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THE ROLE OF THE EXPERIMENTER ASSOCIATED WITH MULTI-EXPERIMENT SCIENTIFIC SATELLITES

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ABSTRACT

The primary objective of the scientific investigators concerned with scientific spacecraft is to obtain interpretable measurements from their sensors. An additional primary objective of university investigators is to train students in the space sciences and research techniques. To achieve these objectives, the investigators must help define mission requirements; participate in mission planning, instrument development, integration and testing, prelaunch activities, and operations; and be prepared to analyze the data upon receipt. NASA, in turn, must keep prelaunch preparations as short as possible commensurate with reasonable success probabilities, provide a reasonable balance between system capability and simplicity, and provide flight data as rapidly as possible. Improvements to present flight programs can be made in several areas. The experiment life cycle needs shortening, and greater simplification of the experiment/spacecraft interfaces is desirable. Technical and management coordination should be simplified and made more direct. In turn, many experimenters need better financial management, improved ability to meet schedules, better quality control, and better preparation for data reduction after launch. Improvements for future flight programs are under study.

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INTRODUCTION

The space-science satellites launched by the National Aeronautics and Space Administration (NASA) are designed to accomplish specific scientific objectives. The satellite scientific instrumentation is carefully selected from proposals submitted by the world's leading scientific investigators. It is a central precept of the NASA space sciences management philosophy that the maximum scientific return can be obtained only if these same scientific investigators are active in the conduct of the flight missions. This active participation is believed necessary to preserve the integrity of each investigation, to encourage participation by the best qualified scientists, and to make the results available at the earliest practicable time.

This policy has resulted in the evolution, at Goddard Space Flight Center (GSFC) and NASA Headquarters, of the present working relationship and division of responsibility between the experimenters and GSFC project managers. This relationship is similar for most of the multi-experiment scientific satellites managed by GSFC, including the various Explorers, Interplanetary Monitoring Platforms (IMP's), Orbiting Solar Observatories (OSO's) and Orbiting Geophysical Observatories (OGO's). It is also somewhat similar for the scientific experiments (as opposed to operational instruments) for the meteorological and Applications Technology Satellites. Most of these spacecraft contain a number of experiments; thus the loss of an individual experiment, although serious, will not result in the failure of the entire mission. Thus, considerable freedom in designing these instruments can be given to the individual investigators. This paper deals with these multi-experiment scientific satellites.

The management of the experiments for the Orbiting Astronomical Observatories, although similar in many respects, has some important differences. The small number of experiments per mission, the very critical relationship between the experiments and the spacecraft, the more complex operational requirements, and the high total cost of performing each experiment place

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these experiments in a major project classification, requiring closer monitoring of the experiment designs. The nature of these astronomical experiments is resulting in the evolution of a national observatory concept, in which large telescopes, designed in concert with the astronomical community, will be placed in space as national facilities. Experimenters then will visit a central ground operations facility to make their observations with those telescopes just as astronomers now visit ground observatories to perform specific investigations.

GENERAL STATEMENT OF THE PRINCIPAL INVESTIGATOR'S ROLE

Upon selection to participate in a flight, a principal investigator becomes a member of the project team and assumes the responsibility for preparing the scientific instruments. He ensures that they are operating properly before launch, assists in establishing and conducting the operational program, and assists in processing, analyzing, and publishing the scientific results. In addition, he is expected to participate in a number of scientific and technological planning functions. Every effort is made to avoid diluting the principal investigator's role. For example, the NASA past experience with the reliability of specific components and techniques is made available to the experimenters. The project management staff may recommend the use or avoidance of certain parts or practices. However, the final decisions on the internal details of his instruments normally are left to the principal investigators. The primary prelaunch test of the suitability of the instrument design is the series of electrical and mechanical design qualification and acceptance tests to which each instrument is subjected by GSFC before flight. The word of the principal investigator concerning the basic ability of the instrument to make the agreed measurements is accepted, since he is assumed to be the best authority on that subject. The ultimate test of the principal investigator is the validity and scientific significance of his findings.

