Chapter 2
A Glint on the Horizon

2.1 The Man for the Job

John Coales was 40 years old when he arrived for his first day as Director of Elliott's Borehamwood Research Laboratory in October 1946. A brief chronology of John Coales' life to that point, largely taken from [1–3], is as follows:

1907	Born at Harborne, Birmingham, on 14 September, only child of John Coales and his wife Marion (née Flavell)
1926	Enters Sydney Sussex College, Cambridge, to read Mathematics. Transfers in his second year to Physics
1929	Graduates in Physics; joins the Admiralty Scientific Service and starts work at the Experimental Department, H M Signal School, Portsmouth
1931	Joins a small team working on Radio Direction Finding (RDF)
1936	Marries Mary Dorothea (Thea) Alison
1937	Leads a group of about a dozen people working on centimetric radar, for naval gunnery control. Team expanded to 40 people by 1940
1941	Admiralty Signal Establishment formed; Coales' section dispersed to Witley, near Haslemere, Surrey. Coales leads the naval gunnery radar development
1945	Awarded OBE for wartime services
1946	Leaves Admiralty to become Director of Elliott's Borehamwood Laboratory

Despite, or perhaps because of, the intense pressure and excitement of life at ASE during the war, John Coales was a youthful 40. He enjoyed tuning his elderly Sunbeam cars – he owned two of them. He was an enthusiastic member of a local Folk Dancing Group, an interest he had developed whilst an undergraduate [4]. He was fond of music and kept a viola in his office. A Cambridge graduate, he was sharp-witted, though his mild stutter and deep, booming voice sometimes made him seem abrupt in conversation. Colleagues spoke of his 'Forceful energy and disarming charm' and remarked that 'he was invariably smiling and in a good mood. His optimism irritated many people, but it made him drive through to completion

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projects that others had despaired of' [1]. As Bob Ford remembers, 'Coales never considered that a thing could not be done' [5].

John and his wife Thea lived with their four children and John's mother, a trained concert pianist, in *Oakwood*, a large house in Radlett situated some 3 miles to the north of Borehamwood. There were two grand pianos in the large drawing room at Oakwood. At weekend house parties, his daughter Alison remembers [6] that there would sometimes be Morris Dancing in the drawing room.

John Coales' two Sunbeam cars, or bits of them, were a feature of the Borehamwood Laboratories that many former staff remember. The cars had names:

(a) 'Her Highness': registration number UW 23, a 1920s convertible
(b) The 'Ugly Duchess': registration number PO 4950, a 1920s saloon

In a way reminiscent of many family businesses of the era, laboratory technicians were called upon by Coales to minister to the needs of the Director's cars (see Fig. 2.1). Actually, *family business* gives the wrong impression: *family university* might be nearer the mark in the sense that Borehamwood was humming with intellectual endeavour and technical innovation. In the early days, Borehamwood

Fig. 2.1 John Coales, the founding Director of the Borehamwood Research Laboratories, was an enthusiastic character. Not only passionately committed to his work, his hobbies included country dancing and keeping his two elderly Sunbeam cars on the road. The facilities of the Laboratory were sometimes called upon to come to the aid of the Sunbeams, as shown here. Archer-Thomson, the stocky Laboratory Superintendent standing second-from-left, appears somewhat doubtful of the car's health!

was run in a relaxed style, more like that of a large university engineering department in the 1960s than an industrial laboratory in the 1940s.

On a personal level, John Coales took a lively interest in his staff. He had a reputation as someone who could see a person's potential. John Bunt, who arrived in September 1949, remembers [7] that: 'Some of the younger staff lived in a company-owned house at Radlett called *Lamorna*. It was conveniently close to John Coales' house, *Oakwood*, and John would bring staff from *Lamorna* in to work in the mornings in one of his two vintage Sunbeams. One of these was a saloon and one a coupé, but in other respects they were identical. One or other of these cars was usually to be found on blocks in the Research Lab. workshops being repaired or awaiting parts which had been stripped to keep the other car on the road…'.

Lamorna had an interesting history. Peter Atkinson remembers [8] it as 'a large house in Radlett which was bought to accommodate a number of German engineers who were to be brought from Germany to work at the Lab on a contract (probably MRS5) for the Navy. This was just after the war. In the event the Germans, when they finally arrived, chose to live in London and *Lamorna* was made available for a number of staff to live in. There were six flats, only one of them was self-contained ... we were all very young and it was a lively and interesting community'. Bill Pearse, a mechanical engineer, who was amongst the first group of six people to be recruited by John Coales, remembers [9] that the Germans included two engineers 'who had been recruited from Peenemunde with four others. The senior man, Weiler, held a position in the German hierarchy reporting directly to Goering and responsible for gyroscope design and supply across the Reich. Weiler (aged 65) was a very talented "natural" engineer'.

Returning to John Bunt's account of his early days, 'After I had been at Borehamwood a few months I was asked to dinner by John Coales at his home at Radlett. All new engineers were asked in due turn and it was a very pleasant evening in a lovely home and garden. I particularly remember the occasion because it was the day in June 1950 when the Korean War broke out. Another notable event was that it was my first introduction to Commander Henry Pasley-Tyler RN who was another guest at the dinner party, and had just joined the company. The Commander, who was always known to his senior colleagues as 'P-T', became the senior man at Borehamwood some while after John Coales' departure'. Commander Pasley-Tyler actually started work officially on 1 July [10]; his part in the Borehamwood story is picked up again later.

Coales' impressive wartime scientific reputation was well-known amongst his new staff, some of whom had come from government research establishments such as ASE and TRE. Most importantly for the success of the MRS5 project, Coales had built up a useful network of Admiralty and naval contacts.

In the immediate post-war years, recruitment of suitably qualified scientific and engineering staff was not easy because there were not enough experienced people available to drive the peacetime renewal of industry and academia. Coales recalls [11]: 'At that time it was extremely difficult for an unknown new laboratory to engage good staff because the Universities were all needing to replace staff lost to the armed services and government laboratories during the war... Although I did not approach any of my wartime colleagues in ASE, a number of the most able of them [for example, Cochrane and Laws] expressed a desire to join me at Borehamwood... Another and most unexpected advantage was that the end of the war had thrown out of work a very large number of technicians ... and many of these turned out to be naturally good engineers and some of them excellent research workers. So in the course of 2 years we built up a laboratory with a staff of two hundred, which acquired a high reputation for the quality of its work in instrumentation, radar, fire-control, automatic and remote power control and particularly in the development of digital and analogue computers and by the end of another two years [i.e. end of 1950] the number employed had risen to 400, of whom at least half were qualified engineers and scientists'.

Coales also developed a good working relationship with the Cambridge University Appointments Board (the 'careers unit' at his *alma mater*) and the Board was happy to send batches of final-year students for interview at Borehamwood. One of the early recruits was John Bunt, who was part of a group of 24 Cambridge final-year students who visited Borehamwood for interviews with Coales in 1949. Bunt's initial salary was £475 per annum which, he recalls, was £25 more than he had been offered anywhere else [12]. Laurence Clarke, another individual that we shall encounter later on in the story of Borehamwood computers, first appeared as a vacation student for a temporary summer job in 1950; he subsequently joined the Laboratory permanently in July 1951 after his graduation from Cambridge.

However, not all recruits were new to industry. A few 'old hands' moved to Borehamwood from Elliott's main factory at Lewisham. Besides H D Hawkes and his R&D staff, it was agreed that a senior designer named C A Gutsell and a few designer-draughtsmen would also transfer to Borehamwood from Lewisham [11]. One interesting arrival from Lewisham was C F (Chris) Phillips, an ex-Naval gunnery officer and mechanical engineer who had worked on the Admiralty fire-control tables manufactured at Lewisham. Phillips has been described [13] as 'the acme of practical engineering and jury rigging'. We will meet him later on as the first designer of the mechanical parts of Borehamwood computer disk storage. Another source of 'old hands' was the few staff who had remained on in the redundant premises of the Admiralty fuse factory. The factory had been operated by S. Smith and Sons Ltd., industrial aircraft instrument makers, but the building belonged to the Admiralty. Arthur Hemingway, who was amongst the first batch of a dozen new recruits to arrive in October 1946 (he recalls being offered the 'princely salary of £600 per annum') oversaw the transfer of infrastructure from Smiths to Elliotts [14]. Amongst the former Smith's employees to be re-engaged by Elliotts in October 1946 were some of the maintenance staff, the Librarian, the Medical Sister, and 'an elegant and soignée lady with glasses and pendant earrings, who was our telephonist. Once heard, she never forgot a voice, so that *Mr This* or *Admiral That* was always correctly addressed by name when he called us up' [11].

There was also the matter of machine tools and furnishings, originally the property of the Admiralty. Some of this equipment, notably lathes and jig borers, was of considerable value, and Elliott's Managing Director seems to have arranged for the more useful items to find their way to Elliott's Lewisham factory.

Summarising Coales' recruitment efforts, we may conclude that trying to poach experienced people from other, better-established, companies was not a fruitful strategy. Most of the Borehamwood staff in the early years were young people fresh from college or those recently released from wartime activity in government research establishments.

There was one large industrial concern that did have a profound influence on the shape of Borehamwood: the General Electric Company (GEC). Coales was a great admirer of the way in which GEC's Hirst Research Laboratory at Wembley was organised (see also Chap. 1, Sect. 1.2.2). Coales adopted this as his pattern. With the agreement of Sir Clifford Paterson, Director of GEC Research, Coales recruited GEC's Lab. Superintendent, H. Archer-Thomson, to oversee the organisation at Borehamwood. To the younger staff at Borehamwood, Archer-Thomson seemed somewhat like a formidable chief-of-police. He was in charge of site security, space-allocation, and the Strong Room. Into the Strong Room went all the secret documents, drawings and photographs pertaining to classified contracts. Coales insisted that the Laboratory notebooks of individual staff should be handed in at the end of every working day, and that all correspondence with the outside world should be handled by his office. Archer-Thomson's job was to enforce this regime. All staff of the rank 'of foreman and above' were required by the government to sign the Official Secrets Act.

Coales adopted two features of the GEC Laboratory organisation. Firstly, he placed staff into semi-autonomous Divisions, each Division being the repository of a particular skill-set. Secondly, he strove to relieve senior scientific staff of administrative duties so that they could devote all their energies to research. Coales had also observed similar arrangements at the Bell Telephone Laboratories in America, when he had visited them in 1944. He was convinced that the Divisional organisation and the devolution of administrative duties were two features that played a big part in creating the excellence that he had observed at the Hirst Labs. and at Bell Labs [11]. In the light of hindsight, we can see that the conditions that permitted these features to flourish were very dependent upon the industrial strength of the parent companies. Elliotts, the parent company of the Borehamwood Laboratory, was not in the same league as GEC or Bell. The wider consequences of Elliott's commercial weakness in the late 1940s have been alluded to in Chap. 1 and are picked up again in Chap. 5.

The number, nomenclature and scope of the Divisions at Borehamwood varied as the Laboratory evolved. The first set of Divisions to be established in 1946/1947 were, in probable chronological order: *Instruments, Circuits, Radio, Theory, Servos* and *Mechanical Engineering*. ('Radio' was a coded title for 'Radar'). Alec Cochrane, who headed the Radar/Radio Division, did not arrive on site until April 1947 [15]. The Computing Division was not formed until the end of 1948, when W S (Bill) Elliott joined Borehamwood.

The main Divisions that existed in 1949 are shown in Table 2.1. Commonly occurring synonyms are given in the left-hand column. The first name in each row in Table 2.1 is the one that we shall prefer to use throughout the rest of this book. In row two of the Table, 'Radio' was actually preferred to 'Radar' in the early Borehamwood days – probably because the British phrase *Radio Direction Finding*

Table 2.1 The principal divisions at Borehamwood in about 1949

Name and synonyms	Divisional head(s)
Circuits; Displays	C A (Coppy) Laws
Radar; Microwaves; Radio; Aerials	C A (Alec) Cochrane; Eric Whitehead
Computing; Computers	W S (Bill) Elliott; Andrew St Johnston
Electrical Engineering; Servos	H M (Harry) Gale; Arthur Hemingway
Theory; Mathematics	Norman D Hill
Instruments; Measurements; Standards	H D (Harry) Hawkes
Mechanical Engineering; Workshops	John Tindale; F Rock-Carling
Physics	Alan Brewer; Albert E De Barr

(RDF) was the original name for what the Americans called *Radar*. In the right-hand column of Table 2.1, we give the Division's senior person in 1949, followed where appropriate by the name of a subsequent Head where there had been a change by about 1953. In addition to the main scientific Divisions, Borehamwood had a Drawing Office, a Library and an Accounts section.

In the early history of the Borehamwood Laboratory, a Division was somewhat similar in scope and autonomy to a traditional University Department. That is, it represented a research discipline. It did not, however, have any say in wider company activities such as product marketing. By the mid-1950s, the concept of a Division at Elliotts had taken on an altogether more substantial and realistic pattern under the guidance of Elliott's renowned Managing Director, Leon Bagrit. Jack Pateman, who joined the Circuits Division at Borehamwood in 1948 and rose to lead Elliott's Flight Automation activities as described in Chap. 12 and Appendix 9, has described the Bagrit-style Division of the 1950s as being 'a semi-autonomous entity with its own engineering, sales production and commercial departments ... market oriented and responsible for a limited range of company products. Several of the new Divisions later became wholly owned Companies' [16]. We shall learn more of the substantial role played by Leon Bagrit as the Borehamwood story unfolds.

