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INTEGRATING SPACECRAFT SYSTEMS

by Allen L. Franta

Goddard Space Flight Center

Greenbelt, Md.

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ABSTRACT

The integration of a satellite or spacecraft system consists of combining the mechanical and electrical subsystem elements into a single entity through the application of logical processes, and takes into account the physical and functional aspects of the subsystem interrelationships. It is characterized by three levels of effort: (a) project management integration, (b) integration of physical systems, and (c) integration by subsystem combination through advanced design. The over-all coordination of a spacecraft project is a responsibility of a project management group assigned the task of translating functional concepts into an operating spacecraft. The actual physical integration of a spacecraft system is accomplished through the combined work of a mechanical integration group and an electronic integration group working together in a concerted effort. Subsystem combination through advanced electronic design is a more sophisticated form of partial spacecraft integration. It is accomplished through improved circuit design utilizing the most advanced electronic packaging techniques.

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INTRODUCTION

By definition, integration is the act or process of making whole or entire—a process of summation. The integration of a satellite or spacecraft system consists of combining the mechanical and electrical subsystem elements into a single entity through the application of logical processes taking into account the physical and functional aspects of the subsystem interrelationships. The integration of scientific spacecraft systems for in-house projects at the Goddard Space Flight Center is characterized by three distinct levels of effort: (a) project management integration, (b) integration of physical systems, and (c) integration by subsystem combination through advanced design (Table 1). The over-all coordination of a spacecraft project is a responsibility of a project management group consisting of a project manager and his staff. This group is assigned the task of translating functional concepts into an operating spacecraft. The actual physical integration of a spacecraft system is accomplished through the combined work of a mechanical integration group and an electronic integration group working together in a concerted effort. Subsystem combination through advanced electronic design is a more sophisticated form of partial spacecraft integration. It is accomplished through improved circuit design utilizing the most advanced electronic packaging techniques. Several subsystem elements are combined into a single, integrated, simplified, more reliable package with many functions accomplished internally, thereby simplifying input and output and eliminating several complex interfaces.

Table 1

Three Levels of Effort of Spacecraft Integration.

Overall	Project Management
Detailed Technical	a. Mechanical b. Electrical/Electronic
Partial	Subsystem Combination (through advanced design)

PROJECT MANAGEMENT INTEGRATION

The project management function can best be examined by considering an in-house scientific satellite program (e.g., the Anchored IMP, one of the Interplanetary Monitoring Platform series). The demand for space research in a specific area of investigation can originate in any of the space-research oriented universities, and organizations in any of several countries throughout the world. At the time of project origin, the major portion of the activity is centered around a feasibility study generated by a small technical staff. This staff is generally headed by the prospective project manager who requests the assistance of qualified technical personnel to assist him in the preparation of this study. Figure 1 addresses itself to the elements involved in the project origin. The mission requirements must be defined in order that the scientific experiments required to accomplish it can be properly chosen. In planning the experiments capable of fulfilling the mission, considerable emphasis must be placed on a practical spacecraft design. If details can be adopted from tried and flight-proven spacecraft designs, the mission feasibility is enhanced (e.g., the Feasibility Study for the Anchored IMP (AIMP-D and E) incorporated the Jet Propulsion Laboratory "kick" motor used on Syncom I into the existing IMP design used on Explorer XVIII). The mission requirements are defined with full consideration given to the choice of a launch vehicle capable of achieving the necessary orbital parameters. Information concerning satellite tracking and data acquisition requirements is included with the orbital requirements. If the established NASA tracking network, commonly known as STADAN (Space Tracking and Data Acquisition Network), can be used for tracking a spacecraft in the planned orbit, the problem is simplified. If STADAN cannot be used, other arrangements must be planned. Last but not least are the resources requirements. What will be the cost in manpower, money and facilities? Are the resources available? Where? What will be the impact on other projects already in progress? What would be the most efficient manner of solving the scientific and technical problems? These and many other questions must be answered in order for Center management to determine whether the project is feasible. After project feasibility has been demonstrated satisfactorily to Center management, the results of the study are submitted for consideration to the NASA Headquarters officials concerned with the technical approval and funding of the proposed mission. The written study is generally followed by oral presentations and discussions to clarify all details and points in question.

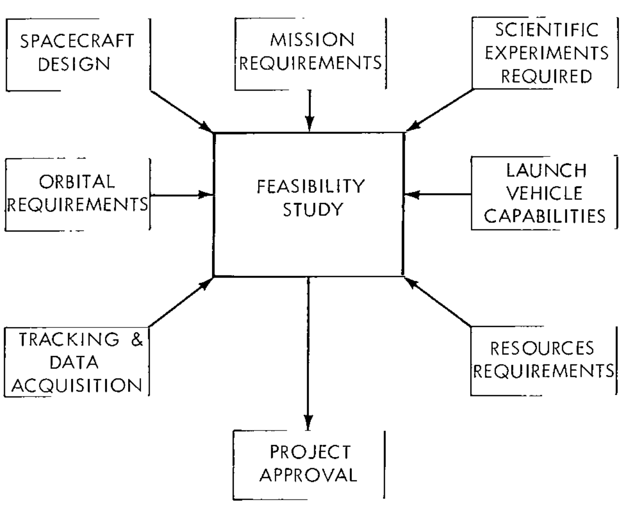

Figure 1—Elements of spacecraft project origin.

When the project has been officially approved, the Director of Goddard appoints a project manager based on the recommendation of an assistant director. The project manager then proceeds to complete his staff with personnel assigned to him. The next order of business is to determine the over-all system design and generate systems specifications, giving full consideration to all spacecraft-vehicle mechanical and electrical interface problems and to the experiments selected by the Space Sciences Steering Committee at NASA Headquarters (Figure 2). After the system design specifications have been completed, detailed subsystem design specifications are generated (Figure 3). The specifications are of two types, mechanical and electrical/electronic. The test specifications required during environmental qualification are factored into all subsystem specifications. Also, design specifications are prepared for the performance analysis and control systems used in spacecraft checkout throughout the integration, environmental qualification, and launch phases.

After all subsystems design specifications have been completed, the subsystem hardware is produced and furnished to the project office for integration into the spacecraft. The overall system integration and coordination and solution of all interface problems is accomplished through the joint effort of the project

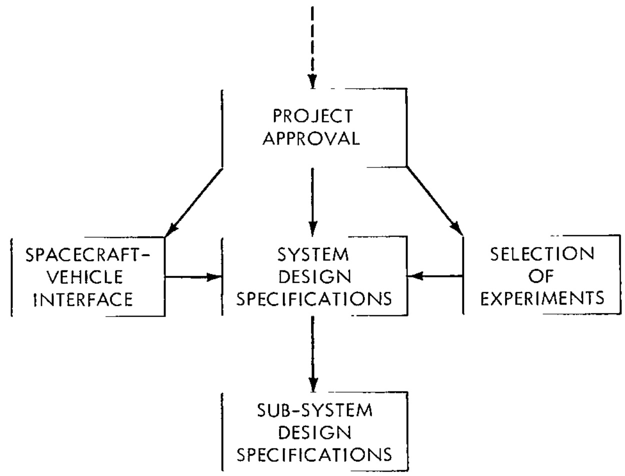

Figure 2—Generation of system specifications.

