INT. J. FOR THE HISTORY OF ENG. & TECH., Vol. 82 No. 1, January, 2012, 1–36

Bloodhound on my Trail: Building the Ferranti Argus Process Control Computer

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Digital computers for process control were developed at the end of the 1950s. They had different design objectives from computers for scientific or commercial use. The Ferranti Argus was among the first computers worldwide used for direct digital control. The Argus was invented at Ferranti's Wythenshawe Automation Division, Manchester, by Maurice Gribble. The starting point was a prototype digital computer developed for the Blue Envoy guided missile using low power hearing aid transistors. Announced by Ferranti as the 'process control transistor computer' in November 1958, Argus came into civilian and military use in 1962. It was used for process control at a soda ash plant for ICI and as part of a Cold War missile guidance system for the Bloodhound Mark 2 surface-to-air missile deployed by the Royal Air Force. While a small team of engineers within Ferranti used Argus to develop digital techniques for guided missile control, another technically powerful group of civilian users led development of the Argus for direct digital control of an ICI chemical plant at Fleetwood, Lancashire. The paper shows how the computer was invented, how it was developed in military and civilian contexts by small communities of practice and how these groups coalesced, grew and dispersed. As projects shifted towards software development, teams became smaller and women programmers were given considerable responsibility. These events highlight a key transition from analogue to digital control in manufacturing industry and defence during the early 1960s. Use of direct digital control by ICI followed commercial logic. The military were forced to switch to digital computation because technical advances in radar meant analogue calculations would not be accurate enough for Bloodhound Mark 2.

KEYWORDS Cold War, automation, guided weapons, digital computer, process control, defence innovation, transistors, ferrite core memory, interrupts, communities of practice, analogue control

Read at the Museum of Science and Industry, Manchester, 26 October 2010

DOI 10.1179/175812111X13188557853928

> If credit for 'invention' must be assigned, it should go to the person or team that first had a clear vision of the principle, saw its potential, fought for its acceptance and brought it fully into satisfactory use. (W. Brian Arthur)[1]

This is the story of an early computer, the Ferranti Argus, from concept to commercial sale. The focus is on the people who made the technology work — those who shaped the way the computer was developed and brought into military and civilian use. The account stands in stark contrast to most histories of UK computer development of the 1950s and 1960s. The Ferranti Argus computer was built by an automation group, not a computer division. Argus had its origins in attempts to control guided missiles. It was designed for process control, rather than scientific analysis or commercial transactions. Contrary to the usual narratives of failure surrounding UK computers, Argus was a commercial success.[2]

Process control computers, such as Argus, are technically significant because they had different design objectives from mainframe computers developed for general purpose scientific and commercial calculations.[3] Different priorities induced innovation. The need to sample data from a wide variety of sensors, calculate time-based derivatives and distribute signals required very strict timing control. Conventional mainframe computers processed material in intermittent batches. Process control computers worked continuously. The imperatives of real time operation brought development of interrupts (direct memory access) for both processors and memory of the sort pioneered by Maurice Gribble in the design of the Argus 200. The overlap with defence brought early adoption of transistors and ferrite core memories and, subsequently, visual display units.[4] There was a need to convert analogue to digital signals. Reliable, continuous operation in a hostile industrial environment required robust equipment as these computers had to operate for months on end, often away from an air-conditioned environment. Argus was built to tough defence standards.

The Argus computer was invented and funded in a Cold War context. Early work on digital control was intended for the Blue Envoy surface-to-air guided missile. The evolution of Argus at Wythenshawe was independent of the activities of Ferranti's own computer Division at Gorton. Development of Argus depended upon two key communities of practice that grew up around military and civilian use. Civilian adoption of the Argus was directed and single-minded, with ICI as a lead user. The switch to digital control on the military side owes a lot to chance events, personal friendships and the shortcomings of arithmetic calculation on analogue computers.

The first part of this account sets the context of Ferranti Automation Systems in Wythenshawe and development of guided missiles, including the widespread use of analogue computers and an early prototype digital computer made with transistors. Wythenshawe was the site for the invention of the digital 'Ferranti process control transistor computer' by Maurice Gribble and the resulting computer hardware, which became the Ferranti Argus computer. Adoption of Argus by ICI at Fleetwood is then discussed and its use for the Bloodhound Launch Control Post. We briefly consider the subsequent development of Argus and conclude with implications for the history of engineering and technology.

Ferranti and the Bloodhound Guided Missile

The firm of Ferranti

Ferranti was a family owned and controlled engineering firm, begun in 1882 as a small-scale heavy electrical engineering business. After the Second World War, the firm diversified towards electronic components, computer systems, avionics and radar while retaining family ownership and control.[5] The firm had a tradition of technological leadership in its chosen sectors, investing for the long term and developing innovative engineering for its own sake. By 1965 the firm employed over 19,000 and had a turnover of £40.9 million (about £620 million at 2010 prices). The Ferranti board gave considerable discretion to divisional management. The firm was a set of feudal kingdoms with little interchange between the divisions. There was rivalry between Ferranti Computers at Gorton and Ferranti Automation at Wythenshawe, just 9 miles apart in Manchester.

Ferranti entered the defence market in a major way in 1943 when the Scottish Group was formed to make gyroscopic gun sights for aircraft with the establishment of a factory in Edinburgh paid for by the UK Government. After the war the firm traded upon its technical excellence and became accustomed to dealing with Government defence procurement. By the 1960s, Ferranti depended upon retained profits for its internal funds. The military divisions at Bracknell, Edinburgh and Wythenshawe in Manchester cross-subsidized civilian activity, both in growth areas such as semiconductors and traditional sectors such as transformers. As the historic advantage conferred by technical leadership in wartime and Cold War waned, so did Ferranti. Ferranti struggled to adapt to civilian life.

Guided missile development — Red Duster to Bloodhound Mark 1

The British government invested heavily in guided missile defence after the Second World War. Guided weapons development was the second largest component of UK government defence Research and Development expenditure — after aircraft — during the 1960s.[6] The Bloodhound Surface-to-Air Guided Missile was developed as part of this post-war programme. It is described as 'one of the most successful, widely deployed and long-lived surface-to-air missiles of the Cold War'.[7] Bloodhound was operated by the Royal Air Force in the UK, in the former West Germany, in Cyprus and in the Far East in Malaysia and Singapore. Bloodhound missiles and guidance systems were sold to the Royal Australian Air Force and neutral Sweden and Switzerland. Export orders were refused for South Africa due to an arms embargo imposed by the Labour Government in the UK.[8]

The Bloodhound missile began life in 1949 as a research project to develop a surface-to-air anti-aircraft missile called 'Red Duster' with the Bristol Aeroplane Company as lead contractor.[9] The aim was to intercept high-flying bombers carrying atomic warheads against Britain. By 1950, guided missiles were accorded the same priority as nuclear weapons development and there was considerable overlap between the two military R&D programmes.[10]

Ferranti was responsible for the forebody of the Bloodhound missile, including the gyroscopes and radar dish, the launch control post and a number of incidental parts including test equipment, data links and fuze safety.[11] Power came from two Bristol

Siddeley kerosene-fired ramjets and there were four detachable booster rockets for launch. The missile was conceived as a twist and steer monoplane with fixed tail fins and moving wings.[12]

Development of Red Duster began at Ferranti, Moston in north-east Manchester but work moved to a purpose-built site composed of laboratories and final assembly facilities at Wythenshawe paid for by the Ministry of Supply, officially opened in June 1954. Everyone at the site signed the Official Secrets Act. The Red Duster development team at Ferranti was led by Dr Norman Searby with strong technical support from Denis Best. Development was organized in small teams. Typically, each team was assigned to one of the labs at Wythenshawe. Each team had the responsibility of designing and testing a component part of the missile.

The Red Duster guided missile entered service with the RAF as the 'Bloodhound' Mark 1 in October 1958.[13] In many respects the Mark 1 Bloodhound was a stop-gap. Initially up to 368 missiles were deployed at eleven sites along the east coast of England. The associated Type 83 Target Tracking and Illuminating Radar was supplied by British Thomson-Houston. This pulsed radar was susceptible to jamming and suffered interference from ground clutter, so the missile could not fire against low-flying targets. These shortcomings brought a switch to continuous wave tracking and illuminating radar (Type 86).[14] Along with other improvements, this culminated in the longer and more powerful Bloodhound Mark 2 deployed from 1 October 1963. The system was finally stood down in 1991. Longevity of Bloodhound Mark 2 as a weapons system is partly attributable to adoption of digital control which gave scope for up-rating as technology progressed.

Analogue and digital computing at Ferranti

Ferranti Automation made considerable use of analogue computing for missile design, testing and control. Analogue computers were developed by US and UK aerospace companies during the 1950s to carry out engineering design calculations and model the behaviour of aircraft and missiles in flight.[15] These analogue computers used continuously variable direct current voltages to represent values in a problem. The voltages were made to follow mathematical relationships 'analogous' to the problem under investigation. The electronic components of the computer forced these relationships to simulate the actual problem. The resulting current outputs gave the solutions.

Analogue machines were usually built up from direct current amplifiers with associated resistive and capacitive networks to shape or modify the signal. A simple analogue computer could be made from radio components. Greater accuracy required an increase in the number and size of components. The operations of addition and subtraction were easy to perform, but multiplication and division were more difficult and required special components or servomechanisms. The accuracy of analogue computers is limited to about 0.1 per cent and errors accumulate.

Analogue computers were ideal for simulating a missile and its target manoeuvring in three dimensions in real time.[16] Circuits were constructed to replicate the pitch, roll and yaw of a fast moving missile. During the 1950s Ferranti Automation built at least two analogue computers in their simulator section to solve aerodynamic problems relating to Red Duster.[17] The initial machine begun in 1950 modelled the three-dimensional trajectory for Red Duster. After trials with an early analogue computer, a ‘Complex End Course Machine’ started work in 1956 to model detailed aerodynamics of the missile and the propulsion system. The simulator section was led by Tommy Thompson and employed ten or a dozen staff, initially in Moston and then at Wythenshawe.[18]

It was normal for users of analogue computers to build their own machines. As Dr Williams of rival missile designer English Electric said, ‘the design and construction of simulators was, in those days, necessarily a ‘do-it-yourself’ activity since no standard computing units were available on the British Market’.[19]

Digital techniques were developed to overcome shortcomings in analogue, notably accuracy and replicability. Digital computers were also ‘universal machines’ which could be put to work on any task, rather than purpose-built to replicate a specific problem. The apparently radical notion of building your own *digital* computer does not seem unusual when you have been self-assembling analogue computers for five or six years and have the relevant skills in electronic circuit design and knowledge of components.

Many aerospace firms turned their analogue expertise into commercial products. Ferranti’s competitor English Electric Co. Guided Weapons Division exhibited their LACE (Luton Analogue Computing Engine) at the same Olympia Exhibition where the Ferranti Argus was first unveiled.[20] Fairey Aviation Co. Weapons Division also developed a similar analogue system shown at the exhibition, alongside machines from two other aerospace companies Short Brothers and Harland and Saunders-Roe. In contrast, Ferranti Automation went digital. This is an example of Vincenti’s ‘variation-selection model’ for the growth of engineering knowledge: all British aircraft companies faced the same problems of development, analysis, evaluation and optimization during the 1950s, but just *one* firm — Ferranti Automation — came up with a different outcome, a digital computer at the 1958 exhibition while the rest showed analogue machines.[21]

Ferranti had already entered the digital computer business after the second world-war, drawing upon wartime experience of radar and electronics research in the UK.[22] Many key radar personnel ended up in Manchester after the war, either working for Ferranti or at Manchester University, having worked together at the Telecommunications Research Establishment (TRE), Malvern — the ‘TRE Mafia’ as Peter Hall describes them.[23] Ferranti found Manchester University was already working on the creation of the world’s first stored programme computer, the Small Scale Experimental Machine. Ferranti received their first order for a digital computer from the University on 26 October 1948 and the firm formed a separate Computer Group in 1949 as an outgrowth of the Ferranti Instrument Department at Moston specifically to develop and manufacture digital computers. The Ferranti Computer Group became one of the world leaders in commercial and scientific computing until the end of the 1950s from their base in Gorton. The main Board of Ferranti was evidently supportive of digital computer development.