EARLY PROJECT PLANNING

Many members of the scientific community contribute to the early planning of new projects. The primary medium at NASA Headquarters within the Office of Space Science and Satellite Applications (OSSA) for liaison with the scientific community is the Space Science and Applications Steering Committee (SSASC) and its various advisory subcommittees. The SSASC is responsible for short-range and long-range space science planning, conduct of supporting research, and selection of scientific investigations and investigators for all flight missions. This steering committee is advised by the advisory subcommittees, which have been established for astronomy, communications, earth resources survey, geodesy and cartography, ionospheres and radio physics, meteorology, navigation, particles and fields, planetary atmospheres, planetary biology, planetology, solar physics, and space biology. These subcommittees are composed of scientists both from within and outside NASA and are responsible, among other things, for recommending space science goals and missions, reviewing scientific proposals, and recommending the scientific investigations to be conducted on each of the flight missions.

In addition to membership on the subcommittees, scientists participate in NASA space-science planning on temporary assignment or as consultants to NASA Headquarters or Field

Centers, by other direct formal and informal contacts with NASA personnel, and through non-NASA groups such as the President's Science Advisory Committee, the National Academy of Sciences, and the National Science Foundation; they also provide information to the committees and subcommittees of the Legislative Branch of the Government.

EXPERIMENT SELECTION

Scientific proposals for specific flight missions are submitted to the OSSA Office Director for the appropriate program area, who forwards them to the proper advisory subcommittees for scientific evaluation and, in some cases, to the designated project management center for technical evaluation. The Office Director then recommends a proposed payload for each flight mission for review by the SSASC and approval by the Associate Administrator for Space Science and Applications. Following the recommendation, initial approval may be given by the Associate Administrator for support of instrument development to the detailed design or breadboard stage. At a later time, each investigator may be requested to discuss and defend his investigations before the other investigators for that flight mission, the project manager, the project scientist, the program manager, the program scientist, and SSASC members. Following this, the flight payload is approved by the Associate Administrator for Space Science and Applications. This payload may be in excess of the capability of the spacecraft or launch vehicle, in which case a priority order is established.

DIRECT PRELAUNCH ACTIVITIES

After NASA Headquarters selects the flight payload, the operating responsibility for that mission transfers to the cognizant NASA project management center, which is GSFC for most of the projects discussed earlier. The GSFC project manager is then responsible for assuring that appropriate contracts or written agreements are issued to the principal investigators' parent organizations. These agreements define the functions of the principal investigators and their responsibilities to the project manager.

Integrity of the Scientific Investigation

The principal investigator is solely responsible for ensuring that his instrument is fundamentally capable of performing the agreed-upon scientific investigation. In carrying out this responsibility, he frequently conducts a research program to determine the detailed characteristics of the sensors and associated instrumentation to minimize the possibility of ambiguous interpretation of the data. This program also will produce the necessary calibration data for his flight instruments.

Spacecraft Evaluation and Improvement

The primary function of the various scientific spacecraft is to support the experiments. In many cases, the investigators participate in designing the spacecraft by specifying mission requirements, reviewing design details, and recommending improvements. This is illustrated by the Small Scientific Satellite (SSS), for which a large number of the senior experimenters in particles and fields were surveyed in 1965 and again in early 1966 to establish the basic requirements. Spacecraft design proceeded according to those requirements until May 1967, at which time representatives from 21 experimenter groups participated in a detailed review of the subsystem design. Another review is planned before the design is frozen. As a result of this process, the SSS is expected to have a wide range of applicability for fields and particles experiments, and has the strong support of the scientific community. This participation in spacecraft design by the investigators has occurred in varying degrees on earlier projects, and is now believed to be an essential element in enthusiastic support of the project by the scientific community.

During spacecraft and experiment assembly and checkout, the experimenters continue to evaluate the spacecraft design and recommend improvements to increase the scientific value of the mission. Incorporation of such changes for that mission or following missions may or may not occur depending on the criticality of the flight schedule, the cost, and the importance of the change to the scientific objectives. The most common changes are those made to reduce mutual interference with instruments in other experiments or the spacecraft subsystems. Fundamental changes in the spacecraft design for future missions are sometimes made to improve the general performance. An example is the increase of the bit rate from 4 to 8 kilobits for the data stored on board the OGO-F to provide a higher information bandwidth for those experiments.