Returning to Table 2.1 and the late 1940s, W S (Bill) Elliott was the founding Head of the Computing Division. Bill Elliott, who had no family connection with Borehamwood's parent company Elliott Brothers (London) Ltd., was born in 1917 and entered Cambridge University to read physics in 1935. The following brief biographical details are taken from [17]. At Cambridge, Bill Elliott was Secretary/Treasurer of the University Wireless Society, sharing an interest in amateur radio with Maurice Wilkes. We will meet Wilkes later in Sect. 2.5 below when we dip into computer history. Bill Elliott graduated in Physics from Cambridge in 1938 and commenced postgraduate research in the Cavendish Laboratory on transit time effects in thermionic valves. During the war, he was sent to work on radar at the Air Defence Research & Development Establishment. After the war, he remained registered as a Cambridge Ph.D. student for some time but eventually decided not to proceed with the valve work which had largely been superseded. He joined Powell-Duffryn's Research Labs. to work on carbon brushes and related electrical equipment. After 2 years with this company, he contacted Edward Shire at the Cavendish Laboratory and asked him for career suggestions. Shire passed the request to John

Coales. John and Bill had previously been in contact during the war regarding jamming and clutter in radar echoes. From the Borehamwood Visitors Books, we see that Bill Elliott came for exploratory talks with Coales several times in 1948 (on 8 and 21 August, 29 September, and 1 and 22 October), before finally joining Coales' team to set up the Computing Division in November or December 1948.

Coales recalled [18] that it seemed a little strange to some people that there should be both a Theory Division and a Computing Division at Borehamwood, implying that there was some overlap of responsibilities. He went on to say that he 'had to keep the peace between them'. We shall comment again on this aspect in Sect. 2.6 and in Chaps. 8 and 10. As far as *building* computer hardware, it was the Circuits Division that took the lead at first, somewhat to the puzzlement of Harry Carpenter and other new staff who had joined the new Computing Division early in 1949. As far as programming and software were concerned, it was the Theory Division that took the lead in the early days, as described in Chap. 8.

Recruitment of professional staff at Borehamwood gathered momentum in 1947, and by the end of that year, the Divisional structure was firmly established. There was, naturally, some transfer of people between Divisions, in an effort to match skills to needs. For example, John Bunt, after graduating in Physics from Cambridge, was originally recruited in September 1949 to work on the project known as the Comprehensive Display System (CDS) in the Circuits Division. He remembers that the research for CDS had largely been finished by then and so he found himself part of a large CDS construction team. After a few months, Bunt was transferred to the Electrical Engineering Division to work on a summing amplifier for the TRIDAC analogue computer (see Chap. 4). After a few more months, he was transferred to Harry Carpenter's team in the Computing Division, to work under Jim Barrow on the 152 computer (see Sect. 2.6). It was here that John Bunt learned the fundamentals of digital computers [12]. He went on to take a leading role in the design of Elliott computers in the late 1950s and the 1960s, eventually becoming Manager of the Mobile Computing Division. After the GEC takeover in 1968, John Bunt was appointed Technical Director of Marconi-Elliott Computer Systems Ltd.

Analysing the growth in the Borehamwood payroll is not always easy because surviving records seldom distinguish between categories of employee, and particularly between *professional* staff who were paid monthly and *support* staff who were paid weekly. For example, in addition to the initial batch of 12 professional staff who are known to have joined Borehamwood on day one (1 October 1946), we should add a modest number of support staff such as lathe operators, secretaries and cleaners who were inherited from Smith's fuse factory. By December 1946, W E (Ben) Bennett remembers arriving as 'employee number 40' and recalls that the Borehamwood group photograph of October 1948 depicted a total of 250 employees [19]. In December 1949, 261 people (most of whom would have presumably had professional qualifications) were recorded as having signed the Official Secrets Act [20]. The Borehamwood group photograph of 1 October 1951 shows 361 employees. By any measure, Coales' empire grew by leaps and bounds.

Coales had originally planned for a total payroll of about 300 people, 'of whom about half would be professional scientists and engineers'. Coales had originally hoped to appoint a Deputy Director as second-in-command to himself. He approached three extremely able people whom he had got to know through their war work but all had recently accepted senior posts – two at Universities and one at the new Atomic Research Establishment at Harwell. In the event, no Deputy was recruited.

Having to name some Borehamwood individuals, but not others, is a divisive but inevitable part of trying to write most retrospective histories. This book focuses on computer developments, with additional treatment of Elliott work in the areas of analogue computers, aerospace and radar. We must therefore pass over the other excellent, but unconnected, developments that were carried out at Borehamwood over the years.

The original organisation of Borehamwood into Technical Divisions was not inherently a bad thing, though in the case of Coales' rather autocratic style of management it proved somewhat unsatisfactory. Coales' divisional structure tended to favour a fragmented approach to equipment development, whereby the sub-units of a larger project were implemented by specialists without much reference to an overall systems architecture. For example, the interconnection of functional units tended to be considered too late in the design cycle. In short, there was a lack of project-centred (as opposed to technique-centred) management. We will return to this theme later, when describing the progress made by Borehamwood on the MRS5 and CDS projects.

2.2 Distant Targets

We saw in Chap. 1 that the 1946 agreement between the Admiralty, John Coales and the Managing Director of Elliotts, Geoffrey Lee, provided for the establishment of a Research Laboratory of about 300 staff. In 1946, Coales' prime objective was to work on two Admiralty contracts, MRS5 and CDS – of which the first was the darling of his eyes. The parent company, Elliotts, had also arranged to transfer their Instrument Research and Development section from Lewisham to Borehamwood, with the expectation that commercial activity in this section would build up to the point where it represented about a third of the work at Borehamwood.

In the light of hindsight, we can detect the seeds of an inconsistency of approach in these arrangements. Two types of research were being planned for Borehamwood:

1. Secret defence-related work, with clear Admiralty rules about allowable expenditure on capital equipment, overheads, etc.
2. Commercial development linked to specific products, guided by the market strategy and financial practices of the parent company

Although both areas would undoubtedly generate research challenges, they required completely different administrative management. We shall return to this theme in Sect. 2.7, when we pick up the activities of Geoffrey Lee and Leon Bagrit at Elliott's headquarters at Lewisham. On the technological side, there was also likely to be an initial divergence of activity between the two research areas. The Admiralty work involved high-frequency electronic pulse techniques and an emphasis, at least within the MRS5 project, on digital computation. The commercial work placed more emphasis on analogue signal-processing and electro-magnetic techniques. Over the next 20 years, the two areas would actually come closer, in the sense that analogue computation was replaced by digital processing as the latter became more reliable and cost-effective. This, however, was still in the unpredictable future in the post-war austerity of the late 1940s.

Putting commercial developments aside, Coales's principal concerns in 1946 were to make progress on the MRS5 and CDS Admiralty contracts. Of the two, MRS5 was the larger project, consuming about two thirds of the total Borehamwood effort during the period 1946–1950 and accounting for about two thirds of the income [18, 21]. We shall briefly describe CDS first because, having so to speak put that project to bed, we can then concentrate on MRS5 and the digital computers that sprang from the MRS5 work.

2.3 The CDS Project

The objectives of the Comprehensive Display System (CDS) were introduced in Chap. 1. From the list of Borehamwood internal research reports given in the Bibliography, it can be seen that 14 Progress Reports were produced for the CDS project between 31 July 1947 and 16 October 1951. The project leader was C A Laws, always known as 'Coppy Laws' because of his striking copper-coloured hair. Coppy was born in 1916. After working for companies making radios, he spent the war years at ASE, where his name appeared on eleven radar patents [22]. From ASE he went directly to Borehamwood, where he stayed until the 1968 merger between Elliotts and GEC described in Chap. 13.

At Borehamwood, the CDS project used *analogue* techniques whilst, unknown to Coales and Laws, Ralph Benjamin at ASE was working towards a *digital* version of the CDS concept. Many years later, Coales was to remember Borehamwood's CDS project with pride but also with some unease [18]. 'We weren't originally intended to have this contract; we were not told that Benjamin was doing some advanced, digital, CDS work at ASE, so we were working with what turned out to be obsolete (analogue) stuff'. In his rather self-centred book [23] Ralph Benjamin, a distinguished government scientist, described the Borehamwood CDS work retrospectively as follows.

> 'Initially a contract had been given to Elliott Brothers to produce the system. In a remarkably short time, their team, under two ex-ASE men, C A Laws and M V Needham, assembled two very sophisticated demonstration systems, one for the RN and one for 'loan' to the US Naval Research Laboratory. These early models did a great deal to demonstrate and 'sell' the operating concept, on both sides of the Atlantic. However, in line with the tradition of the firm, their approach was based heavily on electro-magnetic devices (relays, uniselectors, motors, magnetic clutches, potentiometers, monoscopes, etc.) and the system proved virtually un-maintainable. Meanwhile, work on the electronic (digital) solution continued at ASE'.

Technically, the Elliott CDS system at Borehamwood was ingenious. The CDS group was the first to devise the concept of an interlaced radar scan and operator-interaction via a joystick. The implementation used analogue electronics combined with electro-mechanical techniques. Historically, it was the first project to demonstrate real-time interaction between an operator and a screen. The CDS joystick controlled a symbol, known as a *hook*, interlaced with other data displayed on a CRT, to drag and drop screen information into memory [22]. The concept of interactive displays for general-purpose *digital* computers was not taken up by Elliotts, or by anyone else, for some years until digital memory technology had developed to the point where appropriate storage had become cost-effective. We shall return to the subject of computer history shortly.

As a demonstration prototype, CDS excited considerable attention, not least from the US Navy. A gathering of top US Navy brass and others was held at Borehamwood from 14 to 17 July 1950 (see Fig. 2.2), under the title *UK/US Conference on Data Transmission and Allied Subjects.* Two minor incidents are remembered about this visit [18]. Firstly, the MRS5 group was told not to power up their digital computer on the day of the visit because the Americans were not permitted to know about the MRS5 project and it was thought that the noise of the

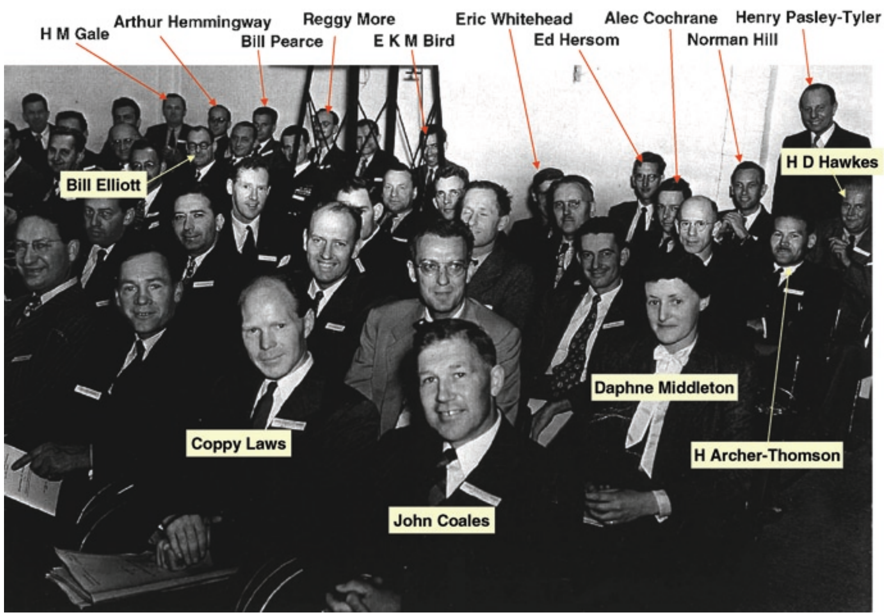

Fig. 2.2 The photo shows some of the senior Borehamwood Laboratory staff and visiting Americans, assembled in July 1950 for the joint UK/US Conference on Data Transmission and Allied Subjects. The prime purpose of this mysteriously named, invitation-only, meeting was to discuss Borehamwood's Comprehensive Display System (CDS) – a classified project. John Coales is seated at the front of the photograph

computer's forced-air cooling system might attract awkward questions. Secondly, Coales thought that pre-lunch cocktails might be welcomed by his American guests. On the morning of the visit, he asked Andrew St. Johnston and Tom Ludlow, both young ex-RN officers, to 'fix the drinks'. In a manner reminiscent of the BBC comedy series *The Navy Lark*, the two young engineers went out and bought several bottles of spirits and mixed a wondrous brew. The effect on Anglo-American relationships is not recorded but, by design, Andrew and Tom ensured that there was plenty of the cocktail left over after the official guests had departed – 'dispensed to all and sundry in enamel jugs!' [24].

Returning to the CDS project, Maurice Needham was sent to America in 1951 to demonstrate the system to the Americans. Whilst there, John Coales instructed Needham to visit Bell Labs. He did so, and returned to Borehamwood carrying three transistors, the first such devices to be brought to Borehamwood. Needham has recalled [25] that Coales could not, regrettably, see clearly the future possibilities of CDS. At one point, Coales remarked to the CDS group, 'Hurry up and finish it so that you can get on with something more important'. This had a rather demoralising effect on the group and was uncharacteristic of Coales, whom Needham generally admired.

The CDS project was wound up at Borehamwood soon after Needham returned from America, the last CDS Progress Report to the Admiralty being dated 16 October 1951. All CDS reports were classified 'Secret'. Although apparently short-lived at Borehamwood, the legacy of the work on CDS is seen today in the Command and Control Centres on all modern warships.

2.4 The MRS5 Project

The specification of the Navy's Medium Range fire-control system MRS5 was, roughly speaking, as follows. Ship-borne radar was required to detect the range, bearing and elevation of an enemy aircraft when it was at least 8 miles away; the radar unit would then lock onto and track this target (*auto-tracking*) until it was either destroyed or had flown out of range. The radar unit was required to feed various parameters, relating to the target, continuously to a central on-board computer that would calculate in real time the target's trajectory. The computer would send appropriate aiming and fusing information periodically to the ship's main anti-aircraft guns, in order that the shells from each gun would explode at, or very close to, the target's predicted position. The central computer was to be *digital*, rather than analogue, and data was to be transmitted in digital form throughout the ship – see Fig. 2.3).

