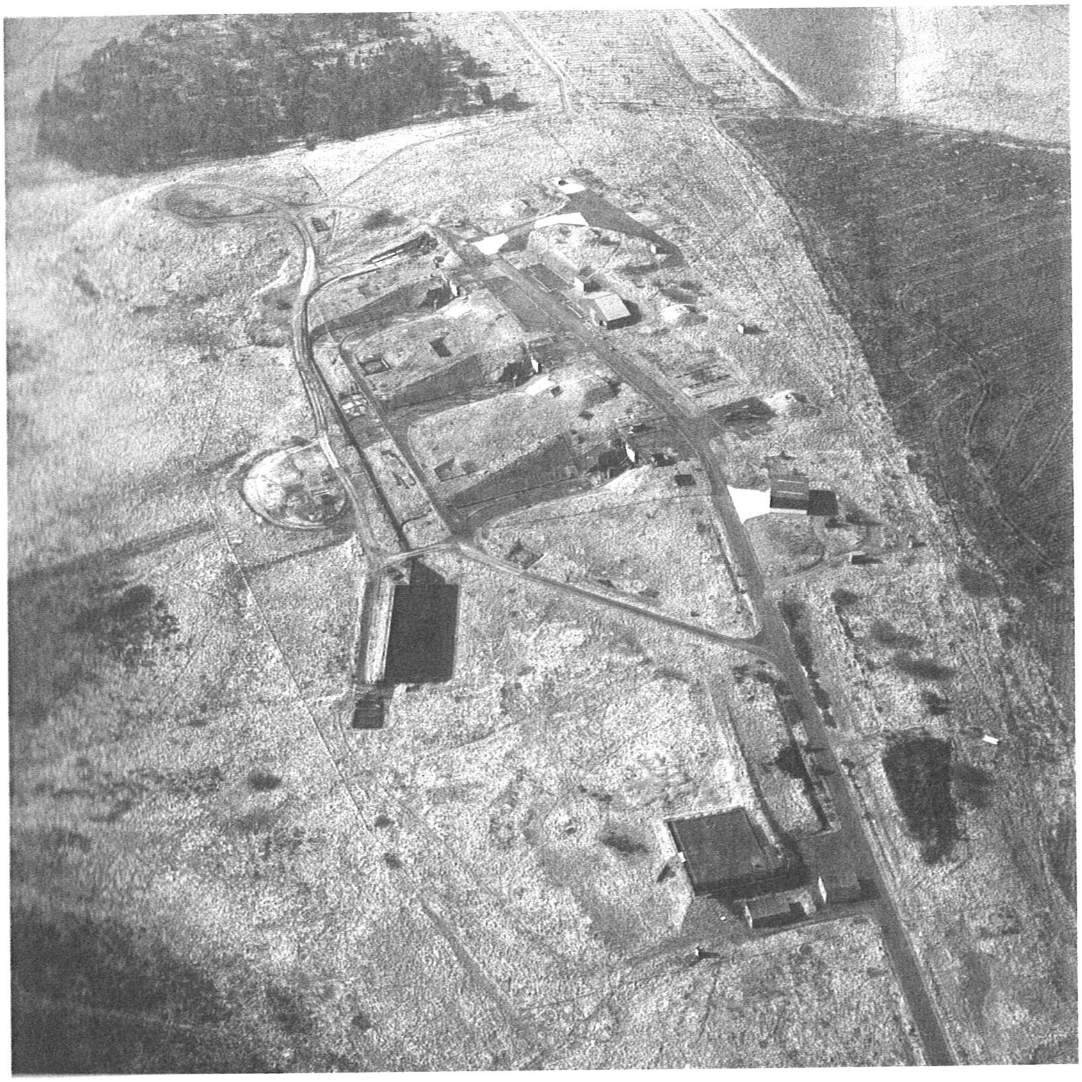
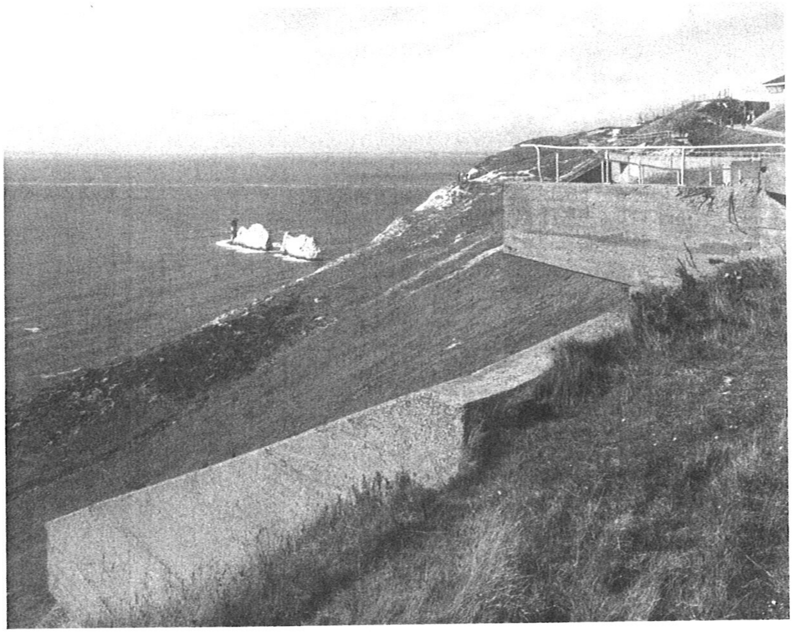