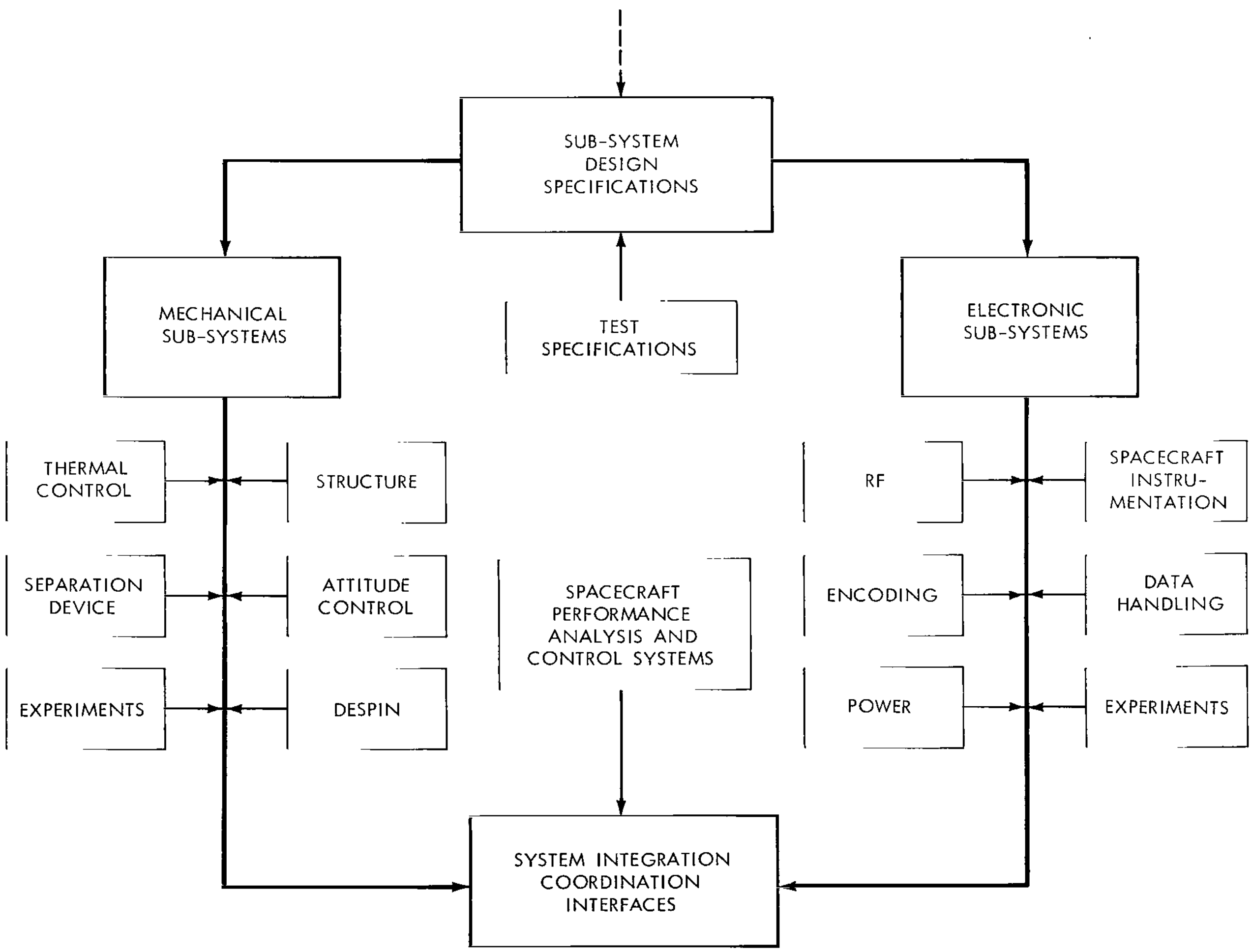

Figure 3—Generation of subsystem specifications.

management staff and the mechanical and electronic integration groups. The output of the physical integration effort are spacecraft logs, spacecraft data and the system status documents (Figure 4). With the completion of spacecraft integration, telemetry test tapes are furnished to the tracking, data acquisition and data reduction technical personnel for compatibility checks. When the project manager, experimenters and all subsystem designers are satisfied that the integrated spacecraft system is operating according to specified performance requirements, it is subjected to environmental exposures (vibration, acceleration, spin, temperature, humidity, and thermal vacuum) at levels equal to or greater than those anticipated under actual flight conditions. The environmental qualification is conducted according to the test specifications and procedures prepared with the subsystem design specifications. When the spacecraft has successfully completed all environmental tests, the results are submitted to the Center Reliability Assurance Council for environmental performance approval. After the project manager is satisfied with the satellite's performance, he certifies to his Assistant Director and the Center Director that the spacecraft is ready for flight. Upon receipt of approval, he orders the spacecraft transferred to the launch site for the start of launch operations.

At the launch site prior to mating and balancing the spacecraft with the vehicle final stage, spacecraft-vehicle interface fit-checks are made, antenna patterns rerun, and the spacecraft-vehicle telemetry interference monitored. After the spacecraft is mounted on the launch vehicle, the integration crew makes final electrical connections and final checks of the system. The electronic integration group is responsible for the spacecraft performance evaluation during the final

