given. Results of the research mentioned have not been published, either by Rüdenberg or by any of his collaborators. The well-known development of the commercial Siemens electron microscope was undertaken by Ruska and von Borries (after they had left the High Tension Laboratory) in a then newly established department of Siemens and Halske, a company concerned with electrical measurement equipment and quite independent of Siemens Schuckert, whose field is electrical power equipment. Their work was completely independent of Rüdenberg's work. In 1943 Rüdenberg wrote a letter to the editor of the *Journal of Applied Physics* (*34*), in which he describes extensively the contents of U.S. patents 2,058,914 and 2,070,319. He claims a priority of 31 May 1931, though the more sophisticated patent applications were filed later.

Summary

Knoll and Ruska developed the first electron microscope during their research to improve the demountable high-voltage cathode-ray oscillograph. Starting with the investigation of the well-known focusing coil, they progressed step by step until, in 1933, Ruska could show the first pictures with resolutions beyond those obtainable with an optical microscope. Reinhold Rüdenberg is sometimes called the inventor of the electron microscope because he was the first to apply for patents on it. Actually, he did not contribute to the development of the first microscope. When he filed his first patent applications, Knoll and Ruska had already built the first model and had shown it to many interested people (*35*).

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Scientific Instruments in Space Exploration

As our mission capability increases, the problems become more complex and difficult.

Raymond L. Heacock

Our rapidly expanding space technology is making possible achievements that men could only dream about a few years ago. The future offers still more promising opportunities for expanding our knowledge of the solar system and the universe. The achievements to date were not easily accomplished. Many complex and difficult problems were faced and solved. As our mission capability increases, the problems become even more complex and difficult. In designing the scientific instruments we face comparable problems, and solutions must be forthcoming if the progress made to date is to be sustained.

Performance and reliability are the two measures to be applied in assessing the potential usefulness of a scientific instrument for missions in space.

The early achievements in space were almost entirely dependent upon the capability and reliability of the launch-vehicle system. Had the early Vanguard satellites been successfully injected into orbit, they would undoubtedly have performed their intended missions. The successes of the Explorer and Pioneer satellites were correlated almost one-for-one with successful injection. This relationship existed because of the complexity of the launch-vehicle system as compared to the payload. With the greater complexity of the larger satellites and spacecraft in use today, the success or nonsuccess of a mission depends about equally on the reliability of the satellite or spacecraft and that of the launch-vehicle system.

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Increasing the reliability of the launch system will place the entire burden of success upon the satellite or spacecraft.

Experience with the Ranger satellite has emphasized the problems of reliability in complex spacecraft systems. The considerable knowledge gained with the early Rangers was successfully applied in a 9-month program for the design, development, fabrication, testing, and preparation of Mariners I and II. The tremendous success of Mariner II in its close-up exploration of Venus on 14 December 1962 is now history (*1*). If such successes are to be repeated with even larger and more complex spacecraft, the greatest possible emphasis must be placed upon performance and reliability. Any scientific instrument flown in future space missions must be a part of this system of design, development, fabrication, testing, and calibration for performance and reliability in space.

Background

The National Aeronautics and Space Administration supports a multifaceted program of space exploration. The program covers both manned and unmanned exploration. It is concerned with launch systems, launch vehicles, satellites, spacecraft, tracking and telemetry, data processing, and so on. In the space sciences, NASA supports a broad spectrum of activities, from basic research through flight instrumentation and from preliminary studies through analysis and interpretation of flight data. This work is sponsored in universities, research institutes, and industrial organizations and at various NASA centers. Through these efforts the required scientific and engineering background is developed in support of this nation's program of space exploration.

For the planning of a mission and the selection of the scientific instruments, there are different philosophies and approaches. The processes of selecting the mission and the scientific instruments for earth satellites and for lunar or planetary missions can and should be entirely different. The difference results primarily from considerations of cost, weight, power, communications, launch opportunities, lifetime requirement, and so on. Because the constraints are more serious in lunar and planetary missions, the scientific instruments for such missions must be "designed" into the spacecraft system.

Significant lunar and planetary missions can be achieved only through very tight integration of all the flight hardware. Optimum configuration, weight, power, and telemetry are obtainable when an instrument is designed as an integral part of the spacecraft system, both mechanically and electrically. This is the approach that allows for the greatest payload of scientific instruments.

Designing scientific instruments for such highly integrated payloads presents unique and difficult problems. These problems are in addition to the more general problems of environment and performance that are common to all earth satellites and spacecraft. The environmental problems appear obvious, and yet the effects are very difficult to assess and test. Principal among these environmental problems are problems of vibration, shock, temperature, vacuum, radiation, and cosmic dust. Radiation and cosmic dust present no significant problems in deep space. The radiation belts and the increased concentration of cosmic dust in the vicinity of the earth make these phenomena of more interest for earth satellites than for lunar or planetary spacecraft. The problems of designing instrumentation as an integral part of the spacecraft and the effects of the environment upon performance cannot be considered in depth in an article of this length, but they are touched upon in the sections that follow.