The main significance of Ferranti Computers to the quite separate development of Argus is the brand name and marketing organization in London. Ferranti Computers became a trusted digital mainframe supplier with a loyal customer base among steel, chemical and engineering companies. These same companies played a leading role in adopting process control computers built by Ferranti Automation. Pegasus was a general purpose digital computer introduced by Ferranti Computers in March 1956.[24] Three Pegasus computers were sold to the steel industry for research calculations; two more to Shell for research and one each to ICI and Babcock and Wilcox.[25] These Ferranti mainframe users were to become Argus lead customers. Customers associated the Ferranti name with computer design. Otherwise there was very little technical cooperation between adjacent technical teams at Gorton and Wythenshawe, or between Wythenshawe and the Military Division at Bracknell, at least up until the mid-1960s.[26]

Blue Envoy, hearing aid transistors and development of the Ferranti process control transistor computer

Maurice Gribble

The Argus digital computer was invented and designed by Maurice Gribble at Ferranti's Automation Division, Wythenshawe, although he was supported by a team of growing size as the computer developed from experiment to prototype and on to commercial production.[27] Maurice was born in Ipswich and a radio ham at the age of fourteen while still at Ipswich School: 'I was always drawing radio circuits in French [lessons]' he confesses.[28] During the Second World War, Maurice trained as a pupil in the local power station for 2½ years before leaving this reserved occupation early in March 1942 to volunteer for the RAF. Here he worked on 'Gee' radar beams for torpedo boat and aircraft guidance, initially in the UK and then mostly in France but also in Germany at the close of the war. He went on to take a University of London degree in physics at Woolwich Polytechnic after the war. He was recruited by Vivien Bowden to work at Ferranti's in 1951, initially on their display for the Festival of Britain at the Science Museum. He moved to Moston to work on the Ferranti Mark 1 computer for Manchester University and developed equipment to drive a big line printer made by Machine Bull in France. He moved on to Ferranti's Automation Division because he wanted to do something 'more theoretical'.[29]

Blue Envoy and command guidance control

By the mid-1950s development of the Red Duster guided missile, which was to become the Bloodhound Mark 1, was well under way at Wythenshawe. At that stage experimental test missiles were under trial, first at Aberporth in Wales and then in the clearer weather of the Long Range Weapons Establishment, Woomera, in Australia. Around the same time, 1954/55, Ferranti Automation was also working on a quite separate surface-to-air guided missile with a very much extended range of 320 km. This surface-to-air guided missile was code-named 'Blue Envoy'. The concern was that Soviet bombers would be equipped with stand-off weapons and needed to be intercepted at greater distance. The missile was intended for both land-based and naval use.

Blue Envoy has been described as 'possibly the most enigmatic project in the field of 1950s United Kingdom weapons development'.[30] It was also known as Bloodhound Stage 1¾. In some respects, such as engine testing, Blue Envoy was a prototype for the shorter-range Bloodhound Mark 2. Otherwise comparison with Bloodhound is misleading since Blue Envoy was under command guidance from the ground during the first part of its flight, whereas Bloodhound used a reflected radar signal and on-board guidance to home in to the target.

Blue Envoy was developed by Bristol Guided Weapons Department and Ferranti. The missile was made of stainless steel, equipped with double-delta wings and was slightly longer and faster than Bloodhound Mark 1. One anti-aircraft option was to fit a low yield nuclear warhead called Blue Fox. The Blue Envoy missile was tested at the scale-model stage, but the full-size missile never flew before it was cancelled in April 1957 as part of that year's Defence Review. In any event, it lacked short-range capability against low-flying attacks under the radar. It is said that the concept of Bloodhound Mark 2 was invented in a London taxi as an urgent response to cancellation of Blue Envoy.[31]

As the name implies, 'guided' missiles need to be carefully controlled, both in terms of direction onto the target and stability during flight. Firing a guided missile is a classic dynamic control problem, like a dog chasing an agile hare. But at least the dog only pursues the hare on the ground in two dimensions. A missile chasing a target aircraft has to deal with three dimensions, predicting the future position of the target from its current location and flight behaviour. Air density varies, so an optimum course may involve a near-vertical ascent to escape the drag imposed by the dense lower atmosphere, before heading off towards the target.[32] To complicate matters, the earth is not strictly round, so allowance has to be made for this feature too.[33]

During the initial command-guidance phase of flight, Blue Envoy received control signals from the ground. The first task was to get the missile on course after launch. The missile needed to correct its course so that it aimed in the right direction towards target interception. (Final closure onto the target was by riding a narrow radar beam.) But, before the missile can manoeuvre onto the target using directions from ground control, it needs to establish its angular error from the likely direction of interception. Circuitry was also needed to actuate the servomechanisms used to control the Blue Envoy missile during its prolonged mid-course flight.

Maurice Gribble developed digital logic circuits to code the angular position of the missile for onward transmission from the ground by a guidance beacon.[34] The data would be decoded when it arrived in the missile and translated into control signals to steer the missile in the right direction. An obvious next step was to see if some of the actual controls on the missile itself could be undertaken digitally in response to these guidance commands from the ground. To this end, a special purpose digital computer was built to experiment with direct control of the servomechanisms.

The hearing aid transistor computer

Maurice Gribble was given considerable freedom. He was a development engineer: 'I didn't really fit in with anything, no one quite understood what I was doing. No one ever questioned. [. . .] There wasn't the tight financial control there is today'.[35]

At the time, a couple of teams in the UK were experimenting with computers built around early point contact transistors in place of thermionic valves. These transistors essentially consisted of a single crystal of germanium with two fine wires.[36] A research student at the University of Manchester, Dick Grimsdale, ran a transistor computer from November 1953 onwards and similar experiments on small-scale transistor-based computers were successful at Harwell from February 1955 onwards.

Against this background, Maurice Gribble developed a prototype digital controller around 1956 using low-frequency junction transistors meant for hearing aid use (25 kHz) made by Mullard known as OC71.[37] His view was that 'a basic clock frequency of 25 kilocycles per second was slow by the standard of mainframe computers working on thermionic valves, but at the time high frequency transistors were not available'.[38] This 'hearing aid transistor computer', as it was colloquially known, could add, subtract and multiply. Division was performed by software using the Newton-Raphson algorithm, while the trigonometric functions used Chebyshev polynomials.

The approach of the hearing aid computer was simple: a single address and serial operation. But, Maurice Gribble appreciated:

> Memory was always a problem on early computers, in fact it is true to say that the type of memory largely determined the design of the computer.[39]

The immediate-access working memory was a set of transistor flip-flops with a capacity of 32 words (Figure 1). These were expensive since the number of transistors increased almost in line with the number of bits of information being stored. Another 35 words were wired into constant locations. But an important distinction can be made between remembering data and storing a programme. The designer says:

> I realized that a computer for process control needed a relatively small amount of working memory, since data was read in, processed and output to the plant in real time. Data only needed to be stored until it was used. The program, on the other hand, would require far more memory and that is why a diode memory, in the form of a plug board, was used. This was cheap and fast, although not quite as flexible as storing the program on the same memory that was used for data.[40]

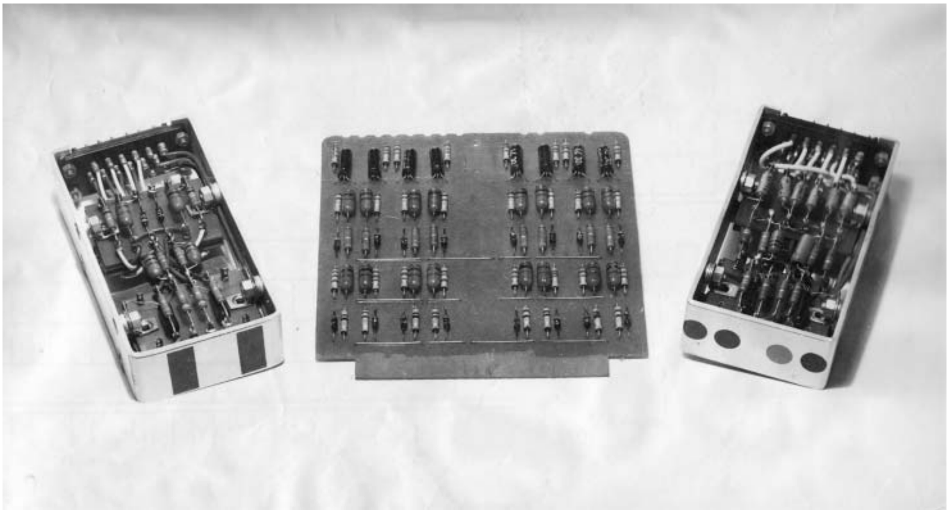

FIGURE 1 The 'hearing aid transistor computer' was developed for digital control of the Blue Envoy Command Guidance Missile. Flip-flops cannister on the left and NOR gates cannister on the right.

So the programme was a plug-board with capacity of 64 words in the main block and 12 sub-routine blocks of 25 words, giving a total of 364 words. The hearing aid transistor computer was, in short, a simple digital computer that could be programmed to give accurate, replicable results using binary arithmetic.

The twist-and-steer elevons at the outer end of the wings of Blue Envoy were operated hydraulically. Circuits were developed to operate hydraulic valves by switching current into them for a length of time proportional to the digital output. The difficulty here is converting angles (or their sines or cosines) into digital form. You cannot readily jump from a 360° angle to a 1° degree angle in digital! The breakthrough was to develop a digitizing disk using a cyclic progressive code which moved gradually and neatly through the angles in small steps.[41] The prototype computer was used for testing of digital servomechanisms, in much the same way that real components were already inserted into circuits in analogue computers. Here again the analogue culture of physical simulation of components reinforced the move to digital control.

A Royal demonstration

The ‘hearing aid transistor computer’, was a major breakthrough in digital control of processes.[42] Although Blue Envoy was cancelled early in 1957, Maurice Gribble carried on with development work.[43] The computer might have remained a laboratory curiosity if Maurice Gribble had not used it in a simple and appealing demonstration of digital parallax correction to Duke of Edinburgh during an official visit to Ferranti at Wythenshawe, on 22 November 1957.[44] This was a shrewd move as preparations for the Royal visit commanded priority in the technical support workshops and the demonstration had the attention of senior management and colleagues.

This royal demonstration of digital control was set up in a Laboratory in H wing at Wythenshawe using two hydraulically operated turntables supporting optical projectors. One projected a green spot and the other a red spot onto a screen. The trick was to get the red spot to converge on the green. The angular position of each of the turntables was measured by digitally coded disks and a similar disk was connected to a control handle for the royal visitor. When the knob was turned, the two spots of light converged as the computer performed the trigonometry for the parallax correction and operated the servomechanisms beneath the lights.

The demonstration used typical short cuts employed by engineers. Photoelectric cells were created by scraping the black paint off the glass capsules of transistors. Car headlamp bulbs were used for illumination. But it was clear evidence to visitor and management alike that digital techniques could be used to control an elementary process. It was always Ferranti’s intention to move into process control.[45] These new digital techniques provided the opportunity.

The prototype Argus

Within a year of the Royal demonstration, the next stage in the evolution of digital control — the Ferranti ‘transistorised process control computer’ — the prototype of the Argus computer — was displayed for commercial sale at the ‘Electronic Computer Exhibition’ at London Olympia, in November 1958.[46] The machine was described breathlessly as:

> [. . .] a type suitable for development for process control work, for use at the centre of an automation process. Its special interest lies in it being made entirely with transistors in place of thermionic valves, and it represents a most important advance in developing these new techniques.[47]

In truth, most of the contents of the cabinets on display were dummies. So when a Russian 'diplomat' showed particular interest in the computer Maurice Gribble had double reason for not revealing more details.

The Argus name was developed in collaboration with Bernard Swann of Ferranti's Computer Centre at 21 Portland Place, London. The name was chosen to complement other mythological names used for Ferranti computers such as Pegasus, Orion and Sirius. It was an apt choice because Argus was a supervisory computer: 'Argus, the all-seeing, had a hundred eyes which slept in turns, so that he was at all times awake'. Bernard Swann saw beyond local differences in Manchester. He understood how a process control computer from Wythenshawe complemented the product range of mainframes from Gorton. The name Argus was used from May 1959 onwards. Argus later became the Argus 200 when a smaller version using only core memory, was designed by Dave Butler, Dave Senior, Stan Redshaw and others, called the Argus 100. This was a serial machine which was programmed from a paper tape. The Argus 100 variant was installed at industrial plants such as the Steel, Peech and Tozer's electric arc steelmaking shop in Rotherham, while ICI bought six to use around its works, including a novel Paraquat plant at Widnes.[48]

The Argus computer was marketed as a digital computer for civilian process control 4½ years before it went into service with the RAF, even though development had been funded by defence contracts. Ferranti recognized the tasks of initial set-up and then controlling a guided missile in flight are the same problems as active control of fast-moving industrial machinery, such as multi-stand rolling mills, where roll gaps and speed need to be set up and immediate response is required in real time once production starts.

Innovations in the Argus computer — interrupts and memory

There were no precedents for the Ferranti Argus. There were no other digital process control devices to copy. A remarkable sequence of innovations in digital computer design emerged at Wythenshawe during the year between November 1957 and November 1958, resulting in the prototype process control computer shown at Olympia. The beautifully written computer manual for Argus shows clear design objectives.[49] The resulting technical developments included the ideas of interrupts and direct memory access, use of both serial and parallel operation, adoption of higher powered transistors and a ferrite core memory, and development of a novel peg-board for permanent programming — all developed to prototype stage in twelve months.

Interrupts

The specification called for real time control and continuous operation. However, it was also necessary to read in and send out data and deal with any other urgent interventions while the computer was still in control. So the notion of interrupts was developed. Precise timing control was essential as the computer would be working in real time.