Figure 6. Rocket Establishment, Spadeadam, Cumbria, Priorlancy Engine Test Area. In the foreground is the protected control room and in the distance the foundations for four engine test stands. To the left is a filtration pond and the footings of a gravel sorting plant from the site's construction (17819/03 © English Heritage).

Company, based at Cowes on the Isle of Wight, developed the Black Knight rocket, while its hydrogen peroxide Gamma engines were manufactured by Bristol Siddeley Engines Ltd at Ansty, Warwickshire. It too required a test site, which was constructed on the island at the Needles on the site of a recently abandoned coastal battery (Figure 7). The architect John Strubbe, Ham, Surrey, designed a facility for two test stands, with gleaming aluminium-clad buildings, which their heyday stood above the white cliffs as a vision of Britain's post-war technological revolution and its part in the space age. After proof firing, the missiles were taken to the Woomera for launching the warhead models. At this time, beyond the two superpowers, only Britain had the capability of launching satellites into space, and RAE's Space Department were considering two concepts for a satellite launcher, either using Black Knight or on a new rocket based on its technology. The second option was chosen and a rocket known as Black Arrow was developed, and on 28 October 1971 it successfully launched a British-built satellite, Prospero. Despite its success the programme had already been cancelled and with its Britain's opportunity to develop a satellite launcher industry.[28]

Figure 7. High Down Test Site, The Needles, Isle of Wight. This view shows the position of test stands set high on the chalk cliffs above the Needles. The hot exhaust gases, or efflux, were directed down the hill slope (BB94/16348 © Crown Copyright. NMR).



THE BOMB

The ending of the Second World War with the destruction of two Japanese cities by atomic weapons dramatically brought to the world's attention the awesome nature of nuclear technology. The military potential of breakthroughs in the understanding of the atom had first been drawn to the Allies attention in 1940 by two British-based European émigrés, Rudolph Peierls and Otto Frisch. Despite other urgent demands on Britain's wartime scientific and industrial infrastructure, a prototype uranium enrichment plant was established in Wales as early as 1942.[29] Nevertheless, it was quickly recognised that Britain's war economy would be unable to support the effort needed — the United States' Manhattan Project cost four times as much as the German V2 programme.[30] Coupled with the threat from air attack, under various wartime agreements existing British knowledge and a number of scientists were transferred to the United States.

Post-war, regardless of the considerable contributions that British scientists had made to the wartime project in November 1946, the United States passed the Atomic Energy Act (McMahon Act) that effectively blocked British access to American nuclear know-how. Despite being almost bankrupted by the war, British politicians saw the new technology as a means of maintaining the peace, global military power and prestige, as well providing commercial opportunities through a civil nuclear programme. On Wednesday 8 January 1947, the Attlee government took the decision that Britain should proceed with the development of the atomic bomb.[31]

At a time when the country was beset by rationing, severe material and manpower shortages, to realise the ambition of a British atomic bomb would require the creation of a vast scientific and industrial infrastructure. Through their work on the Manhattan Project, British scientists were aware of the Bomb's basic design; the challenge was to replicate a device using British-manufactured products. Codenamed Basic High Explosives Research, the project was established with great secrecy under William Penney and 34 scientists at Fort Halstead, Kent, a late 19th-century mobilisation centre. Here they were able to use part of the small wartime filling experimental section to assist in the design of explosive detonators, and to test them in purpose-built detonator and bomb chambers constructed in the old fort.[32]