As Norman Hill explained [26], 'Bearing in mind that in practice the director would be on board ship subject to roll, pitch and yaw, the information coming from the radar system would need to be converted to a stable system of axes [derived from the *master reference gyro*], the future position of the target would then have to be predicted according to the time of flight of the shell fired from the naval guns

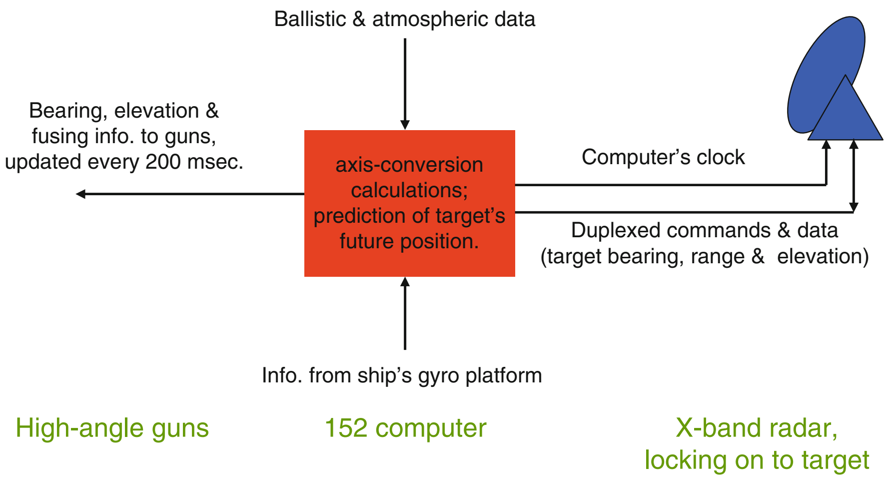

Fig. 2.3 Simplified system diagram of the MRS5 *(medium range system)* fire-control project, showing the connections between the Elliott 152 real-time on-line digital computer, the target-tracking radar and the high-angle (i.e. anti-aircraft) guns. The radar was required to lock on to an approaching aircraft when it was still 8 miles away from the ship

and the information sent to the gun servos converted from the stable system of axes back to the ship's axes all in real time ie almost instantaneously. The mathematical problems were monumentally difficult. Ed Hersom in my team [i.e. the Theory Division] eventually produced a brilliant solution of this problem'. Ed Hersom specified the functionality of, and algorithms for, the MRS5's digital computer.

Alec Cochrane, who joined Borehamwood in April 1947 and became a leading light in the MRS5's radar developments, has said [15]: 'The operative principle as far as I could gather was to break with tradition and break new ground wherever possible.... However one defines the objective of the MRS 5 contract the emphasis was on innovation rather than further optimising the tried and trusted techniques ... The real attention was focussed on the enhanced computation possibility offered by the digital computer.'

2.4.1 Why Digital?

The choice of *digital* processing was a radical departure for the Navy in 1946. All gunnery predictors in service during the war, on land and at sea throughout the world, had used analogue computation. Furthermore, when Coales had visited America in August and September 1944 'to study US Naval Gunnery Radar, US Fire Control and the relation between them', the word *digital* did not appear anywhere in his report [27]. Besides US government departments and establishments, Coales and his colleagues visited MIT and the Radiation Lab., Bell Telephone Labs (at various

Fig. 2.4 Vice-Admiral Sir M M Denny, Controller of the Navy, came to inspect the MRS5 radar installation at Borehamwood early in 1951. John Coales is in the light grey suit, facing Denny. Leon Bagrit is on the far right of the photo

locations), the Ford Instrument Co., and Arma Corp. and were shown many new research projects. Of the Ford Instrument Company Inc., New York, Coales says: 'The [Ford] Mark I computer is, even now, almost certainly the finest high-angle computer in service at sea, and is doing excellent work in shooting down aircraft' (see also [28] for the background to Hannibal Ford's fire-control equipment). The Ford Mark I computer formed part of the US Navy's Mark 37 Fire-Control System, introduced in 1939. It was entirely analogue, and is described in Chap. 4.

It is true to say that, apart from MRS5, all other electronic research at Borehamwood in the period 1946–1949 was analogue. Nowadays, when the word 'computer' implicitly means a general-purpose digital machine, we tend to forget the debates that preceded the digital age. It is sobering, then, to recall the realities of yesteryear. For example, in the book *Electronic computers: principles and applications*, intended for the general reader and published in 1956, the technical content is approximately evenly balanced between analogue computers (42 pages) and digital computers (45 pages) – see [29].

It is interesting to speculate why, in 1946, the Admiralty chose to go digital. It seems quite likely that ENIAC was the spur. ENIAC, a special-purpose American electronic digital computer, had first come into operation in the autumn of 1945, as explained in Sect. 2.5 and Appendix 10. ENIAC's primary task was ballistics computations – not, it is true, real-time on-line ship-board gunnery computations but nevertheless precision computations that were loosely related to the MRS5 project's topic of fire control. Norman Hill, Head of the Theory Division at Borehamwood, recalled [26] that: 'Much interest was generated in ENIAC world-wide and

Mr Coales directed us to study the techniques embodied in it. Many visits were made to view ENIAC [by other British researchers], notably by Maurice Wilkes from Cambridge, Wilkinson from NPL, Professor Hartree from Manchester [later at Cambridge University from October 1946] and Uttley from TRE. These and other people decided to build digital computers at their various Establishments. Our problem [at Borehamwood] was how to seek information on these various plans and designs bearing in mind that we could not reveal our purpose since we were working on a secret contract. I remember going with John Coales in his vintage Humber [actually Sunbeam] registration number UW23, to the NPL for discussions with some of the above-mentioned people together with the great Turing who insisted on running to the canteen for lunch in pouring rain....'

In February 1945, the first non-American to be permitted to see the ENIAC project had been J R Womersley, the new Superintendent of the Mathematics Division at the National Physical Laboratory (NPL). At the end of 1945, when Alan Turing produced a document for the NPL containing what is probably the first complete design for a general-purpose digital computer, it was still uncertain how much memory would be required for practical problems, and whether the memory could be made to operate at sufficient speed and at an affordable price [30]. So although digital computers offered potentially more accuracy than analogue computers, going digital was a step into the unknown.

Besides accuracy, another reason why the Admiralty may have inclined towards digital techniques concerns data transmission. A major complication in ship-borne fire control prior to 1945 had been the means by which the components (director, predictor, guns) were linked. Data transmission was by stepper motors, later replaced by magslips [31] and then the metadyne, for moving pointers. Most of the control was, in the end, achieved by manually following a pointer. It goes without saying that electro-mechanical fire-control systems worked better against (slower-moving) surface targets than against (faster-moving) aircraft. Ships remained vulnerable to attack from the air. There was a need to speed up data-transmission – which may have suggested the need to explore *digital* transmission in projects such as MRS5.

A final, though admittedly tenuous, reason why the Admiralty might have inclined towards digital computing could have been the desire to outdo the Americans. The British analogue High Angle Control System (HACS) in use during the Second World War was a relatively poor performer compared with the American analogue Mark 37 FCS. More details of the differences between the two systems are discussed in Chap. 4. The Mark 37 FCS was introduced to the Royal Navy on a trial basis in one ship in late 1941. The Admiralty was impressed with the performance. More of the Mark 37 systems would have been ordered, but production in America was entirely consumed by equipping US Naval vessels. After the war, the battleship HMS Vanguard was equipped with Mark 37 FCS. In British naval circles, there must have been considerable pressure to develop a better, home-grown, fire-control system – especially since the critical balance-of-payments situation and the associated political problems made dollar purchases very difficult. The Admiralty chose to take a leap into the unknown and specify *digital* computing for the MRS5 project, perhaps in the hope of stealing a march on the Americans due to the expected increase in accuracy of digital systems?

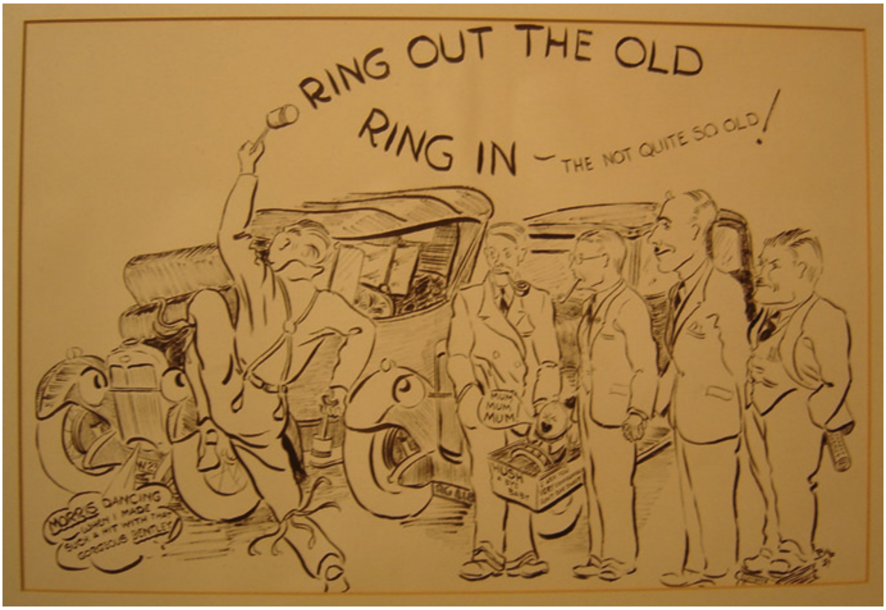

Fig. 2.5 This cartoon, presented to John Coales for Christmas 1949, shows Coales in frantic *Morris dancing* mode whilst senior members of the Laboratory staff hold the secret MRS5 radar aerial – represented by a baby in a cot. The staff are thought to be (left-to-right): John Tindale, Arthur Hemmingway, C A Laws and H Archer-Thomson. The caption '*Ring out the old, ring in the not quite so old*' refers to the Admiralty's cancellation of the MRS5 project and its replacement by the 'Netting' project for radar evaluation

Certainly, the concepts that lay behind MRS5 were ambitious. Close interconnection was envisaged between three types of functional unit: the radar transmitter/receiver; the trajectory-predicting computer; the high-angle (i.e. *anti-aircraft)* guns. Of these three, the required pinpoint accuracy of the radar unit seemed to Coales to present the most challenging problems. Radar was also the topic about which he knew most, and it was advances in radar technology that had contributed most to the improvements in gunnery accuracy during the Second World War. In the event, it was indeed on the radar side of the MRS5 contract that the Borehamwood researchers were able to make the most obvious, world-class, advances. The significance of the MRS5 contract's digital computing innovations was more subtle and slower to blossom in the commercial world, but in the end, they, too, were substantial at the time of their introduction.

The interlaced threads of analogue and digital computing, of sequence-controlled and stored-program computers, and of special-purpose and general-purpose computers, are a fascinating part of the early history of the Information Age. We will describe some of these threads later in Sect. 2.5, as a prelude to Sect. 2.6 where we will describe the computer known as the Elliott 152 that lay at the heart of the MRS5 project. First, though, we continue with the MRS5 story as it unfolded during the period 1946–1949.

2.4.2 Innovative Radar

Returning to the MRS5 contract at Borehamwood, the first priority of Coales' scientists, and particularly of the radar teams led by Alec Cochrane and Eric Whitehead, was research into novel aerial (or *scanner* or *antenna*) systems for monopulse radar. New concepts in aerial design were necessary in order to obtain the very precise angular definition required for MRS5 automatic target-tracking.

The MRS5 radar operated in the X-band, that is, within a frequency band of about 8–12 GHz, equivalent to wavelengths between 4 and 2.5 cm. (A guide to microwave band terminology is given in Appendix 9). An innovative plate-type lens was developed at Borehamwood for the X-band microwave aerial, as shown in Fig. 2.6. In the egg-box construction of the lens, the spacings were determined by the wavelength and the front and rear contours determined the focal length. The lens was in four segments. The differences in target-reflections received by each segment were used to generate up/down, left/right, *misalignment signals.* Servo-mechanisms connected to hydraulic rams moved the whole aerial assembly so as to minimise the *misalignment signals* and thus lock the radar on to the moving target. The Borehamwood radar group was congratulated by the Admiralty in 1949, who were 'very impressed with the work that the firm [Elliotts] had done on plate lenses. A large amount of the work was quite original' [32].

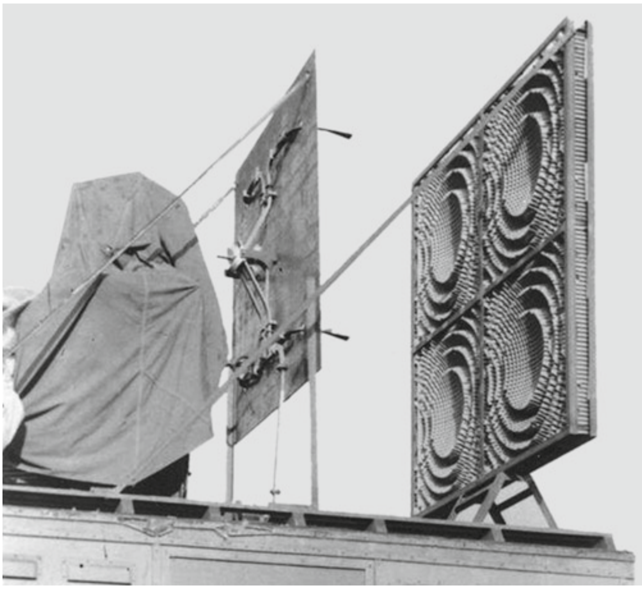

Fig. 2.6 An innovative plate-type lens was developed for the MRS5's X-band radar. The lens was in four segments, here shown under test. The differences in target-reflections received by each segment were used to generate *misalignment signals.* Servo-mechanisms connected to hydraulic rams moved the whole aerial assembly so as to minimise the misalignment signals and thus lock the radar on to a moving target

Radar systems that tracked targets were not new in 1949: the innovative aspect of the MRS5 system was its high accuracy and ability to handle target glint. Glint is a term used to describe the small, dynamic, changes in the position of the returned echo. Glint is caused by the fact that practical aircraft reflect radar signals at a number of angles and from a number of surfaces. The Borehamwood team was to become expert at glint analysis.