Switching from analogue to digital control was not straightforward. At the time it was customary to run industrial and military processes with analogue devices. So control of servos was achieved by a continuously varying signal. Digital is different since the data is discrete and holds the same value until altered. So instead, digital data is sampled frequently to be 'pseudo-continuous'. This was a design challenge. As Maurice Gribble said:

> In the hearing aid transistor computer, the sampling rate was significantly low for it to be a sampling servo and the program was adjusted so that the samples occurred as regularly as possible, bearing in mind that multiplication, which used a short-cut method, took a variable length of time. I realized that this made programming very complicated and invented 'interrupt' where the computer stored what was in its registers and changed to a short program to read in data, output it, or operate a servo. In attempting to patent the idea, we found that it had been patented in the USA a few months previously.[50]

Argus used interrupts at various intervals controlled by a timer, but it was not allowed to interrupt a multiplication or division, or a jump to a sub-routine.

Core memory and read-only memory

The Argus computer had *two* memories: a core memory and a semi-permanent peg-board memory. The core memory was a ferrite core memory. Ferrite cores were developed in the USA from 1950 onwards. They rely on the principle of coincident current selection. The memory is built up on a grid of fine horizontal and vertical wires, resembling the template for a game of noughts and crosses.[51] A small magnetic core — known as a toroid — surrounds each intersection of the grid, like a diagonal bracelet. A half-current applied to either the vertical or horizontal wires alone is not sufficient to alter these magnets. However, if half-currents *do* meet at an intersection, the coincidence of the currents is sufficiently powerful to switch the magnetic core at that particular point. A third wire is used to read the state of these magnets. Since binary operations only require 'on' or 'off' — zero or negative current say, the state of each of these uniquely positioned magnets is sufficient to provide a permanent memory store. The settings were 0 volts (binary 1)/ *minus* 6 volts (binary 0).

A novel contribution of Argus was the second memory, a semi-permanent peg-board memory.[52] In contrast to mainframes, process control computers only require one dedicated programme with a specific purpose. Recall that the hearing aid computer used a plug-board to store the process control programme. It was a logical next step to develop a versatile and durable plug-board to store a programme for Argus. This was done using ferrite pegs. These pegs were the size of pencil leads and made up of baked ferrite, a ceramic material, essentially an iron oxide Fe_3O_4, evocatively known to geologists as lodestone.

Since process control computers only need to run a single programme, the peg-board was a read-only memory. It was programmed by inserting a peg into the appropriate hole in a printed circuit tray. Each peg represented a binary 1, analogous to a hole in an 80-column punch card. Each line of pegs represented a 24 bit word of code. Each tray held 64 twenty-four bit words (plus a parity bit). Each store box held 16 such trays, making 1024 words in all. The launch control post had four stores, making 4096 words in total. This feature was only used on the first design of Argus, the '200'.

The decision to use the peg-board was both considered and pragmatic:

> In the case of the Argus 200, the reasons for using a separate magnetic peg board for program and constants were reliability and speed. The Argus used one of the first, if not the first, transistor driven core memories. Until that time, core memories had been driven by valves. The problem with the germanium transistors available at the time was that fast switching and the ability to handle the high currents and high voltages needed were incompatible, so it was difficult to find suitable transistors. Reliability was not very high, but this did not matter very much for *data* in a process control computer, since a random error would be corrected at the next cycle of computation. However, if the *program* were corrupted, it would be chaotic. The peg board memory was also a lot faster than a core memory read/write cycle of the time. We also had a patent on it.[53]

The insertion of small pegs into a board required great care, but did not have to be done very often since control programmes were seldom modified. Indeed ICI complained 'manual programming is rather tedious and is inconvenient for small changes'.[54] The delicate nature of the peg-boards became part of the folk myth of the Argus 200 since a day's work could be easily undone by an inopportune jolt loosening the pegs, just like sweeping a jigsaw off a table by accident. To minimize these frustrating accidents, the peg-boards of the early machines were fitted with a transparent cover. Derek Whitehead recalled Ferranti days when 'we polished the lid of the peg board so the whole lot flew out on Pete Smith due to the static on the celluloid lid'.[55] Again, Mark Walker remembers times at RAF West Raynham when careful work could be wrecked by a gust of wind catching the unwieldy board during the short journey outdoors from the section hut to a nearby Bloodhound launch control post.[56]

Speed of operation and testing

At 500 KHz, Argus was far faster than the hearing aid transistor computer.

> Argus 200 was designed for speed [. . .] Parallel arithmetic was much too expensive before the invention of integrated circuits, but a series-parallel system, using two bits in parallel, almost doubled the speed. A modified short-cut multiplier was used which dealt with three bits at a time and equally well with positive and negative numbers. A non-restoring divider also improved speed. Finally, the word length was made as short as possible with the option of double length operation when high accuracy was required.[57]

Even so, ICI criticized the speed of Argus in comparison with their mainframes, not that their elderly soda ash plant at Fleetwood required anything like the response speed they were offered.[58]

Argus ran on a machine code which was a modified version of the order code used for the Ferranti Pegasus mainframe computer. This was one of the few areas where Ferranti Automation borrowed ideas from the firm's Computer Division. Use of Pegasus order code had the advantage that both ICI and United Steel could test programmes for the later Argus 100 on their Ferranti mainframes.[59] Programming in machine code is tedious as it is necessary to keep track of the precise location of

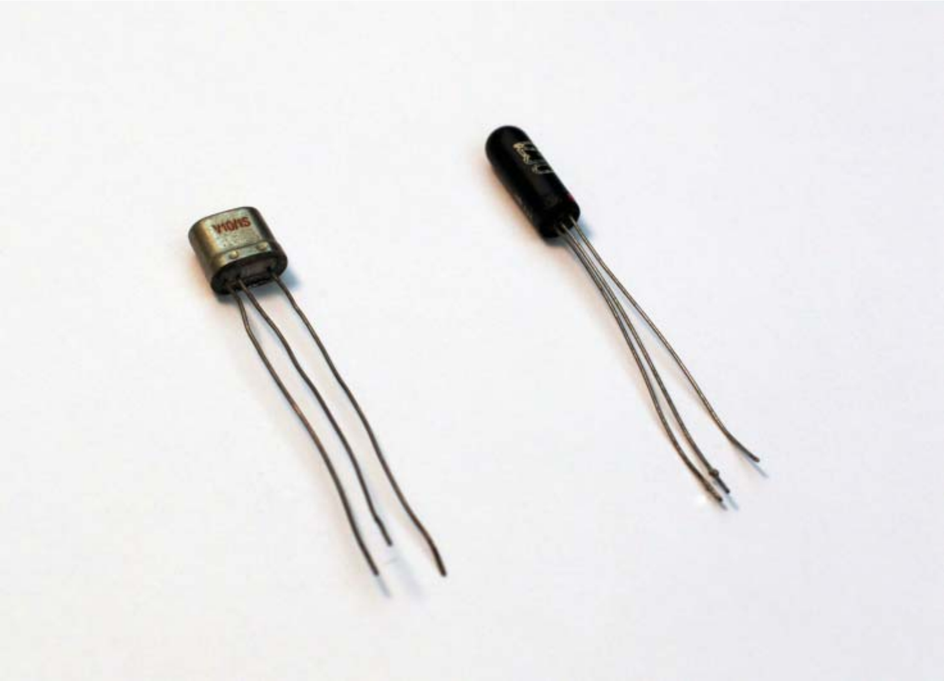

FIGURE 2 Hearing aid transistors OC71 form the memory of the first process control computer developed for Blue Envoy by Maurice Gribble at Wythenshawe. Failure of the V10/1S at the production stage delayed Argus.

every element in the memory and keep a note of the time taken for each operation. You have to remember the difference between two types of binary numbers: the memory address itself and the numerical contents of that memory address.

Technical setbacks and commercial manufacture

It is a myth of technical development that things flow smoothly from prototype to production.[60] Development of Argus was not without its setbacks.

Selection of suitable junction transistors for Argus was one cause of technical difficulties. Maurice Gribble sought advice from the Radar Research Establishment at Malvern since they had experience of working with transistors. They recommended a transistor, V6R8, which would stand a high current. This was made by Pye at Newmarket. A sample was secured and proved better than anything else. Maurice Gribble decided Ferranti should build the whole computer with this one transistor and an order was placed for about 10,000.

Faced with this large order, Pye's subsidiary, Newmarket Transistors, brought out a high power version V10/1S especially for Ferranti Automation (Figure 2). However, Pye decided to manufacture them in a different way. The early model had a soldered can. Pye found they could speed up the manufacturing process by dipping the cans into flux before they were soldered. The finished transistors were then covered in silicone grease to keep the moisture out. But a fatal flaw was that soldering flux is hygroscopic. Moisture took time to work through the silicone grease: it took six months. After final manufacture the Argus computers started dying due to moisture ingress and Maurice Gribble got the blame. In particular, these faulty components delayed the whole Launch Control Post programme for Bloodhound 2 as much time was spent repairing and replacing dud transistors. Fortunately, Ferranti did not have to alter the printed circuits. But there was extensive reworking using an alternative GEC transistor (GET875s) with a welded can, which was less able to switch such high currents.

But the Argus 200 did get into commercial production, selling 63 machines plus 14 of the stripped-down Argus 100 variant. The machine was built at Moston where assembly was led by Bob Grove, 'a marvellous organiser' who honed his skills as a production manager on Bloodhound Mark 1.[61]

Marketing and early sales of Argus for process control

Marketing material for the Argus 200 emphasized reliability and adherence to AID defence standards in construction.[62] The computer had to be reliable and robust to work in severe environments. The technology was — quite literally — 'gold plated': with gold coated connectors for durability and conductivity.[63] Since the first application of Argus was to help make washing soda there could hardly be a more apt illustration of Whitfield's tart observation relating to US Cold War equipment suppliers: 'The push buttons that were designed to make housework easier came from the same laboratories as the push buttons for guided missiles'.[64]

The Argus computer was technically advanced. Core storage of programmes was emphasized — a key selling point at a time when machines with drum memory were slow and difficult to programme. The use of ferrite core storage and random access memory circumvented the slow speed of drum machines with their greater reliance on sequential memory. Transistor circuits, ferrite cores and random access memory became the 'dominant design' for process control computers of the first half of the 1960s.

The first sale of Argus was to engineers Babcock & Wilcox for automated control of a power station boiler at West Thurrock in Kent following discussions in 1958 between Geoff Griffiths of Babcock & Wilcox (a keen Pegasus user) and Maurice Gribble and Chris Wilson of Ferranti.[65] Boiler automation had particular resonance for Maurice who, as already mentioned, had trained as a pupil at Ipswich Power Station in the early 1940s. A team was set up, led by Norman Leece, to build and install an Argus 200 computer for boiler control at West Thurrock power station, then under construction in Essex for the Central Electricity Generating Board. The project ran into severe delays due to the slow pace of power station construction and the computer was put into store for a while.

ICI as lead user

In every sense of the word, ICI was the lead user for Argus. ICI Alkali Division ordered an Argus 200 machine for an elderly soda ash plant at Fleetwood, Lancashire.[66] ICI treated the Fleetwood plant as a commercial scale pilot plant. Adoption of Argus was effectively a giant R&D project.[67] Ferranti wrote the software and provided the hardware (Figure 3). But ICI had the technical competence to develop the project by adding instrumentation, developing actuators to control valves and convert analogue signals to digital and back again.

Civilian communities of practice: the Argus 200 at ICI at Fleetwood

Adoption of the process control transistor computer into practical use required development work by two teams, one military and one civilian. Such teams have been called communities of technological practitioners (by Constant), or communities of practice (by Wenger).[68] Here we use the term communities of practice to refer to small groups of engineers and technologists who get together to implement a novel technology, coalesce around a shared problem, recruit outsiders with relevant skills and then leave to join another small community once the task in hand is complete. The central idea is that learning and problem-solving in technology is a process of social participation.

In the case of the Ferranti Argus, the focus of these efforts was digital control of processes. In the civilian case, this was automation of a complete soda ash chemical plant. In the military case, it was use of digital control to direct a radar dish in the nose of a guided missile. These communities brought together people with considerable prior experience and previous patterns of cooperation, who shared their tacit knowledge and experience, focussed on solving problems of implementing novel process control technologies for their designated project and left a legacy of experts whose experience would be used on related projects.

These communities were democratic and consensual with clear recognition of the respective talents of participants and deference to intellectual leadership. It is said that Dave Evans was selected by his fellows to lead the ICI team for Ferranti.[69] They were subject to little managerial direction and conformed to group norms rather than, say, working hours laid down by the job. They had informal and sometimes unorthodox ways of working.

Group cohesion around a common goal is reinforced by long hours of technical effort, the inevitable reverses and struggle towards an agreed solution. A strong feeling of community is emphasized by signing the Official Secrets Act. Participants could not talk about their work outside of the plant, but could talk to others bound by the same Act and share the gossip and scandal attendant upon such work.

