Central Computer for aircraft Saab 37, Viggen

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Abstract: In the beginning of the 1960s it was decided that the multipurpose attack/fighter Saab 37 Viggen should be designed as a single seat aircraft. A central computer and a head-up display made it possible to dispense with the need for a human navigator. The computer was the central computing and integrating unit for all electronic equipment to support the pilot. This computer, CK37 used in the Saab AJ37, was the first airborne computer in the world to use integrated circuits (first generation ICs). Almost 200 computers were delivered 1970 -1978. The function was reliable and the computers were still in operation, with upgrades, at the early beginning of 2000`s.

Key words: Aircraft computers, CK37

1. Background

In the early twentieth century there were twelve Swedish companies involved in the manufacture of aircraft. They had, however, no support from the Swedish Defence Department. Later, in 1932, Parliament decided that Sweden should be self-sufficient in the supply of military aircraft. The company Saab (Svenska Aeroplan AktieBolaget) was established in 1937 and was contracted by the Swedish Air Force to deliver military aircraft. Three types of propeller aircraft were successively delivered. The international tension grew after the Second World War and the Saab technical ability and capacity was used for new advanced developments. From 1950 four new subsonic jet aircrafts were delivered. The most famous one was the fighter Saab 29 “Tunnan”. In total 661 Saab 29 were delivered in the period 1950-1956 and made the Swedish Air Force the fourth largest in the world. From 1960, three military supersonic aircraft were delivered. These were the Saab 35 Draken, the multipurpose Saab 37 Viggen and Saab 39 Gripen. Saab has produced 14 different types of military aircraft plus four civil types.

Extensive calculations of aerodynamic and material strength problems are necessary in the development of an advanced aircraft. Saab started early to use simulators and calculation machines. An analogue electronic simulating machine SEDA (Saab Electronic Differential Analyser) was used from 1956 for problems in the missile and aircraft design. The first electronic tube computer in Sweden was BESK (Binär Elektronisk Sekvens Kalkylator). Very soon after this computer’s introduction Saab became one of its biggest users. However, this computing capacity was not enough and Saab built its own advanced copy. This was used from 1957 and was the second powerful electronic computer in Sweden.

In 1957 the Royal Swedish Air Force (later Air Material Department, FMV) authorised Saab to make a preliminary study of an advanced robot for "attacks against harbours and establishments on the other side of the Baltic Sea". Part of the navigation system was a computer. A preliminary report discussed requirements on speed, compact design and low power consumption, which could be realised with transistors, ferrite core memory and converters for analogue signals. The project, however, was closed in 1959 in favour of a new aircraft project which was the multipurpose Saab 37 Viggen.

2. A Central Computer

2.1. Digital revolution in an aircraft

Both the Air Force and Saab discussed if the new aircraft, Viggen, should be a twin or single seat plane. A navigator helped the pilot with navigation, radar reconnaissance and other things in earlier military aircraft. It was decided to investigate if the functions performed by the navigator could be replaced by electronic equipment. Analogue systems in earlier aircraft, as in the 35 Draken, were expensive to maintain and change, and also had limited accuracy. Reports from USA indicated similar experiences and pointed to the digital calculator as an alternative. Evaluations at the Air Force and Saab showed that it would be quite possible to replace the navigator's functions with a digital computer. This resulted in a general overhaul of all electronic equipment in the aircraft and ended in a system as shown figure 1. The process was not easily achieved and several aircraft designers were very doubtful of the concept. Several task approaches and specifications were written and discussed before a general consensus of **one central computer** for the aircraft was reached. Later on it was known that the USA-aircraft A-7D had been equipped with a computer system.