Design Philosophies

The design of instruments for space exploration involves the use of the latest techniques of circuit design, the use of exceedingly reliable components, good quality-control practices, and elaborate qualification and testing programs. The design and development of instruments is an engineering task, and no matter how well conceived the scientific experiment may be, it will be only as good as the engineering of the instrument. This raises the question of how good the instrument has to be for a particular experiment. In an exploratory mission, where very little is known about the phenomena being measured, it is probably best to have a wide dynamic range at the sacrifice of accuracy and stability. But if the phenomena are bounded and quantitative determinations are the goal, the instrument should not have to be considered in the data-interpretation processes.

The instrument can be ignored in these interpretation processes only if its inherent accuracy and stability are very high or if it can be calibrated in flight. Absolute accuracy and stability within prescribed limits for any condition of the environment likely to be encountered are obtained by appropriate design, through the use of stable components and feedback techniques. If temperature sensitivity or aging variations exist, it must be determined whether such changes are predictable, so that they can be compensated for, or whether an elaborate in-flight calibration technique must be prepared. One-point calibration of a temperature-sensitive system is not sufficient. Calibration of only a part of an instrument, because this is easily accomplished mechanically, is of no use if those portions of the system which are sensitive to temperature or subject to aging are not included.

Design philosophy is exceedingly important to the success of a mission. It cannot be overstressed. Design philosophy for building a reliable, long-life, stable, and accurate instrument should start with the earliest concepts of the experiment and follow through to the completion of the flight hardware. It has been demonstrated that instruments designed for short-life earth satellites are not generally satisfactory for planetary missions. It has also been demonstrated that it is almost impossible to redesign an instrument for greater stability and long-term reliability once it has been committed to a mission schedule. It is, therefore, necessary that scientists proposing experiments for space exploration have engineering assistance and that they allow a reasonable lead time for design and development of the instrument for the mission in question before committing it to a mission schedule.

Spacecraft System Constraints

Mechanical integration. A spacecraft system can take many shapes, depending upon the design criteria. The Mariner II, shown in Fig. 1, represents a tightly integrated design. In structural form it has the hexagonal shape of Ranger. Full stabilization of attitude is accomplished with solar panels pointed at the sun, and a high-gain antenna pointed at the earth. The scientific instruments are "built in"; there are appropriate mounting positions for sensors, and most of the electronic components of the instruments are in the housings mounted on the hexagonal structure.

The Mariner spacecraft was designed with a launch-vehicle injection limitation of 202 kilograms (446 lb) (*2*). Thus, the weight of the subsystems with nonscientific functions had to be kept to an absolute minimum to allow for scientific instrumentation. The design goal for the weight of all nonscientific components and equipment was 183 kilograms; thus, the weight of the scientific instrument system, which included the weight of power-switching equipment and data-conditioning equipment, was set at 19 kilograms.

Table 1 is a tabulation of data for the elements of the scientific instrument system. As shown in Table 1, the weight of the system was approximately 3 kilograms above the design goal. This excess was, fortunately, offset by a reduction in the weight of the rest of the spacecraft system. The final total weight was approximately 200 kilograms; this was about 2 kilograms below the design goal. If it had been impossible to reduce the weight of the nonscientific components below 183 kilograms, some of the scientific instruments would have had to be left out.

While weight and mechanical packaging and integration are difficult and limiting facets of spacecraft-system design, there are other problems of integration which must be faced. In the Mariner II flight when there was a short circuit in one of the solar panels, there was a shift of 100×10^{-5} oersted in the output signal of the magnetometer. This typifies the interference problems which result from an interaction between the spacecraft and the interplanetary environment, or through parasitic electrical and magnetic effects of spacecraft components upon the scientific-instrument sensors or electronic components.