Communities of practice are *not* the same as a formal development team. These communities transcend organizational boundaries and recruit members from outside the team. The Fleetwood community encompassed both ICI and Ferranti personnel. The Launch Control Post team included Derek Whitehead who was formally assigned to missile development, not ground control. So, a community of practice relates to those who actually deliver the solutions rather than any formal organization diagram.

The idea of applying direct digital control to a chemical plant seems to have been mooted within ICI during a visit to the USA by members of the Alkali Division early in 1957.[70] ICI Alkali Division had a reputation as ‘gentlemen inventors and were prepared to spend money on developments that were not immediately profitable’.[71] At the time, US process plant users were discussing the relative merits of analogue versus digital control, although the only practical experiment that had been attempted was use of a digital computer to advise operators at a Du Pont plant at Niagara Falls down a phone line from Philadelphia.

Alan Thompson, Instrument Manager of ICI Alkali Division, approached Ferranti around the time of the Olympia exhibition in November 1958 with a view to using their 'process control transistor computer' for direct control of a chemical plant. Negotiations took place with Bob Morley of Ferranti who was working on guided missiles at the time, along with Peter Corrin who was involved with design issues. 'Alan Thompson was the key mover', Maurice Gribble said:

> Alan Thompson appreciated you could replace 100 three term controllers with a digital computer. It would then become economical. It was able to control valves. Servos need stabilisation. Alan Thompson realised its potential.[72]

The chemical plant chosen for the experiment was an obsolete soda ash plant at ICI Fleetwood Works in Lancashire built in 1926 at a site originally developed by United Alkali Company in the 1890s to avoid the grip of the Cheshire Salt Union. The plant ran continuously with a single shut down day each year.[73] The plant was controlled manually using hand-turned valves and sight glasses. ICI claimed existing instrumentation was reaching the end of its life, but this was public relations gloss since there was very little instrumentation to speak of. New pneumatic valves were installed, actuated by electrical signals. Soda ash manufacture by the Solvay process

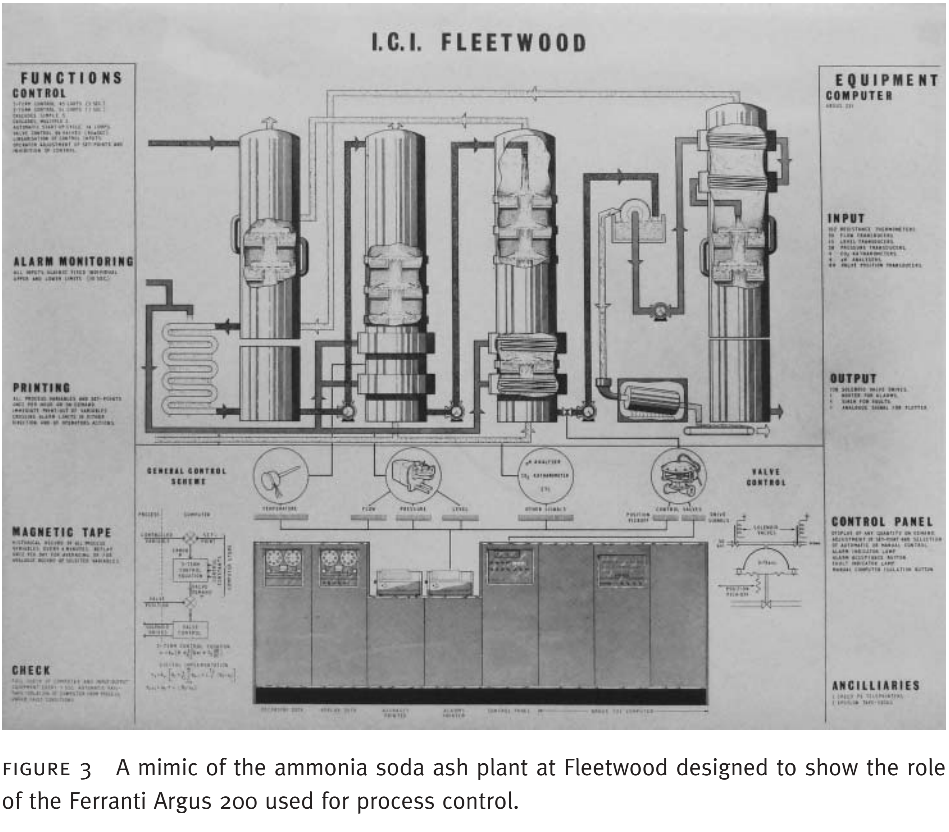

FIGURE 3 A mimic of the ammonia soda ash plant at Fleetwood designed to show the role of the Ferranti Argus 200 used for process control.

is safe and has no explosive or toxic hazards. The plant had complete duplication of pipe work so it was possible to install computer control on one pipe circuit to make sure it worked before implementation of the complete scheme. ICI sanctioned the project in March 1960 using the Ferranti Argus computer.

The Argus 200 for Fleetwood was tested at Wythenshawe (Figure 4). A tiny simulation of the plant was built in a lab H2 at Wythenshawe to test hardware and software with the odd operating loop as a preliminary test. The equipment was not actually delivered until April/May 1962. The computer was disassembled and taken up to Fleetwood on the back of a lorry in parts. The soda ash plant was a hostile environment due to heat and dust. The inside of the plant was covered in a build-up of fine white powder, inimical to delicate circuits. So the Argus 200 computer at Fleetwood was installed in a purpose-built, air-conditioned cabin, complete with interlock doors some 30 feet off the ground right at the heart of the works above the hot moving stoker grates of the bicarbonate bands. The computer control room was both physically and socially isolated. Access was strictly limited to the 'inside' and 'outside' controllers who manned the room. The ten or so men trained to operate the plant were something of a labour aristocracy. The computer had 2048 words of peg-board storage and 1024 words of core storage. The computer controlled 178 valves using information gathered from 102 thermometers, 92 transducers, 8 analysers and 89 valve positions. Input and output signals were distributed over conventional analogue phone lines installed by ICI electrical fitters.

FIGURE 4 Argus 200 destined for Fleetwood installed in Lab H2 of H wing at Ferranti Automation, Wythenshawe, in late 1961 or early 1962. This photo shows the computer used at Fleetwood, later transferred to Winnington until 1980 and now in the Science Museum.

The team installing the Argus 200 at Fleetwood was led by Syd Evans as overall project manager. Mr Evans came from Wythenshawe where he had earlier worked on mid-course guidance as part of the cancelled Blue Envoy project, a clear transition from military to civilian work. The project team for Fleetwood began to coalesce early in 1961 and was composed of four or five Ferranti people, Syd Evans, Frank Moss, Dave Rushton, Norman Leece and Tim Gossling, a mathematician who was the programmer. To this may be added Alan Thompson from ICI who the team met frequently at Winnington and Wythenshawe along with his right-hand man, making perhaps eight engineers in total at the heart of the development. They made frequent visits to ICI offices at Winnington: 'we coordinated with them, spoke the same language'.[74] All the ICI experience was with two and three term analogue controllers. In the event, there were problems to overcome, such as the 'noise' problems in the Fleetwood installation caused by spikes in the electric current in the mains. (The whole works was run on 440 volt direct current supplied by in-house generating plant and later from outside through mercury arc rectifiers which were doubtless the source of the spikes.) They learned the hard way, the usual way to learn on these sorts of projects.

Results showed 99.6 per cent availability for the system in the first 20 months after commissioning.[75] Or, as a local electrician put it, 'When it first started there was a lot of hiccups and that, but it actually settled down very well'.[76]

The role of programmers

As the physical hardware of Argus developed, communities of practice coalesced, grew and dispersed. These teams became smaller as projects became an issue of implementation and software development. Here women were given great responsibility. Instead of a community of practice working on teething problems, there was typically a lone gifted programmer and a Ferranti engineer assigned to each project. Within a year, novel engineering problems had been largely solved. Instead there were now novel software problems.

The Ferranti Argus was something of a standard for ICI. They bought six Argus 100 computers in December 1964, neatly illustrating the way in which an experimental prototype makes the transition to commercial product.[77] One of these Argus 100s was installed at a new chemical plant at Widnes, the No. 2 Paraquat plant at the Pilkington-Sullivan Works of ICI Mond Division Works — 'Pilks' as it was known locally. This was perhaps the first time in the world a chemical plant had been designed and built for direct digital control from the outset. The low temperature sodium process to make Paraquat was both secret and dangerous and had been developed using a pilot plant, the 'Gaskell-Marsh' pilot plant (with a nominal capacity equivalent to 23 tons/year paraquat ion) built at a cost of £100,000 which commenced operation in March 1961.[78] The Argus 100 was to be applied to a new, commercial scale No. 2 Paraquat plant at Pilkington-Sullivan Works at Widnes to produce 3500 tonnes/year of paraquat ion at a capital cost of £3.5 million.[79] This illustrates three things about ICI as a company: Their confidence with the science of a new processes, having made inferences on the basis of a pilot plant. They were willing to take risks introducing a novel route and using direct digital control by computer on a dangerous process. Finally, their sheer professionalism in terms of chemical engineering. So ICI's role as a lead user of Ferranti Argus computers was just one part of a corporate culture of innovation at the chemical company.

Cooperation between ICI and Ferranti was much more limited at the No. 2 Paraquat plant, no doubt for reasons of commercial secrecy. Ferranti were given a list of items to be controlled, but their purpose was blacked out to preserve confidentiality. Eric Johnson from ICI was their link. But otherwise there was little or no interaction with ICI personnel. Ferranti received £123,000 for the hardware and software while ICI spent a further £457,000 on instrumentation and research costs for the plant.[80]

The Ferranti team for Widnes was composed of two people, Peter Sagar the engineer and Scilla Bretscher the programmer and former maths teacher, one of a team of women programmers who joined Ferranti Automation in Wythenshawe in September 1963.[81] Scilla Bretscher had previous vacation experience as a student at Harwell in Oxfordshire programming in autocode for a Ferranti Mercury computer. Programming at Widnes involved frequent trips to the uncompleted plant to test and install programmes in spartan surroundings. This reflects the culture of the two companies: Ferranti left their largely self-taught programmers to 'sink or swim' with little or no supervision. ICI had confidence in their commissioning engineers. Internal ICI reports show computer control at Widnes was a great success and ICI soon issued an invitation to tender for an expansion of computer hardware on the plant in May 1969.[82]

A presumptive anomaly: adoption of Argus for the Bloodhound Mark 2 Launch Control Post

It is widely assumed Argus was intended for use on the Bloodhound Mark 2 Guided Missile.[83] The hearing aid transistor computer was developed for command guidance of Blue Envoy. But the idea that Argus was developed for Bloodhound seems an interpolation backwards from its eventual use on the Launch Control Post for Bloodhound Mark 2. The turn of events that actually led to use of Argus on Bloodhound is both more complex and far more interesting. Use of digital computers for military purposes faced strong opposition and military deployment owes more to friendship, chance and technical genius rather than any high level decision to use the technology for defence purposes.

Use of digital control on the Bloodhound Mark 2 Launch Control Post was due to a problem that could not be overcome using conventional analogue computing. As Derek Whitehead said 'I did it because I didn't think analogue would do what I wanted it to do'.[84] Adoption of digital computing is a clear example of a 'presumptive anomaly', where assumptions of science suggest the conventional solution will fail, so a new technical solution is called for.[85] A closely related idea is Hughes's notion of a 'reverse salient' where concerted action in the form of invention and improvisation is needed to maintain a path of development.[86] English Electric persisted with analogue and tried to reduce similar errors on a rival missile, Red Shoes, by scaling down the analogue calculation to reduce the absolute error and then scaling up the answer. But Derek Whitehead's solution using a digital computer was one that worked.

The guidance system of Bloodhound Mark 2 used a continuous wave radar system which illuminated the airborne target. A radar dish inside the head of the missile picked up the doppler return reflected back from the illuminated target. Continuous wave radar had compelling advantages, including the ability to discriminate between targets at the same range and could detect moving targets amid the clutter of stationary objects which had very different frequency returns. It was less susceptible to jamming. Continuous wave radar is exacting, since it requires a very stable signal so that the missile can pick up the slight doppler shifts returning from the target.[87]

The Bloodhound Mark 2 Launch Control Post

Missile engagement, set up and launch was the task of the Launch Control Post (Figure 5). The Control Post received incoming data such as bearing, elevation and distance of hostile aircraft from the Early Warning Radar via an operations room. The engagement controller in the Launch Control Post would track the assigned target using Target Illuminating Radar (Figure 6). The missile launcher would be moved to face the target and the missile receiver dish on Bloodhound would be tuned on where to expect the target after launch. Once the incoming reflections from the target were sufficiently strong, the computer would indicate a 'free to fire' message and the controller was free to launch.