To support the project required the creation of novel factories, for speed and economy its geography was partly determined by the location of wartime munitions plants and airfields. A production group, under Christopher Hinton, was set up in the former Royal Ordnance Factory, at Risley, Cheshire. Its first task was to construct the industrial infrastructure to produce the plutonium for Britain's bomb. A former poison gas factory at Springfields, near Preston, was rebuilt to produce enriched uranium, and in Cumbria the Sellafield TNT plant was selected for the atomic piles and plutonium separation plant. The work was carried out with the urgency and allocation of resources and manpower comparable to any wartime mission. Construction began in September 1947 with a workforce of 5,000 and the first pile went critical just three years later.[33]

AWRE FOULNESS

As the various components were designed, they all required testing individually and then in combination. In the United Kingdom there were no large wildernesses that could be closed off for nuclear testing.[34] Nevertheless, at the mouth of the Thames was the Shoeburyness range that had been used as an artillery testing ground since the middle of the 19th century. At the end of the war an enclave on Foulness Island was allocated to the Armament Research Department for investigations into conventional explosives and in June 1947 it was transferred to the Basic High Explosives Research team. By this date initial planning of the new ARD range had already begun, probably comprising buildings in the administration area, range instrumentation and office structures, and the explosives handling area. After the transfer to Basic High Explosives Research, the most significant alterations were made to the design of the explosives area. Its proposed oval layout was retained, some of the most significant alterations were to the Explosives Preparation Laboratory (Figure 8) whose size was quadrupled and which was to be used for the assembly of experimental lenses and the test device for the live trial — Hurricane. Many of the buildings of this date have an archaic form; in the explosives area brick buildings with copper-clad doors are more reminiscent of the 18th-century gunpowder magazines at Tilbury Fort than the new atomic age. In a period of building material shortages their appearance may perhaps be accounted for by the readily available supply of bricks from the local brickfields. Also specified in 1947 was the Explosives, Preparation, and Casting building; this survives in near original condition, complete with its plant installed over 60 years ago. This building was probably built to support the range's civil defence experiments and the supply of specially shaped high explosive charges. In the early 1950s further explosives handling buildings were added, including for the hazardous task of machining high explosives. These well-constructed and specialised buildings are some of the few purpose-built explosives handling buildings constructed during the 1950s.

Elsewhere, to ensure safety and security smaller ranges were scattered across the area, their activities compartmentalised into discrete tasks. At the centre of the ranges are small robust brick office and instrumentation buildings, with flat concrete roofs, steel-shuttered windows and often with a heavily protected side facing the firing areas with armoured observation ports. On Range 1, or the large bomb range, the explosive lenses that surrounded the core were brought for test firing. A crucial part of this work was the synchronisation of the electronic firing circuits and detonators, which were designed by one of the Fort Halstead teams.[35]

Another priority for the range was to support Civil Defence planning. Studies of wartime bomb damage in the UK and post-war missions to Germany and Japan had built up a considerable understanding of the effects of blast on different types of buildings. This work was continued at Foulness with small-scale models, which were subject to blast waves created by the detonation of high explosive balls weighing up to 64lb and suspended between two gantries. Responsibility for the design and construction of the models initially lay with a team within the Ministry of Works, led by Dr Francis Walley.

By summer 1952, the team was ready to begin the assembly of up to three live devices, by repute nicknamed *Hero*, *Hengist*, and *Horsa*. In considering the historical significance of X6, it cannot be claimed that the *Hurricane* device was invented and developed in any single place. Nevertheless, over 60 years later X6 retains its late 1940s form and the character of the place where many of the key players in the project came together in summer 1952 to assemble Britain's first live atomic weapon. It is also one of those rare places where we can physically stand at a turning point in history; if the work in this room had failed, British post-war history becomes a matter of intriguing speculation. From Foulness the device, or devices, were taken to Sheerness and mounted on HMS *Plym*, for her voyage to the Monte Bello Islands, Australia, where a device was successfully detonated on 3 October 1952.