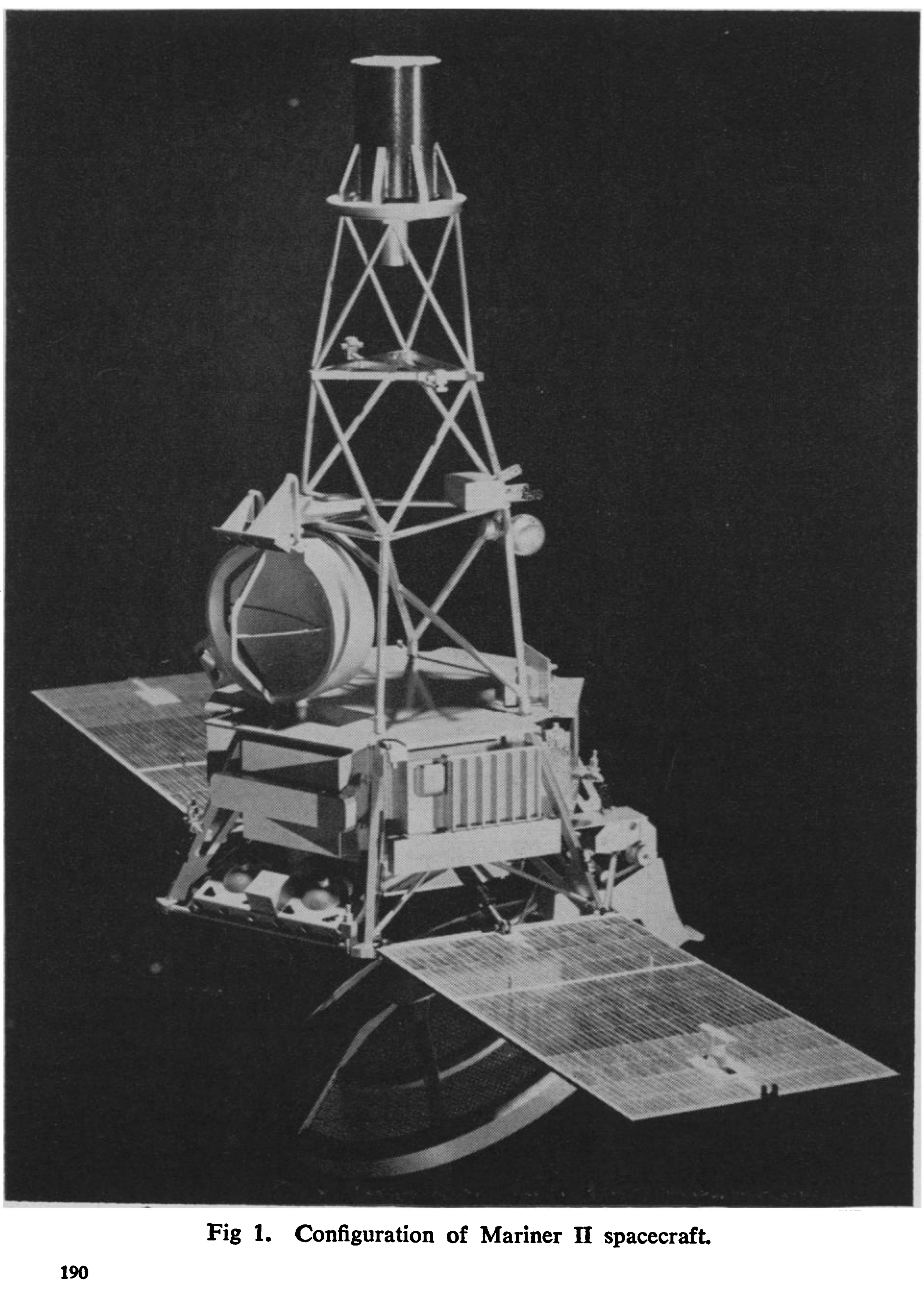

Fig 1. Configuration of Mariner II spacecraft.

In Ranger III, as the result of a decrease in bremsstrahlung effects, the measured cislunar gamma-ray background radiation obtained with the boom, on which the detector was mounted, in the extended position was only half the value obtained with the boom in the closed position. Also, ionizing radiation sources located in an accelerometer, and in the radar altimeter interfered with the gamma-ray measurements. Interference problems of this type must be considered early in the design of a spacecraft system if proper controls are to be included. When a magnetometer is flown, magnetic materials must be kept to a minimum, and appropriate shielding must be used where necessary. Special booms can be used to isolate instrument sensors when interference effects within the spacecraft cannot be sufficiently reduced.

In Mariner II, the magnetometer was mounted high up on the omnidirectional antenna tower to minimize magnetic interference from the spacecraft. The ionization-chamber and particle-flux detectors were also mounted on the tower in order to decrease bremsstrahlung effects from the main body of the spacecraft. The rest of the scientific instruments were located with due consideration given to the problem of shielding from interference that would distort the scientific measurements.

Packaging-design philosophy is important not only from the standpoint of overall integration but also in order that the instruments may hold up under the stress of conditions in space. In Mariner II, equipment housings were mounted on the faces of the hexagonal structure. Individual modules in the housings helped to provide the overall structural strength required. This technique minimizes the total weight of the structure. Packaging considerations include shock, vibration, temperature control, repairability, testing, material, fabrication, and inspection and other quality-control procedures. (For discussion of the packaging approaches for Mariner II, see *3*.)

Power. In spacecraft, power is at present obtained through a combination of batteries and arrays of solar cells. This technique has been demonstrated to be efficient and reliable. Other systems are being considered and will eventually be used. The fuel cell and the radioactive thermoelectric generator are two of the more promising types of systems under consideration. Mission requirements and limitations weigh heavily in determining the proportions of batteries and solar cells to be used in a particular spacecraft. Future missions, such as those for making soft landings on the moon or landings on Mars, will undoubtedly require radioactive thermoelectric generators, or equivalent power sources, so that the spacecraft can operate for long periods when solar power is not available.