Development of Prototype and Flight Instruments

The principal investigator is responsible for developing and constructing the basic sensors and other specialized instruments which are not included as a part of the spacecraft. His instrumentation must conform with the various mechanical, thermal, and electrical spacecraft interfaces, under the expected environmental conditions, and within the schedule and budgetary limitations agreed upon. The units produced by the investigator usually include a prototype, a flight unit, and a flight spare. These units may be built within the investigator's own laboratories or by contractors whom he manages. In any event, the principal investigator has the primary responsibility for ensuring that the instruments operate according to the interface specifications and under the agreed-upon environmental conditions.

Testing and Integration into the Spacecraft

In some programs, the scientific instruments are tested as individual assemblies, while in others they are tested only after they have been installed on the spacecraft. In both cases, the principal investigator assists in establishing the detailed test conditions according to the specifications set up by the project manager and in monitoring and evaluating the performance of his instruments during the tests. The project staff or spacecraft contractor may make many of the measurements during the tests, but the principal investigator may monitor all of the tests and must determine whether his instrument is performing properly during and after each test.

The principal investigator or one of his coworkers frequently participates in the integration of his instrument and the spacecraft. Frequently he participates in special tests to determine the effects of various interference sources and assists in the correction of problems. Also, he usually calibrates his instruments on the spacecraft to ascertain the effects of the spacecraft subsystems and the telemetry system.

Preparation for Orbital Operations

The principal investigators assist in the establishment of the desired orbital characteristics; this is followed by a launch window study by the project manager to ascertain the extent to which the various constraints can be met. These launch constraints include such diverse factors as the fraction of time the satellite will be sunlit as a function of time, behavior of perigee height vs. time for eccentric orbits, alignment of the last stage relative to the sun during coast between burns, initial alignment of earth-tracking devices to ensure early satellite attitude control, alignment of the spin axis in space or relative to the sun, orientation of experiment sensors as a function of time, and many others. The launch window studies usually indicate compromises which will permit a launch. The principal investigator must then assist in selecting the final launch time interval which assures the best set of compromises.

The smaller spacecraft have had a small command capability in the past; therefore a limited ability to modify the operation in orbit has existed. Later spacecraft, especially the larger ones such as OGO, have included a larger command capability, so that it has become increasingly necessary for the experimenters to participate in the orbital operations. Thus, they now are generally required to specify the various conditions, both for varying the operation of their experiments, and for operating the spacecraft and acquiring the data. This work must be completed well before launch in order that the personnel at all ground operation sites, including the control centers, communications network, data acquisition network, and data processing facility can be instructed properly before launch and have an opportunity to practice. This practice in operating the experiments and spacecraft and in acquiring and processing the data is usually provided by series of operational readiness tests in which data taken from the spacecraft during an earlier phase of the test program are distributed to all operating sites, and the launch phase and orbital operations are simulated as closely as possible. Although these tests concentrate on the early spacecraft operation, experimenters who have special operational requirements frequently participate, and all experimenters may participate if they wish.

In addition to the work just described, experimenters frequently develop portions of their data processing programs before launch. This practice varies widely depending on the experience and capabilities of the investigators, the degree to which the present experiment differs from past experiments for which computer programs already exist, the ability of the investigator to predict the ranges of behavior of his results sufficiently well to define the processing program, the experimenter's workload, and other factors. In any event, the experimenters are expected to have sufficient data processing capability before launch to verify the prelaunch performance of the flight instruments, to participate in the early flight evaluation of the instruments, to support the orbital operations, and to permit the early presentation of preliminary results.

Launch Operations

Spacecraft are usually shipped to the launch site a few weeks to a few months before the planned launch. There, they are checked, mounted on the launch vehicle, rechecked, and launched. The experimenters are expected to participate in all of these tests that involve the operation of their instruments. Each principal investigator is required to evaluate the performance of his instruments and to give a final approval before launch.

ORBITAL OPERATIONS

Orbital operations are normally divided into three phases—initial operations, normal operation, and special operations.