The whole assembly of MRS5's radar system, complete with electronics and servo motors, was known as the Director, thus adopting the traditional warship terminology of the day. The MRS5's Director weighed approximately 14 t. Of this, the radar nacelle, containing the lens system, weighed about 2 t. The nacelle was mounted on heavy-duty elevating/training structures which formed a stabilised platform similar to those in use for naval guns (see Fig. 2.7). Coales' group invented, and patented in 1948, a binary encoding disk system for accurately representing the radar aerial's angular position as a bit-pattern. The encoder is described in more detail in Sect. 2.6 below.

The MRS5 Director was installed in the car park behind the main Borehamwood Laboratory in May 1950, with a clear view of the sky as required for practical tests on aircraft. A series of fly-past trials took place during the period October 1950 to

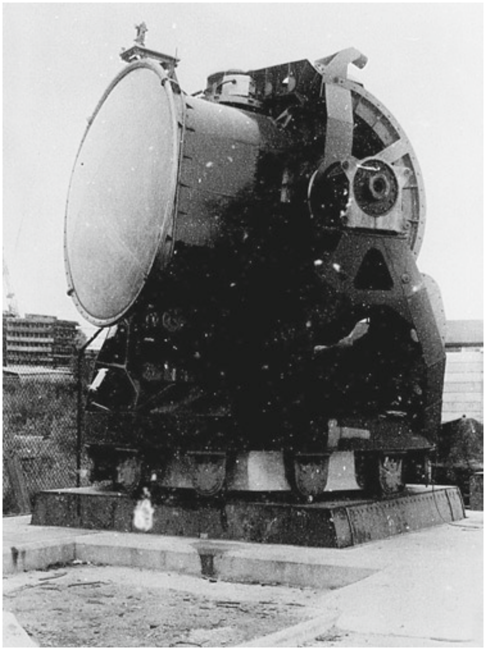

Fig. 2.7 The radar aerial and associated electronics for the MRS5 project was housed in a *Director* assembly weighing about 14 t. The photograph shows the Director as located on open ground to the rear of the Borehamwood Laboratory. Successful target-tracking tests involving Lancaster bombers and Mosquito fast reconnaissance fighters were carried out in the period October 1950 to November 1951

November 1951 – though the analysis of the target-tracking data was funded by a different Admiralty contract, as described below.

The MRS5 contract, number CP.12349/46, was placed with Elliotts by the Admiralty in October 1946. Activity on the MRS5 project spanned the years 1947–1950. The Admiralty's appraisal of the project half way through is reflected in the following quotation, taken from the ASRE's hand-over notes written by Commander F C Morgan in December 1948 to his successor, Commander T W Best [33]: 'Elliotts have a long term research and development contract for MRS5 and are tackling the problem as a whole quite fundamentally, without preconceived notions of how this or that should be done, and without tying their hands with past conservative practice. They have a highly competent, immensely keen team of scientists and engineers on the job, and are investigating new techniques and methods in a large number of fields. If we can be but patient I personally believe that something quite startlingly good will eventually be produced by this group. It is of more than passing interest that visitors from the USN and US Industry have been more impressed by the work going on at Elliotts than at anywhere else in this country'.

A listing of relevant Borehamwood Internal Technical Reports produced during this period is given in the Bibliography, from which it can be seen that the first MRS5 Progress Report was dated 1 October 1947 and the last Progress Report (number 11) was issued on 5 April 1950. Some time in late 1949, to the surprise of the entire team, the Admiralty gave notice that it intended to cancel the MRS5 project.

2.4.3 The Cancellation of MRS5

Why did the Admiralty suddenly consider withdrawing support from what was, at any rate from the radar standpoint, an excellent piece of development?

Cochrane's radar system of phase comparator simultaneous lober (based on the egg-box lens) was a world-beater, credited by C A Calpine (from Admiralty Operations Research) with being the most accurate angle measurer he had reviewed [15]. Cochrane was supported on the analytical side by Eric Whitehead, described as 'a brilliant theoretician' [34]. Whitehead recalled that: 'The times I spend at Borehamwood ... contained the most exciting professional experiences I have had at any time ...' [35]. The semi-official history of naval radar [3] says: 'Although the *type 905* [the MRS5 radar] never went into production, the study was of particular interest in that it incorporated electronic scanning for the first time in a British naval weapon radar'. Subsequent radar activities at Borehamwood are recounted in Chap. 11.

Although the cancellation of MRS5 came as a significant shock to the radar group, the team leader, Alec Cochrane, admitted in 1995 [15] that it had become clear to him at the time that 'MRS5 was doomed and the real problem at Borehamwood was survival'. By *survival* Cochrane was touching on the wider issues of the financial viability of Elliott Brothers (London) Ltd. and hence of the Borehamwood Laboratory. The Elliott company's finances are considered later, in Sects. 2.8 and 2.9. Cochrane continues: 'The only real alternative to naval contract work [for the radar team] was missiles and I nudged things in the direction of millimetre waves' [15]. It was whilst considering the problems of fitting a suitable aerial for a 9-mm wavelength guidance system inside a missile that Cochrane patented the remarkable Cassegrain aerial ([15] and Appendix 9). This patent did, in the end, attract a considerable royalty payment to the company.

The Admiralty, of course, was well aware of the promising radar results that were emanating from Borehamwood in 1949/1950. In fact, they proposed to ask Borehamwood to continue this radar development, whilst ceasing to work on the larger digital fire-control activity. We will introduce Borehamwood's new radar contract, called the *Netting* project, in Section 2.4.4. First, though, it is interesting to speculate on exactly why the Admiralty wished to cancel MRS5. There appeared to be no single reason for cancellation, but amongst the factors for consideration would have been the following:

(a) Budgetary constraints being imposed by government in 1949 on all defence projects – see the defence-spending Table in the Introduction to this book. In [32] the Superintendent of the Admiralty's Gunnery Establishment (AGE), who effectively oversaw the MRS5 project, said that 'financial stringency has led to drastic modifications of all our development contracts'.
(b) The realisation by UK Defence chiefs that guided weapons, rather than guns, were going to be a more appropriate measure against attack by aircraft.
(c) The fact that Borehamwood appeared to be falling behind schedule with progress on MRS5's digital computing and control system. At a progress meeting held on 16 June 1949, it was stated that 'the director and computer were the unknown dates, whereas the rest seemed reasonably well in hand' [32].
(d) A growing unease at AGE with MRS5 project-management procedures and the strained relationship that had developed between Coales at Borehamwood and the Elliott management at Lewisham led by Leon Bagrit (due in large measure to the financial weakness of the Elliott company at that time).
(e) The knowledge that a more modest, interim, analogue fire-control system based on the *Flyplane* principle (see below) could be brought into operation within 2 or 3 years.

We shall comment further on point (d) in Sect. 2.7, after we have described the MRS5's computer developments. With regard to point (b), some in the Admiralty had begun to consider guided weapons, at first called *Guided Anti-aircraft Projectiles (GAP)*, as early as 1943 [36]. Certainly, research in Britain for a beam-riding guided missile had begun at TRE during the latter stages of the war. The first flight tests of the *Long Shot* experimental missile were carried out on the Army's Salisbury Plain artillery range in 1948. Harry Carpenter, who joined the Borehamwood Computing Division in January 1949, was an electronics specialist at TRE who had been a member of the guided weapons team since mid-1945.

Regarding point (e) above, in 1947, the Admiralty had placed a development contract for an analogue fire-control predictor based on the *Flyplane* principle with the Instrument Department of Ferranti Ltd. at Moston, near Manchester [37]. The contract, worth £32,000 per annum in 1947, led to sea trials of fire-control systems incorporating Flyplane predictors from about 1950 onwards. In 1955, a separate Fire Control Department was established at Ferranti Ltd., by which time annual sales of Flyplane-related predictor systems had expanded to over £900,000 [37].

As recalled in a 1950 Admiralty report [38], the Flyplane system contained 'nothing sufficiently novel, i.e., novel in the sense that it had not previously been considered rather that previously used.... For at least 25 years there has been a recurrence of proposals for solutions of the anti-aircraft problem based on the use of the fly-plane.... The starting point in all such solutions is that if we assume straight-line flight of the target during the time of flight of the shell, then that straight line and the point of observation (the gun position) define a plane known as the fly-plane; if now all our operations (computations and movements) can be carried out with no other reference than to this plane the problem, normally regarded as a 3-dimensional one, is reduced to a 2-dimensional one and so is simplified'.

The analogue Flyplane Predictor System (FPS), as installed in Royal Naval ships in the 1950s, is discussed in Chap. 4.

2.4.4 The **Netting** *Project and the Legacy of MRS5*

Coales has said [18] that, upon learning that the Admiralty had invoked the 3-month termination clause on the MRS5 contract, he went to see the Admiralty's Director of Physical Research, W R (Bill) Cook. Coales recalls that he spoke bluntly to him, as follows: 'Firstly, I cannot advise my Board to accept a purely radar contract, because this is not in line with the company's main business directions. Secondly, if the change in contract results in any redundancies then I will advise Elliotts to close Borehamwood down'. The Admiralty, Coales recalls, had never before been spoken to in such stark terms. Cook subsequently made strenuous efforts to find other government work for Borehamwood. It was thought by Coales to be largely thanks to Bill Cook that Coales' team obtained the TRIDAC contract for a massive analogue computer for three-dimensional simulations, as described in Chap. 4. The first TRIDAC Progress Report appeared on 14 July 1950 (see Bibliography). Additional government computer contracts of a more secret nature were also to come to Borehamwood, as described in Chap. 3.

Although the main MRS5 contract was, in fact, cancelled formally in 1950, the Admiralty did indeed award Borehamwood a subsidiary follow-on contract – referred to locally as the 'Netting' project (contract number CP.888/50). (It has not been revealed why the title *Netting* was used: Possibly, because of the image it conjured up of flying objects being captured in a net?) Anyway, the objective of the project was to use the MRS5's existing advanced radar unit and the soon-to-be-completed digital computer to carry out a comprehensive analysis of the radar system's performance, especially with respect to the glint phenomenon. It was arranged that two types of aircraft (the Mosquito fast reconnaissance fighter and the Lancaster heavy bomber) would over-fly Borehamwood, in a series of trials that spanned the period October 1950 to November 1951. Ben Bennett implies [19] that the fly-pasts actually started in June 1950, but he may have been referring to slow-moving initial tests that Norman Hill says [26] were performed first with a meteorological balloon and then with a helicopter, before the use of faster aircraft, ‘all to the great interest of the locals’.

There was, naturally, liaison with the Fleet Air Arm and with Air Traffic Control and a naval officer was appointed by the Admiralty as Trials Officer. The broad conclusion of the Netting trials was that the radar system was capable of accurate measurement of target position around 10,000 yd (five nautical miles), with useful data being obtained at ranges as far out as about 20,000 yd (ten nautical miles). Ten miles was the limit of the high-performance optical cine-camera being used as a reference during the fly-past tests [39].

During the ‘Netting’ trials, the response-signals from the radar system were recorded in real time and then analysed off-line. The data from the 1950 trials was captured by analogue pen recorder because the digital system was not yet ready. Digital recording, on 35-mm film, took place from August 1951 onwards. This data-capture and subsequent analysis, performed largely under the direction of Ross Cameron [18], were to become the only useful task that the MRS5’s digital computer, known as the Elliott 152, performed in earnest. However, the digital film-reader was the weakest part of the process and full-scale off-line digital analysis did not begin until about May 1952. Only a modest amount of actual digital computation had been completed by the project’s deadline of 30 June 1952 [39]. There is anecdotal evidence that the central computer performed this small amount of analysis satisfactorily. However, a large quantity of (digital) recordings remained un-processed. These recordings were, 10 years later, still regarded by Eric Whitehead, by then Marconi’s Chief Scientist, as the most comprehensive set of glint data in existence [40]. From the listing in the Bibliography, it can be seen that the ‘Netting’ project produced nine Progress Reports between 9 June 1950 and 5 August 1953.

So, what of the MRS5’s computer? To understand how this, the first of the Borehamwood digital computers, stands in relation to other pioneering projects elsewhere, it is appropriate to remind ourselves of the state of play of high-speed digital computing developments worldwide in the 1940s. We will then return to the design of the MRS5 computer itself in Sect. 2.6.

2.5 A Little Computer History

There are probably three reasons why it is sometimes hard for succeeding generations to comprehend and trace the early development of the modern digital computer:

- *Complexity of cross-fertilisation*: Early pioneers may or may not have had knowledge of, or concerns for, what other contemporary groups were doing; interactions may or may not have taken place.

- *Storage technology*: The design of electronic circuits for the central computation and control functions of a digital computer was not too difficult, compared with the problem of devising suitable high-speed memory, or storage, technologies.
- *Limited end-user experience*: Whilst the basic concepts of the 'universal digital computer' soon became reasonably well-known, how to put those concepts to efficient use, and for what potential range of applications, was far less clearly understood.

To illustrate how such factors might have influenced events at Borehamwood, we need to remind ourselves of some of the pioneering landmarks of automatic digital computing.

In Appendix 10, we review a selection of 15 digital computing projects worldwide, most of which were conceived before 1947 and might therefore have been known to researchers at Borehamwood in late 1947. Firstly, there are five pre-1945 projects which, as shown in Appendix 10, are not really fully-fledged operational *stored-program* machines. These are:

(a) Charles Babbage's Analytical Engine, designed in the 1840s
(b) Konrad Zuse's Z3, which first worked in 1941
(c) Howard Aitken's Automatic Sequence-Controlled calculator (ASSC), also called the Harvard Mark I, which first worked in 1943
(d) The Colossus Mark I and Colossus Mark II cryptanalytical machines that worked at Bletchley Park in 1943 and 1944, respectively
(e) The ENIAC (Electronic Numerical Integrator and Computer), first working at the Moore School, Pennsylvania, in 1945

Although all were innovative at the time, none of the above projects possessed what we would now recognise as a practical internal read/write memory for the storage of program and data. Of these five machines, it is believed that the Borehamwood engineers would only have been familiar with the details of the last one, ENIAC. Furthermore, none of these five machines is within the scope of the chart of *post-war* British electronic digital know-how that has been presented in Fig. 1.3.