Present spacecraft systems have a power limitation because of weight limitations. Spacecraft equipment and, especially, scientific instruments must be designed to operate on the least power commensurate with reliable performance. An excellent example of electronic design for low power consumption is the design of the solar-plasma instrument that was flown on Mariner II. On 1 watt of power, this instrument operated the following devices: (i) a transistorized electrometer with a vibrating-reed capacitor input modulator and a 7-decade dynamic range covering 10^{-13} to 10^{-6} ampere; (ii) a digital programmer to sequence the instrument through 13 operational steps of proton detection, involving 12 energy ranges, from 100 to over 5000 electron volts; and (iii) a feedback-stabilized high-voltage power supply to operate the curved-plate electrostatic analyzer used to focus protons into a Faraday cup for detection by the electrometer. The power supply develops a plate-to-plate differential of over 2000 volts, symmetrically referenced with respect to ground.

The basic design of an instrument may be improved through the necessity of designing for minimum power consumption, as a result of simplification of design or elimination of components, or because of the depth of the design considerations required to achieve operation at lower power. The designer of the instrument should not commit himself to a particular design until he has investigated the operational margins both analytically and experimentally.

Communications and data handling. Mariner II had two data systems. One system, the data encoder, was used for monitoring the performance of the spacecraft. The second system, the science-data conditioner, accepted the outputs of the scientific instruments. The data conditioner provided analog-to-digital conversion, accumulation of rate data, instrument timing, and commutation of data from the scientific instruments, through the data encoder, to the spacecraft transmitter. Using two data systems has advantages when the requirements of different missions dictate appreciable changes from mission to mission in the scientific payload but not in the engineering system. Such an approach makes it possible to provide the best possible data system for the particular instruments included in the mission without jeopardizing the reliability of the engineering measurements (see *3*).

Table 1. Scientific instrument system of Mariner II.

Item	Weight (kg)	Power (watts)
Data conditioning with power switching	3.7	2.0
Microwave radiometer with scan actuator	10.8	10.0
Infrared radiometer	1.2	1.5
Solar-plasma instrument	2.2	1.0
Magnetometer	2.1	6.0
Cosmic dust detector	0.9	1.0
Particle flux detector (Geiger-Müller tubes)	.8	0.3
Ion chamber	.4	0.1
Totals	22.1	21.9

The communication rates utilized in the Mariner II mission were 33 bits per second for the first 2 days of engineering telemetry and 8.3 bits per second for the balance of the mission. The commutation sequence was 16.8 seconds of engineering telemetry and 20.16 seconds of scientific data, except during the encounter with Venus, when only scientific data were transmitted.

The low communication-rate capability places the most serious constraint upon planetary missions. Many instruments have potentially high rates and volume requirements of information output. When an instrument cannot be scaled for real-time or near-real-time operation through the communication system, it is necessary to provide a buffer storage system. Such a storage system can have any of several configurations, depending upon the particular requirement. In future missions to Mars in which surface photography of the planet is required, a system, such as a tape recorder, that can handle a high volume of data will be used.

Problems concerning sampling rate, sample accuracy, storage requirements, and the form of output data must all be considered by the instrument designer, the data-conditioner engineer, and the engineer responsible for the integration of spacecraft and instruments. Only through close coordination and cooperation can the requirements of both the scientific instrument and the spacecraft be satisfied.

In Mariner II, a central computer and sequencer and a radio command system were used for performing various spacecraft-control functions. In some instances the two had to operate together to perform a function (for example, a mid-course maneuver), and in others, the radio command system provided a redundant capability, backing up the central computer and sequencer. The Mariner II encounter sequence with Venus was to have been initiated by the central computer and sequencer, but when this system failed, the radio command system initiated the sequence.

The control of a scientific instrument may be achieved in several ways. The control may be internal, requiring only an external turn-on command, or control functions may be obtained from the data-conditioner system, the central computer and sequencer, or the radio command system. The approach to be utilized depends upon several value judgments. It is important for the scientific instrument system to be as independent of other spacecraft systems as is practical. Spacecraft systems such as the central computer and sequencer and the radio command system should not be complicated unnecessarily, or arbitrarily changed from mission to mission. Such changes could jeopardize a particular design which has successfully demonstrated reliability.

Temperature control. In a spacecraft system where weight and power are at a premium, it can be very difficult to meet the temperature-control requirements. Passive temperature control is obviously preferable because of constraints of power and weight. The vacuum of space requires that passive temperature control be achieved through the processes of conduction, radiation, and absorption. Problems of thermal balance in space are complicated by the very high input of solar energy to surfaces exposed to the sun.

