O. Hoberg



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# SATURN SA-1 FLIGHT AND ITS INSTRUMENTATION

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The picture (slide no. 1) you are now viewing shows the Saturn SA-1 shortly after take-off on its first flight test. One can imagine the excitement of the MSFC people, who were either watching the flight or observing indicators, recorders, or the doppler tone until the mission was so successfully completed.

For the next 30 minutes, I will present to you the importance of instrumentation associated with a space vehicle development project such as Saturn. More particularly, we will see how Saturn SA-1 was instrumented and how the instrumentation system performed during the first flight test.

In setting the background, I would first like to say a few words about the Saturn project itself. The need for a more powerful space vehicle became drastically apparent during the time of Russia's satellite and manned space flight successes. The Saturn project will assure that this country's space flight requirements will be met; however, such a development of this size will take time. Not only is the development of the vehicle itself required, but extensive facilities and ground support systems must also be provided.

Slide no. 2 shows the area of Pacific Missile Range built up as launch complex.

Slide no. 3 shows the blockhouse, and slide no. 4 is typical of the activities in the launch control room during the flight operation.

The Saturn project, for the purpose of this discussion, can be easily divided into several phases.

1. Saturn C-1, SA-2 through SA-4, called Block I
2. Saturn SA-5 through SA-10, called Block II
3. Saturn C-5, SA-501, etc., called advanced Saturn

The SA-1 through SA-4 configuration — you will remember from the first slide — has only one active stage, whereas the upper stages (numbers 2 and 3) are only dummies.

Block II, SA-5 through SA-10, will have two active stages, the S-I and S-IV. After flight SA-10, this type of vehicle is considered to be operational. The advanced Saturn C-5 will have five times as much take-off power and will carry two live upper stages with even greater capability.

Slide no. 5 shows the configuration representing Saturn, Block II.

Slide no. 6 is an artist's conception of the advanced Saturn, C-5. Slide no. 7 compares the missile configuration with the Statue of Liberty.

Let us now return to the Saturn SA-1.

Slide no. 8 shows the major features of this particular vehicle configuration in more detail. The S-I stage carries eight engines, similar to the type flown in the Jupiter and Thor programs. Its tank configuration is clustered with eight outside tanks of 70" diameter, surrounding one inner tank of 105" diameter. The adapter section between the first and second stages carries four instrumentation canisters where all instrumentation control and other electrical equipment are housed. The second and third stages are dummies S-IV and S-V, respectively; the nose resembles the Jupiter nose cone with angle of attack meters and protective cover material as used with the Jupiter project. The lift-off capability is roughly 920,000 lbs. and the take-off thrust is about 1,300,000 lbs.

Instrumentation, which must be located in the vicinity of the engine compartment, is mounted below the tanks.

Slide no. 9 shows the trajectory that had a propelled time of 111 seconds where the four inboard engines were cut off. At 117 seconds, the outboard engines were cut off and, from then on, the vehicle followed a ballistic trajectory. When fired under an azimuth of 100° east of north, the vehicle reached an altitude of 143 kilometers and impacted 365 kilometers from the launching site.

The task of an instrumentation engineer is to assure that data for such a flight test — representing a sizeable effort in engineering and dollars — is suitable to analyze the performance of the eight-engine propulsion system, the structure, tanks, the use and behavior of propellants, the flight dynamics, and control.

The task of a development engineer is immense. MSFC, particularly the Astrionics Division, utilized experience gained in the Redstone, Jupiter, and Pershing guided missile programs to help instrument this Saturn. Flight data requirements, which were to solve all those problems anticipated to assure flight readiness during propelled flight and coasting period, were submitted and amounted to almost 2,000 requests. All these many parameters were supposed not only to be measured, but also to be transmitted by telemetry systems capable of handling such a volume of data as close to their original characteristics as possible.

Furthermore, in the radio frequency systems area, command destruct capabilities had to be provided to assure the destruction of the vehicle in case of malfunction.

To determine the vehicle's exact trajectory, transponders of various types had to be carried and suitable antennas for radio frequency transmission had to be provided; therefore, the instrument effort was concentrated in three areas: the measuring system, the telemetry system, and the radio frequency system.

Slide no. 10 shows a condensed measuring program, broken down in various groups such as propulsion, temperature, control, signal, etc. This program was agreed upon after duplication had been eliminated and after lengthy meetings with the help of "friendly persuasion" and flat decisions. Out of 603 measurements, 98 were required for monitoring and tests to assure flight readiness of the vehicle and 505 were monitored during the flight.

Slide no. 11 shows a similar breakdown for Saturn SA-2. Changes incorporated here reflect experience with SA-1 as far as the short time available allowed.

Slide no. 12 shows a block diagram of the measuring system and gives a few typical arrangements for sensing elements, so-called adapters, and distribution of signals to the input of the telemetry systems. The input of the telemetry system had been conveniently standardized to be of a magnitude of 0 to 5 volt DC into 100 k$\Omega$. However, in many cases, this is not in the output of the sensing element; consequently, amplifiers of various types or "modules" are required to adapt to this condition. Potentiometer type gauges are fed by centrally provided 8 DC to DC converters with regulated output voltage of 5 volts DC.