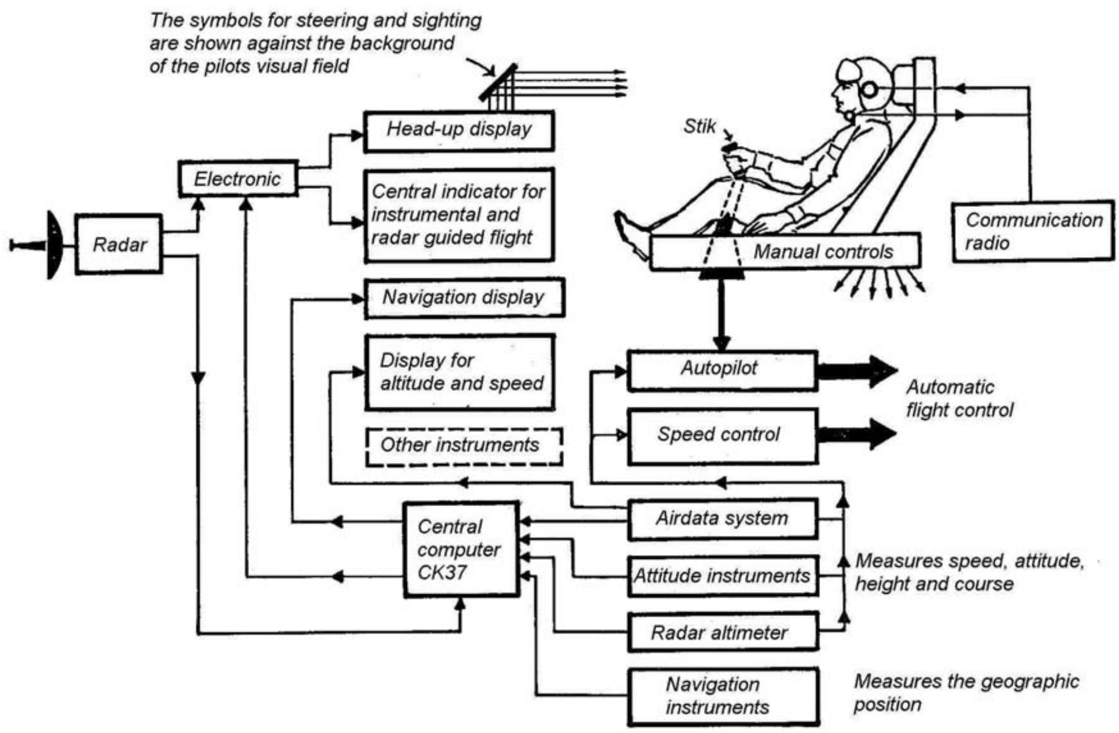

Figure 1, Electronic Equipment in Viggen

An important advantage of using a computer was the flexibility of programs and also that constants and tactical behaviour could be changed easily. The program functions could be developed in successive editions during the whole period up to serial delivery. Later these advantages were to prove much more important than was expected at the time of decision. The interaction between pilot and machine also came to be a very important area of development.

2.2. Computer prototype

It became necessary to give a practical demonstration of a digital computer using transistors, core memory and analogue/digital conversion. The Swedish Air Force commissioned Saab to build a prototype and to show if it would be feasible to use such a computer in the new aircraft. The prototype was finished in 1960, had a weight of 200 kg and was placed on a table. The computer worked with a word length of 20 bits and had a calculation speed of about 100.000 instructions /sec. It was equipped with two ferrite core memories, one for programs and one for variable data and had fast converters for analogue in/out signals. About 5000 transistors and 25.000 other components were used. Sighting- and navigation programs were executed during demonstrations of the computer capabilities. The computer was named SANK (Saabs Automatiska Navigerings Kalkylator). It was also shown that a more compact design was possible for airborne use. This prototype was the origin of both the airborne computer Saab CK37 and the Saab D21which was to be used for commercial applications.

Figure 2, Computer Saab SANK/D2 with strip reader, punch, digital display and the operator.

2.3. System development

At the same time, the System Department at Saab studied how a computer could handle navigation and information from other electronic equipment in order to present the necessary information to the pilot. The introduction of a head-up-display and a central computer made it possible to dispense with the need for a human navigator, see fig 1.

The computer was like a spider in the web and its function confused many designers. An early proposal of possible functions of a computer and its author were considered as "a danger for system 37". It was a pioneering exercise in conjunction with other equipment suppliers to develop this new electronic system. Most of the electronic equipment and instruments were of analogue type. Part of the job was to specify all signals, both analogue and digital, to and from the computer. Saab was designated as the main supplier of the system and earlier suppliers of electronic equipment got a changed role. Finally the computer was given the name CK37 (Central Kalkylator).

A new way to test parts of the system programs was early introduced through connecting the SANK/D2 computer, 2.2, to an analogue computer in a hybrid simulation. An important part of the development of hardware and software was to determine computer speed, instruction types and memory size. The speed was determined by the requirement that the entire program should be executed within max 100 milliseconds. The memory sizes became a compromise between cost, physical size and the volume of the program. Several times the program code had to be optimised to fit into memory and time. The System Department prepared flow-charts, program blocks and programming. A special assembler with interpreter were developed and used. The computer programs were also tested in realtime simulation in a prototype CK37 connected to the analogue computer SEDA.

Later on the whole electronic system, computer and co-operating equipment, was connected in a "System Simulator" configuration on the ground, where the whole system, "flight mission", performance could be checked before flight. A program co-ordination function was established to keep track of all variables, names, routines, instructions, archives and changes. Many new administrative routines had to be introduced. System reliability was calculated as MTBF (Mean-Time-Between-Failures). This work resulted in a total electronic system reliability of the same order as the basic aircraft. The system architecture and related routines were then transferred and improved from the attack version, Saab AJ37, to the fighter version, Saab JA37, and also to the next generation, the Saab JAS39 Gripen.