Less than two years later, on Monday 26 July 1954, the Cabinet confirmed the decision to proceed with the development of a thermonuclear weapon.[36] So began a period of feverish activity for the Atomic Weapons Research Establishment. Scientifically, its staff still had to work out the precise method of creating an H-bomb.[37] Work in the establishment also came under the highest political scrutiny and pressure, as successive prime ministers strived to restore the special nuclear relationship with the United States, possession of the H-bomb was seen as the ultimate bargaining chip.[38] A further demand to complete the work quickly was created by a proposal from the United States for a moratorium on further H-bomb tests.[39]

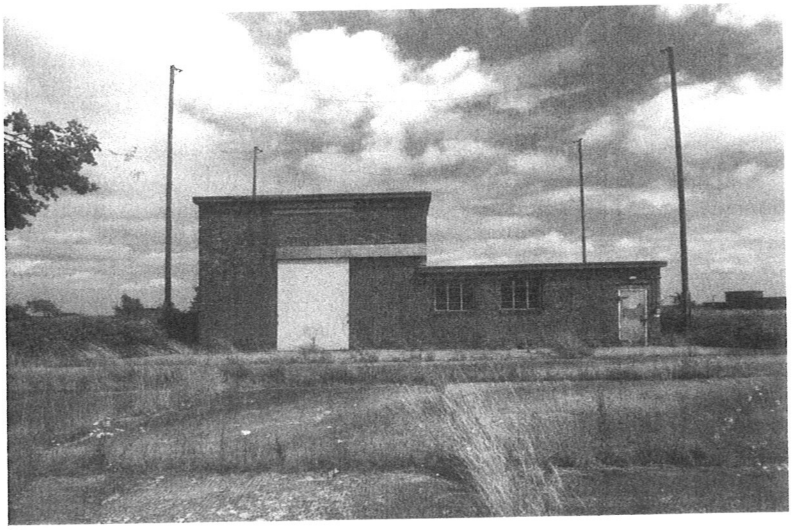


Figure 8. Atomic Weapons Research Establishment, Foulness, Essex. Explosives Preparation Laboratory X6; in 1952 the United Kingdom's first atomic bomb was assembled in this building (DP035925 © English Heritage).

In the weapons establishments the programme was marked by new buildings, at Foulness its urgency was reflected by the use of a contemporary prefabricated lightweight building system, which may be seen as model of its type.[40] The system combined economy of materials with speed of erection, while presenting a modern industrial design (Figure 9). These buildings housed offices and larger workshops, along with electronic and photographic laboratories. In addition to the development of weapons Foulness was also responsible for designing calibration instruments for use on the range and overseas trials,

Figure 9. Atomic Weapons Research Establishment, Foulness, Essex. Mid-1950s prefabricated laboratory (DP035967 © English Heritage).

and had a particular expertise in transducer technology for measuring blast pressure. Its workshops were also equipped to manufacture small one-off items for trials work, sometimes using exotic metals. The estimated cost of the mid-1950s building programmes was £500,000.[41]

To deal with the extra workload Foulness' staff complement was predicted to grow from 297 in 1954 to 408 by March 1955, about a quarter of whom were scientific staff.[42] In contrast to the wartime Manhattan Project, which drew together some of the world's leading physicists, the post-war British programme was staffed by members of the civil service. One of the largest buildings constructed during the mid-1950s was the visually striking Canteen and Common Room built in an up-to-date architectural style, though internally its layout reflected the conservative and rigid civil service hierarchies of the day and that of contemporary British industry and society. To the east is a large open and airy dining room floored in a chequerboard pattern of blue and white tiles, and to the rear is a bar area dominated by a large world map. Beyond it is a smaller dining area for the senior staff, with a dedicated entrance and wooden parquet flooring.

The conclusion of the 1958 Mutual Defence Agreement with the United States illustrated how intertwined the fortunes of the high-tech defence industry was with high politics.[43] This agreement, which the research establishments had helped to secure, gave the United Kingdom access to United States nuclear know-how. In the following years, it combined with fiscal pressure and questions from the highest circles about the utility of some types of nuclear weapons, led to a drastic scaling back in the number of research projects and the standardisation on a limited number of designs.[44]

In 1964, the Partial Test Ban Treaty ended atmospheric nuclear testing and with it access to data crucial for developing and verifying warhead designs, stockpile stewardship, and for investigating the effects of nuclear explosions. To work within these new political restrictions new facilities were developed to model the four main effects of a nuclear explosion, blast, heat, electromagnetic pulse, and radiation. Shock tubes had been used from the early 1950s to produce standardised blast effects, and in the early 1960s a 660ft blast tunnel was constructed that was large enough accommodate a Centurion tank. Research continued at Foulness until 1997; in the intervening decades few new permanent structures were added, and many of the later temporary structures built for specific trials have a Heath Robinson character.