Slide no. 13 is an example of various types of gages required to determine all those different parameters. In some cases, higher accuracies are required in comparison to what can be achieved with only one potentiometer turn.

For the precise measurement of acceleration (for example, slide no. 14), a multi-turn potentiometer with servo follower has been used which gives a ten times higher accuracy but requires an additional transmission channel to solve redundancy. To adapt non-potentiometer type measurements to correct input level and impedance of the telemetry system, 287 modules mounted in 37 racks were required for Saturn SA-1.

Slide no. 15 shows various types of DC, AC, and carrier amplifiers that have been used in the respective numbers as shown.

Slide no. 16 shows the circuit diagram of a typical module. The heart of this module is a DC amplifier which, by inserting a module board, can be adapted to various amplification ranges; furthermore, it can be tested by ground control for proper operation and calibration.

A particular application of thermocouples is shown in slide no. 17. One important characteristic, namely, the temperature rise, in the engine area is determined; in case behavior is not normal, fire cannot only be detected but can also be automatically extinguished.

The telemetry system selected for SA-1 to transmit data of the described nature and number is shown in slide no. 18. It consists of eight telemetry links of the PAM/FM/FM type, in various combinations and arrangements: standard FM/FM, FM/FM/FM, 216 channel time division multiplexed. The latter arrangement gives in one subframe zero and maximum calibration plus one information from 8 engines each of identical nature.

Slide no. 19 shows the different types and the utilization of the eight telemetry links with respect to continuous and commutated channel capability.

Slide no. 20 shows the somewhat modified telemetry system of the SA-2 vehicle where again eight links are employed, including, for the first time, the new telemetry system of the SS-FM type. This single-sideband telemetry system has a capability of transmitting fifteen information channels, each requiring a frequency response from 50 to 3,000 cycles. It is developed for space vehicle use based on techniques employed in transmitting telephone conversations.

Slide no. 21 shows a block diagram of a single-sideband. Difficulties during the development, which showed up particularly in the filter system, made a minor modification with respect to mounting orientation necessary.

Slide no. 22 shows a picture of an FM/FM set as flown.

A picture of a time division multiplexer used in connection with the FM/FM system is shown in slide no. 23.

The radio frequency systems carried on SA-1 are shown on slide no. 24. The command system required for range safety operation was of the type DRW 13. Two of these sets are required in parallel. The AZUSA system, the C-band radar, S-band radar, and UDOP system were employed to provide tracking data and, in case of AZUSA and C-band, computer input data for range safety purposes as well.

Slide no. 25 shows the location of antennas utilized in the SA-1 test flight. The telemetry UDOP and command system antennas are cavity-backed slot antennas; whereas the AZUSA, C-band, and S-band antennas are permanent waveguides, mounted and directed with respect to their pattern according to the respective line-of-sight for anticipated trajectory and location of ground stations.

In slide no. 26, the VSWR characteristics of the Saturn telemetry antenna are compared with the telemetry antenna used with the Jupiter project. This antenna shows a practically flat characteristic from 220 to 400 megacycles; it allows, therefore, a convenient multiplexing of different radio frequency carriers into one antenna system.

Quite a requirement in planning and engineering is necessary to provide all these instrumentation components and systems. Such a system must be provided not only in time available for the assembly of a space vehicle, but also properly tested and calibrated as well. It, furthermore, must have the capability to incorporate changes on a reasonably short notice. Laboratory personnel of the Instrumentation Development Branch performed the necessary development, testing, and calibration work. The successful flight of SA-1 on October 27, 1961, and SA-2 on April 25, 1962, showed rewarding results for the instrumentation engineer.

Slide no. 27 shows the result of an evaluation of the measuring and telemetering system performance. Areas broken down in a similar manner as previously in the measuring problem are quoted with respect to a total number of measurements. The number of successfully recovered data which is only partially usable or unusable is expressed in number as well as percentage. The percentage of unusable measurements was 1.6 percent; partially usable, 2.1 percent.

SA-2, slide no. 28, revealed even better results. The percentage of unusable information dropped to .76 percent and the same percentage is shown as partially usable. These figures apply to the complete length of flight, which in case of SA-2 was terminated by command at an altitude of 65 miles in Project High Water.

In addition to an exceptionally good performance of the measuring and telemetry system, the radio frequency system also worked perfectly. The problem of flame attenuation had been anticipated, but because of proper designing and locating the antenna systems, the field strength received in various locations was practically as expected. All transponders performed correctly. Good trajectory data were consequently recovered. On SA-2, the command system had been actuated and showed proper reaction in connection with Project High Water.

Slide no. 29 shows plottings of the telemetry signal strength predicted for a station located at the Cape compared with the field signal strength actually received from SA-1 and SA-2. Similar plottings are shown on slide no. 30 for a station located down range.

Concluding, the instrumentation planned for the Saturn's first two flights and the data received will enable the design engineer to analyze the performance of the complete vehicle system. He has gained an extensive amount of information which enables him to apply this knowledge to further developments. This is the service expected from the instrumentation engineer.