Table 2 provides a summary of the expected temperatures on Mariner II at encounter with Venus and the actual temperatures. The latter ran dangerously high and undoubtedly were the principal factor in the failures which did occur. The Mariner spacecraft in the Mars mission of 1964 will have the opposite problem. The solar input will be continually decreasing as the spacecraft approaches the orbit of Mars.

Good temperature-control design requires that all spacecraft hardware be considered in the design processes. Testing can be performed in the large space-simulation chambers which are available.

Sterilization. There has been controversy over the need for sterilization in lunar and planetary exploration. The controversy arises when an attempt is made to weigh the potential gains against cost and effects upon reliability. Consideration of the potential interest of the moon and the planets to biology leads one to conclude that sterilization is required principally in a mission to Mars.

The environment of the moon's surface may be as severe as the sterilization technique currently in use. The lack of an atmosphere would greatly limit distribution of any organisms which might survive this extremely hostile environment. The environment of Venus appears equally hostile to earth organisms, although airborne life forms might survive if the constituents of the atmosphere are appropriate.

Mars offers far more promise of extraterrestrial life. Every effort should be made to prevent contamination of Mars, so that this unique opportunity to advance man's knowledge of life is not lost. Since sterilization is a generally agreed upon requirement for a mission to Mars, the necessary techniques and processes are being developed.

The present approach involves thermal soakage (with dry heat) at 135°C for 24 hours or more. The period may be shortened only if higher temperatures are used. The thermal soakage provides complete sterilization of a unit. Should a sterilized unit be exposed or handled, it may be resterilized by exposing the surfaces to a mixture of ethylene oxide and freon in a ratio of 9 to 1.

Obviously, the requirement for sterilization of scientific instruments presents problems. The extremely high temperature and the long soakage preclude the use of many generally acceptable components. Special consideration must also be given to materials. If any part of an instrument would be damaged by the high temperature, the component must be made sterile by some other technique in the course of fabrication. Such units may then be incorporated with heat-sterilized units, surface sterilization being carried out during assembly of the instrument. The effects of ethylene oxide upon materials, components, and sensors must also be considered (see *4*).

Environmental Constraints

Temperature. Problems of temperature in space programs are not limited to problems of temperature control or of thermal sterilization. In studies of temperature control one studies the balance of an instrument's loss of heat through internal dissipation and its losses or gains through conduction and radiation. Such studies indicate the limits of the extremes of temperature to which the instrument will be subjected. It is also necessary to consider the effects of variation in temperature upon performance and to solve the problems that arise from this variation.

An instrument should not be designed merely for satisfactory performance at expected temperature extremes. The problem can be attacked in several ways. The first and preferable approach is to design for absolute stability and accuracy over the required temperature range. If sufficient stability in the design cannot be achieved, or if a backup check is desired, the capacity for automatic periodic calibration can be incorporated into the instrument. Automatic calibration cannot be utilized as a crutch for poor design. Ideally, for such calibration, the primary sensor is stimulated in the same way as the phenomena to be measured over a sufficient range to account for nonlinearities of response. Such an ideal is usually not attainable and some compromises must be reached. A calibration technique representing such compromises can be next to useless in an instrument that is sensitive to change in temperature. Can an instrument which has this sensitivity be stable in this respect with multiple temperature cycling or aging? In general, such sensitivity cannot be depended upon to stay constant over long periods, particularly not when the temperature-sensitive components are exposed to extreme environmental conditions. If a calibration technique does not include all of the elements that affect accuracy, the experimenter cannot depend upon the instrumental measurements. The problems of design stability cannot be overemphasized.

Vacuum. The hard vacuum of space presents problems peculiar to space exploration. The full range and depth of problems of materials are not fully understood. The problem of loss of materials through evaporation or sublimation, with subsequent change of characteristics, can be serious in itself. The effects of these evaporated materials upon other surfaces and various components and devices present another problem. The effects of a fogging film upon optical elements are obvious.

The problems of materials in space are amply treated in a report by Jaffe and Rittenhouse (*5*) and in the *Space Materials Handbook* (*6*). Jaffe and Rittenhouse deal exclusively with considerations of the effects of various environmental factors. In part 3 they discuss the effects of a vacuum. The *Handbook* covers a wider variety of phenomena, including system-induced environmental factors, such as shock and vibration. In it the space environment is defined and the effects of the space environment and the selection of materials are discussed.

Shock and vibration. Shock, vibration, and linear acceleration also present serious constraints in the design of many scientific instruments. Such constraints are new to many scientists and to the manufacturers of scientific instruments, and development of the required understanding and skills takes time. The designers of equipment for spacecraft systems have drawn on the knowledge and skills built up to support the military-missile programs. Much of this experience can be applied directly in designing scientific instruments. However, in designing many scientific-instrument sensors, problems of shock and vibration are encountered which have not been tackled before, since there had been no requirement for such extreme ruggedness. It has been found easier to have an expert in problems of shock and vibration work with the sensor specialist than to try to train the sensor specialist to handle these problems himself.