Figure 10. Atomic Weapons Research Establishment Orford Ness, Suffolk. Vibration Test building, or Pagoda (DP068503 © English Heritage).

AWRE ORFORD NESS

In 1954, a requirement was identified to proof test nuclear devices prior to overseas trials. Although they were tested without their fissile cores, some mid-1950s weapon designs still used large quantities of conventional high explosives. Foulness Island was already very overcrowded and instead a new location was selected at the Ministry of Supply bombing range at Orford Ness, Suffolk. The first development phase began in early 1956 and comprised three laboratories, one for vibration tests, a climatic test cell, and a third laboratory that was equipped with a centrifuge during its last operational phase. In common with other explosives buildings they were designed to project any accidental explosion vertically rather than laterally. These facilities played a crucial role in testing Britain's first atomic bomb, Blue Danube, before its live drop during the October 1956 Buffalo at Maralinga, Australia. They also played a vital part in the development of the Red Beard tactical atomic bomb and the far more powerful hydrogen bomb.

In 1959, it was proposed to expand the environmental test programme to simulate the conditions weapons would be subject when they were issued to the services, including sustained vibration and temperature variations during transport, storage and operational use. At this time, to the planners at AWRE the full implications of the 1958 Agreement and fiscal constraints had yet to bite and they were envisaging a very intensive development programme running into the 1960s. To increase the establishment's capacity, two new vibration laboratories were planned, with a requirement that they should be able to resist an accidental explosion of up to 400lb of high explosives.[45] After design studies at Foulness with small amounts of explosives on one-tenth scale models, the distinctive pagoda form was derived (Figure 10). To further ensure the personnel's safety they were operated from a remote control room.

Later developments were one-off facilities for specific projects. Around 1963 the hard impact facility was created for the WE177 freefall bomb trials; it comprised a rocket sled that was used to propel test rounds against a solid concrete wall to simulate the forces it would experience as it hit the ground. In the mid-1960s the last development was a second centrifuge, during which time the establishment was focussed on the development of warheads for the Polaris missile programme. By the end of the decade Britain had standardised on a relatively small number of warhead designs, and with a consequential reduction need for research, coupled with demands for spending cuts, AWRE Orfordness closed in 1971.

Civil Science

The Second World War and large government-sponsored defence projects also gave a boost to large civil science projects; they had created a pool of trained scientists, engineers, manufacturing and construction companies, with the confidence to undertake large scientific and technically advanced projects. As early as autumn 1945 the Atomic Energy Research Establishment was set up at Harwell airfield, Oxfordshire, for the peaceful exploitation of the atom. Its early priorities included reactor designs and later new outstations were set up at Culham, Oxfordshire, and Winfrith, Dorset. The civil nuclear programme was entered into with great optimism that it would produce power too cheap to meter. It would mark the final break with Victorian England and its dominance on smog-producing coal. Radioisotopes offered new possibilities for medicine and industry. In 1960, research began at Culham into cold fusion, the holy grail of power generation.

National prestige was still considered as a valid reason for carrying out many of these projects, although the promised economic dividends were rarely achieved. During the era many notable firsts were achieved, illustrating mastery of many new technologies. The Comet, the world's first jet airliner, flew in 1949. Calder Hall built in the shadow of the Windscale Piles, and opened by the Queen in October 1956, was the world's first civil nuclear power station connected to a national grid. Cold War needs were never far away and in its early years it was run on a cycle to produce electricity and plutonium. One of the most iconic structures of the era is the radio telescope at Jodrell Bank, Cheshire (Figure 11). Construction began in 1952 and the first signals were received in August 1957, just in time to track the path of the Soviet satellite Sputnik. As steam engines still raced past on the adjacent mainline, it became as recognisable as the Eiffel Tower, a highly visible symbol of national technical prowess with a place in the space age as the leader of the new science of radio astronomy.[46] A few years later the Goonhilly earth station in Cornwall picked up the first transatlantic satellite television broadcast.