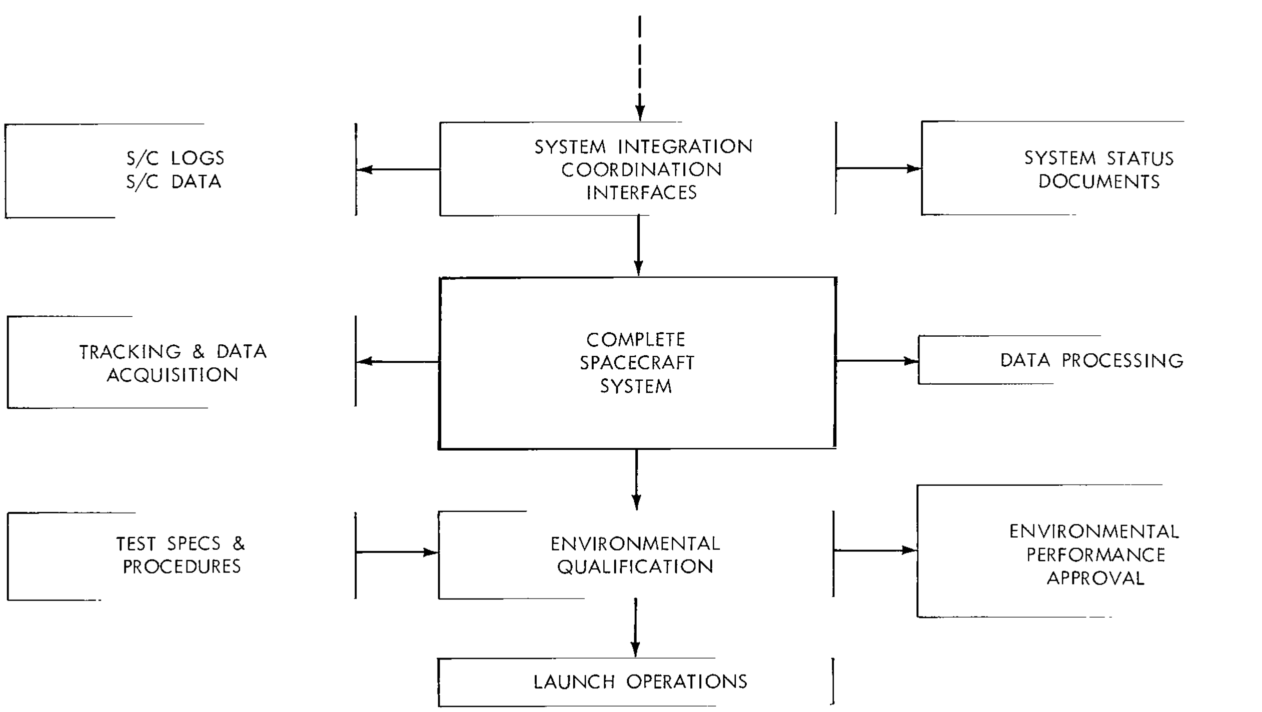

Figure 4—Integration, environmental qualification, and launch operations.

countdown. All of this is accomplished by the integration and launch crews under the direction of the project manager and his staff.

After the spacecraft has been successfully launched, it is tracked by STADAN to establish the orbit. The data acquired is recorded on magnetic tape and sent to the data reduction facility for processing (Figure 5). Both orbital and scientific data are reduced and processed prior to being sent to the individual experimenters for analysis. The project manager coordinates all of these activities. Once the data analysis has been completed, it is distributed to the scientific community through symposia and scientific journals.

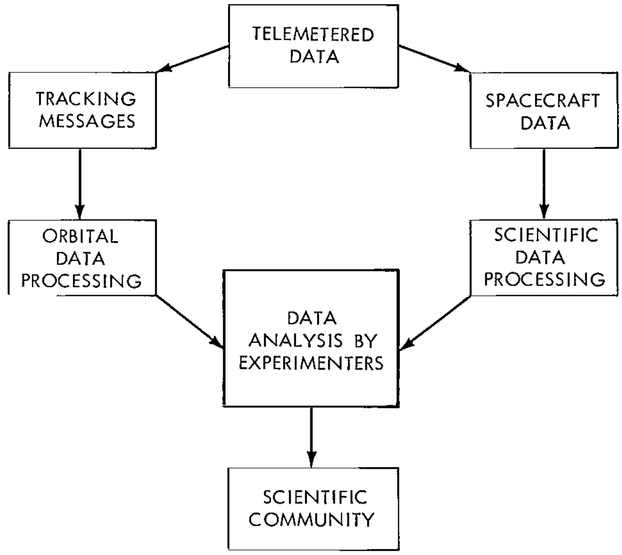

Figure 5—Data acquisition, reduction, and analysis.

It is this over-all integration function as portrayed in Figures 1 through 5 that is the responsibility of the project manager and his staff. They integrate the efforts of everyone involved in the project. It may be seen that their efforts of planning, designing, and project administration from conception through completion are most vital to the success of any space flight program.

DETAILED TECHNICAL INTEGRATION

The actual detailed technical integration of the spacecraft physical systems is carried out by a mechanical integration group from a mechanical systems branch and an electronic integration group from an electronic systems integration branch working side by side. This work involves planning, designing, fabrication, assembling, and performance testing until all subsystems have been integrated into a reliable, operable system meeting all established performance criteria prior to environmental qualification and launch. At the outset of the program, the two groups begin more-or-less independent efforts, contributing spacecraft design information to the feasibility study and, after project approval, assisting with the preparation of system and subsystem design specifications (Figures 1 and 2). At this point, the efforts of the two groups gravitate into a joint effort with close liaison and remain so throughout the actual mechanical and electronic integration, environmental qualification and launch operations.

Planning and Pre-Integration Activity

The mechanical group is directly responsible for the design and production of several major spacecraft subsystems, namely, the basic structure, despin mechanism, spacecraft-vehicle separation device, reeling devices, experiment booms, and release mechanisms. Because of their structural design responsibility, they become involved in the mechanical design for all subsystems. As a result, they contribute extensively to the project feasibility study, whereas, the electronic group furnishes general information with regard to electrical and electronic design.

Feasibility Study

Once the mission requirements have been defined and a tentative list of scientific experiments chosen, the mechanical group does a preliminary structural design, conducting stress analyses, as required, and producing preliminary designs of all their subsystems. After obtaining information from all other subsystem designers, they furnish the vehicle personnel with an approximate spacecraft weight to aid in the determination as to whether the vehicle performance can satisfy the mission and orbital requirements. If the satellite is spin-stabilized, they calculate approximate despin numbers. The electronic group with the mechanical group examines the vehicle to determine the umbilical plug, turn-on plug, and battery charging requirements. Though the mechanical group does not do the spacecraft thermal design, they do work with the problem insofar as it relates to the design of the structure. They also assist the power group of a space power technology branch by supplying a lightweight structural design for the solar paddles with dimensions that will fit within the suggested launch vehicle nose fairing or heat shield. The mechanical group examines the physical aspects of all the experiments considered in the feasibility study.

Spacecraft System Design and Design Support

After project approval, all elements considered in the feasibility study are made definite in a detailed specification of the complete system. The final selection of experiments is made and all subsystems detailed sufficiently to fix size and approximate weights in order that the mechanical group may determine final spacecraft weight and moments of inertia. At this point, it is also essential to uncover any possible spacecraft-vehicle problems. To this end the mechanical group furnishes the vehicle group of a launch-vehicle projects office with an accurate weight estimate, an outline of the spacecraft's physical configuration, and spin-rate calculations. Though the spin-stabilized satellites have no active attitude control system, as contained in large spacecraft systems such as the Orbiting Geophysical Observatory, the mechanical group is concerned with attitude changes due to perturbations of the spacecraft, while in orbit, caused by solar radiation pressure and magnetic torques. To maintain a favorable orientation of the spin axis, the spacecraft system must be designed so that the ratio of the spin-axis moment of inertia to the pitch-axis moment of inertia is always greater than unity. This is another reason for the constant monitoring of the spacecraft weight which always seems to grow.

The mechanical and electronic groups work very closely in determining the optimum location of all subsystems within the spacecraft structure. The preliminary layouts are made with spin stability as the only concern. Power dissipation, noise, r-f interference, and induced magnetism are all considered next in the detailed system design. The final design is a compromise, with no individual subsystem designer being completely satisfied (e.g., if the mechanical designers located all of the appendages with no consideration given to the antenna pattern, the antenna designer would have a hopeless task. Also, experiments with large angles of view cannot be completely free from seeing an appendage even though they are afforded the most ideal location). Many potential trouble areas are avoided through this mechanical and electrical integration interplay.