Initial Operations

Initial operations refer to the first several days or weeks during which the satellite, including its experiments, is placed in full operation and its performance is verified. During this period, the experiments are energized and adjusted as necessary. It is customary for the principal investigator to participate in this phase to the extent necessary to permit him to report the state of his instruments to the project scientist. If the spacecraft departs from expected performance within the initial phase, then re-optimization of the operation and data acquisition program is necessary to assure the greatest possible scientific return for the reconfigured mission.

Normal Operation

After the spacecraft and the experiments are completely checked and placed in full operation, the normal operational phase begins. During this phase, experimenters may be present in the control center at any time that they wish to observe their data or have special commands initiated. Advance notification of such visits is desired, but emergency requests are accommodated whenever possible.

During normal operations, the data are shipped to the experimenters some time after data acquisition at the stations because of the time required for shipment of the data tapes to GSFC and for processing in the central facility. Quick-look passes are sometimes scheduled to provide occasional data to the experimenters with only a few days of lag so that they may keep a continuous check on the performance of their instruments. On the missions for which these quick-look data are provided, they are generally taken approximately once every week.

Special Operations

Special operations are arranged by the project operations staff. They include, for example, commanding special experiment or data system configurations in response to solar flares or other natural phenomena, response to abnormal operation of an experiment or spacecraft subsystem, major changes in the mode of operation of the spacecraft or its orientation in space, or orbital changes such as circularization. These are planned as far in advance as possible, and principal investigators are normally invited to participate in those special operations which involve their experiments.

DATA PROCESSING, ANALYSIS, AND PUBLICATION OF RESULTS

The data received from the satellites at the data acquisition stations are shipped to GSFC for tape evaluation, data cleanup, establishment of bit and formal synchronization, conversion to computer tape form, editing, time-correction, and sorting. These operations result in the generation of experimenter data tapes which contain the best estimates of the raw data from each experiment and the time and housekeeping information necessary for analyzing the results. In addition, each principal investigator usually receives the satellite orbit and the attitude history of the spacecraft coordinate system, and therefore of his detectors. In order for the personnel of the GSFC Central Processing Facility to be prepared to process these data tapes soon after the launch of the spacecraft, the experimenters must specify the desired contents and formats for his tapes well in advance of the launch dates. In addition, they are also responsible for checking test data processed before launch to avoid changes in the Central Processing Facility programs after launch.

After the satellite is placed in operation, the principal investigator is responsible for that further data reduction which is necessary for the timely analysis and publication of his results. The primary media for the dissemination of the results from space experiments are the scientific literature and the various scientific meetings. Occasionally project scientists arrange for special symposia to disseminate especially interesting or timely information. Also, NASA may arrange special sessions at the regular scientific meetings or special publications of results from particular flight missions or sets of missions. In general, however, each experimenter is expected to present and publish his results as soon as he is reasonably sure of their validity. He is further expected to correlate the results of his experiment with those of other space experiments and ground observations. It is generally assumed that prompt handling of the data, correlation of results, and publication are in the experimenter's best interest, and that he will exert all reasonable efforts to achieve these goals.

RELATIONSHIPS BETWEEN THE PRINCIPAL INVESTIGATORS AND THE PROJECT STAFF

Conducting a space investigation is a sizable effort requiring contributions from many people within the principal investigator's organization and at the Goddard Space Flight Center. The principal investigators, who carry the responsibilities described earlier, normally employ staffs consisting of co-investigators, graduate students, and other professional and technical personnel. The GSFC project manager, who is assigned the direct responsibility for project execution, employs a sizable staff to assist him. The GSFC project scientist, who is assigned the responsibility for the scientific aspects of the project, works closely with the project manager. These individuals form a close-working project team. The project manager normally directs and coordinates all technical, operational, management, and budgetary aspects of the mission, including the development, launch, and operation of the experiments and spacecraft. The project scientist works closely with the principal investigators and the project manager to ensure that the scientific results planned for the mission are achieved. Working-group meetings are called when necessary by either the project manager or the project scientist for the coordination of technical information, planning for the various mission phases, early exchange of preliminary results, and the mutual correlation of data.