High-Tech Manufacturing

Post-war most of the established defence industries remained in their traditional locations, bound by their specialised infrastructure and plant, and skilled workforces. The state-run Royal Ordnance Factories and many private plants for newer armaments, such as armoured fighting vehicles and aircraft, were at most a couple of decades old. Following lessons learned during the First World War many had also been designed as flexible large open spaces that could

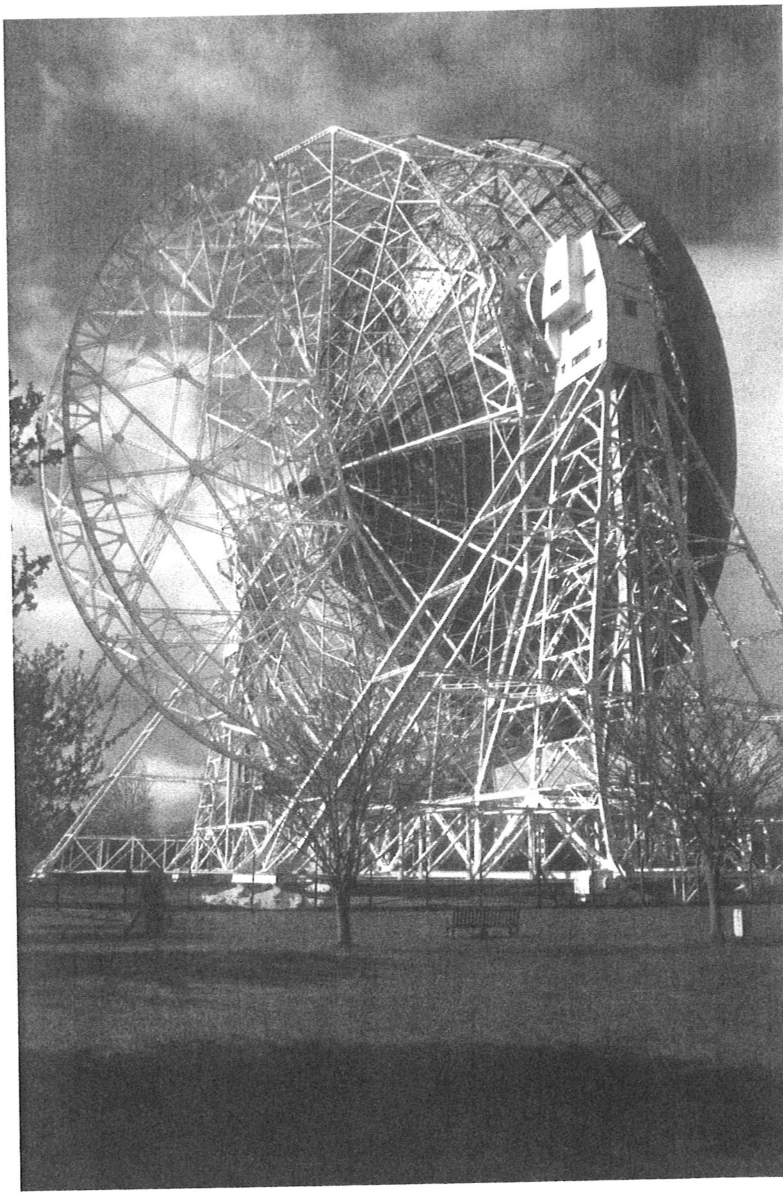


Figure 11. Jodrell Bank, Cheshire. The steelwork was produced by the Dalmarnock Iron Works, Glasgow (© W.D. Cocroft).

be modified for new uses.[47] Large aircraft factories, such as A.V. Roe's Woodford plant, Greater Manchester and Gloster's Brockworth works, that had been used to assemble piston engine aircraft, were readily adapted to manufacture jet aircraft. Likewise, in the aero-engine industry production lines were rearranged to assemble jet and rocket engines, although both types were characterised by the proliferation of new specialised testing and proof facilities (Figure 12).

A similar locational inertia also existed in industries supplying the armed forces with more mundane items, such as clothing and footwear, a massive undertaking in the early 1950s when the number of army personnel exceeded over 800,000.[48] The new research establishments and Cold War facilities were heavily reliant on the existing heavy engineering industry to supply steelwork, electrical generators and cooling plant. They also created a market for new recording equipment and other types of specialist instrumentation. On many sites a quick inventory of manufacturers' plates will quickly reveal the industrial base that was required to sustain the Cold War. During the 1950s the construction of new bases and the remodelling of existing sites represented a huge undertaking to quarry gravel, manufacture cement and steel reinforcing rods, and then to assemble large workforces in remote locations.