The electronic group contributes to the over-all design of the spacecraft by virtue of their advisory responsibilities to the subsystem designers. They exercise an influence on the selection of housekeeping functions and on the methods of telemetering them. They serve a liaison function between the power system designer and subsystem designers, exercising some influence on the design of all subsystems. They establish the guidelines with regard to system electrical design and fabrication, and, based on previous experience, they assist in the system design by identifying and suggesting solutions to potential noise, interference between subsystems, and magnetic problems.

Spacecraft Subsystem Design and Design Support

The major mechanical subsystems are the structure, thermal control, separation device, attitude control, despin mechanism, and parts of experiments. The major electronic subsystems are the r-f portion (modulators, transmitters, antennas, and command receivers), spacecraft instrumentation (performance parameters, housekeeping functions, and attitude control), encoding, data handling, power (solar paddles, batteries, converters, regulators, and power supplies), and the experiments. Except for the experiments, furnished by the scientific experimenters, all of these electronic subsystems are produced by a spacecraft electronics branch, a flight data systems branch, and a space power technology branch, which also assist in the detailed technical integration as required.

An integral part of the structural design is the consideration of thermal control. This subsystem is the responsibility of a thermal systems branch. If the thermal control is to be of a passive nature, the mechanical group designs the spacecraft outer surface to accept the desired paints or coatings. Another example of their thermal control assist is their design of a thermal shroud necessary to keep the Lunar Anchored IMP "kick" motor warm after a long coast period so that it will ignite on command. The mechanical group assists the experimenters and subsystem suppliers with any mechanical design problems they may encounter. They have designed special mechanisms and booms for the experimenters and pressurized containers for flight tape recorders. They assist the power group by designing special cases and containers, heat sinks for converters, and solar paddle structures. The electronic group works with the mechanical group in designing electrical circuits for supplying power to all the mechanical areas, such as release mechanisms and erection systems.

The electronic-integration personnel function as the electronic systems group for the project. Information contained in the system design specifications are furnished to all subsystem designers to assist them in the completion of their specifications. After the system design specifications have been completed, the electronic group informs the experimenters with regard to the system philosophy and physical design, alerting them to possible system problems. The electronic group acquires detailed information with regard to experimenter's needs and desires. This helps to resolve individual problems at an early date. They assist the experimenters and subsystem suppliers by furnishing them with design guidelines covering materials to be used, electronic fabrication practices, corona, noise, r-f interference, induced magnetism problems, and preparation of electronic ground support equipment.

Design and Fabrication of Support Equipment

While all of the subsystem suppliers are engaged in the detailed design and fabrication of their prototype and flight hardware, the integration groups design and produce all of the necessary ground support equipment. The mechanical group takes care of all the jigs, fixtures, spacecraft handling dollies and shipping containers simultaneously with their design of the over-all structure. The electronic group, having acquired detailed information with regard to all the electronic subsystems, designs and produces the spacecraft control and spacecraft performance analysis systems prior to integration.

The spacecraft electronic control system furnishes external power to the spacecraft during integration in the absence of solar paddles (Figure 6). It furnishes to individual experiments: power, control and monitoring. It is used to stimulate experiments, to change the mode of operation, and to supply test pulses for experiment calibration (e.g., specially timed light sources were provided to obtain a complete operational check of the Explorer XVIII optical aspect sensor). Certain special experiment test devices are contained in this system. An external synchronizer unit is included to provide timing pulses that exercise the experiments in the proper order. The system is capable of decommutating the spacecraft data handling system without employing the r-f system.

The performance analysis system must decommutate the spacecraft telemetry, process the received data, and present it in a readily usable form. The increasing level of complexity of

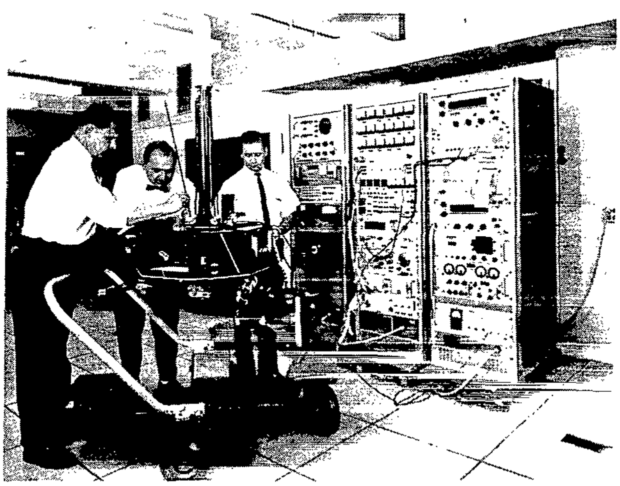

Figure 6—IMP spacecraft control system.

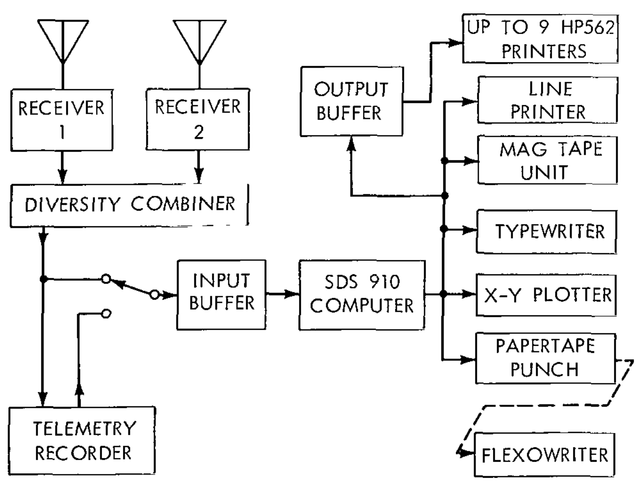

Figure 7—IMP mobile performance analysis system.

spacecraft systems has necessitated the development of ever more sophisticated analysis systems. The Explorer XVII and Explorer XVIII electronic integration groups developed systems using medium-speed digital computers, line printers, and other computer-driven peripheral display equipment.* These computer-centered performance analysis systems enabled these groups to perform continuous monitoring of their respective spacecraft with the results arranged in a format designed for accurate and convenient analysis and for permanent test documentation. Figure 7 is a block diagram of the Explorer XVIII (IMP A) Mobile Performance Analysis System showing how the system is designed around a medium-speed, general-purpose digital computer.

Qualification of Subsystems and Experiments

The electronic integration group is often requested to assist with the qualification of spacecraft subsystems and experiments prior to the start of physical integration. For in-house spacecraft this is a task of small proportion. However, when one electronic integration group acquired the job of performing extensive subassembly tests for a large out-of-house project (the Orbiting Geophysical Observatory), the task increased by an order of magnitude. To accomplish it, two major systems had to be developed—a spacecraft simulator and a performance analysis system.