3. Computer development

3.1. Computer design and specification

It was a real challenge to develop a computer for the aircraft AJ37 Viggen. The design team of young engineers had an inspiring job. The requirements and design of an airborne computer was almost unknown. Component and computer development in USA was followed in magazines. General computer development in the industrial area could also be followed, especially the in-house commercial Saab D21 system. Much had to be learnt by first hand experience, e.g. component reliability, logic circuit design, transistors for core memory and power unit, handling of in/out signals, reliable soldering, testing, maintenance and quality control. A compact and stable mechanical design that could withstand vibrations and shocks had to be designed. Circuit solutions for arithmetic calculations, converters for analogue signals with adapters and power supply were also investigated. Electronic circuits had to work reliably between –40 to +70 degree C. Different circuits, together with mechanical parts of the computer, were built and tested. Several tests were extended over months to examine long term reliability and environmental hardiness. This pioneer work extended over several years with many revised specifications and two generations of prototype.

The hardware development interacted with program development and changed requirements from ground and flights tests. Several specifications and design approaches were demonstrated and discussed at meetings with people from the Swedish Air Force, Saab System Department and Electronic Production Department. One of the earlier computer specifications, Appendix 1, could not be accepted, especially because of the size.

3.2. First prototypes

Redesign started with several new assumptions. At this time, in 1961, the first generation of integrated circuits became available for use. The mechanical design took a new approach with support of components and cables in an aluminium frame between two circuit cards (patented), fig. 3. This design was used in general except for the power unit, which became different because of larger components. The use of integrated circuits gave a considerable reduction of the number of components. The volume and weight could consequently be decreased. On the other hand the memory requirements increased to 8192 words in only one memory unit. The number of basic instructions was also increased and the handling of in/out signals was simplified. More specific information about the aircraft environment became available for the designers.

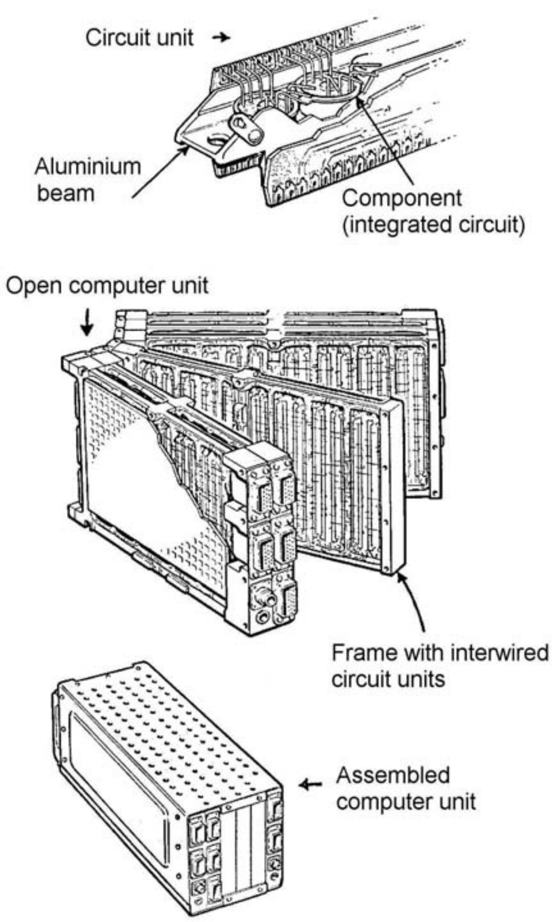

Figure 3, Circuit unit with aluminium beam and components soldered between two circuit cards. Several circuit units are mounted in a frame with interwiring. A final computer unit consists of several frames, some of them fitted with connectors. Four computer units formed an operational computer for installation in the aircraft.

The Swedish Air Force wanted to check the Saab design and arranged to obtain information about a computer from Hughes Aircraft. This was very compact and used welded components, not the new integrated circuits. It was considered, however, that this computer did not fit the proposed system of AJ37. In 1962 the Air Force expanded the development order to also cover the manufacture of 5 prototypes for different types of test. A specification of these prototypes is shown in Appendix 2.

The first prototype was finished in the middle of 1963 for test of function margins and programs. The other four prototypes were ready for tests in 1964, one for system test, one for simulations, one for a special test rack and one for environmental test. From 1965 one prototype was checked in operation during flight tests in the aircraft Saab Lansen 32 alfa. This was possibly the first flight in the world of a computer with the first generation of IC´s.