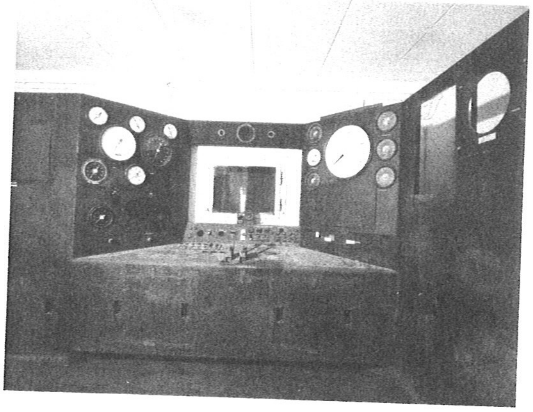


Figure 12. Gloster aircraft factory, Brockworth, Gloucester, 1953. Control panel for the jet engine test cell (BB95/10878 © Crown Copyright. NMR).

Figure 13. Marconi, Waterhouse Lane, Chelmsford. Its position on ring road is typical of many post-war electronics factories, as is the high proportion of the building given over to technical design and administrative functions compared to assembly activities (AA99/01821 © Crown copyright. NMR).

During the post-war period one of t major growth areas was the demand f defence electronics, most of which were rel tively small, high in value and produced comparatively small production runs. T factories producing these types of items we fairly footloose. Numerically, by the 198 most defence firms lay in a band between th Isle of Wight and Essex, with other marke concentrations to the south of the Avon in the West Midlands, north-west, and th Strathclyde region.[49] In the south-east th new electronics industries predominate new towns and expanding urban centres wer keen to attract these industries, where the were able to offer their well-paid and skille workers housing and an attractive environ ment. They were also within easy reach o their Ministry sponsors in London and th majority of government research establish ments. The Chelmsford area had a lon association with the Marconi Company an radio electronics dating back to the 1890s During the war the growth in the applicatio of radar opened up new opportunities fo the company, both in defence electronic and in civil aviation and maritime spin-offs The expansion of its business was reflected in new factories built alongside the town's new ring road. The company and others, such as Cossor electronics at Harlow, built on this local expertise to establish other new defence electronics factories around growing towns, such as Basildon and Brentwood (Figure 13). Stevenage new town was also heavily dependent on new defence industries, to the extent that, by 1960, 63 per cent of the Gunnels Wood Industrial Area's workforce was employed in guided-weapons-related work.[50]

Given the large wartime legacy of relatively modern defence industry factories, few ones were built in the post-war period. One exception was the De Havilland factory at Stevenage, which was built around 1953 to produce components for the Comet airliner and which was later extended to manufacture Blue Streak missiles. This was finished in a simple functional style, and to present a more modern image their existing Hatfield factory site was refronted in a similar design. Government research establishments also favoured this contemporary image that was economic in materials and through the use of a standard range of building components and colours presented a unity of design. In contrast to the general trend, Hawker's chose an archaic classically-inspired façade for their Kingston works. Given contemporary infatuations with missiles and rockets, one commentator regarded it 'as the mausoleum under which the manned fighter was buried'.[51] These large office ranges not only reflected company pride but also the increased complexity of the manufacturing task. By 1962, it was estimated that 39.5 per cent of the aircraft industry's workforce was employed in managerial, administrative, technical or clerical roles.

Housing

The huge growth in government scientific establishments and a corresponding expansion in private industry created intense competition for the restricted pool of skilled scientists, engineers and other workers. Most of the government establishments were bound by civil service pay and conditions, and were limited in the financial inducements they might make. In an era of housing shortages, one incentive they might offer was housing. At some locations, such as Harwell, where the Atomic Energy Authority took over a former RAF station, they were able to use existing housing. This was allocated according to grade and marital status; bachelors (most of the scientific staff were men), lived in hostels, while married staff had access to the limited number of houses. Elsewhere, the establishments made special arrangements with local authorities for access to council housing.

Later, in the new and expanding towns of the Home Counties staff might also look to houses built by private companies or development corporations. In remoter areas adequate housing was an essential part of ensuring the success of a project. The creation of the Rocket Establishment at Spadeadam required at first the construction of a large temporary navvy camp. In the administration area a hostel or mess for the single staff was built and in the nearby town of Brampton a large housing estate was added. Similarly, the Sellafield nuclear complex, which today employs around 10,000 people, created a huge demand for housing. Close by at Seascale a housing estate was added, many workers also lived in the nearby towns of Egremont and Whitehaven, and as car ownership increased it widened the options to live further afield. Likewise, many of the new nuclear power stations were in relatively remote locations and new estates were required to house their workforce, such as the one at Southminster, Essex, to serve Bradwell.