Technical development at Wythenshawe followed the standard pattern of aerospace engineering. The overall missile was broken down into packages for individual design teams to develop. In turn, these packages were devolved into sub-assemblies. The Launch Control Post for Bloodhound was one such sub-assembly. Design of the

FIGURE 5 Bloodhound Mark 2 was an archetypal cold war weapon. The air portable Launch Control Post is shown to the left of the missile.

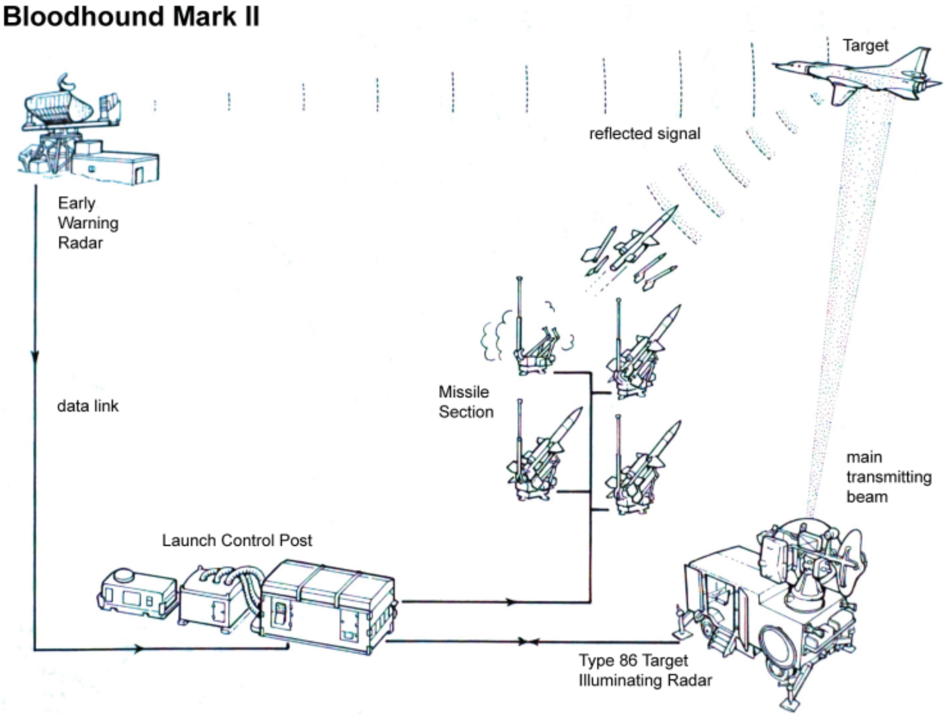

FIGURE 6 Bloodhound Mark 2 relied upon the doppler return from continuous wave radar reflected off an incoming target aircraft (copyright English Heritage).

Launch Control Post for the Mark 2 Bloodhound was undertaken by a Development team led by Frank Fensome who had early experience in radar receivers at Ferranti Edinburgh. Frank Fensome joined the receiver section of the guided weapons department at its inception in Moston in 1949. He went on to lead the ground equipment section in one role or another from 1954. He conceived the overall design of both the original Red Duster launch control and the uprated mobile launch control post for Bloodhound Mark 2, ‘Frank Fensome conceived the whole thing [. . .] from scratch. He then parcelled it out to three or four of us to develop our bits of it’.[88] The team for the Mark 2 Launch Control Post was a very small community of practice made up of, at most, five people. Keith Barker was given the related task of developing the simulator.[89] This community transcended the boundaries of task groups as Derek Whitehead was really part of a group working on servo control for the missile itself rather than the Launch Control Post.

Resistance to digital in the defence sector

Derek Whitehead was initially assigned a different task — making an analogue computer to solve fuel/range computations.

> I did a design and made a model, but because there were a lot of sites it seemed to me that this was going to be a hell of a job to build all these things and very expensive. It seemed to me to be the wrong way to do it.[90]

At that time, Derek Whitehead and John Waterworth went on a course to learn how to programme a digital computer at 21 Portland Place, the Ferranti Computers' office in London.

> Neither of us had done any programming before. In two weeks from a cold start we wrote a programme — I must admit we put some bloody hours in — we wrote a programme which took into account a squadron of Russian aircraft approaching from the east with missile sites in various places, predicting where the impact point was, building in the fuel/range coverage pattern which varies as a function of height, and when the predicted impact point came within the fuel/range coverage it gave a 'free to fire'. Much to our surprise and pleasure, and everybody else's surprise [...] it did work and it was startlingly good.[91]

So Derek Whitehead proposed the national Orange Yeoman surveillance radar system could also act as a digital computer-based centre for guided missile control for the UK. Derek took the idea of a system wide digital solution to the person responsible for military radars in England, Norman Alder at RRE.

> I was rather surprised I was able to get an interview with him because he was roughly equivalent to God [...] And I took all this stuff in and I must have spent all of five minutes with Norman Alder because he listened to what I had to say and then he said 'There is no place for digital computers in military systems and there never will be'.[92]

Whatever the official position, the idea of direct digital control of missile systems was out of the box.

'Maurice's Gizmo' and the need for accurate arithmetic

Derek Whitehead also faced the problem of directing the radar dish on the new Bloodhound Mark 2 Guided Missile which was to use continuous wave radar for guidance. The radar dish in the forebody of the missile was locked for launch (the missile was subject to some 30 g on take off) but had to point in the right direction as soon as it was unlocked. Remember there are perhaps only 30 seconds between unlock and hitting the target.[93] When the dish was unlocked in flight, two features were *crucial*: that the dish pointed in the right direction to find the target and the doppler gate was set to the right frequency. Recall that continuous wave radar meant the dish had to search for velocity, as well as the angle and range required for the first Bloodhound. Swift and accurate calculation was imperative to aim the dish after launch. The radar dish did not have the luxury of time to search for the incoming radar returns.

The radar on the missile is looking for a reflection. The aerial on the missile spins and forms a cone in space. The beam width at X band, that is to say 3 cm or 10,000 MHz, is about 1°. This gives a good signal when pointed in the right direction. But this is also a very narrow arc of sky. This incoming signal from the on-board aerial is crucial because it resolves to give a steering signal for the missile itself, both to track the target and to calculate a point of interception by working out the rate of change of the sight line angle, 'the sight line spin'. (The missile does not aim directly at the target, but at an interception point. The missile had proportional navigation which always steered towards a collision point.)

So the dish had to be set up to anticipate both the direction of the target and set the doppler gate. When the missile is on the ground, the doppler shift in the frequency of the signals reflected back from the illuminated target aircraft is known. But, once launched the missile will be travelling above Mach 2. So, when the dish unlocks, you have to anticipate both the speed of the target and the speed of the missile. You have to anticipate the doppler frequency of signals returned from the target at these relative speeds.

> We can calculate and *pre-set* [. . .] where the doppler gates will be at the end of the boost phase. *That's easy*. What's bloody difficult is pointing the dish in the right direction in space.[94]

This involves some fast and accurate trigonometry, to estimate the combined effect which could not be accomplished by analogue computation:

> So you got about four or five trigonometrical stages to get what the azimuth angle was and what the up-down angle was. And with the errors you could get in analogue terms at each of these stages I reckoned that there was no way that I could produce an analogue computer that would go out into the services field that would be accurate enough. I couldn't, I knew I couldn't, I knew I was beaten. Now, with the wisdom of hindsight which is granted to us all, that was probably the most important and valuable and worthwhile decision that I have ever made in my life, knowing that I couldn't do it.[95]

Derek Whitehead was a friend of Maurice Gribble. He followed what Maurice had been doing on digital control.

> Maurice Gribble was developing a gizmo. He developed for a demonstration for the Duke of Edinburgh a scheme whereby you could effectively have a thing in space and something there and something here and you could turn one of the knobs and it did some trigonometry and it would track the thing that was moving, digitally. *Wow*![96]

So Derek Whitehead and Peter Smith proposed to Bruce Calveley and then to Denis Best that the 'process control transistor computer' should be used for positioning the radar dish after launch on the Bloodhound Mark 2.[97] It is not clear when the Argus was adopted for the Launch Control Post, but surviving minutes suggest it was a possibility before the autumn of 1959.[98] Peter Smith and Stuart Thomas wrote the software. The Launch Control Post was also designed to be compact so that it could be air transportable. The size of the computer meant the Launch Control Post was a cramped space for the military operators. There was much relief when the Posts were later upgraded with more compact digital equipment.

Once it had been decided to fit a digital computer into the Launch Control Post, other tasks were added. At some stage the firing sequence came to be initiated from the computer. There was a further problem of crossing targets. When the target aircraft is almost at right angles, the doppler drops towards zero and is undetectable as you cannot measure low frequency returns.[99] The target disappears. So you need to pick up the target again once it has passed that point. The ground illuminating radar had a crude analogue servo for predicting a crossing target of this sort. But the Argus computer in the Launch Control Post was much better at predicting through this zero doppler point. The computer commanded scans if the zero doppler point was about to be reached in order to look for a reappearance of the signal. The longer the time without a signal, the bigger the scan. There was feedback from the computer to the illuminating radar. So using Argus on the Launch Control Post for Bloodhound Mark 2 not only solved a problem of accurate arithmetic but also left computation capacity for additional tasks.

Subsequent technical developments and learning to market Argus

Ferranti's Automation Division survived sale of the firm's mainframe computer business at Gorton to International Computers and Tabulators (ICT) in September 1963.[100] The Ferranti Argus series became a mainstay of process control computing, selling some 1263 units by May 1979 (Table 1), excluding many used on weapons systems. The computer evolved, switching from transistors to microcircuits. Over half the total sales were realized for variants of the final Argus 700 system.

The UK was a centre of process control innovation during the 1960s alongside the USA, playing a pioneering role in the automation of rolling mills, chemical plant and power stations.[101] By 1965, Ferranti's domestic rival, Elliott Automation, had 7 per cent of world sales of process control computers and by 1968 had become the *world*'s second largest supplier with total sales almost three times those of Ferranti (Table 2). So there was a strong potential market for Argus.

Growth in market share by Ferranti was the result of a learning process as the Automation Division appreciated it had to supply tailored systems to meet customer needs and become competitive on price. Ferranti was forced to learn how to market and support a product in cost-conscious civilian markets.[102] The Argus increased its share of the fast growing global market for process control computers from 1.8% in 1963, to 2.3% by 1965 and up to 4.1% by 1968 (Table 2) — the last year for which we have figures. This was despite new entry in the USA, Japan and Germany. Three breakthroughs enlarged the market for Ferranti — powerful lead users, stronger technical support and software development, and more aggressive pricing.

Evidence on the pricing policy for the Ferranti Argus is limited. Eli-Lily used direct digital control to run twenty fermenters at a new factory built by their subsidiary Dista Products, in Speke in Liverpool. Their engineer, John Thorley said:

> When establishing the plant we were told it had to be digitally controlled. We went to see an ICI plant at Fleetwood where a Ferranti computer controlled the valve actuators, but this was far too expensive for Dista Products.[103]

Dista turned to Elliott Automation.

The 200 and 100 model Argus computers were over-specified for a civilian use. They used military components and sockets designed to withstand extremes of temperature, shock and rough handling. Even the early 500 series had military specification power supply and gold plated connectors. There was a transition period in the late 1960s when, as one project engineer put it 'they had to stop thinking in military'.[104] Wiring diagrams went through the drawing office at Wythenshawe and emerged as neat blueprints. Yet it was his experience that American civilian process control computer maker GE used simple typed lists. Ferranti wiring was routed in neat trunking and cable runs. At GE in Phoenix wiring was wrapped 'point to

TABLE 1

SALES OF ARGUS COMPUTERS TO END 1979 BY TYPE AND CUSTOMER

Industry	Type and Model											Total
	Transistor			Microcircuit								
	200	100	300	400	500	600	700					
							E	T	S	F	G	
Chemical[a]	1	5		2	17		2			1	2	30
Oil (including offshore)					13		8		14		8	43
Process					6	5		1				12
Manufacturing[b]			3	12	21	54	74	7	2	18	25	216
Steel Industry		4	1	1	24	1	19		32	6	8	96
Public Utilities	2	1		4	27		21	34	17	23	13	142
Extractive[c]		1		2	1							4
Paper & Print				2		2	1					5
Distribution					3	4						7
Commerce				3	2	4	2	47			2	60
Transport			2	62	4		6	53	9	4	5	145
Communication					16		34		2		9	61
Public Service				3	8		29	21		10	2	73
University & Research		2	2	17	22	13	11	3	3	4	8	85
Software Houses							4		6	4	14	28
Printing and Typesetting CS7					2			1		5	8	16
Civilian	3	13	8	108	166	83	211	167	85	75	104	1023
Military	*60* *(Bloodhound?)*	1	14	1	29		22		8		6	141
'Wythenshawe'			3	14	41	12	8	12	3			93
Service						6 loan						6
Total	63	14	25	123	236	101	241	179	96	75	110	1263

SOURCE: Ferranti Limited, Wythenshawe Division, List of Principal Argus Computer Installations, Excluding Military Sales, May 1979, p. 2 (John Rylands University Library, Manchester).