The spacecraft simulator shown in Figure 8 is electrically identical to the spacecraft at the experiment interfaces and can accommodate a full complement of experiments simultaneously for a specific mission. Functionally, it provides any experiment under test with power, sync and timing signals, and commands. It accepts the output data in either analog or digital form. All of the electrical interface signals can be independently controlled and

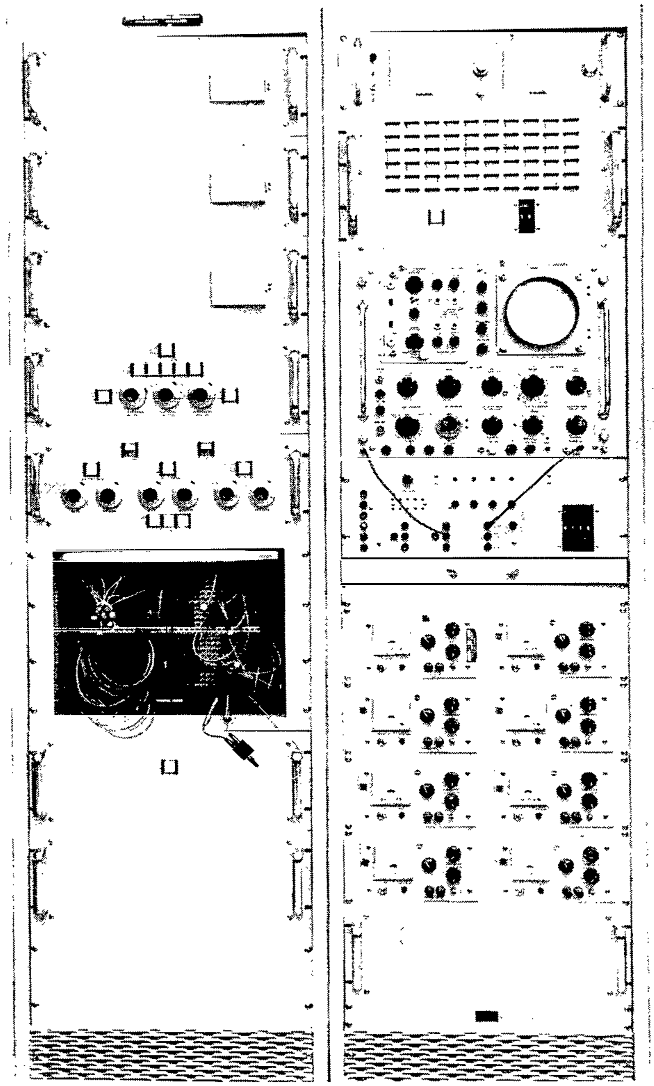

Figure 8—OGO spacecraft simulator.

*Grant, M. M., Stephanides, C. C. and Stewart, W. N., "Explorer XVII (1963 9A) Real Time PCM Telemetry Data Processing and Display Test Stand," NASA Technical Note D-2318, June 1964.

worst-case orbital conditions simulated while the experiment is still on the bench. Since the environmental test facilities are located in different areas, several simulators were required to efficiently handle all of the experiments as they passed through the various test phases.

The 64,000 bit-per-second PCM (Pulse Code Modulation) data from the simulators are telemetered to the OGO Experiment Performance Analysis System for reduction and display. This system, in addition to providing the necessary decommutation and analog recording equipment, employs a medium-speed, general-purpose, digital computer. With the use of the computer and its peripheral equipment, the system can rapidly reduce and display the experiment data in engineering units. Figure 9 shows a one-megacycle analog tape recorder and four eight-channel analog strip-chart recorders. Figure 10 shows 12 binary-light display units, 32 eight-bit digital-to-analog converters, a 24-channel optical oscillograph, the telemetry receiver, a bit synchronizer, the PCM decommutation equipment, an input core buffer, and the digital computer. Figure 11 shows an x-y plotter, the computer interrupt controls, the intra-facility communications, and three digital magnetic tape transports. Figure 12 shows a card reader, the alpha-numeric line printer, the photo reader and paper tape punch. The system capacity is such that it can reduce and display all of the data from all of the experiments simultaneously. Prior to the use of this system, the spacecraft contractor required an average of from five to eight days to perform a single, integrated systems test on the spacecraft alone. With the use of this performance analysis system, the total time required to perform the same test, including all of the experiments, was reduced to less than 10-1/2 hours.

Integration of Physical Systems

Electronic integration involves the solution of all interface, noise, electrical interference, and magnetic interference problems. After all of the subsystems have been fabricated, they are furnished to the mechanical group for installation within the main body of the spacecraft. The assembly is then transferred to the electronic integration group where electronic integration proceeds according to a prepared flow diagram which relates the most effective manner of checking out the subsystems one at a time. The mechanical group is on standby during electronic integration with no integration duties to perform other than those related to the installation of the spacecraft electrical interconnection system. This system is the one part of the spacecraft designed and produced by the electronic group. After installation of the interconnection harness, the subsystems are performance-tested in the following order: power system (without paddles), spacecraft instrumentation, encoding, data handling, experiments, and finally the r-f system. After all experiments and subsystems have been integrated into the basic structure and the system is operating according to specified performance requirements, the spacecraft is subjected to environmental exposures.

Environmental Qualification

Environmental qualification is conducted by a test and evaluation division according to the test specifications and procedures prepared along with the subsystem design specifications. It generally begins with tests that are mechanical in nature (vibration, acceleration, separation, boom deployment,

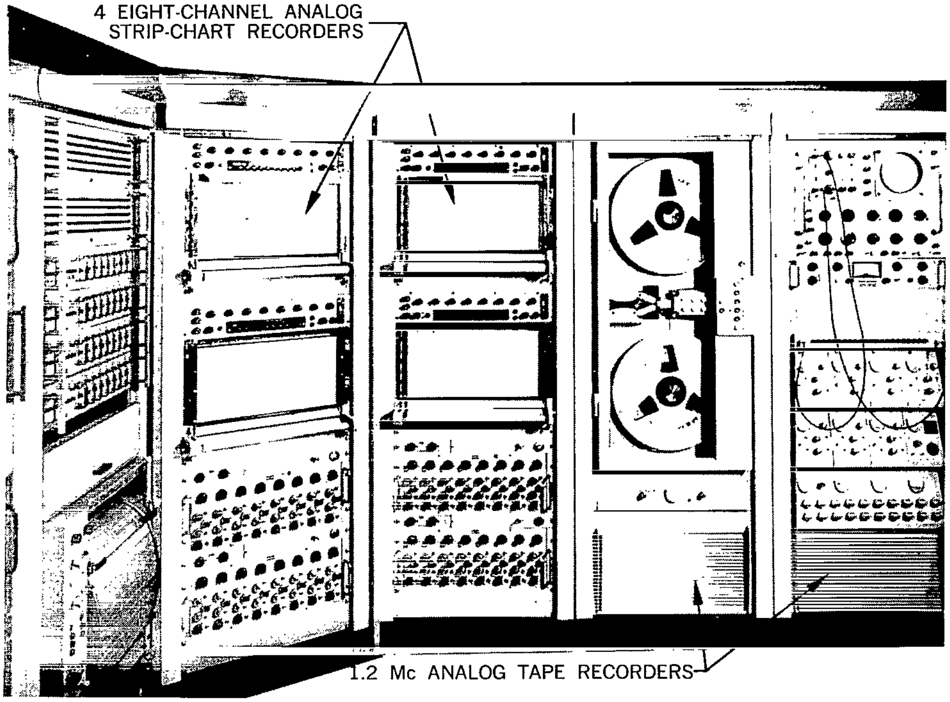

Figure 9—OGO experiment performance analysis system (right side).