What levels of shock and vibration the designer must consider depends upon the launch-vehicle system to be used, the design of the spacecraft, and the mission to be performed. Equipment for the rough-landing Ranger capsule was designed to survive shocks of 5000*g*. The rest of the Ranger spacecraft was designed to survive shock levels of 30 and 200*g*, depending upon the duration of the impulse.

The vibration experienced in actual systems is a multiple-frequency stimulus. This is simulated in equipment testing through band-limited white-noise excitation to the vibration table. Usually a prepared magnetic tape is used for sequencing through different intensities and types of signals. In many applications, a swept-frequency sine wave is added to the noise during some portion of the test tape in order to stimulate any resonant modes which may exist. Vibration levels of 15 to 20*g*, with frequency spectrums from 15 to 1500 cycles per second, are representative. Test tapes generally last from about 3 minutes, for acceptance tests, to upward of 10 minutes for type-qualification tests. These tests vary in accordance with the design philosophies for the projects.

Designing an instrument that can resist vibration and shock requires specific design knowledge. The basic structure should have sufficient strength and stiffness to support components without excessive flexure, but no excess material should be used because of the weight. There are various approaches to the problem of mounting components and integrating them into the structural units of an instrument. The use of flat terminal boards with printed wiring and full availability of components for test and repair has its advantages. In view of the demands for inherent reliability in space instrumentation, a valid argument exists for the use of modular welded assemblies. According to the argument, if the reliability is not sufficient to warrant the use of throw-away welded modules, then the reliability is not sufficient to warrant flying the equipment.

The packaging approach should lend itself to solving the specific problem at hand. Ruggedness can be achieved with any of several packaging techniques. The reliability of a particular packaging approach is maintained through appropriate quality-assurance and quality-control processes.

Quality Assurance and Control

In operations which demand maximum reliability, it has become standard practice to utilize a separate organization to set standards and to make sure that they are met. These organizations usually report directly to top management of the scientific-instrument manufacturer. The processes of establishing standards is carried out in cooperation with the engineering and manufacturing or production divisions. The areas covered involve component parts, materials, layout, construction techniques, process controls, and so on. Every aspect of the fabrication sequence and every physical device must be brought, in the design stage, to the attention of the quality-assurance organization, so that appropriate standards may be set and appropriate quality-control criteria established.

Table 2. Predicted and actual temperatures for Mariner II at encounter with Venus.

Item	Temperature (°F)	
	Predicted	Actual
Plasma experiment (case I)	92	155
Spacecraft:		
Case II	90	152
Case III	89	149
Case IV	80	124
Case V	84	134
Lower thermal shield	58	122*
Upper thermal shield	215	153
Solar panel, front face	262	250-254*
Battery	91	130*
Power boost regulator	114	129
Earth sensor	90	165*

*Extrapolated data.

Quality-control inspection is made in the course of fabrication and again when the unit has been completed. Often when a device is repaired it must be reinspected to make sure that it still meets the criteria. Quality control is also extended to the qualification-testing of equipment. A quality-control monitor usually observes the testing program, to make sure that all the required tests are properly carried out and accurately reported.

Suppliers of scientific instruments have varying degrees of difficulty in arranging for formal inspection for quality assurance and control. Obviously, most scientists do not have large and elaborate inspection organizations supporting them. Most manufacturers of scientific instruments do not have their own space-program-oriented organizations concerned with quality assurance and control. They depend heavily on personnel from the responsible NASA center in establishing the required standards and setting up the inspection program for particular instruments. Experience has demonstrated that close adherence to the requirements of a good quality-assurance and quality-control program pays big dividends in reliability.

The calibration of scientific instruments for space exploration requires special consideration. The problem of calibrating scientific instruments for planetary encounters such as that of Mariner II is merely an exaggeration of a problem common to all spacecraft missions. The detailed calibration of these instruments is performed over a 4- to 7-month period before they are used at the time of planetary encounter. The length of this period emphasizes the need for stable instruments and for long-term checking of the instrument for gross failures, with simple calibration techniques.

Ideally, the calibration of scientific instruments for space exploration should be performed under simulated space conditions and over the expected range of critical environmental parameters, such as temperature. The difficulty of calibrating instruments under simulated space conditions dictates that other approaches be used when possible. Calibration over a wide range of temperatures is obviously important, since temperature is a relatively unrestricted parameter.

The effects of environmental factors such as shock, vibration, and vacuum-thermal cycling on the reliability of the instrumental calibrations must be determined. The instrumental calibrations cannot be depended upon after launch if changes in calibration occur during shock- and vibration-testing. A periodic calibration check on an instrument in "life test" is highly desirable for long-life instrumentation. Such life tests and calibration checks on instrumentation identical to the flight hardware make it possible to place confidence in the calibration characteristics of the flight instrument for interpreting data. This is particularly true when the life-test unit is subjected to the same conditions of pressure and temperature to which the flight instrument will be subjected, and over the same periods.