Appendix 10 describes a selection of ten later computer projects whose details would have potentially been more relevant to Borehamwood designers, if indeed sufficient details were readily available. These are:

(f) The small-scale experimental machine (SSEM), also called the Baby, which first ran a program on 21 June 1948 at Manchester University
(g) EDSAC, which first ran a program on 6 May 1949 at Cambridge University
(h) CSIRAC, first working at the Commonwealth Scientific and Industrial Research Centre (CSIR) at Sydney, Australia, in November 1949
(i) SEAC, the American Bureau of Standards' *Eastern Automatic Computer*, May 1950
(j) SWAC, the *Standards' Western Automatic Computer*, August 1950
(k) Pilot ACE, National Physical Laboratory, Teddington, Middlesex, May 1950

(l) Ferranti Mark I, delivered to Manchester University in February 1951
(m) UNIVAC I, delivered in March 1951
(n) Whirlwind, first working at the Massachusetts Institute of Technology (MIT) in March 1951
(o) IAS, first working at the Institute for Advanced Study (IAS), Princeton University, in the summer of 1951

What influence, if any, did the above 15 projects have on Borehamwood in 1947? It is clear from Norman Hill's remarks quoted earlier in Sect. 2.4.1 that, from the beginning, the general principles of stored-program computers were familiar to the Theory Division. Indeed, Norman Hill and John Coales visited NPL and met Alan Turing and others – probably in the first half of 1947, judging by Turing's movements [30]. Hill and Coales would, no doubt, have been made aware of Turing's plans for the ACE computer but the ACE project was not, at that stage, in a stable form that would have commended itself to those interested in robust digital hardware for a real-time on-line gunnery application.

Although the Computer Division was not established until the end of 1948, it is certain that its leader, Bill Elliott, already knew about computers from contact with his long-standing friend at Cambridge, Maurice Wilkes (later to become Professor Sir Maurice Wilkes FRS). Wilkes and Elliott had been fellow-undergraduates at Cambridge and shared an interest in amateur radio. Wilkes' Mathematical Laboratory at Cambridge remained an influence on the Borehamwood work, Wilkes himself becoming a Consultant to Elliott Brothers (London) Ltd. Norman Hill remembers [26] that: 'At around that time [1949 onwards?] Maurice Wilkes at Cambridge held a series of colloquia in the Mathematical Laboratory every two weeks at which experts on digital computing techniques were invited to give a talk followed by free discussion and tea and buns. As a forum for exchanging information these colloquia were invaluable and they greatly contributed to the growth of knowledge in this new and exciting field. We were able to keep up to date with progress on the different machines which were being designed and built. At about this time, 1947, Bill Elliott arrived at Borehamwood to lead the Computing Division. He had numerous friends at Cambridge, TRE and other places'. Actually, Bill Elliott did not join the staff at Borehamwood until after October 1948 – see above.

Apart from contacts via Cambridge, did individuals from other pioneering groups interact with Borehamwood? Looking at Fig. 1.3, one might reasonably assume that a general awareness of the SSEM, EDSAC and Pilot ACE projects would have found its way into the electronics industry by about 1950. Indeed, an inspection of the Borehamwood Visitors Books reveals the identity of several people who were (or were to become) knowledgeable about various aspects of digital computers. The purpose of their visits is not recorded, but it is interesting to quote names and dates, as shown in Table 2.2. The total period covered by Table 2.2 is October 1946 to December 1951. It is immediately apparent that very few computer-related names crop up over this 5-year period, indicating that the vast majority of visitors to Borehamwood had no known connection with digital computing.

Table 2.2 Computer-related visitors to Borehamwood between 1946 and 1951

Date	Person	Stated affiliation at that date
6 May 47	G G Scarrott	Cavendish Lab., Cambridge (later, at Ferranti Ltd)
6 June 47	A M Uttley	TRE
13 Oct. 47	J M Wilkinson	NPL
13 Oct. 47	H D Huskey	Ex-ENIAC, working at NPL (later, at SWAC).
2 Jan. 48	J M M Pinkerton	Cavendish Lab., Cambridge
10 April 48	M V Wilkes	Maths Lab., Cambridge
9 Nov. 49	L J Comrie	Scientific Computing Service, London
19 June 50	M V Wilkes	Maths Lab., Cambridge
2 Aug. 50	J M Bennett	Maths Lab., Cambridge (later, at Ferranti Ltd.)
23 Nov. 50	B V Bowden	Ferranti Ltd., Moston
23 Jan. 51	F C Williams	Manchester University
1 Feb. 51	J M M Pinkerton	J Lyons & Co.
19 Feb. 51	D Brunt	Royal Society
19 Feb. 51	B Lockspeiser	Dept. of Scientific & Industrial Research (DSIR)
25 Sept. 51	D R Hartree	Cavendish Lab., Cambridge
25 Sept. 51	M V Wilkes	Maths Lab., Cambridge
19 Nov. 51	C Strachey	National Research Development Corporation (NRDC)

In addition, NRDC staff (principally H J Crawley) came to Borehamwood on 10 Aug. 1950, 25 Sept. 1950, 19 Feb. 1951, 28 Sept. 1951, 16 Nov. 1951 and 19 Nov. 1951

Interestingly, in view of the mutual interest in CRT storage, members of the computer design group at Manchester University do not recall any visitors from Borehamwood coming to Manchester before the Ferranti Mark I Inaugural Conference in July 1951 [41]. However, as is explained in Appendix 1, Borehamwood researchers first met Professor F C Williams at an Institution of Electrical Engineers colloquium in London in November 1948.

Let us return to the 15 pioneering computers mentioned earlier, whose hardware performance is summarised in Appendix 10. In 1947, Borehamwood had a rather specialised interest in the entirely new field of real-time digital control, which required high computational speeds. On the key matter of performance, an obvious candidate for consideration by Borehamwood would have been the MIT Whirlwind computer, which was the only one having appropriately fast addition and multiplication rates. However, the first published report of this computer is probably Forrester's paper presented on 29 July 1948 at the Modern Calculating Machinery and Numerical Methods Symposium at the University of California, Los Angeles. Almost 3 years were to elapse before Whirlwind was fully operational.

In any case, information about Whirlwind and similar defence-related projects may have travelled slowly. Julian Bigelow, an IAS designer speaking in 1976, said: 'Several people have asked questions about what we were thinking at the time, when we got our ideas, and in particular how much we knew about – and possibly gained from – developments taking place at other places such as project Whirlwind at MIT and the ex-Moore School team in Philadelphia. The answer is that we had no communication contact except rumors, and as far as I know each of these groups proceeded along its own avenues, directed towards its own goals and developing its own criteria of what constituted excellence' [42].

The principal cause for delays in the Whirlwind project was problems with the MIT version of electrostatic (CRT) memory. When the first bank of memory tubes was attached to Whirlwind in July 1950, they proved unreliable and 'the behaviour of the storage depended on the programs used and their frequencies, and it varied when different areas of the storage surfaces were used. There was evidently much that we did not understand about the operation of the storage as an integrated part of the computer' (see Whirlwind Summary Report no. 24, third quarter 1950, page 6, as quoted in [43]. Borehamwood was to employ another, quite different, version of CRT storage, as described in Appendix 1.

More generally, storage issues had caused, or were causing, difficulties for several other computer design groups. In 1949, Nathaniel Rochester of IBM commented as follows in the premier US electronics journal of the time: 'The most difficult problem in the construction of large-scale digital computers continues to be the question of how to build a memory, and the few papers written do not reflect the greatness of the effort which is being exerted' [44].

Wartime radar experiments with equipment for permanent-echo calculation (e.g. at TRE) and Doppler radar (e.g. at ASE) had shown in principle that pulses could be stored as acoustic waves in a mercury delay line, but at that time, the techniques had not yet been applied to the long trains of pulses necessary to represent numerical information. Without a suitable read-write memory, general-purpose digital computers could not exist. The Cambridge EDSAC was, in May 1949, the first machine to exploit successfully the mercury delay line system in a fully functional stored-program computer. This system was not considered to be fast enough for MRS5. Other possibilities such as electrostatic CRT storage were still in the experimental stages in 1947.

In conclusion, the computer *hardware* developments at Borehamwood proceeded relatively independently from those of other contemporary design groups, principally because the MRS5 requirements for real-time operation placed severe demands upon arithmetic speeds obtainable with digital electronics. Furthermore, devising fast numerical algorithms for three-dimensional digital trajectory-prediction in MRS5 was a relatively new field of research. Finally, on a practical note, it was not certain that digital equipment based on thermionic valves (tubes) could be made reliable enough and compact enough to withstand the rigours of life at sea. One pulse lost from a radar system was recoverable; one pulse lost from a digital computing system could be catastrophic. It would not be until the mid-1950s that the inherently more reliable semiconductors began to replace valves. The basic properties of 'crystal triodes', or transistors, were demonstrated at the Bell Telephone Laboratories in America in 1947, but it was not until November 1953 that the first, modest, transistorised computer worked – at Manchester University [45].

2.6 The Elliott 152 Computer

The MRS5 project was given the internal number 152, in accordance with a Borehamwood classification system which, it is believed, gradually evolved over the years so as to reserve numbers in the range 100–199 for Admiralty-sponsored work, 300–399 for other classified Ministry of Supply work, and 400–499 for general-purpose computers sponsored by the National Research Development Corporation. We shall see later that this numbering system had largely become obsolescent by 1955.

Since the fire-control computer equipment lived on after the demise of the main MRS5 contract (see Sect. 2.4.4), it became usual at Borehamwood to refer to this first Elliott computer as ‘the 152’. We shall henceforth adopt this convention.

The dominant requirements for the 152 computer were as follows. It should have sufficient speed to be able to send/receive data to/from the radar unit, compute the trajectory calculations from radar-derived data, and then send updated target information to the guns – repeating this sequence at sufficient speed to enable an aircraft flying at several hundred miles per hour to be tracked and destroyed. As is described in Appendix 1, this amounted to an ability to perform the necessary axis-conversions and to produce one update of {range, bearing and elevation} every 4 Milliseconds. In modern terms, the Elliott 152 computer was the brains at the centre of a real-time, on-line digital control system. In particular, each transmitted radar pulse was triggered by the 152 computer, the radar therefore being synchronised with the computer’s internal clock. The central portion of the special ‘egg-box’ radar aerial, together with the Director’s electronics and hydraulics, performed electronic scanning of the target as previously described. Radar-derived data, together with the aerial’s angular position as read from an optical disc encoder, was transmitted as binary numbers back to the Elliott 152 computer.

The 10-in. diameter optical shaft-encoder disc on the MRS5 Director was a neat piece of advanced precision engineering [46]. Scribed with a pattern accurate to within one thousandth of an inch, the scale was projected onto a single photocell and photomultiplier, which was scanned by a CRT. The binary encoder not only gave a digital value of the current bearing but also the sine and cosine of this angle. The provision of trigonometric data produced a great saving of central computing time. (The alternative, namely sines and cosines stored in a fast look-up table within the 152, would have been very costly.) The 1948 shaft-encoder patent was filed in the names of J F Coales, N D Hill and S E Hersom (patent number 707212 dated 15 January 1948). This was also the first ever patent related to digital computing to emerge from the Elliott company. The encoder equipment is within the nacelle pictured in Fig. 2.7.

In the light of hindsight, the optical disc encoder patent could have been a huge money-earner for the company. However, as Norman Hill subsequently remarked [31], ‘Although we and our patent agents tried to anticipate every possible application for this invention we failed to realise that the reading of the marks on the discs could be achieved by many small photocells in parallel instead of one single moving light spot. Subsequently these discs were widely used [by others] but our patent was of no use because in every case the reading was done in parallel instead of serially’.

Details of the Elliott 152 computer are given in Appendix 1. The architecture was complicated, being based on low-level functional parallelism imposed on a bit-serial ALU. There were separate data and instruction stores. Each of four programs was stored in a read-only memory so that the calculations for bearing, range and elevation could proceed relatively independently.

In the words of Norman Hill [31], ‘It was decided to use a parallel system comprising essentially a series of units e.g. adder, multiplier, input, output, each operating in the same time scale with input and output gates which could be opened or shut simultaneously. Thus, at the expense of somewhat complicated programming, all the units could be set to operate at the same time and then reset to complete another series of simultaneous operations and so on. In this way we made a very fast, fixed-program real-time computer way ahead of its time’.

Here is a summary of the main characteristics of the Elliott 152, in modern terminology:

Word length	16-bit two’s complement integers, with the binary point being *two* positions from the most-significant end (see below)
Instruction length	20 bits
CPU clock-rate	333 kHz
Multiplication-time	60 μs
Input/output data-rates	From radar director: 70,000 bits/s in; 10,500 bits/s out
Primary memory	CRT electrostatic RAM, using the Williams Tube *anticipation pulse* method. 16 tubes storing 256 digits each. In modern terms, this gave 512 bytes of RAM

Numbers were represented in the Elliott 152 as two’s complement fractions, but with the implied point being *two* positions from the most-significant end. In the words of Ed Hersom, when describing a later Elliott computer called Nicholas [47]: ‘I decided that the binary point should be two from the most-significant end, because I expected to be undertaking a lot of trigonometrical calculations such as axis conversion. The most-significant bit would be the sign, and the one next to it the overflow bit. (I never gave the idea of a separate register for overflow a single thought, again on economy grounds). The overflow bit also allowed a function like sin(x) to equal 1, or even slightly more due to rounding error, without causing severe mistakes’. This convention of imagining that an ‘overflow’ bit exists within each word has sometimes been used on other computers. The Apollo Guidance Computer, a 16-bit machine designed at MIT in the early 1960s, used a somewhat similar scheme [48].

