- Chapter Two -
- Computers On Board The Apollo Spacecraft -

The Abort Guidance System

[59] The computer in the Abort Guidance System (AGS) is probably the most obscure computing machine in the manned spaceflight program to date. The 330-page "Apollo Spacecraft News Reference" prepared for the first lunar landing mission does not contain a single reference to it, compared with several pages of description of the Primary Guidance, Navigation, and Control System (PGNCS) computer and its interfaces. The invisibility of the AGS is a tribute to PGNCS, since the AGS was never needed to abort a landing. It was, however, an interesting and pioneering system in its own right.

The AGS owed its existence to NASA's abort policy; an abort is ordered if one additional system failure would potentially cause loss of crew[160]. Hence, the failure of either the PGNCS or the AGS would have resulted in an abort. The AGS operated in an open loop, parallel to the PGNCS in the LEM, and gave the crew an independent source of position, velocity, attitude, and steering information[161]. It could verify navigation data during the periods when the LEM was behind the moon and blacked out from ground control. The Apollo program first exercised this capability during Apollo 9 and Apollo 10 leading up to the first landing mission[162].

The AGS was a pioneer in that it was the first "strapped-down" guidance system. The system used sensors fixed to the LEM to determine motion rather than a stable platform as in conventional inertial guidance systems[163]. The entire system occupied only 3 cubic feet and consisted of three major components: (a) an Abort Electronic Assembly (AEA), which was the computer, (b) an Abort Sensor Assembly (ASA), which was the inertial sensor, and (c) a Data Entry and Display Assembly (DEDA), which was the DSKY for the AGS.

AEA and DEDA: The Computer Hardware

As with the PGNCS computer, the AGS computer went through an evolutionary period in which designers clarified and settled the requirements. The first design for the system did not include a true computer at all but rather a "programmer," a fairly straightforward sequencer of about 2,000 words fixed memory, which did not have navigation functions. Its job was simply to abort the LEM to a "clear" lunar orbit (one that would be higher than any mountain ranges) at which point the crew would wait for rescue from the CM, with its more sophisticated navigation and maneuvering system[164]. The requirements changed in the fall of 1964. To, provide more autonomy and safety, the AGS had to provide rendezvous capability without outside [60] sources of information[165]. TRW, the contractor, then decided to include a computer of about 4,000 words memory. The company considered an existing Univector accumulation machine but, instead, chose a custom designed computer[166].

The computer built for the AGS was the MARCO 4418 (for Man Rated Computer). It was an 18-bit machine, with 17 magnitude bits and a sign bit. It used 5-bit op codes and 13-bit addresses. Numbers were stored in the two's complement form, fixed point, same as in the primary computer. Twenty-seven instructions were available, and the execution time varied from 10 to 70 microseconds, depending on the instruction being performed[167]. The computer was 5 by 8 by 23.75 inches, weighed 32.7 pounds, and required 90 watts[168]. The memory was bit serial access, which made it slower than the PGNCS computer, and it was divided into 2K of fixed cores and 2K of erasable cores[169]. The actual cores used in the fixed and erasable portions were of the same construction, unlike those in the PGNCS computer. Therefore, the ratio of fixed memory to erasable in the MARCO 4418 was variable[170]. TRW was obviously thinking in terms of adaptability to later applications.

The DEDA was much smaller and less versatile than the DSKY. It was 5.5 by 6 by 5.19 inches and was located on the right side of the LEM control panel in front of the pilot, about waist height[171]. Sixteen pushbutton keys were available: CLEAR, READOUT, ENTER, HOLD, PLUS, MINUS, and the digits 0-9. It had a single, nine-window readout display. Three windows showed the address (in octal), one window the sign, and five, digits[172]. This was similar to the readout in the Gemini spacecraft for its computer.

Software for the AGS

Since hardware in the AGS evolved as in PGNCS, software also had to be "scrubbed" (reduced in size) in the AGS. Mirroring the memory problems of PGNCS, by 1966, 2 full years before the first active mission using the LEM, only 20 words remained of the 4,000 in the AGS memory[173]. Careful memory management, became the focus of TRW and NASA. Tindall recalled that the changes all had to be made in the erasable portion, as the fixed portion was programmed early and remained set to save money. However, changing the erasable memory turned out to be very expensive and a real headache, the developers fighting to free up storage literally one location at a time[174]. Also, some software decisions had to be altered in light of possible disastrous effects. The restart program for the PGNCS has been described. In it, a restart clears all engine burns. The first versions of the AGS software also caused engine shutdown and an [61] attitude hold to go into effect when a restart occurred. This would he potentially dangerous if a restart began with the LEM close to the lunar surface. The solution was to give the crew responsibility to manually fire the engines during a restart if necessary[175].

Software development for the AGS followed a tightly controlled schedule:

1. 12.5 months before launch: NASA delivers the preliminary reference trajectory and mission requirements to TRW.

2. 11 months: Program specification and AGS performance analysis is complete.

3. 10.5 months: NASA conducts the Critical Design Review (CDR).

4. 8 months: The final mission reference trajectory is delivered.

5. 7 months: The equation test results, verification test plan, and preliminary program goes to NASA for approval.

6. 6.5 months: The First Article Configuration Inspection (FACI) conducted.

7. 5 months: The verified program and documentation is delivered to NASA.

8. 4.5 months: NASA conducts the Customer Acceptance Readiness Review (CARR).

9. 3 months: The operational flight trajectory is delivered by NASA to the contractor.

10. 2 months: The final Flight Readiness Review (FRR) is held.

11. 1.5 months: The tape containing the final program is delivered[176.]

One method of software verification was quite unique. To simulate motion and thus provide more realistic inputs to the computer, planners used a walk-in van containing the hardware and software. Technicians drove the van around Houston with the programs running inside it[177].

Use of the AGS

[62] The AGS was never used for an abort, but it did contribute to the final rendezvous and docking with the CM on the Apollo 11 mission, probably to avoid the problems encountered with the rendezvous radar during landing[178]. It did monitor PGNCS performance during all missions in which it flew. The only criticism of its performance was from astronaut John Young, who remarked that "one mistake in a rendezvous, and the whole thing quit"[179]. Apparently, restarts occurred as part of the recovery from some operator errors. The AGS was actually like a parachute&emdash;absolutely necessary, but presumably never needed.

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