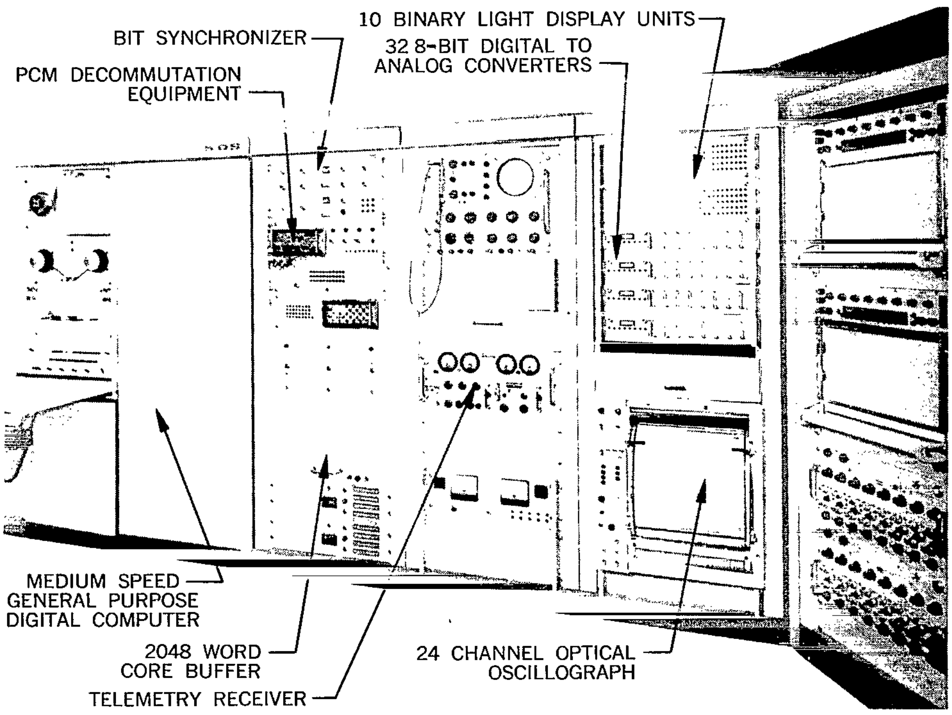

Figure 10—OGO experiment performance analysis system (center).

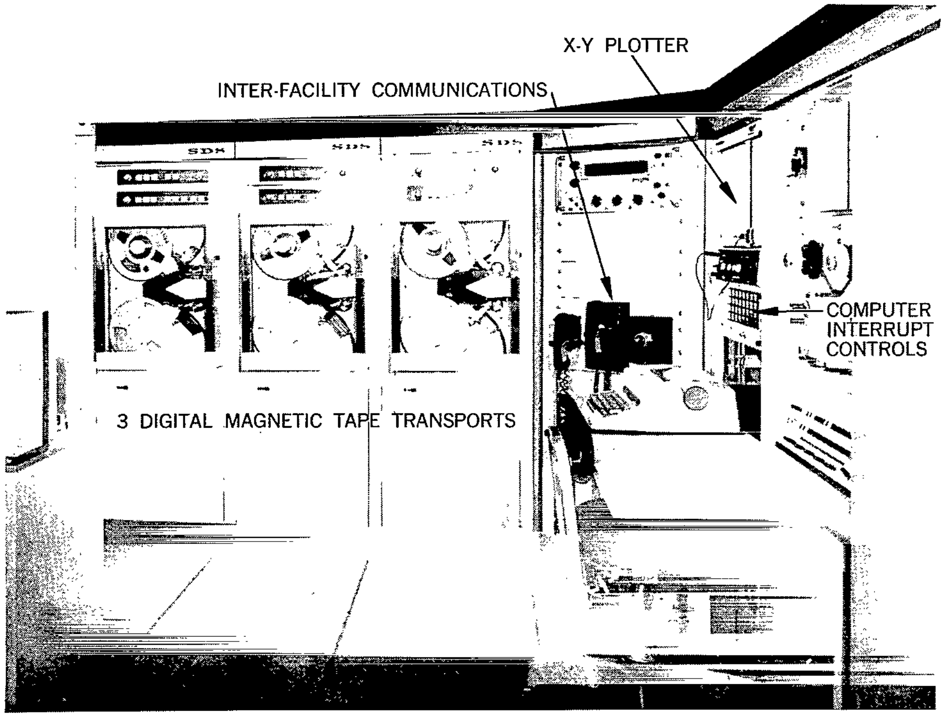

Figure 11—OGO experiment performance analysis system (left side).

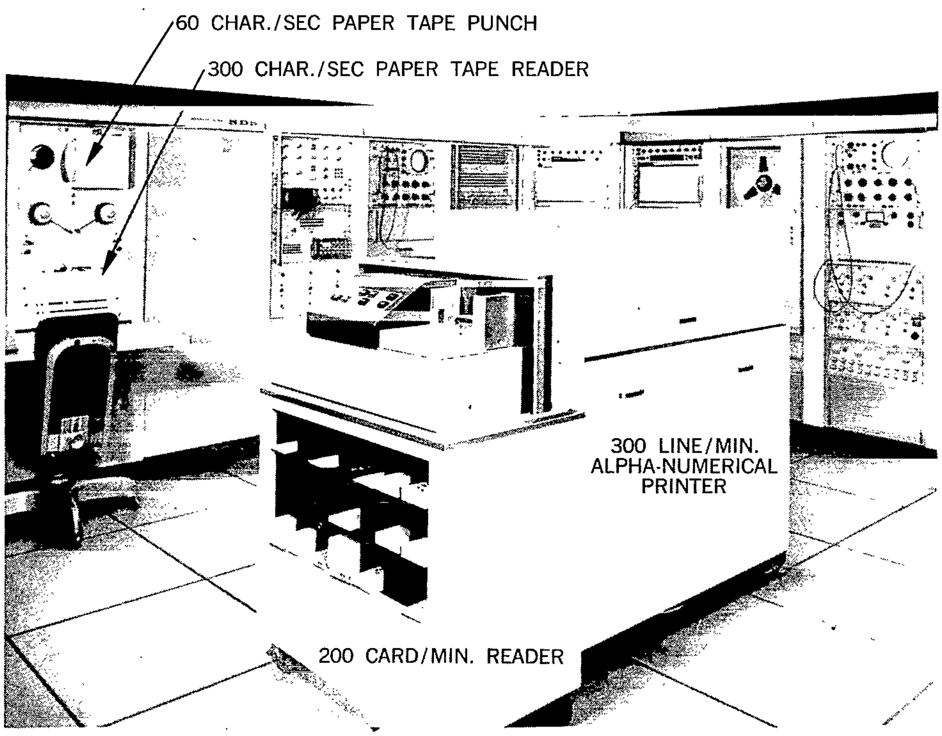

Figure 12—OGO experiment performance analysis system (oblique view).