The fastest storage technology available in 1947, anywhere in the world, was the CRT system being developed by Williams and Kilburn at Manchester University. Borehamwood chose to develop its own version of this CRT system for the Elliott 152. Williams had filed his first CRT storage patent, using the *anticipation-pulse* method, on 11 December 1946. The first Internal Report describing Borehamwood’s CRT storage is dated 26 February 1948 (see Appendix 1). For a while, the storage

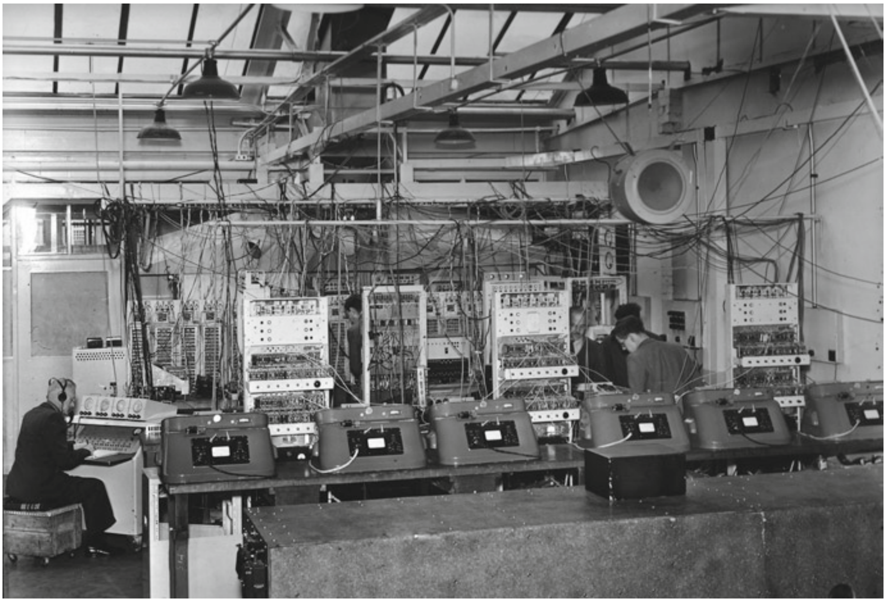

Fig. 2.8 The Elliott 152 computer in 1952, photographed during the off-line analysis of MRS5 radar data. The computer used 16-bit integers and 20-bit instructions, had a clock-rate of 333 kHz and a multiplication time of 60 μs. In modern terms the computer had 512 bytes of RAM, with instructions stored separately in ROM. The units in the foreground of the photograph are the set of six digital film cameras, each handling cassettes containing 400 ft reels of 35mm film on which was recorded radar tracking data. More photographs are given in [50]

group, first under M V Needham (Circuits Division) and then under R C Robbins (of the Circuits Division and then in the Computing Division), attempted to get the *anticipation-pulse* method of Williams-Kilburn storage to work at a pulse repetition rate of 1 MHz. Unsatisfactory results caused the clock-rate to be lowered to 333 kHz, some time in 1949. 333 kHz then became the standard clock-rate for all Borehamwood computers – and indeed for not a few Ferranti computers – for some years, as is described in Chap. 10. The 152's storage developments are discussed more fully in Appendix 1.

It would seem that initial development of digital techniques for use in the 152 computer began in the summer of 1947. In that year, D L Johnston of the Electrical Engineering Division started on the design of glass plate printed-circuit boards for the 152, intending to use the sub-miniature pentode valves (thermionic tubes) that were under development elsewhere. All through 1947 and 1948, therefore, the emphasis at Borehamwood was on developing the underlying technologies that would provide the necessary speed and reliability for the 152. It was probably not until the start of 1949 that work on what might be called the logical design of the arithmetic units of the 152 really got under way. By January 1949, when Harry Carpenter arrived, the overall systems architecture and the numerical algorithms for trajectory-prediction had not been decided upon. Carpenter was placed in charge of the central processor design. Incidentally, on the day that Harry first joined Borehamwood, Bill Elliott gave him a copy of Alan Turing's famous *On computable numbers* paper to read [49]. Harry, naturally, found it incomprehensible! He says [40] that he has often since wondered why Bill gave him (an engineer) this particular paper to read.

The people most closely associated with the implementation of the 152, under the general control of their respective Divisional Heads, included those named in Table 2.3. Since this list encompasses people from five Divisions, project co-ordination was sometimes problematic. The 152 project was supposed to have two types of regular (e.g. fortnightly) meetings: (1) A Steering Committee of Divisional Leaders and Archer-Thompson (the Laboratory's Security Officer), which mostly discussed non-technical matters; (2) a Systems Committee of engineers who were actually doing the design. Carpenter recalls that in his time at Borehamwood, the Systems Committee never met. He only found out about its nominal existence many years later, in retirement, when chatting about old times with Eric Whitehead [40].

In 1949, Carpenter, who was placed in charge of the central processor, decided on a modular architecture for the 152 (see Appendix 1).

In the rush to finish the Elliott 152 before the Admiralty money ran out, corners were cut. Carpenter was asked to take his engineers off the machine before he was satisfied about reliability. Matters came to a head when Coales ordered a partition to be erected which cut off the view of the machine from Carpenter's office across the open-plan factory bay at Borehamwood. One can imagine that tensions ran high!

The Elliott 152 computer carried out its first simple computations in mid-1950, according to a retrospective paper written in 1971 by Coales [46]. The first programs are described by S E Hersom, of the Theory Division, in an internal report dated 25 May 1950 (see Bibliography). The 152 can lay a claim to being the first

Table 2.3 Some of the people involved in the implementation of the 152

Name	Date joined EBRL	Area of design and implementation activity
Jim Barrow	Jan. 1948	Circuit & logical design
John Bunt	Sept. 1949	Circuit & logical design
Johnny Cane	Early 1948	Circuit & logical design
Harry Carpenter	Jan. 1949	Overall architecture; arithmetic unit design
D S Evans	1947	Optical disk encoder
Ed Hersom	Oct. 1947	Algorithms; functional specification; software
Andrew St Johnston	Autumn 1949	Circuit & logical design
Tom Ludlow	Jan. 1948?	Circuit and logical design
D L Johnston	Early 1947	Glass PCB design and construction
Norman Muchmore	1948	Power supplies
Maurice Needham	Oct. 1947	Initial CRT storage experiments
R C Robbins	Summer 1948	CRT storage
John Tyndale	1946 or early 1947	Cooling system

machine to attempt real-time digital process control, though a perusal of contemporary Borehamwood research reports suggests that it was only used for this purpose under test conditions, rather than in earnest. Taking a broader view, the field of process control is one in which Elliotts as a company, and John Coales as an academic researcher, were later to excel. The company's pioneering excursions into industrial automation are described in Chaps. 6 and 7; John Coales subsequently founded the Control and Systems Group at the University of Cambridge in 1953 after leaving Borehamwood.

The principal production work that the Elliott 152 performed was probably the analysis of MRS5 radar data, carried out in the spring and summer of 1952. This is described in Sect. 2.4.4 for the 'Netting' project. The radar specialists used the computer to analyse radar tracking data obtained from aircraft flight trials, with particular emphasis on the glint phenomenon. Data-capture was achieved in real time, but analysis was done later. The digital data, as described above, was first recorded optically on 400 – feet reels of 35-mm film, using six cameras simultaneously [50]. During subsequent analysis by the 152, the films were read back in a separate operation, using flying-spot scanners, tracking circuits, and high-speed servos to maintain alignment and to permit accurate start-stop. The optical films were developed at the Denham Film Studios, a few miles from Elliott's Borehamwood Laboratories. The subsequent use by Elliotts of 35-mm film stock for digital magnetic recording in the mid-1950s is mentioned in Chap. 10.

The 152 computer was, as John Bunt has remarked, 'a machine of remarkable power (when it worked), which employed every conceivable advance in technology known to man at the time. Printed circuits on glass plates, plated-through holes, deposited resistors, semiconductor diodes, plug-in units and so on. Some notable advances in techniques had been achieved in its construction, but unfortunately in a machine of its size, it was more often suffering from a breakdown than in robust health. I got to be quite good at locating faults in very quick time and Jim Barrow taught me how to repair faulty units by scratching out unwanted silver connections made by tracking across the glass and by using bits of wire to by-pass the plated-through holes. Between us we achieved quite remarkable running times for the machine before another breakdown occurred' [7]. To put the 'remarkable run times' in the context of 1950, John Bunt has also said [12] that: 'If the whole system could be made to work for a minute or two without breakdown – film readers and computer together – useful results were obtained'.

The problems of reliability had three main causes: (a) intermittent faults with the CRT storage system; (b) excessive heat generation; (c) rather optimistic physical design of the printed-circuit boards. The storage issues are described in Appendix 1. To cure overheating, Tyndale of the Mechanical Engineering Division designed what he called a *positive displacement wind engine*, *DPWE*, based on a large fan and wooden chamber or reservoir 'about 20 feet long and three feet high and wide', in the best Victorian engineering traditions. This solved the problem, but at the expense of excessive noise and oil pollution. The PDWE 'made a noise like the Gosport Ferry and had bearings that required greasing every morning' [7].

The printed-circuit problems, the responsibility of the Electrical Engineering Division, were not so easily rectified. There was electrolytic creep, or tracking, between adjacent printed silver conductors. The designer (D L Johnston) had, in the view of the Computing Division, tried to get more components per plate than was sensible, by doubling up on the edge-connectors. The mechanical design of the resulting edge-connectors left much to be desired, and many faults were found to be due to contact problems.

The lack of reliability notwithstanding, the 5-in. by 3-in. printed-circuit plates, shown in the photograph of Fig. 2.9, were a valiant attempt at packaging which was to influence Elliott's computer design philosophy long after the 152 had faded away. By the use of the (admittedly expensive) miniature pentodes that were becoming commercially available from Mullards in mid-1949, Borehamwood was able to pack a complete binary adder-stage on a single 5 × 4-in. plate. The multiplier consumed a total of 60 plates. The use of double-sided printing with plated-through holes, and deposited resistors etched to achieve the desired values, were two of the advanced features of Borehamwood's circuits that impressed visitors. More than one transatlantic visitor to the Laboratory urged Coales to take the technology to the market place and capitalise on the research [40].

Whilst all this hot technology was bubbling away to the north-west of London, there was another sort of activity coming to the boil at the main Elliott factory at Lewisham in the south-east of London.

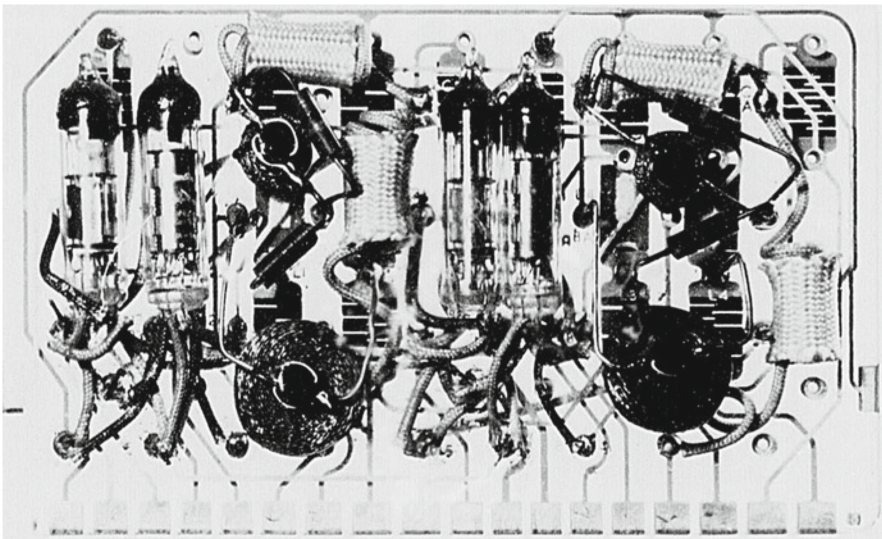

Fig. 2.9 The 152 computer used 5-in. by 3-in. glass printed-circuit plates, with double-sided printing, plated-through holes and deposited resistors. Four miniature pentode thermionic valves (tubes) are mounted on this plate

2.7 Enter the Entrepreneurs

We introduced Geoffrey Lee, the new go-ahead Managing Director of Elliott Brothers, in Chap. 1. Lee had by 1946 become a player in a wider circle of talented entrepreneurs whose ambition (it is deduced) was to run profitable companies that exploited the technical opportunities revealed by wartime R&D. By 1948, Lee was taking third place at Lewisham to Leon Bagrit and Lotti Ross, who were also introduced in Chap. 1. Of these three, Leon Bagrit provided the main entrepreneurial force. Behind all three of them lay the financial support of Higginsons.

Higginson and Company of Bishopsgate, London, a leading firm of merchant bankers, was founded in 1907. Higginsons was appointed managers from 1946 of the General and Commercial Investment Trust Ltd. – a fact which may have played a part in events at Lewisham. Subsequently, Higginsons merged with Philip Hill in 1951 to form Philip Hill Higginson & Co., then merged with Erlangers in 1959, then merged with M Samuels to form Hill Samuels in 1965, and finally became part of Lloyds Bank and the Lloyds TSB Group. It appears that Higginsons, knowing that the bank would have capital to place at the end of the war, sought advice on which industrial sectors were targets for profitable investment. They were told that the British instrument industry was ripe for development because it was characterised by a large number of small privately owned firms. It is not necessary to describe the details of all Higginsons' interactions with the instrument industry in the 1940s. Instead, what follows is a summary of events as they affected Bagrit, Ross and the Elliott company, drawing largely on the information in [21].

Like all engineering companies during the war years, Bagrit's company B & P Swift obtained plenty of government work manufacturing munitions and continued to expand. After a while, seeing the need for electronic instruments, Bagrit and Ross set up a subsidiary called Electromethods to develop and sell this type of device. This was possibly the first tangible sign of Bagrit's passion for electronic control – an area that developed into what became known as Automation. The full story of Bagrit's seminal influence in the introduction of industrial process control in the late 1950s is given in Chaps. 6 and 7.