3.3. First IC´s

At the end of the 1950's both Texas Instrument and Fairchild invented two different types of integrated circuit (IC). Fairchild, whose founder was Robert Noyce, demonstrated their type at a Nato conference in Oslo in 1961. These were called MLE (Micro Logic Elements). The family included 6 types, nor-gate, flip-flop, half adder, counter adapter, half shift register and a buffer. The elements worked between –55 to +125 degree C and had a delay of 50 nanoseconds. Chip density was about 2 transistors per square millimetre (fig 4); not impressive compared to the IC´s density of today (notice Moore´s law). The packing density of separate transistors with resistors and capacitors was about ten times larger compared to the new MLE. This was a very big advantage together with fewer soldering points and a higher reliability. The original price was §125 but was predicted to be below §5 once it was in volume production. The MLE looked promising for use in an airborne computer. Both the Swedish Air Force and Saab were at first sceptical about this very new and unknown technique. Soon, however, all understood that the use of MLE was the only possible way to realise the required type of computer. Later, it was shown to have been a successful selection. An extensive MLE investigation program started including:

- evaluation of electric properties as design criteria and specification for purchase
- design of larger circuit blocks as arithmetic, counter, decoder, controller etc.
- the mechanical support of an MLE together with wiring, see figure 3.

Disturbing margins and delay were evaluated in one batch of MLE. These factors were considerably improved when Fairchild changed the manufacturing process to RTL (Resistor-Transistor-Logic). The reliability was checked in different ways, both in laboratory and in computer tests. Our early tests and information from manufacture and other users indicated that the element could reach a satisfactory reliability. In June 1966 a total of 38,000,000 MLE-hours including 319,000 during flight had been accumulated in computer prototypes. One observed catastrophic failure after 3000 hours resulted in a failure frequency less than 0.006% per thousand hours, which was encouraging. We also examined the TTL-logic elements (Transistor-Transistor-Logic) from Texas Instrument. They were faster, had a lower disturbing margin but had to be mounted on multi-layer cards, which had a relatively low reliability at that time. We thus continued with the first choice of Fairchild who also gradually extended the MLE family. Saab was one of the biggest customers of Fairchild beside NASA in the beginning of the1960s. Early component investigations and tests used a lot of MLE. The first 5 prototypes, delivered during 1962–1963, needed about 3000 MLE each.

It was a big step for a circuit designer to change from transistor to IC-design. The work became easier and faster. It was no longer necessary to use detailed calculations as for transistor circuits. The MLE´s were smart and it was easy to build large computer blocks with the new design rules, figure 5. We had good relations with Fairchild who used our experiences and made changes to the MLE to better fit our building of computer blocks.
The navigation programs included a large number of multiplications so we studied different methods and decided to use the two-shift multiplication. This resulted in a time of 23.8 microseconds at a cost of a number of extra MLE. We noticed about the same figures for addition, volume and power in an American computer journal, which compared different military computers. Our multiplication time, however, was about 50% lower, thanks to the two-shift method used.

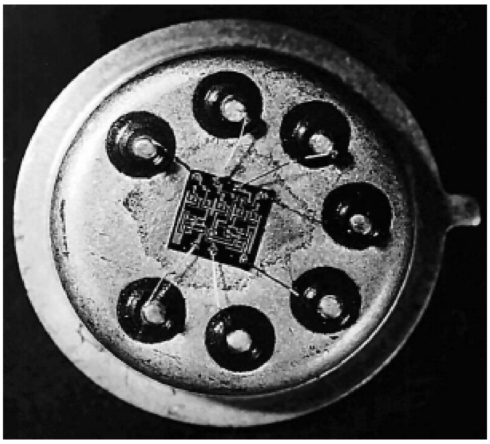

Figure 4, Interior of one of the first MLE, which reached Saab in 1961, enclosed in a TO5 capsule with 7 connections. The chip is 2x2 millimetre.