Less obvious is how these establishments have affected the social character of an area. Employment in the high-technology industries was something to aspire to; they offered training through local apprentice schemes, the prospect of secure and well-paid jobs in turn helping to create stable and prosperous communities. They also attracted highly-educated graduates to remote areas where they were responsible for founding cultural and other social clubs and societies.

The Industrialisation of the Military

As warfare became increasingly mechanised and technical, the nature of military life and its social composition changed as the routine of servicing mechanical and electrical equipment occupied a greater percentage of the personnel. This was reflected in the layout of military sites, as garages and vehicle stores replaced stables and wagon sheds. In naval dockyards, coal yards and later oil storage became vital installations. On most military airfields, if we analyse the daily duties of their personnel, many are involved in light engineering and maintenance tasks, to the extent that on a typical modern airfield, such as the recently closed RAF Coltishall, Norfolk, a community of around 3,000 was required to support around 30 aircraft and a similar number of pilots. Work included set overhauls after each flight, regular dismounting, stripping, reassembly and testing the aircrafts' engines, servicing complex electronics, as well as minor repairs and modifications to the airframes (Figure 14). Another vital task was the examination of the pilots' safety equipment, and tailoring of flight clothing and accessories to ensure an exact fit. In turn, to sustain a community of service personnel and their dependants a large proportion of the workforce was employed in stores, catering and laundry services, all of which were conducted on an industrial scale. In the post-war decades, radar and missile sites relied on temperamental and power-hungry glass valves that in turn generated a lot of heat. Heavy generators and cooling plant were essential for their operation, all of which required a large number of technical personnel to ensure their serviceability.

The analysis of many defence sites has much in common with the way we might approach the understanding of large industrial sites. They have a material culture of

Figure 14. Friday 24 March 2006, Adour Engine Assembly Facility, the assembly of the last Rolls-Royce Turbo Meca engine at RAF Coltishall, Suffolk (DP029249 © English Heritage).

buildings and artefacts, often objects of such complexity that they might be regarded as assemblages to be dissected and studied. At a site level functional zones may be characterised, and within them the activities understood as sequence flows, which may in turn be related to structures and rooms. At Bloodhound surface-to-air-missile sites, missiles arrived in their component parts for assembly and testing before being placed on their launchers, and then were regularly taken down for servicing and testing. Military sites are also tightly controlled social spaces where access is restricted according to task, rank and to a lesser extent gender. With the study of documentary sources it is possible to understand how they fitted into national command chains and interlocking defence systems, their use nesting in wider political landscapes of alliances and strategic plans — relationships that also determined access to technology, alternatively a policy of independence, which might in part extend to collaboration between allied countries, might provide access to alternative defence systems.

CONCLUSION

In summary, the post-war decades brought together a unique combination of politics and technology that encouraged the growth of high-tech defence research establishments and industries. Technologies that were in their infancy during the Second World War — radar, jet engines, atomic bombs, missiles and computers — were quickly developed to prosecute the Cold War. The experience of world wars and the failure of appeasement created a political climate in which the pursuit of the most modern armaments went virtually unquestioned until the late 1950s. It also left a legacy of governments who were prepared to spend vast sums of money on armaments research and production, and administrative structures to bring them to fruition.

The resulting 'golden age' of Big Science was also found in the United States, Soviet Union, and France, all of whom pursued similar policies of large government-backed science and technology projects, and all were connected by a complex of family tree of technical diffusion.[52] The course each country followed was determined by many factors, including the cultures, organisation and relationships between research establishments and manufacturers, differing defence requirements, and the strength of their economies.

Just as in post-war decades the country's Victorian industrial infrastructure and plant was being dismantled, so too over the past decades most of the relics of the white heat of post-war technology have also been demolished. A handful are listed: some of the wind tunnels at Farnborough, satellite station No. 1 at Goonhilly, and the Jodrell Bank radio telescope. By chance, rather than initial design, the National Trust is the custodian of the rocket test site at the Needles and the Atomic Weapons Research Establishment Orford Ness. Places such as Harwell and Winfrith, former civil atomic research centres, are being transformed in to 21st-century high-technology parks. Elsewhere are legacies of social landscapes of highly skilled workers and spin-off industries, Stevenage, for example, is now one of the world's largest satellite manufacturers. Tom Rolt was an early, and rarely quoted, opponent of the nuclear age and its trappings. Yet, if we wish to characterise the nature of the new post-war high-tech industries, they were, to paraphrase Professor David Edgerton, the products of 'a militant and technological nation'.[53]

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