Needing more manufacturing space, B & P Swift had leased two factories during the war. As hostilities ended, one of these premises had to be relinquished. An agreement was reached with Geoffrey Lee that B & P Swift and Elliotts would jointly apply to the government for part of the huge Short Brothers aircraft factory at Rochester Airport, where the RAF's four-engined Stirling bomber had been manufactured during the war (see Appendix 9 for more on the history of the Rochester factory). When the war ended, aircraft production at Rochester was rapidly curtailed, and in 1946 the government decided to concentrate all the Short Brothers' activities at Belfast. The Rochester factory became vacant. Bagrit's strategy was that Elliott's long-standing (though fading) reputation as a defence equipment manufacturer would strengthen B & P Swift's chances of acquiring the Rochester property. The bid was successful, resulting in the acquisition of about five acres of potential floor space [51].

Meanwhile, by the end of the war, Elliotts at Lewisham was a company now showing definite signs of decline. The influential and technically gifted Chairman Sir Keith Elphinstone had died in 1941, leaving only one member of the Board, D C Harben, with any real technical knowledge of the company's products. This greatly disturbed the Admiralty, which was wrestling with the problems of updating and supplying fire-control equipment to its ships. Elliotts was the prime developer and provider of such equipment. In 1943, the Admiralty had written as follows. 'Having regard to the variety and complex character of its manufactured products it would be reasonable to expect the firm to maintain an exceptionally large design and drawing staff capable of feeding new developments. This section, however, is not large enough in relation to the whole works activities. In the period 1936–39 of pre-war re-armament programmes, the firm progressively enlarged its scope and volume of production to meet Admiralty requirements and achieved a considerable increase over the volume handled in the period 1932–35. Since the outbreak of war, however, the preceding rate of increase has not been maintained and in comparison with various other Admiralty firms the overall increase in this firm's contribution to the war effort is not outstanding' [52].

Criticism was not confined to technical matters. In 1943, the Managing Director, L W Smith, was described by Admiralty officers [52] as 'not endowed with a faculty for adjusting human relationships on a sympathetic and harmonious basis' and the working conditions and pay of the staff were said to be 'manifestly the reverse of generous'. In the same year, the Ministry of Labour carried out a survey report LC.13399/43 which contained 'severe criticism of the firm's management and indicates poor utilization of labour and facilities' [52]. It is also very probable that, under the financial dominance of Siemens Brothers of Woolwich who were majority shareholders, Elliott Brothers had been starved of capital during the war. Indeed, the financial control exercised by Siemens Brothers is described in [52] as 'a millstone round the necks' and a 'hostile parasitic incubus'. Strong words indeed.

As mentioned in Chap. 1, in the summer of 1945, Higginsons arranged to buy out Siemens Brothers' holdings in Elliott Brothers. £90,000 of Elliott Share Capital was purchased at £6 per share and distributed amongst Insurance Companies and Investment Trusts. G R Lee was appointed as Managing Director in July 1945. At the time, Lee was also on the Board of B & P Swift. Higginsons placed a nominated member on the Board of Elliotts, as shown in Table 2.4.

Table 2.4 The board of Elliott Brothers (London) Ltd. in the autumn of 1945

Board member	Comments
Sir Walter Jenkin	Chairman; resigned in November 1950; replaced by Rudolph de Trafford, a partner in Higginsons
G R Lee	Managing Director; installed by Higginsons as MD in July 1945
D C Harben	Works Director; resigned in May 1947
L W Smith	Brother of R O Smith; associated with the company for many years
P J A Lachlin	A partner in Higginsons
R O Smith	Secretary; brother of L W Smith (see above)

Shortly after his arrival at Lewisham, Lee appointed a young B & P Swift Works Manager, Woodruff, to understudy Harben and employed another young engineer, Klepp from Smiths Instruments, to take charge of development work at Lewisham. Klepp was to become the principal liaison person between the Elliott Directors at Lewisham and Coales at Borehamwood [21]. Klepp and Woodruff were nominally under Harben, but actually they reported directly to Lee. It seems very probable that Harben, and others of the *old guard* at Lewisham such as L W and R O Smith, found themselves gradually distanced from the policy-making processes and they soon faded from the scene.

During 1946, Lee approached various smaller instrument companies suggesting merger with Elliotts, but none would agree. Then in January 1947, Lee put a plan for merger with B & P Swift to the Elliott Board. The older-established Board members, particularly Harben, felt that B & P Swift's profits were too low and that the proposed price to be paid for their shares was too high, so they opposed the merger. Shortly after this Board meeting, the diligent Harben took extended sick leave due to stress and effectively left the company in May 1947. In this very month, the merger between B & P Swift and Elliott Brothers took place. Immediately, Bagrit was appointed Managing Director of Elliotts in place of Lee, and Dr Ross became Technical Director. From that moment onwards, things were never the same again at Lewisham.

At about this time, as Coales recalled [21], the British security services (MI5) visited him at Borehamwood and 'specifically warned him against admitting Directors of B & P Swift of alien origin who became Directors of Elliott Brothers to the secret work'. A perusal of the Visitor's book suggests that MI5's visit may have occurred on 10 April 1947. On his part, Bagrit announced at an Elliott Board meeting that he could not tolerate a situation in which he could not know what was going on at Borehamwood and that therefore he must have managerial access to classified projects. Discussion on the matter was postponed to the next Board meeting, by which time Bagrit reported that the matter 'had been settled'. The first recorded visit of Bagrit to Borehamwood was on 30 April 1947, according to the Visitors Book. Surviving correspondence shows that, certainly by 12 September 1950, Bagrit was enjoying the full confidence of the security services [53].

Bagrit set about re-positioning Elliotts. Bagrit employed business techniques that Coales, removed as he was from the cut-and-thrust of the marketplace, found extremely worrying. For a start, financial control of Borehamwood was placed firmly with Lewisham. Coales found that his orders for equipment and payments to suppliers were being deliberately delayed. In a letter to Geoffrey Lee (Elliott's former Managing Director and still on the Board) dated 21 January 1948, Coales wrote as follows:

> 'It has now come to my notice that the Company [i.e. Elliotts] has been blacklisted in at least one credit circle and it is rapidly becoming impossible to obtain the supplies necessary to carry out work either commercial or for the Admiralty.
>
> 'There is already a very great delay in the placing of orders on our behalf by Lewisham, and it now appears that the organisation has, to all intents and purposes, broken down.

> There are, of course, two serious effects which arise from this situation. Firstly, that the sense of frustration of the staff here is increasing daily and it is impossible to prevent it becoming generally known that the Company is not paying its bills. The second effect is that not only is the goodwill of the Company as a whole being squandered but that, inevitably, the good name of the Laboratories is also being dragged down. So far, I have been able to maintain the high morale that was evident at the time of DNO's [Director of Naval Ordnance] visit but this is daily becoming difficult and unless immediate action is taken a crisis is likely to be reached within a few weeks.
>
> 'With regard to the second effect, it is clear that it is most important to maintain the good name of this Establishment [i.e. the Borehamwood Laboratories] since, if the Company does, in fact, founder, provided the goodwill of this Establishment is not impaired the Company can build up again around this Establishment.
>
> 'It is an intolerable situation that small firms should be put into serious financial difficulties because of the difficulties of this Company, particularly so when much of the work has been done under Admiralty contract for which the Company has, in fact, been paid by the Admiralty.
>
> 'Further, because the majority of our purchase orders are for materials to which the staff at Lewisham are unaccustomed, the fact that our orders have to go through Lewisham results only in very considerable delays and in a large number of queries which increases the work of our staff here. For this reason, a very great saving in manpower would be effected if the ordering was done direct from Borehamwood'.

After two more paragraphs of comment and suggestions, Coales' letter ends with this poignant paragraph:

> 'I very much regret having to issue what is to all intents and purposes an ultimatum but unless we can find some way of eliminating the delays, at any rate where the Admiralty work is concerned, I shall have to send copies of this letter to Mr Brundrett and Captain Lees and ask them what course of action they would suggest since under the present conditions I am unable to fulfil my obligations to the Admiralty. I realise that you are in a difficult position and I do not wish to embarrass you but there is no sense at all in my allowing the position to deteriorate to such a degree that there is little hope of retrieving it'.

We can now see that Lewisham was giving Borehamwood the cold shoulder, most probably because Bagrit considered that the activity at Borehamwood was not sufficiently directed towards either short-term or longer-term commercial profit. For his part, Coales clearly felt that Borehamwood was fulfilling its contractual research objectives and that Lewisham's problems were of its own making. Here, in truth, was an irreconcilable clash of cultures. On the one hand were Bagrit, Ross and Herzfeld, an entrepreneurial triumvirate who had ambitious plans to rescue the fortunes of the Elliott company. In the expression of the day, 'they meant business!' On the other hand was the scientist Coales who, as one loyal colleague was later to remark anonymously, 'was essential to the start-up of the Borehamwood Lab. but useless afterwards and not suited to the business world'.

In fairness to Coales, he did try strenuously to understand the economics of running an R&D department. The following section reveals the great personal struggle that consumed Coales in the period 1948–1951 as he fought to save the kind of research laboratory that he knew and loved. If the next section appears one-sided, it is because no official Elliott company documents have yet come to light that give Bagrit's responses to letters from Coales. Perhaps there weren't any. Bagrit had more than enough to think about at Lewisham, as he and Ross and Herzfeld struggled to turn round the fortunes of a seriously sick company.

2.8 Borehamwood's Financial Struggles

Coales has since stated that, at the end of 1947 and beginning of 1948, 'we thought Elliotts would go bankrupt. What we did not know was that Bagrit could go to Higginsons and borrow £500,000 on his note of hand! I made arrangements to borrow £5,000 from the bank on the security of my FSSU [Federated Superannuation System for Universities] Endowment Assurance policies, which were sitting in my safe at Borehamwood' [54]. Coales' plan was to go it alone. In January 1948, he produced a 16-page document entitled *Proposals for setting up the Research Laboratories of Elliott Brothers (London) Limited, Borehamwood as a separate company*. This report contained a detailed financial analysis of actual income and expenditure to date, plus estimates for 1948 and 1949. The proposal ends with the following note on the distribution of capital for the new Company:

'It is recommended that the Share Capital be limited to 15,000 ordinary shares of £1 each, of which 5,000 each be offered to the Business and Technical Directors. The remaining 5,000 shares should be offered to the employees of the Company. It shall be a condition that the ordinary shares must be held by the employees of the Company. The remaining £60,000 [required to float the Company] would, if possible, be obtained as a loan and it is proposed that the Government sponsored Industrial Finance and Investment Corporation for Industry be approached with a view to arranging this loan'.

Coales had obviously had enough of firms being bought and sold by City Suits! His document, however, was 'not yet distributed', according to a note on the title page signed by Coales and dated 29 February 1948.

A further draft report and financial analysis were produced at Coales' private request by Pennington & Son, solicitors, of Lincoln's Inn Fields, London, between March and October 1948 [21]. The invoice for £15-15s-0d, rendered to Coales by Messrs Pennington & Son on 29 October 1948, mentions 'long interviews with you with regard to the position of yourself and your staff and the Company's operations, and the proposed scheme for a new Company'.

In Table 2.5, extracted from information in [21], we summarise the actual research expenditure at Borehamwood from the start of operations to mid-October 1947 and Coales' predictions for 1948. It is seen that Admiralty contracts rise from about 50% of activity to 85% of activity, that a contract in the Physics Division to develop magnetometers for the Ministry of Supply (Air) rises from 0% to 8%, and that all other work is predicted to drop from 50% to about 7%. Under the 'Other work' heading comes the market-oriented developments being undertaken for Lewisham. John Coales' prediction of shrinking Lewisham work cannot have pleased Leon Bagrit.

Table 2.5 Analysis of percentage expenditure on labour and materials at Borehamwood, for the principal research projects in the years 1946–1948

Project, expenditure heading	1946 (%)	1947 (%)	1948 (%)
MRS5, labour	32	53	–
MRS5, materials	15	41	–
CDS, labour	19	10	–
CDS, materials	33	18	–
MRS + CDS, labour	–	–	85
MRS + CDS, materials	–	–	85
MOS (Air), labour	0	0	8
MOS (Air), materials	0	0	9
Other work, labour	49	37	7
Other work, materials	52	41	6

Coales described in [54] the usual basis in 1947 for calculating the annual profit allowed by the Admiralty on contracts. This was:

$$\{(7.5 \times \text{capital}) / (\text{annual turnover})\}.$$

Thus, if the capital is turned over once per annum, a profit at 7.5% of amount charged to the Admiralty would be allowed. If the capital is turned over twice per annum, then only 3.75% would be allowed, etc. When due allowance had been made for all items classed as 'capital', Coales was confident that the Admiralty would permit Borehamwood to make 7.5% profit on the MRS5 and CDS contracts. In addition to this, overheads were allowed to be charged at 108% on Admiralty contracts. These figures, of 108% overheads and 7.5% profit, are believed to have been considerably lower than the commercial and manufacturing targets to which Bagrit had been accustomed.

Later in 1948, Coales was to revise upwards his estimate in Table 2.5 of 'Other Work', which by then had included development of street lighting controls, colour printing controls, potentiometer recorders and plans to manufacture Flamitrol and Capacitrol devices under licence from the American company Wheelco. These estimates are shown in Table 2.6.

There is no evidence to suggest that Coales showed his private calculations to Bagrit. However, had he done so, the figures in Tables 2.5 and 2.6, encouraging though they appear, would hardly have impressed the industrialists unless more evidence had been forthcoming. One might conclude that Coales was now out of his depth. At the time, however, he was an honourable man, making great efforts to defend his staff and their research from what can only have seemed to many Borehamwood researchers to be the forces of darkness.