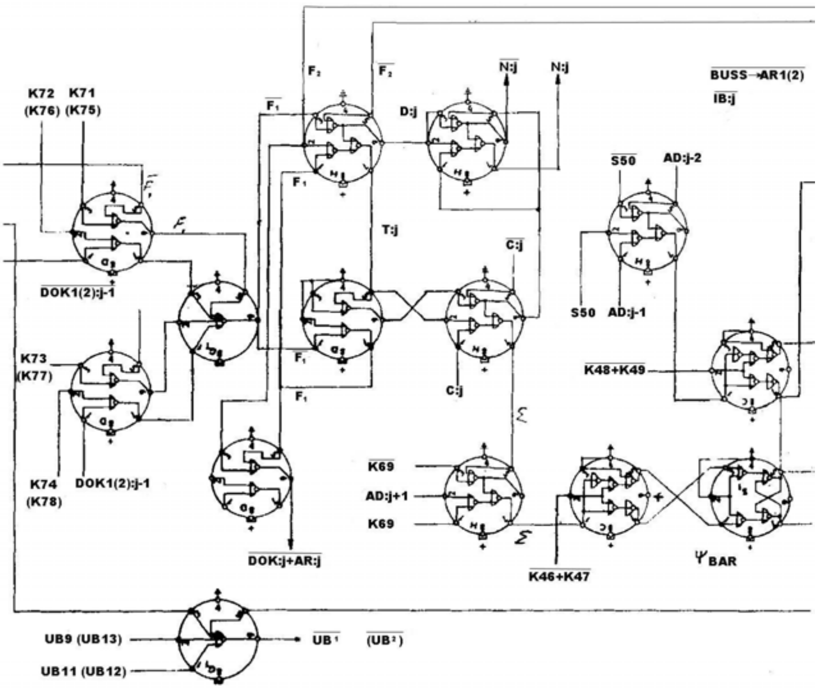

Figure 5, MLE symbols (on a sticker), placed on a drawing, are interconnected to a computer block. The schematics show both logic and electric function.

3.4 Second batch of prototypes
In 1964 the Air Force ordered Saab to build 10 new prototypes for test and evaluation. The order also included serial adaptation with tools and loading/test equipment for final delivery and service. The memory unit was to be of the biax type, with Honeywell as supplier. The biax memory, however, failed in function and deliveries were delayed (described below). During this difficult period Saab developed another type of core memory, based on the five first prototypes and similar to memories in commercial computers. The "heart" of the memory unit, made up of 229.376 small ferrite cores (around one millimetre in diameter) each threaded with 4 wires, was developed in co-operation with Plessey in England. Several tests ware made to prove the reliability against shocks, vibrations and a large temperature range. The Air Force ordered this form of memory from Saab for the later part of the prototype period.

The computer was a real computing centre for all co-operating electronic equipment such as air data, reference platform, airframe mounted accelerometer unit, radio altimeter, navigation equipment and the attack radar. Computer inputs also came from a data panel and panels for navigation, weapons, radar and test. Output signals went to the head-up display, radar display, and other displays in the cockpit. All programs and input/output variables had to be repeated 10-60 times per second to keep track of the aircraft's position. The computer contributed also in an overall electronic system test before take-off. The number of system variables was about 700 in about 30 program blocks.

The 10 prototype computers were delivered between 1965 and 1968. Specification data of the computer are shown in Appendix 3. They were used in aircraft Saab Lansen 32 alfa and gamma and in the Viggen 37-3. A careful notation of the prototype reliability indicated at the end of 1967 an MTBF of 1000 hours (calculated 1200) during ground operation. Component reliability and soldering reliability were also satisfactory and indicated that an MTBF during flight operation of more than the required 200 hours could be reached.

3.5 The Biax memory intrusion
The Swedish Air Force studied similar military aircraft systems in USA in parallel with the system and computer work at Saab. One question was the reliability of a ferrite core memory. Information had to be stored permanently over a long period of operation. The commonly used memory cell to store one bit of information during the 1960´s was a ring-shaped, small ferrite core (this was before semiconductor memory arrived). A new type, the biax core from Honeywell, was square-shaped, fig 6. Both types used one core per bit and had to be threaded with up to 4 thin copper wires per core. They required a lot of electronic circuits to read and write. The ring-shaped core, in the coincidence memory, was destructive. Core information became always zero before the required information, 1 or 0, was stored. Information in a biax core, 1 or 0 was permanently stored, called a non-destructive type of memory. The biax memory seemed to be more reliable from this point of view. The Air Material Department decided to use the biax memory type from Honeywell in the ten CK37 prototypes to be delivered 1965-1968 from Saab. Programs had to be loaded into both types of memory from ground based equipment.

Saab started the co-operation with Honeywell in 1963. First task was to specify the interconnecting signals. Next step was to inspect the electrical and mechanical design, service actions and spare parts to get similarity to the other CK37 units.

A number of different failures occurred during function test of separate memories and together with CK37 units. Sufficient earlier design tests had evidently not been made before final and environmental test. The memory contained a large number of components. MTBF calculations gave a larger figure than a coincidence memory. The ground loader and tester unit was clumsy and difficult to handle. The problems caused delays in delivery of biax memories from Honeywell. Time for flight test came closer and restrictions in the use of the memory unit had to be specified. New failures during flight and in ground system tests were observed.

