Early Computing in the Aircraft Industry: Avro's at Chadderton

Avro's, as the aircraft company of AV Roe was known, took delivery at its Chadderton factory of a large-scale scientific computer in 1954. It was a Ferranti Mark 1* from the nearby factory of Ferranti's. The computer consisted, inter alia, of a drum for background storage and 12 cathode ray tubes for temporary storage, plus numerous valves and other components on racks, all connected by wires of various colours in great quantity; input was by means of 5-track paper tape, as was output.[i] The machine generated 8kW of heat which necessitated a refrigeration unit, also used by the engineers on occasions to cool drinks. It was housed in a purpose-built room of which the walls were screened by copper mesh to avoid interference with the bits (binary digits) stored on the face of the cathode ray tubes, with power obtained directly from the local power station at Chadderton to protect it from power cuts and fluctuations of power. Everything possible was done to provide the company's considerable investment with a near-perfect operating environment.

However good the hardware, it was the uses to which it was put by means of software that would allow the computer to pay its way, at the same time advancing the aircraft industry, enabling it to produce results faster and more accurately. Avro's was at the cutting edge, taking advantage of the computer which only recently had been known as an electronic brain.

Chadderton, Manchester, was the home of the Vulcan bomber, which at that time cost £250,000. It was manufactured on the shop floor there, the fuselage and delta wings, together with associated parts, being shipped separately on long low-loaders to the Avro airfield and facility at Woodford where it was assembled and flight tested. Three wind tunnels were also housed at Woodford: low-speed, the cross-section of which was large enough to walk into, necessary to mount a finely crafted wooden model (of a wing, say) on a sting; a medium-speed tunnel, and a high-speed tunnel with a very small working section, the model for this being of metal. (Tunnels could be blown at subsonic, transonic, and supersonic speeds, as appropriate.)

Many thousands of calculations are necessary to arrive at the optimum design for an aircraft; they were previously carried out on analogue devices when the design engineers would laboriously crank a handle to achieve the results. Two teams of mathematicians were engaged to write the necessary programs (software) for the computer: one group for stress, the other for aerodynamics. Ferranti's provided some basic software, including subroutines which could form part of a program written by a mathematician. Everything was in machine code: there was no such thing as autocode at that time. Moreover, the machine operated in fixed-point, integers only. To achieve floating point a short subroutine had to be written and included in the program. These early programmers were the pioneers.

Groups of 5 bits represented a character, the 32 possible characters of 5-track paper tape, known as the order code. (The least significant side is at the right.)

00000	0	ϕ	01000	8	B	10000	16	J	11000	24	S
00001	1	£	01001	9	C	10001	17	K	11001	25	T
00010	2	½	01010	10	D	10010	18	L	11010	26	U
00011	3	0	01011	11	E	10011	19	M	11011	27	V
00100	4	@	01100	12	F	10100	20	N	11100	28	W
00101	5	:	01101	13	G	10101	21	P	11101	29	X
00110	6	$	01110	14	H	10110	22	Q	11110	30	Y
00111	7	A	01111	15	I	10111	23	R	11111	31	Z

Note that the alphabetical sequence omits the letter O since the character (or 0 called O!) had already been used for 3. Holes in the paper tape represented 1s, no hole a 0. Reading from the right, a small sprocket hole between tracks 2 and 3 defined the left and right of the tape as well as being essential for the tape reading mechanism. To signify the beginning of a tape, there would be a few inches of blank tape followed by about 2 inches of binary 14 codes – a strip of the H character, a run where the middle 3 holes are punched. Similarly, the end of tape was denoted by a run of Zs or binary 31 (all holes punched) between stretches of blank tape. Thus if a tape was dropped, there was no doubt as to the beginning and the end – added to which the computer needed to know the start and end of input.

The combination of 4 codes represented functions. It was functions the mathematicians used in groups of 4 to write a program on coding sheets. Although there were computer assistants to punch their programs and data for the individual programs, all programmers were well-versed in punching their own coding and reading perforated tape. Double-punching was the best way to detect errors, when the two punched tapes, allegedly identical, were examined under an Anglepoise lamp for possible discrepancies.[ii]

Programmers would develop their own programs on the computer, fault-finding in sessions of perhaps half an hour. When they were developed, and added to the program library, it was possible for a computer assistant to take over production runs on the computer with new data applied to the program; even so, many programmers preferred to run their own, especially if a run would not be straightforward; for example, the inversion of a large matrix. Here the matrix had to be partitioned and run in sections, with intermediate output providing input for the next stage. This was necessary owing to limitations of storage. Large chunks of machine time would be booked for such production runs. Usually the operator would be watching the countdown of iterations on the B-lines displayed on a monitor mounted on the computer console to check progress. (The primary use of B-lines was to modify instructions.)