NOTES: a — includes BP chemicals which might otherwise be classified under oil.
b — includes aluminium foil mills which might be classified as 'metals' alongside steel.
c — includes cement manufacture.

point' — a 'rats nest', but cheap to assemble. The American competition provided more cost-effective design and assembly techniques for civilian applications.

Around 1970, Ferranti seem to have revised their pricing policy, winning the project at the British Steel Corporation Llanwern Scheme 'C' blast furnace in 1971 on price against competition from IBM, Honeywell and GEC helped by a strong reference list in South Africa.[105] Ferranti also benefitted from customer lock-in. Machine specific

TABLE 2

MARKET SHARE IN PROCESS CONTROL COMPUTERS, 1968

	Total installed July 1968		
	Manufacturer/Supplier	Number sold	Market share
1.	General Electric (GE/PAC)	326	11%
2.	English Electric (Elliott)	307	11%
3.	IBM	270	9%
4.	Westinghouse (PRODAC)	240	8%
5.	Scientific Data Systems (SDS/Sigma)	216	7%
6.	Honeywell CCD	195	7%
7.	GEC-AEI	145	5%
8	Ferranti	119	4%
9	Systems Engineering Labs	119	4%
10	Digital Equipment (DEC PDP)	117	4%
11	Siemens	115	4%
12	Bunker-Ramo[a]	91	3%
13	Bailey Meter	74	3%
14	Toshiba (TOSBAC)	48	2%
15	Hitachi (HITAC, HICOM, HIDAC)	45	2%
16	Control Data	43	1%
17	Leeds and Northrup	40	1%
18	Foxboro	38	1%
Others		342	
Total Installations Worldwide		2,890	

SOURCES: 'A staff survey: On-line computer scorecard updated', *Control Engineering*, 15.7 (1968), 79–90, table 1.
NOTE: a — Some Bunker-Ramo machines may have been reassigned to GE.

programming skills reinforced their hold over customers such as the British Steel Corporation and the nuclear power industry. These organizations had large in-house R&D departments with staff who could adapt the hardware to their needs or had Automation Development Departments specifically tasked with computer development.[106]

Ferranti began to sell complete packages of technology, notably in airline reservations for BOAC. In 1967 they integrated their knowledge of cathode ray tubes for electronic displays with their process control expertise to win the BOADICEA contract for a seat reservation system for the airline BOAC. This alone resulted in a first order for 51 Argus 400B computers delivered during 1968 and 1969. Here too a small, enthusiastic community of practitioners clinched the deal. Sales of four Argus 500 computers to Esso led to the development of a control software language called Consul (Control Subroutine Language) applicable to any process industry. By 1968, Ferranti were selling a cut-down system Consul B which ran in core store on an Argus computer. Core storage was far more reliable than a disc system. Software was the missing part of the process control package for Ferranti. Writing bespoke software every time was 'fraught and time consuming' for both Ferranti and their customer.[107]

Conclusions

The Ferranti Argus computer was invented by Maurice Gribble working in the automation division of Ferranti at Wythenshawe. He built a digital computer using hearing aid transistors to control the Blue Envoy command guidance surface to air missile. While the missile was cancelled, rapid development of the computer led to a prototype for civilian use which was displayed at a trade exhibition in London in November 1958 under the name the 'Ferranti process control transistor computer'. At the time, Ferranti's rivals were persisting with analogue computers. The commercial product was developed with the name Argus 200 both as a computer for civilian process control and as part of a military cold-war missile guidance system. The chemical firm ICI was a crucial civilian lead user. The deployment of Argus for defence purposes was due to a presumptive anomaly — potential shortcomings in use of analogue computation for control of the radar dish on the new Bloodhound Mark 2 missile. Personal friendship led Derek Whitehead to propose accurate digital calculation for the complex trigonometry required, despite opposition from RRE to any digital schemes.

The paper tracks the way in which the computer was conceived, how it was developed in military and civilian contexts by small communities of practice, how these groups coalesced, grew and dispersed, and then shrunk to a handful of people as projects became routine (Figure 7). One community of practice emerged around the Bloodhound Mark 2 Launch control post and another around software and instrumentation for an ICI soda ash plant. Ferranti Automation Division learned to market and support a novel product in cost-conscious civilian markets.

This account of development at Ferranti draws on interviews with the Argus inventor, engineers, builders, programmers and users. This approach gives a different perspective on the history of engineering and technology. Here we look at individuals working as designers, developers, problem solvers and troubleshooters, in small communities of practice characterized by group cohesion, easy exchange of technical ideas and a certain amount of gossip and scandal. These communities were ideal ways to share experience and tacit knowledge about the problem in hand. This practical focus downplays the role of senior managers and government officials. Rather, the computer emerges among gifted designers and practitioners, helped along by a certain amount of bootlegging, a great deal of engineering verve and enthusiasm, and some gifted women programmers. The focus of this narrative stands in contrast to archive-based treatments of computer history which emphasize the role of senior managers and government R&D institutions.

In a wider context, development of Argus is an example of Cold War technology development which defies simple notions such as 'spin out'. The computer was, at the same time, part of a secret weapons system as well as the focus of a group of civilian users who led adoption of Argus for process control. Official secrecy allowed free exchange of ideas among those with security clearance. As personnel moved from military to civilian applications, wider overlapping communities of practice emerged

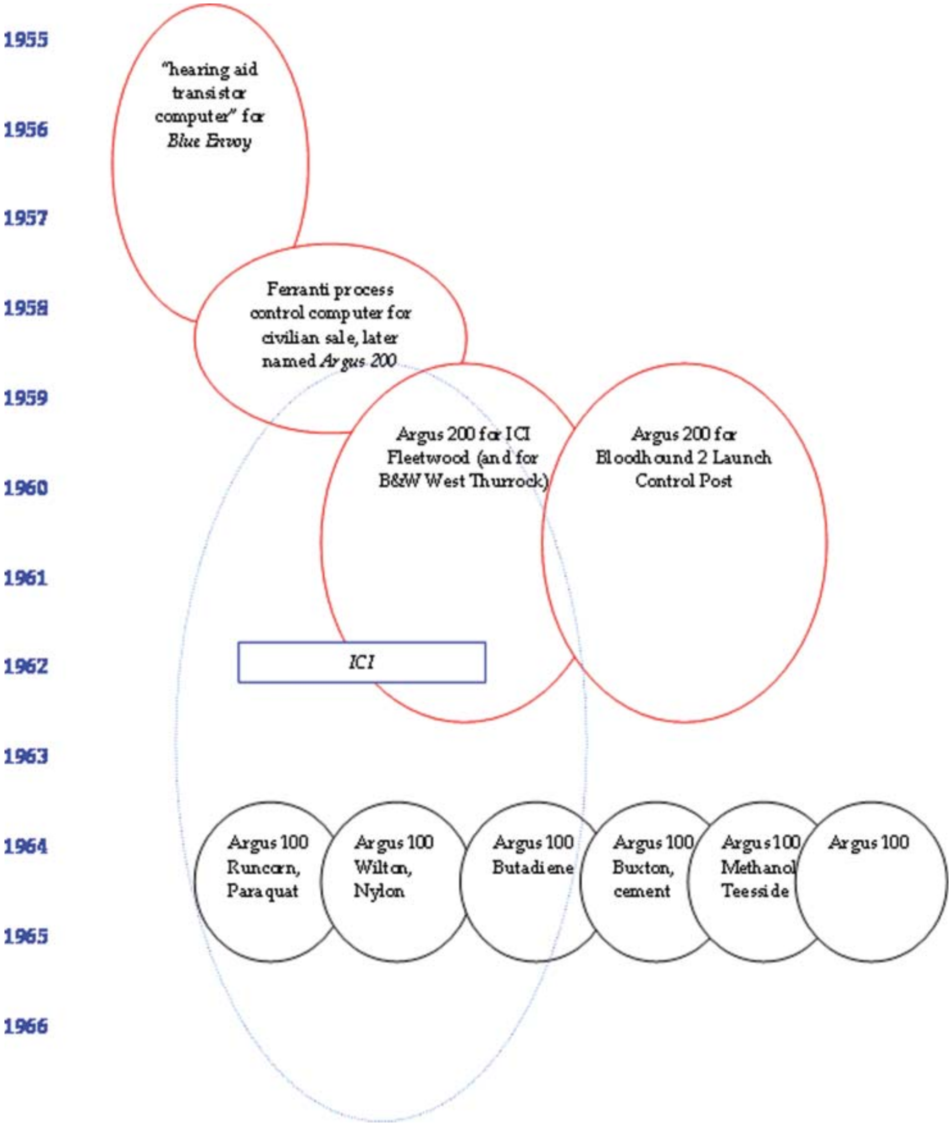

FIGURE 7 Communities of practice surrounding the development of the Ferranti Argus computer.

around software and instrumentation for the Argus. Simultaneously, Argus was both part of the closed world of Cold War weaponry and at the centre of an open network of innovators.

Acknowledgements and data sources

This paper draws on interviews with twenty-three people involved in the development path towards Argus and Bloodhound, focussing on their tacit knowledge and links between those involved. These respondents cherish many unpublished reports and memoranda.

The author is deeply indebted to participants in the development process at Ferranti, ICI and the RAF who gave their time and help. Particular thanks are due to two people: Maurice Gribble who was tireless and a tremendous help across three interviews. Derek Whitehead inspired the paper with the remark 'you had better come and talk to me' and gave extensive and colourful advice over four years. In addition, Fred Axon, Keith Barker, Humphrey Bowen, Bruce Calveley, W. F. Cartwright, Peter Collins, Albert Dodd, Audrey and Syd Evans, Alan Foss, Peter Hall of ICL, Roger Houghton, Derek Hughes, Emily Innes, Tom Lunt, Scilla and Dave Senior, Jean Shaoul, John Thorley, Mark Walker and Peter Wolstenholme all responded patiently to questions.

The paper has been strengthened by advice and corrections from sometime rocket scientist Dr Frank Fitzgerald; control pioneer Crawford MacKeand; Professors Simon Lavington, Peter Hall and Philippe Laredo; author Chris Gibson and participants at conferences on 'Technological Innovation and the Cold War' at the Hagley Museum and Library, Wilmington, Delaware, March 2007; the British Society for the History of Science, Manchester, June 2007; the Department of International Studies, Padua, June 2008; a joint meeting of the Newcomen Society, Computer Conservation Society and IET, Manchester October 2010; and a workshop in 2011 with colleagues Mike Pryce and Etienne Wenger.

Warm thanks are due to John Blewett at Catalyst, Widnes; Fleetwood Museum; Fleetwood Library; the Imperial War Museum, Duxford; the Public Record Office, Kew and the Ferranti Pension Fund.

Notes

1 W. Brian Arthur, *The Nature of Technology: What It Is and How it Evolves* (London: Allen Lane, 2009), p. 126.

2 The key exception is an account of Ferranti Automation's leading competitor, Simon Lavington, *Moving Targets: Elliott-Automation and the Dawn of the Computer Age in Britain, 1947–67* (London: Springer-Verlag, 2011). For the decline thesis see John Hendry, *Innovating for Failure: Government Policy and the Early British Computer Industry* (Cambridge, Mass.: MIT Press, 1989).

3 Thomas Stout and Theodore J. Williams, 'Pioneering Work in the Field of Computer Process Control', *IEEE Annals of the History of Computing*, 17.1 (1995), pp. 6–18; Jonathan Aylen, 'Megabytes for Metals: The Development of Computer Applications in the Iron and Steel Industry', *Ironmaking and Steelmaking*, 31.6 (2004), pp. 465–78; Jonathan Aylen, 'Promoting the Prosaic: The Case for Process-Control Computers', *IEEE Annals of the History of Computing*, 32.3 (2010), pp. 94–96.

4 Ernst Braun and Stuart Macdonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, 2nd edn (Cambridge: Cambridge University Press, 1982); E. W. Pugh, *Memories that Shaped an Industry: Decisions Leading to IBM System/360* (Cambridge, Mass.: MIT Press, 1984).

5 John F. Wilson, *Ferranti: A History, Building a Family Business, 1882–1975* (Lancaster: Carnegie Publishing, 2000) and John F. Wilson, *Ferranti: A History, Volume 2, From Family Firm to Multinational Company, 1975–1987* (Lancaster: Crucible Books, 2007). On broader issues such as the dominance of engineers in aerospace and dependence of the industry on the State see: David Edgerton, *England and the Aeroplane: An Essay on a Militant and Technological Nation* (Macmillan, 1991).

6 Stephen Twigge, 'Ground-based air defence and ABM systems', ch. 4 in *Cold War Hot Science: Applied Research in Britain's Defence Laboratories 1945–1990*, ed. by Robert Bud and Philip Gummett (London: Science Museum, 1999).

7 Wayne D. Cocroft and Roger J. C. Thomas, *Cold War: Building for Nuclear Confrontation 1946–1989*, ed. by P. S. Barnwell (Swindon: English Heritage, 2003), p. 173.