Detailed calibration of the instrument cannot be performed independently of the experimenter. The responsible scientists must have a detailed knowledge of the performance of the instrument in measuring the phenomena of interest in order to interpret the data correctly. A detailed knowledge of the characteristics of the instrument and its areas of weakness can be invaluable in making useful interpretations of data obtained under nonstandard conditions.

Systems Testing and Field Operations

The scientific instruments form a part of a large and complex system. It is necessary that these instruments be integrated with the other spacecraft equipment into a model spacecraft, not to

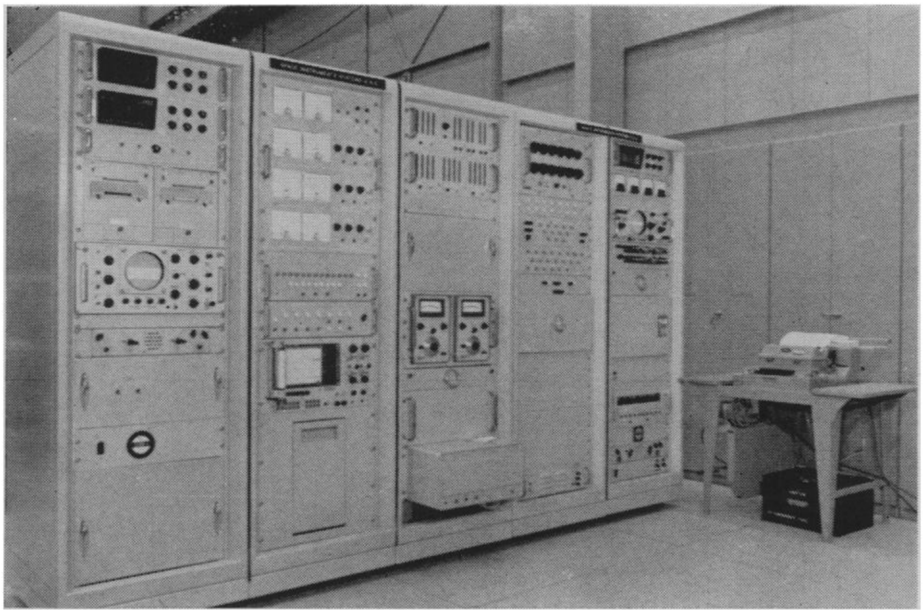

Fig. 2. Operations-support equipment for the scientific instruments of Mariner II.

be used in flight, for troubleshooting and general testing for compatibility. These models are called "proof-test-model" spacecraft. The scientific instruments must be delivered early, so that they may be tested in the model spacecraft. Delivery may be required as early as 1 year before launch, in order that the multitude of complex devices that make up the spacecraft and its payload may be integrated and tested. The model spacecraft must be available early enough to allow changes to be made in flight hardware should the integration processes or testing program indicate that they are necessary.

The model spacecraft is also useful in developing procedures for testing the system and subsystems and in training personnel to carry out the systems-test and launch-sequence operations.

Next in the preparation cycle comes the arrival at the assembly facility of fully qualified and inspected equipment. This equipment is mechanically installed in the spacecraft, in accordance with a controlled sequence of installation and checking procedures. When the installation and checking have been completed, a "power-on" test is performed. If all units can be successfully powered, the subsystem operational tests are next carried out. Each subsystem has its own set of "operations-support equipment." With this set of equipment the subsystem equipment can be completely operated and tested independently when it is mounted in the spacecraft. The operations-support equipment for the Mariner II scientific instruments is shown in Fig. 2. Such equipment is used both at the NASA center and at the launch facility for complete systems-testing prior to launch. The complete verification testing program involves subsystem-operations tests, sub-system compatibility and interference tests, complete system tests, space environment simulation tests, spacecraft shock and vibration tests, and mission-simulation tests. Such testing is carried out on both the model spacecraft and the flight system.

The proof-test-model spacecraft is usually subjected to an additional life-test program. The life test is run either in advance of, or concurrently with, the mission. The model spacecraft has proved invaluable as an aid in understanding and interpreting nonstandard performance of the flight spacecraft. It can be subjected to the same general conditions as those encountered by the flight spacecraft, or it can be used in attempts to simulate malfunctions that have occurred in flight. Several difficulties that occurred in the Mariner II flight were investigated through this technique.

Mission Operations

Once the spacecraft has been launched and injected into orbit, the mission sequence for lunar and planetary spacecraft is initiated. For stabilized spacecraft, this involves solar acquisition, earth acquisition, and the establishment of high-gain antenna communications. Some scientific instruments are turned on at launch and allowed to operate throughout the launch and injection sequences. Other instruments must be left turned off because of high-voltage corona problems, or because they are susceptible to damage from shock and vibration while they are operating. In some instances, scientific instruments are turned off until operation of the solar panel is assured, in order to conserve battery power.