FMV had followed the problems with the biax memory. The parallell design of a coincidence memory at Saab resulted in good performance in ground and aircraft tests. Biax memory work was stopped in 1967. Honeywell had promised a biax memory, twice as fast, half as expensive and with half the volume compared to the coincidence memory. The experiences resulted in, half as fast and double in price and volume.

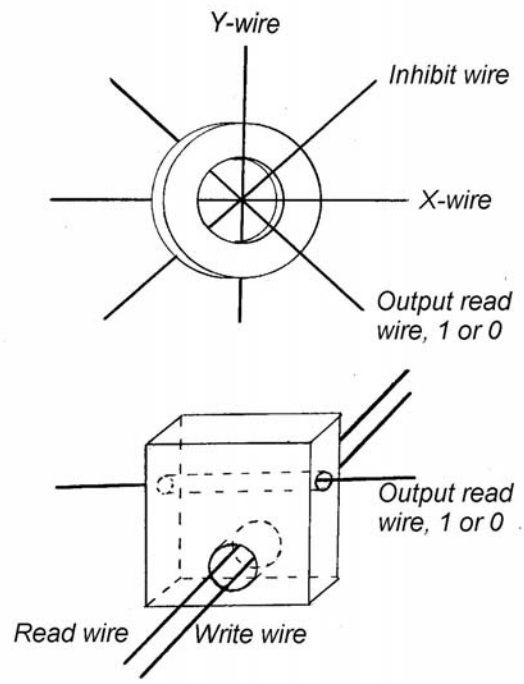

Figure 6, A ring-shaped and a square ferrite core, with a size around one millimetre.

4. Results

4.1 Serial deliveries and flight service.

In January 1969 the Swedish Air Materiel Department FMV ordered serial production of the computer CK37, 114 units. First delivery was in April 1970. The same year the number of computers was increased to 196. A serial acceptance test 1971-1972 resulted in a necessary modification. This was added to new deliveries and retroactively in already delivered units. Last computer delivery was May 1978. The final serial version of CK37 consisted of 4 units, each with a weight between 11 and 16 kg. The two earlier in/out units had become one as the number and of in/out signals had been rationalised. Power consumption was about 600 watts. Datasaab Saab Production Department was in charge of guarantee maintenance until 1983.

FFV Aerotec in Arboga then took over the maintenance work in a central repair and test shop. Faulty units from all air bases were transported to this place were also a number of modifications were made. The memory was increased (with semiconductors) and an extra microprocessor was included to incorporate programs for newer weapons. The aircraft AJ37 Viggen with the computer was still in active service in the very early twenty-first century.

4.2 CK37 reliability

One big problem for the design team was the operational reliability in an airborne environment. How to be able to achieve this reliability in the manufacture of hundreds of computers, each with thousand of small interconnected components. The designers learnt early on that the reliability depended upon catastrophic component failures and soldering quality. An approved soldering technique with certified workers and a careful inspection was used during the manufacturing process (figure 7). Catastrophic failure rates of components were collected from literature and foreign sources. In house experience from the operation of 15 prototypes also became very important. Component failures were recorded and examined together with the respective manufacturer. This work resulted in a basic component failure prediction in 1968, Appendix 4.

FFV Aerotec in Arboga has been in charge of central maintenance of all CK37 units from 1983, when the Saab guarantee ended. Each computer unit with a failure in flight or ground operation was examined at the FFV repair shop. Measures for each unit as repair type, modification, test without remark, none action, program loading of memory unit and cassation was noted in FMV-F-DIDAS material failure lists. Component failures from repair actions in the four CK37 units during the10 years of computer operation from 1983 to 1992 are shown in Appendix 4 together with the Saab predicted values. The predicted component failures account for about 25% of the total computer failure frequency, solders and contacts for 50% and the rest spread out on different components. The summary for 1992 shows a somewhat lower figure for semiconductor components. An integrated circuit with around 25 transistors has about the same failure figure as a single transistor. Solders and contacts show a remarkably lower figure. This lower frequency of catastrophic failures has a direct effect on computer failures in operation. The FFV summary of failures per year, during the 10-year period, together with the Saab prediction, is shown in Appendix 5. The table shows that the number of catastrophic failures is about 5 times lower than predicted 25 years earlier. Other types of remark such as wrong maintenance test without remark, reloading etc have been noted by FFV and have contributed to a somewhat higher frequency of remarks during computer operation.

In summary it can be seen that component reliability has been better than predicted. It was also beneficial that the early integrated circuits were more reliable than predicted. Component manufacturers were selected critically based upon Saab's own specification, tests and measurements. The mechanical design and manufacturing also contributed to a minimisation of faulty soldering joints.