The auxiliary store, the drum, was large, but with slow access speed, whereas the access speed of the working store, the cathode ray tubes, was fast, but limited in capacity. Transfer speeds were slow, and programmers were at pains to minimize them. A good programmer was often judged by his space-saving techniques which resulted in faster running of his program as well as great personal satisfaction.[iii]

Groups of 4 characters were used to represent functions, for example that commencing with J being for addition, K for subtraction, and M for transfer. Subroutines would be incorporated in programs, early ones being supplied by Ferranti's.[iv] By the end of 1955 there were 29, referenced by an identifier A1 to A29. These included, for example:

- basic operations
  - write, page punch, multi-page print, factored input, factored output
  - integer outlay, decimal outlay

- floating point sequences
  - output, decimal input, decimal output

- trigonometric functions
  - cosine or sine, natural logarithms
  - floating point cosh or sinh

- others
  - safeguard, rollcall

One function of the computer was the hooter, which could be included in the coding of the program to alert the operator that the end of a section had been reached. It was sometimes used for another purpose, as when Prince Philip came to view the computer installation it played God Save the Queen.

The software for the Vulcan Mk IIIC was building up, as was the design knowledge gained when the results were analyzed. Not all software was written specifically for the Vulcan, the company's military jet bomber, or the 720 rocket interceptor, with its distinctive 'knitting needle nose' as one female programmer described it (this machine was still at design stage).

Numbering for programs started at 50, the last number allocated being 142 by the end of 1957, development continuing on the majority although also providing results. Among the many programs were those developed for basic operations as well as specific projects, of which many examples are listed in the Appendix.

Paper tape output from the computer would be run through off-line on a Creed teleprinter. Later 1957 additions were a card-tape converter and a tape-card converter. These were designed to enable the transfer of work carried out on Hollerith punched cards to be input on tape to the computer, and vice versa. Not a great success, alas.

The mathematicians at Chadderton were not the only Avro employees to use the computer. All work on missiles was carried out at the Woodford site. This meant a car-load of mathematicians from Woodford would regularly descend on the Chadderton site to run their programs. This was secret work, and no one was permitted to enter the computer room when Woodford staff had booked the machine. On returning to Woodford they would take all paper output; indeed nothing was left in any waste bin.

Computer time was also taken by Armstrong Siddeley's staff. Programs were run for the design of aero engines: one was the Mamba, with contra-rotating propellers, installed in the Fairey Gannet used for coastal work; another was the Viper which went into the Jet Provost trainer. Armstrong Siddeley's would buy time on the Avro's Mark 1* until it took delivery of its own machine in 1957.

Research on machine-tool control was carried out in the Computer Department at Chadderton, with a view to making metal models for the wind-tunnels if I remember rightly. This was in 1957. The first output tapes were prepared on the computer, and run through the computer-controlled machine. Unfortunately, the joints were only finger-tight, with the result that oil was sprayed under pressure all over the lab.

I recall the day too when the government contract for the 720 rocket interceptor was cancelled. This work had been the mainstay of the drawing office. The following day it was impossible to hear yourself speak for the noise of paper being torn up. The next week the office was clear, all drawing office staff having been made redundant. A few designers remained at the end of the design office, engaged on testing early computer-assisted design (CAD) equipment, but that was all. At the other end an area was screened off for the New Projects office, to which entry was not permitted. It led to more work for the computer.

There was continual development, the aircraft industry leading the way with scientific software, much as in the 1980s the defence industry led the way for CALS (Computer-Aided Acquisition and Logistic Support), based on the SGML (Standard Generalized Markup

Language) standard for structured information systems, and conformity to which was a requirement of the US Department of Defense. The UK Ministry of Defence followed suite, with companies such as British Aerospace (into which Avro's had merged) and Rolls-Royce needed to conform in order to gain contracts. Then came the Web, and the rest is history.