Some scientific instruments scheduled for operation at encounter with the planet are turned on in advance of encounter for calibration checks, and some are not. The requirement for such turn-on sequences complicates the overall design of the spacecraft. In Mariner II, both the microwave and the infrared radiometers were put through automatic turn-on and calibration sequences periodically during the flight. No pre-encounter automatic turn-on and calibration is proposed for the encounter experiments in the projected Mariner mission to Mars in 1964. It was felt that the added complexity that such turn-on and calibration would require would unduly lessen the reliability of the mission.

Mission operations are complex activities involving a large number of separate facilities and personnel. In lunar and planetary missions the operation at the launching facility is a very small part of the total operation. The three Deep Space Instrumentation Facility (DSIF) stations and the Jet Propulsion Laboratory's Space Flight Operations Facility must be operational throughout the flight. The spacecraft signals are received by the DSIF stations, and the information is relayed by teletype to the Space Flight Operations Facility for processing, interpretation, and utilization. Tracking information is provided, along with data transmitted from the spacecraft. Computers calculate the trajectories and the required mid-course corrections, while teams of experts review the status of the spacecraft from the telemetered data. The interpretation of the scientific data is carried out independently, but assessment of the performance of the scientific instruments is a necessary part of the entire assessment of spacecraft performance.

The spacecraft-operations director is supported by teams of individuals trained in spacecraft-data analysis, flight-path calculation, mid-course determination, and science-data analysis and command requirements. Through his support personnel and his direct contact with the DSIF stations, the operations director maintains close control over the spacecraft in order to take action as required, in either standard or nonstandard sequences.

Summary and Conclusions

The path is a long one between the conception of a scientific instrument for space exploration and the goal of obtaining scientific measurements from space, from the moon, or from the atmosphere or the surface of a planet. These instruments must be designed to meet the scientific objectives under adverse environmental conditions and within the constraints of a complex spacecraft system. The limitations of weight, power, telemetry, integration, and reliability must be assessed and appropriately dealt with in the design, development, fabrication, testing, and calibration of the instrument. The instrument must operate satisfactorily in a vacuum-thermal environment for long periods after having been subjected to extreme shock and vibration during the launch and injection sequences.

To successfully fly a scientific instrument in space is an achievement involving a considerable number of man-years and dollars. Such an effort and expenditure of funds must be properly compensated through the attainment of scientific information. If billions of dollars are to be expended on the exploration of interplanetary space and of the moon and the planets, every possible effort must be made by the scientists and engineers in NASA, in universities, and in industry to see that this money is profitably spent.

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Institute for Experimental Surgical Instruments in Moscow

Doctors and engineers in a unique cooperative effort have developed a group of surgical stapling devices.

Timothy Takaro

Under the U.S.-U.S.S.R. exchange agreement, an arrangement was made recently for me to study the structure and function of the Scientific Research Institute for Experimental Surgical Apparatus and Instruments, in Moscow. I first spent 2 months at the institute itself (1 April to 30 June 1962), where I carried out a short experimental project. During the third month I visited nine hospitals, in Moscow, Leningrad, and Kiev, to try to assess the clinical usefulness of the specialized instruments which the institute has developed and for which it is well known. A working knowledge of the Russian language, which I had acquired in previous study in the United States, was invaluable.

The Soviet tradition of close collaboration between surgeons and the designers and makers of instruments is said to stem from the days of Peter the Great, who established a large instrument plant in St. Petersburg. Such names as Pirogoff, Elansky, and Kuprianov are associated with this plant, the oldest and largest of its kind in the Soviet Union. After the Revolution of 1917 it was renamed Krasnogvardets or Red Guard, and, as such, it has continued to function up to the present time.

The Institute in Moscow was founded in 1951, shortly after publication of a report by Gudov, a Russian engineer, describing the first Soviet vascular suturing device (*1*). This instrument, together with other stapling instruments which were developed in subsequent years for a wide variety of uses, have been the institute's principal claims to fame outside the Soviet Union. A great deal of experimental work on the use of these devices has been reported, and a few of the instruments have been used extensively in clinical practice.

More recently, the institute's attention has been focused also on such problems as extracorporeal circulation, with pulsatile flow; hemodialysis; the preservation and transplantation of tissues and organs; and electronarcosis and related fields. A study of synthetic polymers as prostheses to replace blood vessels, joints, cardiac valves, trachea, esophagus, ureters, and bile ducts is also under way. I did not observe any revolutionary advances in any of these fields.

Facilities

The institute is housed in a rather inconspicuous five-story brick building on the northern edge of Moscow. (There are subsidiary branches in Kazan and in Vorsma.) Under one roof are housed a large machine shop; a library; offices for engineers, designers, physicians, and surgeons; and complete laboratory facilities for biological experimentation. In an adjacent building, one of the Moscow city hospitals serves as a clinical base for the institute.

Approximately 350 people are em-

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