8 Ferranti, Museum of Science and Industry Archives, Manchester, File 1996.10/2/3/311, folder marked 'Bloodhound'. Correspondence relating to South African purchase enquiries, 1969.

9 The 'Red Heathen' specification, Operational Requirement OR.1124 that led to 'Red Shoes' for the Army (Thunderbird from English Electric) and 'Red Duster' (Bloodhound Mark 1 from Bristol and Ferranti.) Public Record Office, Kew, London. Also see AVIA 13/1285 Ministry of Supply, Guided Weapons Department, 'Red Duster Development and Proposals — Missile', original file number GWS\1238\1\1 Part 1, Feb 1958 to Dec 1959; AIR20/10554 Air Ministry, 'Air Defence S.A.G.W. Future Policy (Development of Bloodhound and MK2)' Runs from 20 May 1958 to 7 March 1963; DEFE7/1338 Ministry of Defence, 'RAF Production Programmes, Guided Weapons, Bloodhound'. Original File no. T.S.95/03/0311/59 Annex 'D'; T225/2488 Treasury Part A, Guided Weapons Research and Development Contracts 'Bloodhound Mk II' (S.A.G.W.) Runs from 4 April 1960 to 14 January 1964.

10 Twigge, p. 91; Cocroft, ch. 7.

11 The fuze (*sic*) was a small pulsed radar proximity device just behind the nose cone. (Interview with Mark Walker, former Launch Control Post Technician, A Flight, 85 Squadron, RAF West Raynham, 10 January 2008, London.) This so-called 'pranger fuze' was developed by Brian Jackson of EMI to replace a previous design based on continuous wave radar which proved temperamental (interview with Derek Whitehead, Cheadle, 15 February 2011).

12 The alternative is a Cartesian monoplane with fixed wings and elevators and ailerons on the tail, like the rival English Electric Thunderbird. D. J. Farrar, 'The Bloodhound', *Journal of the Royal Aeronautical Society*, 63 (January 1959), 35–50; also see <http://www.radarpages.co.uk/mob/bloodhound/boodhound1.htm> [downloaded 23 November 2006].

13 J. M. Hallett, 'Biplanes to Bloodhounds', *The Ferranti Journal*, 17.1 (1959), pp. 2–5.

14 Ferranti Defence Systems, *Type 86 Target Illuminating Radar for Bloodhound MKII Missile: The First 25 Years*, transcript of presentation given in 1987 supplied by Imperial War Museum, Duxford, Bloodhound Object File.

15 E. Lloyd Thomas, 'Analogue Computation', *British Communication and Electronics*, 5.5 (1958), pp. 348–58.

16 T. E. Ivall, *Electronic Computers: Principles and Applications*, 2nd edn (London: Iliffe and Sons, 1960), ch. 6 'applications of analogue computers'; James S. Small, *The Analogue Alternative: The Electronic Analogue Computer in Britain and the USA, 1930–1975* (London: Routledge, 2001), ch. 6, 'The Origins, Commercialisation and Decline of Electronic Analogue and Hybrid Computing in Britain, 1945–1975'.

17 I. N. Cartmell and R. W. Williams, 'Guided Weapon Simulators', *The Aeronautical Journal*, 72.688 (April 1968), 356–60; interview with Audrey Evans, former Laboratory Technician, Simulation Department, Ferranti, 25 November 2010, Cumbria.

18 A. G. Biggs and A. R. Cawthorne, 'Bloodhound Missile Evaluation', *Journal of the Royal Aeronautical Society*, 66 (September 1962), pp. 571–85.

19 Professor R. W. Williams speaking about the Guided Weapons Group at English Electric, Luton in Cartmell and Williams, p. 357. On building an analogue computer see: Granino A. Korn and Theresa M. Korn, *Electronic Analog Computers (D-c Analog Computers)*, 2nd edn (New York: McGraw-Hill, 1956).

20 'Electronic Computer Exhibition', *Process Control and Automation*, 5.11 (1958), pp. 487–96.

21 Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: The John Hopkins University Press, 1990).

Engineering does not always work in this neat evolutionary way: there is a role for intuition, informed technical judgement, aesthetic considerations and elegant solutions in deciding what works best.

22 Brian Johnson, *The Secret War* (London: BBC Publications, 1978), ch. 2, 'Radar'; Anthony Gandy, 'The Entry of Established Electronics Companies into the Early Computer Industry in the UK and USA' (PhD thesis, London School of Economics and Political Science, awarded 1993).

23 Peter Hall, 'West Gorton and all that', lecture to the Computer Conservation Society, Manchester: Museum of Science and Industry, 21 November 2006; see also Simon Lavington, *Early British Computers: The Story of Vintage Computers and the People who Built Them* (Manchester University Press, 1980), ch. 7, 'The Manchester Mark 1'.

24 Simon Lavington, *The Pegasus Story: A History of a Vintage British Computer* (London: Science Museum, 2000).

25 D. G. Owen, *Computers and Steel* (London: British Iron and Steel Research Association, 1957); Tata Steel UK, Shotton Records Centre, department 378, consignment 4, box 8, location 041425, file 'Computers 1957/59'; Lavington, *The Pegasus Story*, table 4.3.

26 A point explored during interviews to the point of tedium.

27 Tom Lunt proudly said they had a 'first class team for computer control of the Bloodhound missile'. Interview with Dr Tom Lunt, former personnel director, Ferranti Ltd, 7 October 2003, Manchester.

28 Interview with Maurice Gribble, designer of Argus, 28 January 2011, Gwent. Quotes from Maurice Gribble draw on phone interviews, two day-long conversations with the inventor in Gwent and e-mail exchanges. Radio Hams played a central role in early computer development, see for instance Christophe Lécuyer, *Making Silicon Valley: Innovation and the Growth of High Tech, 1930–1970* (Cambridge, Mass.: MIT Press, 2006), ch. 1. Arnold Spielberg, designer of the GE412 process control computer, was another radio ham, see Joseph McBride, *Steven Spielberg: A Biography* (London: Faber and Faber, 1997), ch. 1.

29 Interview with Maurice Gribble, 14 March 2008, Gwent.

30 Chris Gibson, 'Blue Envoy's Peaceful Legacy', *Prospero, Proceedings from the British Rocket Oral History Conferences at Charterhouse*, 2 (Spring 2005), 65–78. Also S. R. Twigge, 'The Early Development of Guided Weapons in the United Kingdom' (PhD thesis, University of Manchester, awarded 1990, Joule Library, University of Manchester Thesis TH16433), pp. 497 and 500. The USAF surface to air Bomarc B guided missiles carried nuclear warheads. Part of the thinking was that a high flux of neutrons from a low yield atomic explosion would 'poison' an incoming hydrogen warhead through the R-1 effect, thereby reducing the yield if the bomb was detonated.

31 Cancellation of Blue Envoy is said to have prompted the design of Bloodhound Mark 2 in a London taxi outside Ferranti's head office by David Farrar, Taffy Higgenson and Don Rowley. See A. R. Adams, *Good Company, The Story of the Guided Weapons Division of British Aircraft Corporation* (Stevenage, Herts: British Aircraft Corporation, 1976), p. 55. Adams credits Norman Searby of Ferranti with lobbying for the acceptance of Bloodhound Mark 2.

32 Fred P. Adler, 'Information Theory and Missile Guidance', ch. 6 in Allen E. Puckett and Simon Ramo (eds), *Guided Missile Engineering* (New York: McGraw-Hill, 1959). This edited book is an essential source for those wishing to understand early surface to air missile design.

33 I owe this recondite truth to interviews with Derek Whitehead, 12 February 2008, Cheadle and 14 May 2008, Manchester. Ballistic missiles face a similar problem of varying gravitational pull, see Donald A. MacKenzie, *Inventing Accuracy: An Historical Sociology of Nuclear Missile Guidance* (Cambridge, Mass.: MIT Press 1990). For solutions, see John M. Wuerth, 'Principles of Missile Navigation', ch. 7 in Puckett and Ramo.

34 M. W. Gribble, 'The Argus Computer and Process Control', *Resurrection*, 20 (Summer 1998), pp. 20–29.

35 Gribble interview, 14 March 2008, Gwent. On the prevalence of individual or covert research work see Peter Augsdorfer, *Forbidden Fruit: An Analysis of Bootlegging, Uncertainty and Learning in Corporate R&D* (Aldershot, Hants.: Avebury, 1996).

36 Braun and Macdonald, ch. 4 'The Bell Laboratories'; Lavington, *Early British Computers*, ch. 9 'Transistor Computers'.

37 The hearing aid transistor computer was belatedly written up in D. M. Butler, 'Technical Memorandum: Command Guidance Two Dimensional Digital Computer', Ferranti, Wythenshawe, Secret, mimeo, 14 October 1958, document CG/26 WY73/14/JL (author's collection). The title 'Command Guidance Two Dimensional Digital Computer' seems to have been an opportune renaming for budgetary purposes in 1958. It was referred to as the 'hearing aid transistor computer' in all interviews.

38 Maurice Gribble was right to bet on the improvement potential of junction transistors. New transistors were devised to handle higher and higher frequencies and speeds around 500 *MHz* were to become commonplace by the early 1960s. Braun and Macdonald, ch. 7.

39 Email exchange between Maurice Gribble and the author, 20 January 2011.

40 Gribble interview, 14 March 2008, Gwent. A flip-flop is a simple circuit where an external electric current will cause it to 'flip-flop' from one conducting state to another. In that fashion the circuit can store binary information. A series of these circuits can be used to count. Two changes in the state of the first flip-flop induce a change in the state of the second flip-flop. In turn, two changes in the second induce a change in the third and so on to the end of the circuit. Addition is just counting and multiplication can be done by successive addition. So a flip-flop is a basic building block of computation.

41 Cyclic progressive codes are discussed by Gribble, 'The Argus Computer'. Also see F. G. Heath and M. W. Gribble, *Chain Codes and their Electronic Applications*, IEE Monograph no. 392M (July 1960).

42 Maurice Gribble thought it was perhaps '*the first computer to control something*'. Arguably the first computer to control a commercial process was fitted to a reversing roughing mill for steel slabs on the continuous hot strip mill at the Aliquippa works of Jones & Laughlin in the USA. This had three distinctive features: use of digital control; storage of the rolling schedule in a memory; and the first use of transistors in steel industry operations. Westinghouse Electric were responsible for both drive motors and the PRODAC computer control system. See A. W. Smith: 'Card Programmed Control System Applied to Hot Strip Reversing Roughing Mill', *Iron and Steel Engineer*, 33.10 (1956), pp. 164–65. The market for process control computers was developed in the USA by another guided weapons developer, Ramo-Wooldridge (variously known as Thompson-Ramo-Wooldridge and then Bunker Ramo.) Ramo-Wooldridge announced the first computer specifically designed for industrial process control — the RW300 — in September 1957, fourteen months ahead of Ferranti (see 'Bunker-Ramo Dropping Process Control Computers', *Control Engineering*, 12.6 (June 1965), p. 22.) In January 1958, the Texas Oil Company announced the purchase of a RW 300 to help control its polymerization process at Port Arthur, Texas which went on-line in April 1959 (ISA, *The Computer Control Pioneers: A History of the Innovators and their Work* (North Carolina, Research Triangle Park: Instrument Society of America, 1992), ch. 2). But this did not achieve complete digital control of the sort pioneered by ICI Fleetwood.

43 The idea of command guidance did not go away. There is extensive discussion in the Public Record Office about development of a Bloodhound Mark 3 command guidance missile to be fitted with a nuclear warhead called 'Tony' which was cancelled in January 1960. This was intended for defensive anti-aircraft use (see DEFE7/1338; AVIA 13/1285 and AIR 20/10554). At one stage Bloodhound 3 was also considered as a tactical surface-to-surface nuclear missile to be developed in collaboration with the French (see T225/2488).

44 Disruption to tea breaks and keeping up appearances were major concerns relating to the Royal visit. Dr N. H. Searby requested

'all sections, whether on the Prince's route or not, will remain (ostensibly at least) at their work [. . .] to give the best possible impression', 'Canteen Arrangements, 22.11.57', Ferranti Wythenshawe, typescript, 15 November 1957.

45 Gribble, 'The Argus Computer'; Lunt interview, 7 October 2003, Manchester.

46 Ferranti Limited, Computer Department, *The Ferranti Process Control Transistor Computer* (West Gorton, Manchester and Portland Place, London: Ferranti Ltd, Computer Department, November 1958), Temporary list DC. 39 (St George's Library, University of Sheffield). This temporary sales pamphlet is the only place where a Gorton address appears on an Argus publication.

47 *Process Control*, p. 492.