In any multi-experiment mission, it is expected that there will be conflicts between the technical and operational requirements of the various experiments, and between them and the spacecraft. Conflicts that affect the scientific value of the mission are resolved by the project scientist, who recommends a solution to the project manager. If a principal investigator disagrees with a decision or objects to some other aspect of the mission, his appeal route is from the project manager to the Director, GSFC, to the NASA Headquarters Program Scientist, to the Director of Sciences, OSSA, and finally to the Associate Administrator for Space Science and Applications.

PRESENT TRENDS IN MULTI-EXPERIMENT SATELLITE TECHNOLOGY

Several trends in the evolution of multi-experiment satellites are in evidence which will influence the principal investigator's role.

Onboard Processing

Since the experiments are investigating the various phenomena in ever increasing detail, they are becoming increasingly complex. This is leading to the development of advanced onboard processing equipment, including general purpose onboard computers that will permit experiments which are now impossible because of present limitations in telemetry information bandwidth. This equipment will also allow many directional experiments on simpler spinning spacecraft through the use of advanced sampling and analysis techniques.

Simplification of the Experimenter's Onboard Instruments

The inclusion of general-purpose, onboard processors and the development of standard modules for interfacing with these processors will reduce the efforts of the experimenters in developing the specialized processing circuits for their flight equipment. For the Small Scientific Satellite, for example, standard counting and timing functions, multiplexers, accumulator, and analog-to-digital conversion modules are planned for the central processor for use by the experimenters as required. This arrangement is expected to shorten the development time for new experiments and to decrease the time required for experiment integration and checkout on the spacecraft.

Real-Time Data Processing

Larger command capabilities and advanced onboard processing techniques are resulting in increases in the real-time and near-real-time data processing requirements for making operational decisions. Thus, the experimenters may expect to work more closely with the control centers during the operational phases of future missions.

AREAS NEEDING FURTHER ATTENTION

For three primary reasons—the size of the effort for a space mission, the requirements for close coordination between the investigators and the GSFC project staffs, and the fact that the activities are always conducted very close to the limits of present technology—a certain amount of pressure and other discomfort can be expected for all personnel. Although this situation cannot be eliminated entirely, there are several areas in which improvements can be made in these working relationships. First, NASA should strive to shorten the experiment life cycle, which presently extends over a period ranging from 5 to 10 years. The onboard processor described earlier may simplify the experiment instrumentation and decrease the time required for experiment integration and testing. Further efforts in simplifying prelaunch activities are desirable. Also, flight data should be made available to the experimenters more rapidly, and standard computer programming modules for processing telemetered data should be developed for use by the experimenters. It must be remembered that the experimenter's goal is to obtain the greatest possible scientific return with a minimum of effort and, for many experimenters, to train students. Anything that can be done to reduce the experimenter's purely technological development efforts without threatening the integrity of his scientific investigations would be useful.

Another area for improvement is to make the technical and management coordination between the experimenters and project staffs more direct and simpler. This might be aided to some degree by further simplification of the interfaces between the experiment instrumentation and spacecraft subsystems; however, it is somewhat questionable whether this can be done in light of the increasing complexity of experiments and the increasing amount of onboard processing.

Secondly, there are several areas in which the experimenters could improve their efforts. Many experimenters need to provide better financial management so that the project and experiment costs can be kept under better control. This is especially true for data reduction and analysis costs, which have been extremely difficult to predict accurately. The experimenters also need to improve their abilities to meet instrument delivery schedules. This problem was not as serious earlier because the spacecraft schedules occasionally slipped and prevented experiment delivery from becoming a limiting factor. However, experiment delivery is becoming the item that paces the launch schedule for an increasing number of missions. Finally, the experimenters need to be better prepared to process and analyze their data soon after launch. Again, this problem was not as serious in the past because GSFC sometimes required many months for processing and shipping flight data to the experimenters. However, the backlog for most recent scientific satellites is now only several months and is expected to remain at this level or less. Thus, experimenters should expend more effort in the early development of processing programs.

CONCLUSION

The present role of the principal investigators and the working relationship between them and the project staffs at GSFC have evolved over the past 8 years, during which time approximately 38 multi-experiment satellites of the type discussed have been launched. Although improvements can certainly be made in this working relationship, it operates quite smoothly in most cases. The best evidence of its productivity can be seen by observing the large number of significant scientific results that have resulted from this team effort.

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