When I started at Avro's in the mid-1950s, four Shackletons were parked on the shop floor, the aircraft sometimes described as 100,000 rivets flying in close formation. This aircraft had not benefited from the design by a digital computer, but was based on experience gained from the Avro Lincoln bomber. Used mainly for long-range maritime reconnaissance work, it continued in service somewhere in the world for many years. As for the Vulcan, the first time I saw one was in the course of manufacture on the shop floor at Chadderton, then on another day being taken to Woodford to see one on the runway; I walked under the bomb bays, marvelling at the size. I saw the last one flying over my home in 2015 – after 60 years in service, now too expensive to maintain and fuel. Together with the Lancaster bomber, these aircraft were indicative of the ethos at Avro's, with Sir Roy Dobson at the helm. He led the way whether for the actual design of the aircraft or for the means of ensuring the calculations were correct. No wonder he bought a large-scale scientific computer for his designers.

Ferranti's sold seven Mark 1* computers as an arrangement with NRDC (National Research Development Corporation) which had sponsored the computers for onward sales, although the first for the Ministry of Supply may not have been associated with the NRDC agreement. This was purchased by the Ministry of Supply (1953), and would have been the one that went to the Government establishment at Fort Halstead in Kent, used by some of the early programmers at Avro's until their own machine was delivered in 1954. Other computers went to AWRE (Atomic Weapons Research Establishment) in Aldermaston (1954), and another purchased by the Ministry of Supply which must have been that installed at GCHQ (Government Communications Headquarters), Cheltenham (1955), at that time very much a secret establishment, Armstrong Siddeley, Coventry, having the last in 1957. The other two were exported, one to Shell Labs in Holland (1954), the second to Italy for the National Institute for the Application of Mathematics in Rome (1955). Eventually that at GCHQ was sold on to Armstrong Siddeley's for spares for the machine that company had purchased. The cost of a Mark 1* to a customer is recorded as being £83,000, £100,000 if sent abroad.

Appendix

Many of the titles issued for software projects:

- basic operations
    - simultaneous equations, solution of 1st order non-linear differential equations, matrix inversion, evaluation of convolution integrals, stress/strain analysis, polynomial quadratic factors, evaluation of convolution integrals, expansion of a determinant as a polynomial, polynomial quadratic factors, overall modes by branch system

- aircraft general
    - flutter determinant, flutter coefficients, Richardson's method flutter derivatives, forced flutter vibration analysis, balance calculations, frame stressing, Multhopp subsonic load grading, Weber and Newby chordwise loading, variation of friction drag, weight and stress data scheme, integration of control surface derivatives, frame stressing, open and closed loop frequency response, calculation of pressure heights, heat transfer coefficients, calculation of the centre of gravity

- wing specific
    - Schuerch wing stressing analysis, Williams wing analysis, distributed flange wing analysis, wing stressing by plate theory, Kuchemann wing loading, wave drag, wing lofting calculations, harmonic analysis, calculation of lift and moment, anti-icing heat flow, Etkin-Woodward wing loading, matrix for wing pressures, calculation of wing twist, supersonic wing wave drag

- sandwich data
    - honeycomb sandwich data, corrugation sandwich data

- engine specific
    - design of engine intake, engine inlet data reduction

- performance
    - climb performance, descent performance, rolling power, coefficient of aerodynamic stability equation, refuelling system, fuel sloshing, engine performance, single leg undercarriage performance, cruise performance, general climb and descent performance, whirling speeds, take off and landing performance

- wind tunnels
    - supersonic wind tunnel nozzles, wind tunnel wall control

- machine tool control

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[i] Binary working for the computer was enabled magnetically on the drum coated with nickel particles, which were magnetized north/south or south/north; electronically on a cathode ray tube as charge or no charge; on paper tape as hole or no hole; and electrically along a wire as pulse or no pulse.

[ii] A duralumin hand punch, made by the engineers at Avro's, and opaque sticky tape judiciously applied to both sides of the paper tape, were used to rectify errors.

[iii] At Avro's Ron Lane was a master of the art.

[iv] Ferranti's also supplied a routine for the solution of a set of 84 simultaneous equations (written by Mary Lee Berners-Lee when employed by Ferranti's). This was used for wing stressing, for example.

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