spin, and balance) in order to verify the integrity of the basic structure and the proper performance of all mechanisms. The mechanical integration group is heavily involved during these tests. The electronic integration group participates by monitoring the electronic performance of the spacecraft before, during, and after mechanical tests, as requested. During the environmental exposure tests (temperature, humidity, and thermal vacuum), the electronic group is directly concerned with monitoring spacecraft performance. The mechanical group remains on standby to be called only in case of specific failures. After environmental testing has been completed, the results are submitted for environmental performance approval which must be received before the spacecraft can be transported to the launch site.

Launch Operations

Both the mechanical and electronic integration groups are heavily involved in all work related to launch. Their degree of involvement may be seen by considering the many tasks that must be completed after qualification and before launch. Prior to being transferred to the launch site, the spacecraft is "buttoned-up" before being placed in its special shipping container. The first test conducted at the launch site is a sunlight check (weather permitting) to determine the performance of the entire power system. Next is a recheck of the antenna pattern using dummy solar paddles. This is done with the prototype unit which is then taken to the spin facility, mated to a dummy final stage to check mechanical compatibility, then carried in a prescribed manner to the launch tower and installed on the launch vehicle by the launch crew made up of personnel from a launch operations branch and a vehicle contractor. This exercise is a complete "dry run" for training purposes. The nose fairing is installed to determine its fit with the spacecraft mated to the final stage. The locations of the umbilical plug and turn-on plug access doors are checked. With the nose fairing attached, tests for interference between the vehicle telemetry and the spacecraft telemetry are conducted.

If no prototype spacecraft is available, the launch operation requires more time. Generally, the prototype is sent to the launch site two weeks in advance of the flight spacecraft. Antenna pattern and sunlight checks are also made with the flight unit before it is mated with a live, final-stage motor and installed on the launch vehicle. Even though both the flight spacecraft and the final stage have been independently balanced dynamically, they must be balanced as an assembly due to last-minute wiring additions and also the addition of foil wrapped around the final stage. All additional balance weights are added to the final stage motor. After final balance, the flight assembly is transported to the launch pad in its special container and installed on the launch vehicle. Electrical systems tests and final calibrations are conducted during final days of the countdown. The day before scheduled launch, the nose fairing is installed and all control of the spacecraft is shifted to the blockhouse. All spacecraft monitoring is performed by the electronic integration group. Monitoring is accomplished via r-f transmission between the launch pad and the hangar where the performance analysis system has been installed. The mechanical group's work is complete once the fairing has been installed and the turn-on plug locked in place. The electronic group, however, participates in the final countdown by monitoring the performance of the spacecraft. If their system possesses the capability and the project manager so requests, the integration group records and analyzes data received from the first few passes to provide a quick-look at the spacecraft's performance in orbit.

Documentation

A considerable amount of documentation is produced during the design, fabrication and integration phases. The mechanical group produces drawings and schematics covering the mechanical design of the complete spacecraft system. They assist in the preparation of all mechanical test specifications to insure against both over-test and under-test. The electronic group produces a complete book containing all functional block diagrams, wiring diagrams, and electronic circuit diagrams. They maintain all of the spacecraft logs and keep all of the electronic test data records in log books and on printouts. They produce a performance parameter calibration document and a technical description document which describes the purpose, operation, physical layout, read-out, and integration tests for all subsystems and experiments. Upon completion of the launch operation, both groups prepare their final reports.

INTEGRATION BY SUBSYSTEM COMBINATION

Subsystem combination through electronic design is another approach to spacecraft integration. Many advantages accrue from combining several functional elements into a single, simplified, integrated package. With many of the functions accomplished internally, the input and output to the package are greatly simplified and several complex interfaces are eliminated. With the elimination of a large portion of the external connectors, the reliability of the spacecraft is enhanced.

Figure 13 depicts the evolutionary process of integration through subsystem combination. The seven blocks shown represent the experiment sensors, sensor analog electronics, sensor digital electronics, accumulation and storage, commutation, encoding, and programmer video. On satellites employing the Pulse Frequency Modulation (PFM) type of telemetry, these functions, along with the r-f, constitute the entire spaceborne portion of the information system. By means of improved electronic circuit design and the adoption and extension of new electronic packaging techniques, the accumulation, storage, and commutation functions can be incorporated into the spacecraft encoding system. The packaging techniques employed are spot welding and microelectronics. The tendency toward increased complexity in succeeding spacecraft is also indicated in this figure by the increasing number of transistors in the encoding system. The Explorer XII encoder contained 200 transistors and 600 other components (resistors, capacitors and diodes), telemetered data from 34 discrete experimental outputs, provided an information rate of 250 bits per second, and was packaged in a volume of approximately 120 cubic inches.* The packaging technique employed discrete components and printed circuit modules on printed circuit boards. It is to be noted that the experimenters on Explorer XII did their own accumulation, storage, and commutation. The associated digital and analog oscillators were located in the encoder. With the advent of Ariel I,

*White, H. D., Jr., "On the Design of PFM Telemetry Encoders," NASA Technical Note D-1672, June 1964.