For Coales, this was indeed a most stressful period. In another letter to Geoffrey Lee dated 24 February 1948, but never sent [21], Coales opens with the following blunt statement: 'You are, I believe, going to the meeting at the Admiralty on Friday to discuss the future of the Research Laboratories at Borehamwood. Since I have

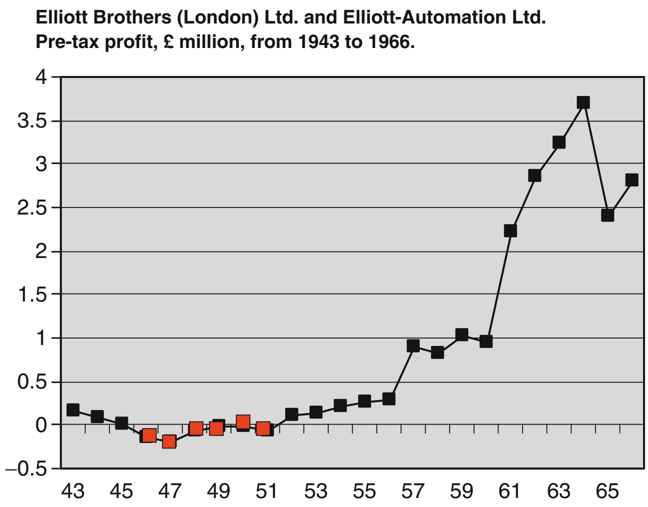

Fig. 2.10 Graph of the pre-tax profits of Elliott Brothers (London) Ltd. and Elliott-Automation Ltd., from 1943 to 1966. It is seen that Elliotts was trading at a loss from 1946 to 1951.The numerical data for this graph is given in Table 2.7

Table 2.6 Revised estimates on 'Other work' at Borehamwood, 1948–1949

	In 1948 (£)	In 1949 (£)
Estimated labour costs of other work	12,500	20,000
Estimated materials costs	12,500	20,000
Overheads (management, inspection, etc.)	5,000	8,000
Share of rent, rates, power, etc.	7,000	12,000
Notional profits on above	12,500	20,000
Therefore, total turn-over on other work	50,000	80,000

not been invited to attend the meeting, nor have you asked me to give you my views beforehand on a matter which vitally affects my own future and that of my staff, I am sending you our views uninvited'. Coales then goes on, for five typed pages, to state 12 points of issue, some of which are amplifications of the matters mentioned in his letter of 21 January (see above). Additional points raised include the following sentences:

(a) 'Failure to manufacture at Lewisham, equipment required by us after agreement has been reached that it should be done. The arbitrary stopping of work for Borehamwood without reference to me or anybody here and without even telling us that the work has been stopped'.
(b) 'There has been a complete refusal to spend the necessary Capital to provide even the bare necessities of furniture for staff engaged'.
(c) 'Before I joined, it was agreed that the Research Laboratories would be provided with a motor car, and later, it was specifically agreed with you and Mr Bagrit, that the black and white Vauxhall would be transferred to

Borehamwood as soon as a new Standard was delivered at Lewisham. This agreement was never implemented, apparently because Dr Ross damaged his own car and the Standard, as soon as it arrived, was handed over to him for his personal use'.

(d) 'Despite the fact that at Borehamwood we have had both people and facilities which could have helped the Company by the manufacture and sale of special instruments at a time when Lewisham's output was negligible, instead of being asked to help we were discouraged and even forbidden to do so'.

(e) 'The addition to the claims for payment by the Admiralty of what, in my opinion, are unreasonable sums for the work done at Lewisham and the failure to let me know what sums have, in fact, been claimed'.

(f) 'Although on my appointment as Research Director there was talk of my now being one of the "inner circle" whatever that may have meant, I have never been consulted about the Company's business, and I have, apparently, been kept as far as possible in the dark about the Company's financial position and the policy for the future. It is quite clear from this that either the Board of Directors has no confidence in my ability to help the Company through a difficult time and does not wish to enlist our help, or else it does not require a Research Director. This is born out by the fact that the Organisation Chart shows a Research Laboratory at Rochester of which I have not been officially informed and concerning which I have not been consulted. This is a very strange state of affairs'.

Coales concluded thus: 'To sum up, there is a clear indication of determination on the part of you and Mr Bagrit to maintain a tight control of all that goes on in the Research Laboratories by means of financial sanctions, even in the case of contracts for the success or failure of which we are entirely responsible. Research cannot flourish in such an atmosphere'. True though this last remark may have been, it would have taken a very well-established and wealthy parent company, such as GEC, to have supported the kind of research program that Coales had in mind. At that time, Elliotts could not afford the luxury.

Geoffrey Lee, the putative recipient of the above letter, quickly faded from the scene, and after 1948 Leon Bagrit became the main target of John Coales' frustrations. Although seldom mentioned specifically in surviving company documents, the name of Dr Lotti Ross should be implicitly coupled with that of Bagrit. This coupling is explained in a retrospective comment by Hugh McGregor Ross, who left Borehamwood to join Ferranti Ltd. in 1953: 'John Coales, who was and is one of my 'hero friends', is of the highest integrity and capability. … Leon Bagrit was an entrepreneur of extreme skill and a true visionary … Dr Ross was very acute in his appreciation of technical situations and tended to make up his own mind. Leon Bagrit relied exclusively and implicitly on Dr Ross in connection with all technical matters… Now it was obvious to me, even at my third level [down the management hierarchy], that John Coales and Dr Ross, who were as different as chalk from cheese, would have difficulty in agreeing on what was the right course of action, what were the right projects to work on, what was the best way of spending the limited funds. … It was inevitable that any difference between them would turn into a difference between Coales and Bagrit. And equally certain that Coales would be the loser and have to leave' [55].

Coales battled on for four more years, finally leaving Borehamwood in April 1952, as described in Chap. 5. Both Coales and Bagrit and the research activity at Borehamwood all went on to achieve greatness in other directions – so we shall see that there *were* happy endings. However, let us finish this very stressful part of the Borehamwood story with two revealing anecdotes.

One lunchtime in about 1951, Leon Bagrit and Lotti Ross came into the canteen at Borehamwood with Coales. Ross (or was it Bagrit?) was seen to hand his hat and coat to Coales, as if to a cloakroom attendant at a Club. Many staff remember being shocked by this incident; indeed, Hugh McGregor Ross recalls it as his trigger for searching for a new job [56, 57].

A couple of years later, Laurence Clarke remembers that there was a row of parking slots outside Elliott's main Borehamwood building. 'The one nearest the front door was for important visitors. There was an enthusiastic security guard who, when a Rolls Royce pulled onto it, rushed up and told Dr Ross that he could not park there because it was reserved for the Managing Director. Ross merely said with a smile - "And who do you think I am – Robin Hood?"' [58].

2.9 Pulling Out of the Mire

John Coales resigned from Borehamwood in April 1952. Although he had not the satisfaction of seeing his cherished MRS5 project accepted for sea trials with the Navy, he did negotiate an arrangement with the National Research Development Corporation whereby the digital technology of the Elliott 152 computer was eventually transformed into a successful range of commercially available computers (the Elliott 400 series machines; see Chap. 5). After leaving Borehamwood, John Coales was invited in 1953 to form an Automatic Control Group in the Engineering Department at the University of Cambridge and was appointed an Assistant Director of Research. In 1957, he became a founding member of the International Federation of Automatic Control (IFAC), and by 1966 he had become the first Professor of Control Engineering at the University of Cambridge. He was elected a Fellow of the Royal Society in 1970, was the President of the Institution of Electrical engineers in 1971/1972 and was appointed CBE in 1974. One of his last professional activities was the initiation, in 1985, of a project to produce a history of naval radar during World War Two [3]. He died in Cambridge on 6 June 1999 aged 91. For further biographical details, see [1, 2].

Following Coales' departure from Borehamwood in 1952, there were a few months of uncertainty during which day-to-day administrative decisions at the Laboratory seem to have been the responsibility of W A P Wykeham, who had been appointed General Manager by Bagrit in the autumn of 1951 [59]. Coales has remarked [60] that Bill Wykeham was an old friend from ASE days and his appointment 'didn't cause any real trouble'. The summer and autumn of 1952 was a period during which research decisions at Borehamwood were the province of a group of senior divisional heads known to junior staff as the Fog Box – a reference to meetings held in a smoke-filled office under the effective chairmanship of Alex Cochrane and including Norman Hill and Bill Elliott. The 'fog' also gave a hint of uncertainly. Would Borehamwood be allowed to survive as a leading-edge electronics research centre, after Leon Bagrit had ordered what he called a necessary 'pruning' of staff numbers? Indeed, would Elliott Brothers (London) Ltd. survive as an independent company?

In fact, the period 1952/1953 did see staff resignations at Borehamwood but the net loss was nowhere near the rumour [10] that 'just after Coales left, 30% of staff was asked to find another job within 3 months'. Norman Hill remembers [26] that about 15% of staff were effectively sacked by the Fog Box, after 'many afternoons and evenings were spent in going through lists of staff selecting those who were to be asked to go, taking into account factors such as length of service, age, children, mortgages being repaid etc. while meanwhile the whole staff were in turmoil awaiting their individual fates…. We all felt that the astonishing technical achievements [of MRS5, CDS, etc.] had not been recognised, appreciated or understood by company management at Lewisham'. A consequence of all this was that some good people, such as Alex Cochrane, *chose* to leave (in 1954), but some of the new arrivals during this period were to prove equally talented. Bill Elliott managed to ensure that no member of the Computing Division was asked to leave the company during the Fog Box period [61].

Direction of the Borehamwood Laboratory was soon taken over by an ex-Naval man, Commander Henry Pasley-Tyler, known to all as 'P-T'. He had actually been appointed to the staff by Bagrit in July 1950, as someone who would liaise between the Admiralty and Elliotts at a time when tensions between Coales and Lewisham were threatening to disrupt the whole company. Regrettably, P-T became known as 'Leon's Spy' and Coales tended to freeze P-T out of Borehamwood staff meetings. However, by mid-1952 Pasley-Tyler seems to have gained the confidence of the research staff and henceforward became an effective and respected top-level negotiator in Borehamwood's research contracts, especially those involving the Ministry of Defence.

Meanwhile, Elliott Brothers (London) Ltd. was pulling back from the brink of insolvency. In Table 2.7, we give the pre-tax profits over the period 1943–1967, culled from the sources listed in [62]. It is seen that the company traded at a loss during the financial years 1946–1951. From 1952, although Coales' departure may have dented the morale of the research staff at Borehamwood, the company as a whole began to make real progress in the marketplace. From 1956, the company's main trading name was changed to Elliott-Automation Ltd.

Behind the scenes, the company's financial fragility remained for a couple of years after Coales' departure. An article in *The Statist* for 13 February 1954 stated that: 'The company still has, however, a substantial bank overdraft (amounting at present to approximately £290,000) and the directors consider it a matter of commercial prudence now to raise additional finance by the issue of further share capital…. The issued capital after the proposed rights issue has taken place will amount to £308,000 in Ordinary stock and £150,000 in Preference shares'. We pick up the financial threads again in Chap. 13.

Table 2.7 Pre-tax profit (£m), for Elliott Brothers (London) Ltd. and (from 1956) Elliott-Automation Ltd. over the period 1943–1966. This data is shown graphically in Fig. 2.10

Year	Pre-tax profit (£m)
1943	0.154
1944	0.079
1945	0.016
1946	–0.157
1947	–0.198
1948	–0.077
1949	–0.012
1950	–0.018
1951	–0.077
1952	0.102
1953	0.143
1954	0.223
1955	0.261
1956	0.293
1957	0.91
1958	0.82
1959	1.02
1960	0.96
1961	2.21
1962	2.86
1963	3.24
1964	3.70
1965	2.39
1966	2.81

Although the Elliott company's liquidity was modest in the early 1950s, Coales' legacy of research enthusiasm and innovative prototyping was flourishing at Borehamwood. Here are some technological highlights of the early 1950s, arranged chronologically:

1951 Mopsy shipborne anti-aircraft missile project initiated, leading in 1952 to a prototype radar with the renowned Elliott Cassegrain aerial (see Chap. 11)

1952 The Elliott Nicholas computer first worked (see Chap. 8)

1953 The Elliott 401 computer first worked (see Chap. 5). Also, an Aviation Division was established and research started on the design of a three-axis autostabiliser for the Lightning Mach 2 fighter. This was to lead to Elliott's involvement in world-class avionics, as recounted in Chap. 12

1954 The huge TRIDAC analogue computer was delivered to RAE Farnborough (see Chap. 4). The Elliott 153 computer and the 311 (Oedipus) were delivered to classified GCHQ locations (see Chap. 3)

1955 The Elliott 403 (WREDAC) was delivered to Woomera, Australia (see Chap. 3). The first of ten Elliott 402 computers was delivered (see Chap. 5). Elliotts get a contract to develop the inertial navigation system for the Blue Steel nuclear missile

1956 The first of 33 Elliott 405 computers was delivered (see Chap. 8)

The above list highlights computing achievements, in line with the main subject of this book. However, the sale of digital computers probably only accounted for less than 10% of the total sales income of the Elliott-Automation group of companies (see analysis in Chap. 13). Turning to other Borehamwood activities, Bob Ford, who joined Borehamwood in July 1951, describes the period 1955–1965 as ‘the hey-day of the company when we were all inspired by Bagrit’s vision of ‘Automation’ and thriving under his divisional structure was a great time’ [5]. Bob worked in the Guided Weapons Division at Borehamwood when it was formed in 1952, went on to be Head of Airborne Radio & Radar Division and left the company in 1969 to join the Negretti & Zambra Group – eventually becoming Chairman.

We shall see in later chapters that the traditions of technological excellence, established by John Coales at Borehamwood, outlasted both Leon Bagrit and Elliott-Automation and thrived especially in the area of avionics under new company structures. In Chap. 3, we start by describing three secret digital computer projects that were completed in the period 1954–1956. Indeed, both Chaps. 3 and 4 are primarily concerned with defence-related applications, both analogue and digital. Readers with little interest in the military may understandably be tempted to skip to Chap. 5 where the civil applications – the ploughshares from swords – are introduced.

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