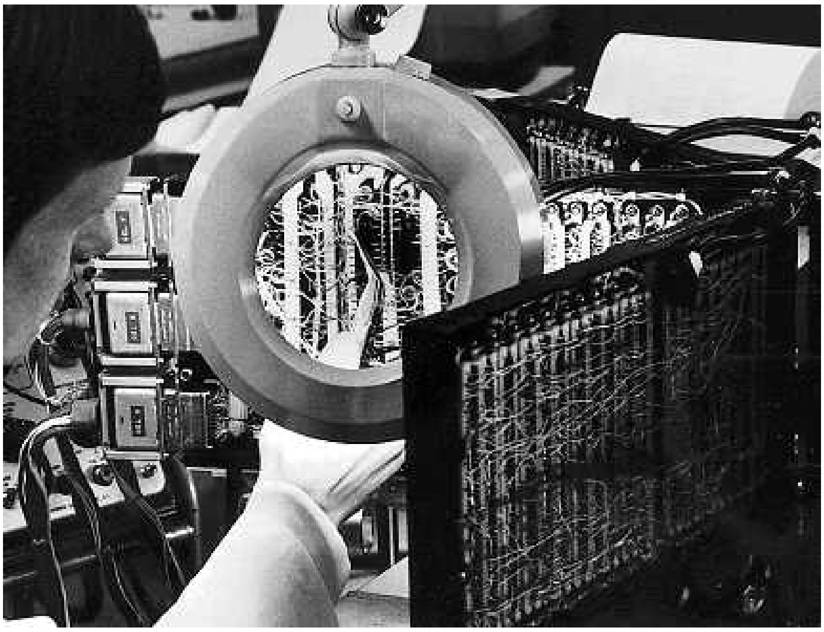

Figure 7, Soldering connections are checked through a magnifying glass.

4.3 Crash resistance

A newly delivered Viggen aircraft crashed in the beginning of the 1970´s. The pilot was saved by using the ejection seat but he could not inform as to the reason for the crash. The computer memory unit was found relatively unhurt. One of the design engineers could read out information which had been stored some seconds before the crash and power break. The computer had collected data from air data, radar altimeter, accelerometers etc and calculates height, speed, orientation, attitude angles etc. All this information was stored in the core memory and could be read out. This, together with data from other crashes, helped to explain the accidents. The reason was an abrupt wing break during a turn. The break was so sudden that the pilot had no time to observe what happened before he was automatically ejected. These aircraft accidents showed, however, that the CK37 computer was a very crash durable unit

4.4 Computer for JA37 Viggen

FMV examined requirements for the next generation of Viggen; the fighter-attack version JA37, during the end of 1960´s. It became quite necessary to implement big changes to all electronic equipment and create a more powerful computer than the about ten years older CK37. The requirements of a new computer were given in a specification from FMV. Computing capacity had to handle 47 programs and 1500 system variables, almost twice the earlier AJ37 requirements. The Datasaab-division designed and manufactured a prototype D6/37 during the period 1971 to 1974 and in 1975 offered the product in competition with USA based companies.
The winner was Singer-Kearfott with a computer developed for the withdrawn aircraft B1. Datasaab was, however, selected in 1976 as the licensed manufacturer of the JA37 computer, named CD107. The licence work with manufacturing preparation became very extensive because of the prototype character of the computer. Many improvements had to be made to increase the reliability. The Datasaab personnel took design responsibility in close contact with the licenser. The work also included the responsibility for arranging and securing the purchase of all components, most of them from USA. Saab manufactured some of the memory circuits, made in hybrid technique. Different conditions in connection with the nature

and reliability of the computer were not fulfilled and FMV had to be design responsible instead of Saab. This was the second computer for the Viggen aircraft to be manufactured at the Datasaab production unit in Linköping. First delivery and flight was in 1979. The manufacturing of 100 units ended 1985.

Some data of the two computers D6/37 and CD107 are shown in Appendix 6.

Appendix 1
One of the first specifications from the beginning of 1960 included:

Task:	Sight calculation for three robots and bombing attacks. Navigation, including Decca-support, according to different alternatives and the remaining flight distance. Standard programs as trigonometric functions and self test.
Memory:	Programs 2048 word, constants 512 words. Word length 20 bits. Ferrite core memory with a cycle time of 6 microsec.
Instructions:	21 basic. Short instructions 7.2 and multiplication 23.2 microsec
Signals:	42 in- and 42 outsignals of digital and analogue type with converter.
Size:	8 separate units, 98 kg, 300 watt.

Most of the communicating equipment was analogue. Conversion with adaptation of all signals utilised over 40 % of the total computer volume. The electronic design was based upon germanium transistors, welded together with resistor and capacitor (as in the SANK-design) and moulded in plastic to withstand vibrations. The necessary mechanical support of components and cabling required most of the space and weight. One part of the computer, the arithmetic unit, was built and run, satisfactorily, in environmental tests. The computer size and all cabling to and from the computer choked the aircraft designers, and could not be accepted.