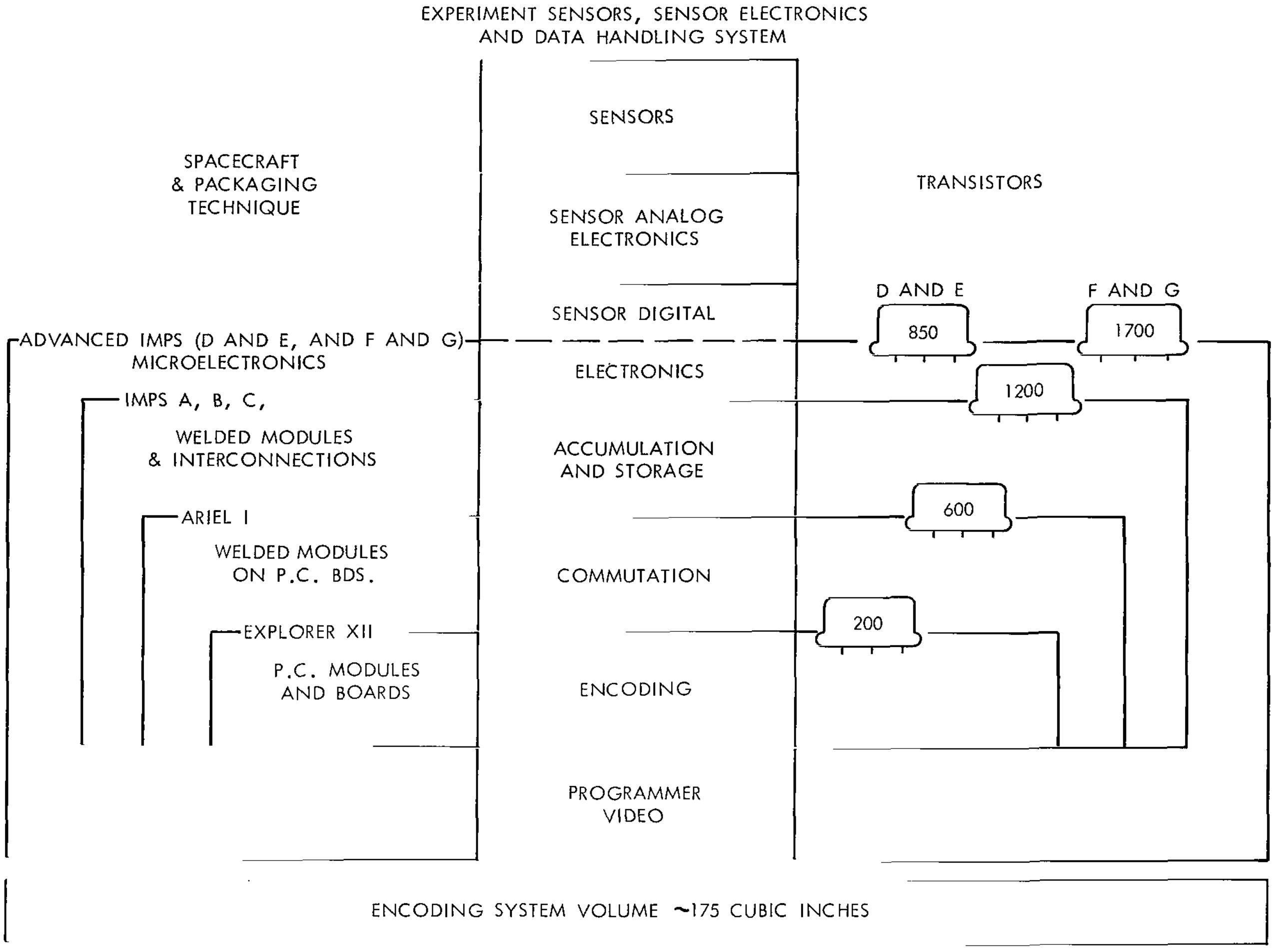

Figure 13—The evolutionary process of integration through subsystem combination.

the complexity of the encoding system increased because it employed two encoders: a high speed for real-time and a low speed for stored data. They contained 600 transistors and 1800 other components, telemetered data from 100 discreet experimental outputs, and provided an information rate of 150 bits per second. In the interest of expediency, the analog and digital oscillators and commutation electronics were fabricated in the United States and sent to the United Kingdom for installation in the experimenters' packages instead of being incorporated in the GSFC encoding system. The technique used in fabricating the experimenters' cards and the encoder boards was to solder weld modules to printed circuit boards.

In satellites containing experiments digital in nature, the accumulation, storage, and commutation functions can be readily incorporated in the encoding system instead of in each experimenter's electronic package. This vastly simplifies the encoder-experiment interface and frees the experimenter to concentrate on his sensor problems. This incorporation of the accumulation, storage, and commutation functions into the encoding system was accomplished on a PFM satellite for the first time in Explorer XVIII, one of the Interplanetary Monitoring Platform series. To do this, 135 bits of memory had to be added. This assembly contained 1200 transistors and 3600 other components, telemetered data from 160 discrete experimental outputs, provided an information rate of 18.75 bits per second, and was packaged in 175 cubic inches through the use of welded modules interconnected with a welded matrix. This encoding system was also incorporated in Explorers XXI and XXVIII, the next two of the IMP series.

Due to the requirements for increased digital bit rate and memory in the advanced IMP programs, the encoding system has been expanded and improved by increasing the bit rate and memory for the Anchored IMP's D and E by a factor of 1.5, and for IMP's F and G the bit rate has been increased by a factor of 5 and the memory tripled. In addition, part of the sensor digital electronics and the programmer video have been added to the encoding system along with the accumulation, storage, and commutation functions for all of the advanced IMPs. This assembly for AIMP's D and E has 850 metal oxide silicon field effect transistor (MOSFET) blocks,* 150 transistors, and 2,000 other components which are packaged in a volume of approximately 140 cubic inches through the use of the welding technique. For IMP's F and G this assembly contains 1,450 MOSFET blocks, 250 transistors, and 3,500 other components all packaged in a volume approximately 280 cubic inches.

These systems use three types of MOSFET integrated circuit blocks, one binary and two logic configurations, each packaged in an 8-lead TO-5 can. The entire system is packaged in one unit thereby eliminating intercard connectors for internal sync pulses. This has simplified the spacecraft design tremendously. The number of clock pulses and sync pulses being sent to the experimenters for switching their sensor digital electronics have been reduced from an estimated 500 to 50. In addition to these outputs, the advanced IMP encoding systems require only power input, inputs from the sensor electronics, and one output to the modulator unit. These design improvements would not have been possible if it were not for the direct communications between the experimenters, the encoder circuit designer, and the electronic packaging engineer. By combining the five functions referred to in Figure 13 into one encoding system and furnishing it to the spacecraft electronic integration group as a unified assembly, the integration task has been greatly simplified and the system reliability increased.

CONCLUSION

It is the integrative function in a project manager's operation that stands out loud and clear. He and his staff integrate the efforts of everyone involved in their project. There is an ever-present requirement for joining the many parts and tasks into a whole. It is their efforts, supported directly by the mechanical and electronic integration groups in planning, designing, fabricating, integrating, and administrating from conception through completion, that are vital to the success of any space flight program.

Only one method of organizing and implementing the integration of spacecraft was considered here; there are undoubtedly several others. The philosophy of management and integration

*White, H. D., Jr., "Evolution of Satellite PFM Encoding Systems from 1960 to 1965," GSFC Document X-631-65-114, March 1965.

described may not necessarily be the best; however, the unqualified success of the many programs undertaken in the manner described herein, without a single failure, clearly demonstrates its effectiveness. The cases in point are the management and/or technical integration of Explorers VIII, X, XII, XIV, XV, XVII, XVIII, XXI, XXVI, and XXVIII and Ariels I and II.

Perhaps the foremost reason for the success of this approach, as applied to these small inhouse scientific spacecraft projects, is the fact that the functions of management, mechanical and electronic design, and technical integration were confined to one organizational line element of the Center. This promoted project success by facilitating the solution of technical problems with a minimum of effort through simplified communications and the elimination of organizational interfaces.

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