48 J. Tippett, A. Whitwell and L. H. Fielder, 'Controlling Megawatts in Steelmaking', *Control Engineering*, 12.6 (1965), pp. 68–70; Roger Houghton, interview with former programmer at Steel, Peech and Tozer, 18 August 2010, Tabley, Cheshire; Dr Humphry Bowen, Discussion with former ICI Engineer, Winnington, 10 January 2008, Surrey; Ferranti, *List of Principal Argus Computer Installations, Excluding Military Sales* (Manchester: Ferranti Limited, Wythenshawe Division, catalogue C31, May 1979) (National Archive for the History of Computing, John Rylands Library, University of Manchester). Numbering of Argus models is confusing. The initial Argus became the Argus 200 when the Argus 100 was launched. Technical documentation distinguishes between various sub-models of the 100 series: the Introduction to ch. 4 'Core Store' of a Ferranti manual explains helpfully: 'Computers of the Argus 100 series may have one, two or three core store units. Such computers are designated Type 104, 108 and 1012, respectively, since their combined storage for program and data is approximately 4000 words per core store unit' (p. 4.1); see Ferranti, *Argus Mobile Process — Control Computer I.C.I. Ltd. Argus 104* (Ferranti Limited, Wythenshawe, 1964), file 1996.6/3/18, Museum of Science and Industry, Manchester.

49 Ferranti Limited, *Argus Programming Manual* (February 1962), code number WY54/E6 published at: Automatic Control Division, Shadowmoss Road, Wythenshawe, Manchester, 22 and London Computer Centre, 68–71 Newman Street, London W1 (Ferranti Pension Fund Collection, Ringway, Manchester).

50 Gribble, email exchange, 2011.

51 Pugh.

52 M. W. Gribble, '"Argus" Pegboard Stores Program in Ferrite Plugs', *Control Engineering*, 8.1 (1961), p. 123.

53 Gribble, email exchange, 2011. The patents were Maurice Woolmer Gribble and David Rushton, 'Improvements relating to Information Storage Devices', *GB Patent 868,775*, application 17 March 1959 (published 25 May 1961); Maurice Woolmer Gribble and David Rushton, 'Information Storage Devices', *US Patent 3,061,821*, patented 30 October 1962.

54 See A. Thompson, 'Operating Experience with Direct Digital Control', in Instrument Society of America, *Digital Computer Applications to Process Control* (New York: Plenum Press, 1965), pp. 55–78 at p. 58.

55 Derek Whitehead blames another member of the Launch Control Post team, Dave Shanks for the prank (interview 2 June 2010.) The heat of a ship's cargo hold in the Red Sea led to a switch to metal covers as the plastic covers buckled at high temperatures (interview with Peter Wolstenholme, 4 February 2011, Prestbury, Cheshire).

56 Walker interview, 10 January 2008, London.

57 Gribble, email exchange, 2011.

58 Interview with Sydney Evans, former Project Engineer, Ferranti Automation, 25 November 2010, Cumbria; Ferranti, Wythenshawe, 'Minutes of Commercial Progress Meeting held on Monday, 13 November 1961', circulated by Dr C. M. Cundall, item 1.

59 Bowen discussion, 10 January 2008, Surrey, and Houghton interview, 18 August 2010, Tabley. Maurice Gribble suggested the Pegasus code was used on Argus to please Babcock and Wilcox as a lead customer. The original process control transistor computer used a code that Maurice invented (interview, 14 March 2008, Gwent).

60 On setbacks, cussing and swearing associated with technical development see Philip Scranton, 'Technology-Led Innovation: The Non-Linearity of US Jet Propulsion Development', *History and Technology*, 22.4 (2006), pp. 337–67.

61 Wolstenholme interview, 4 February 2011, Prestbury.

62 The high level of military reliability was appreciated in an industrial setting. Writing about the Ferranti Argus series, Corbett (p. 5) speaks of 'the impeccable reliability of core RAM based process computer systems in 1969' (Brian Corbett, 'The First Thirty Years of Digital Control at Port Talbot Steelworks', paper presented to The Institution of Engineering and Technology 34th Annual History Weekend Meeting, University of Swansea, 7–9 July 2006.) This is borne out by 99.6% availability for the Argus 200 at Fleetwood. Rivals GE achieved similar remarkably high levels of reliability too (Aylen, 'Megabytes for Metals', p. 471). High levels of availability were one feature of the defence inspired dominant design of process control computers in the 1960s.

63 Fred Axon, Discussion with former Bloodhound circuit engineer at Hawker-Siddeley, Salford, 24 February 2007.

64 Stephen J. Whitfield, *The Culture of the Cold War*, 2nd edn (Baltimore: The John Hopkins University Press, 1966), p. 74.

65 Maurice Gribble, *Computer Notes*, manuscript, Ferranti Pension Fund Collection, Ringway, Manchester.

66 Evans interview, 25 November 2010, Cumbria; Thompson, 'Operating Experience'; C. S. Evans and T. H. Gossling, *Digital Control of a Chemical Plant*, mimeo manuscript (Wythenshawe: Ferranti Ltd, *c.* 1965) (Cumbria); Ferranti Limited Automatic Control Division, Wythenshawe, *Argus Project Report No. 1, Digital Computer Control of an I.C.I. Plant at Fleetwood*, mimeo (*c.* 1963). The Argus 200 was later moved to another soda ash plant at Winnington, Cheshire and subsequently acquired by the Science Museum, London who keep it in store.

67 Discussion with Crawford MacKeand, former Project Engineer ICI, Wilmington, Delaware, USA, 9 March 2007.

68 Edward W. Constant, *The Origins of the Turbojet Revolution* (Baltimore: The John Hopkins University Press, 1980); Etienne Wenger, *Communities of Practice: Learning, Meaning and Identity* (Cambridge: Cambridge University Press, 1998); A. Delemarle and P. Larédo, 'Breakthrough Innovation and the Shaping of New Markets: The Role of Communities of Practice', in Ash Amin and Joanne Roberts (eds), *Community, Economic Creativity and Organization* (Oxford University Press, 2008).

69 Interview with Keith Barker, 4 February 2011, Prestbury, Cheshire. Speaking of Fleetwood he added: 'We were all scared to death it wouldn't work'.

70 A. R. Legard, J. S. Hunter and A. Thompson, 'Imperial Chemical Industries, Alkali Division, Notes on a Visit to America', internal ICI Report, 8 February 1957 (private collection, Surrey).

71 Interview with Dr Humphrey Bowen, formerly of ICI Alkali Division, Winnington, Cheshire, 22 February 2008, Leatherhead, Surrey.

72 Telephone interview with Maurice Gribble, 23 February 2008.

73 Interview with Derek Hughes, former Electrician at Fleetwood Soda Ash Plant of ICI, 27 January 2011, Fleetwood; additional information from email correspondence with Crawford MacKeand, May 2010.

74 Evans interview, 25 November 2010, Cumbria.

75 Thompson, 'Operating Experience', p. 67.

76 Hughes interview, 27 January 2011, Fleetwood.

77 Email exchange with Humphrey Bowen, January 2011.

78 W. H. Wilson, *Paraquat — Notes on Future Development Programme Following a Discussion at Fernhurst 9th April 1962*, Imperial Chemical Industries Limited, General Chemicals Division, Development Department, Note No. 1939, 19 April 1962, archives Catalyst, Widnes.

79 J. S. Smith, *Imperial Chemical Industries Limited, Mond Division, Pilkington-Sullivan Works, No. 2 Paraquat Plant, The Paraquat Plant Computer from the Viewpoint of the Plant Manager*, internal

ICI report, 26 February 1968; A. N. A. Dicken and J. S. Smith, *The Development of a Process Optimisation Procedure for a New Paraquat Plant*, internal ICI paper, Mond Division, Research Department/Mathematics Group, Symposium on On-Line Process Optimisation, Billingham, 23/24 September 1965, both private collection, Leatherhead, Surrey.

80 Smith, *Imperial Chemical Industries Limited*.

81 Interview with Scilla Senior (*née* Bretscher), Herefordshire, Wednesday 5 January 2011. She modestly argued Ferranti recruited female programmers because they were cheaper, but there was a tradition of recruiting female programmers. Personnel policies at Ferranti were hardly enlightened but there was early implementation of equal pay (interviews with Jean Shaoul, Manchester, 12 February 2008 and Emily Innes, former personnel manager, Ferranti Automation, Manchester, 19 February 2008). The No. 2 Paraquat plant at Widnes was not the only example where women programmers assumed awesome responsibility for development. The ICI Nylon plant at Wilton was programmed by Shirley Mitchell working with Roger Wilde as engineer.

82 Smith, *Imperial Chemical Industries Limited*. The upgraded Argus survives in the Catalyst Museum store.

83 For instance, in Wilson, *Ferranti: A History, Building a Family Business*, p. 429, he claims 'This move was one of the era's most celebrated adaptations of a military technology to civilian use, because in converting the computer employed in the Bloodhound launch control post into a machine capable of controlling real-time processes [Ferranti] established the basis of a business which expanded rapidly over the following twenty years' which simplifies the complex route by which a computer designed for Blue Envoy found its way into civilian use and thence into Bloodhound Mark 2.

84 Discussion with Derek Whitehead, 14 May 2008, University of Manchester.

85 Constant, pp. 15–16.

86 Hughes notion of a 'reverse salient' refers to an area where the advance of technology had fallen behind the broad line of progress. See Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: John Hopkins University Press, 1983), pp. 79–80. The point is that analogue had reached its limits in terms of accuracy and expense.

87 The 'Fuze', which used conventional pulse radar, would only detect the target itself and detonate the charge when it got into very close range. Walker interview, 10 January 2008, London.

88 Discussion with Derek Whitehead, 1 February 2011, Heald Green; Correspondence from Mrs Jean Fensome, 12 January 2011.

89 Barker interview, 4 February 2011, Prestbury.

90 Discussion with Derek Whitehead, 15 February 2008, Stockport. On the complexity of range equations see Allen E. Puckett, 'Aerodynamics of guided missiles' in Puckett and Ramo, ch. 2.

91 Whitehead discussion, 15 February 2008, Stockport. Also interview with Dave Senior, former project engineer Ferranti Automation, Herefordshire, 5 January 2011 who attended the same course.

92 Whitehead discussion, 15 February 2008, Stockport — edited to spare Derek Whitehead's blushes. Derek Whitehead had not heard of the American SAGE air defence system being developed along similar lines at the time. If Norman Alder was aware of what was going on with allies in the USA, he clearly did not approve! See Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (London: MIT Press, 1996); Kent G. Redmond and Thomas M. Smith, *From Whirlwind to Mitre: The R&D Story of the SAGE Air Defense Computer* (Cambridge: MIT Press, 2000).

93 The Mark 2 variant of Bloodhound was designed to also work against low-level targets and at ranges as short as 6.9 miles, so speed of computation was a key issue (Gribble interview, 28 January 2011, Gwent).

94 Whitehead discussion, 15 February 2008, Stockport. For a discussion of these principles with crucial details omitted — presumably for security reasons — see Renne S. Julian, 'Radar', in Puckett and Ramo, ch. 13.

95 Ibid. (Whitehead).

96 Ibid. (Whitehead).

97 Interview with Bruce Calveley, former project manager Bloodhound ground installations, Handforth, Cheshire, 11 August 2010.

98 Ferranti, Wythenshawe, *Minutes of Ground Equipment Progress Meeting Held on Monday 21st September, 1959*, circulated by Mr F. Fensome; however, Peter Wolstenholme in his interview (4 February 2011, Prestbury) recalls an early presentation to staff in the cinema at Wythenshawe which suggested the radar dish of Bloodhound 2 would be controlled by 'a huge mass of (analogue) synchro resolvers'.

99 Interview with Dr Bill Penley, former head of UK Military Electronics Development, Dorset, 25 March 2008.

100 G. Tweedale, 'A Manchester Computer Pioneer: Ferranti in Retrospect', *IEEE Annals of the History of Computing*, 15.3 (1993), 37–43; Martin Campbell-Kelly, *ICL: A Business and Technical History* (Oxford: Clarendon Press, 1989).

101 Aylen.

102 Lunt in his interview (7 October 2003, Manchester) said 'Marketing and sales were not in their make-up'. Similarly, Keith Barker joined Honeywell from Ferranti Automation and felt the American firm was 1½ years behind Ferranti technically, but they made money.

103 Discussion with Eur Ing John F. Thorley, 6 October 2004, Old Trafford, Manchester and follow-up correspondence. It is apocryphal that the Elliott watchword when selling was, in topical allusion to the Goon Show, the acronym *Eccles* — 'Elliott computers cost less'.

104 Interview with Ted Higgins, former Project Engineer Ferranti Automation Systems Division, Wythenshawe, Manchester, 5 February 2007. Ferranti were not unique among defence contractors in facing these difficulties. Similar issues were raised about US chipmakers which had been successful in military market then faced difficulties winning commercial orders, where technical requirements were more diverse and changed more quickly. Non-technical factors such as price and delivery schedules were far more important to civilian customers than defence contractors, see John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992), p. 259.

105 Corbett.

106 Email interchange with David Robinson re automation at Richard Thomas and Baldwins, in South Wales in the early 1960s, 18/19 March 2006.

107 Corbett.

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