Appendix 2
A specification from the beginning of 1963 defined the first five prototype design and requirements:

Task:	Defined requirement on speed, memory size, word length and type of instructions. Test and program loading from ground equipment.
Memory:	8192 word, 26 bits, cycle time 2.8 microsec.
Instructions:	Length 13 resp. 26 bits, 48 basic instructions. Short instruction 5.6 long 23.8 microsec. Clock frequency 2,860 MHz.
Signals:	45 in and out, both analogues and digital.
Size:	75 kg. 600 watts. 5 units, memory, logic, power and 2 in/out units.

The manufacturing and final delivery test was made at Datasaab Production Department. All solders, about 50.000, were made by licensed people and 100 % checked through magnifying glass. All components, including almost 3000 integrated circuits (Fairchild) per computer, were 100% inspection tested. Plessey in England was supplier of the core memory. Computer programs treated the layout of cabling in order to facilitate the production. This again was pioneering work.

Appendix 3
A specification from 1964 defines the 10 later prototypes:

Task:	Computing speed about 200.000 instructions per second with fixed point arithmetic.
Memory:	8192 words, 28 bits with 2 parity bits (about 25 kbyte). Variable part 1536 words, the rest write protected. Cycle time 2,8 microsec. The biax memory had a similar specification.
Instructions:	48 basic. Add/subtract 5,6, jump 4,2, multiplication 23,8 and divide 44,8 microsec.
Interrupt:	6 priority graded internal signals for jump to special programs.
Signals:	64 analogue in/outsignals with converter, 0.2 % accuracy within –10,24 to +10,24 volt. Conversion times about 200 microsec. 450 bits of binary in/out-signals, mainly collected in 13 bits word, represented by 0 or +12 volt. All signals are protected by in/out filter.
Selftest:	An internal self test program with about 90 % efficiency per unit except in/out unit with only 35 %. The self-test program executs every 0,1 second.
Size:	70,5 kg, 550 watt, 5 units.
MTBF:	The goal was a minimum of 200 hours during flight operation.

Special circuits handled power off and on. A priority signal initiated a memory stop sequence when a power off occurred. Memory information was stored, memory cycling stopped and circuit voltages could decrease. Memory started when all voltages had reached nominal values after power on at the stop address. Some circuits were changed after experiences from circuit and prototype tests. A few new MLE types from Fairchild (with SGS Fairchild in Italy as second source), also analogue, could be used.

Appendix 4. Catastrophic component failures per million hour

Component type and number		Saab prediction 1968	FFV summary 1992
Integrated circuit	2700	0.03	0.02
Transistor, low power	1400	0.04	0,02
Diode, low power	650	0.04	0,01
Resistor, low power	3800	0.008	0,002
Capacitor	750	0.03	0,005
Solders and contacts	51000	0.01-0.001	0,0002

Appendix 5. Catastrophic failures per computer unit per year

	Saab prediction 1968	FFV summary 1992
Logic unit	0.5	0.06
Memory unit	0.5	0.05
In/Out unit	0.4	0.04
Power unit	0.2	0.12
Total computer	1.6	0.27

Appendix 6

The design of the Datasaab computer prototype D6/37 took account of experience gained from the commercial minicomputer D5/30 and 10 years of technical development with respect to CK37. The memory was 128 kbyte, a ferrite core memory, with 32 bits. Computing speed about 700,000 (more than 3 times CK37) instruction per second with floating point arithmetic. The components consisted of thick-film-hybrids with individual components and gold type of wiring enclosed in glass and ceramic. The components were mounted on two circuit cards with air-cooling. MTBF during flight operation was 1100 hours. The design made it possible for a mean time of 15 minutes to repair a component. Total weight was 31.4kg exclusive of a unit for adaptation of in/out signals. The prototype was subject to different prolonged environmental tests with positive results. The computer and test results fulfilled the FMV requirements.

The Singer-Kearfott prototype CD107 also had a core memory of 128 kbyte with a word length of 16/32 bits. Calculation speed was 500,000 instructions per second with floating point arithmetic. All components, mainly flat types, were mounted on 41 circuit cards/units, connected to a common motherboard. Some memory components, thick-film-hybrids, were manufactured by Saab. 40 analogue and 700 digital signals could be handled but the adaptation was outside the computer. Total final weight was 26 kg and the power consumption 585 watts. The memory was increased during the 1980´s to 240 kbyte with a semiconductor memory in order to handle new weapons for the aircraft.

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