2 mid

NASA TECHNICAL
MEMORANDUM

NASA TM X- 62,288

NASA TM X- 62,288

STUDY OF AIRBORNE SCIENCE EXPERIMENT MANAGEMENT CONCEPTS FOR APPLICATION TO SPACE SHUTTLE

VOLUME I – EXECUTIVE SUMMARY

Donald R. Mulholland, John O. Reller, Jr.,
Carr B. Neel, and Louis C. Haughney

Ames Research Center
Moffett Field, Calif. 94035

July 1973

AIRBORNE SCIENCE/SHUTTLE EXPERIMENT

SYSTEM SIMULATION

(ASSESS)

TABLE OF CONTENTS

SUMMARY

The Ames Airborne Science Office (ASO) is conducting a two-phase study program (ASSESS) to identify and document management concepts and operating procedures of the Airborne Science program as they may apply to the planning of Shuttle Spacelab operations. Phase A is the study of ongoing ASO missions; Phase B consists of missions constrained to simulate selected aspects of Shuttle Spacelab experiment operations. This executive summary is the first of three volumes that document the entire spectrum of applicable ASO and experimenter activities observed for ongoing airborne research operations from April to November 1972. Other aspects of ASSESS Phase A and the simulation effort of Phase B are covered in other reports.

During the observation period, there were 5 airborne missions on the CV-990 aircraft and 17 on the Lear Jet. The CV-990 missions involved 62 experiments and 76 experimenters, while the Lear Jet missions involved 17 experiments and 50 experimenters. Analysis and discussion of the observational and numerical data gathered on these missions (Vols. II and III) yielded the following key characteristics of the airborne science experience:

1. Full experimenter involvement and responsibility throughout the entire mission leads to low cost and high reliability of payloads through minimal documentation and controls needed for payload management, simplified procedures for experiment preparation, and the availability of experimenter expertise in operation and maintenance, which ensures a high level of experiment performance in flight.

2. Small management staff, direct interaction between principals, and rapid decisions minimize experiment development time and reduce payload costs.

3. Experimenter flight experience enhances research accomplishments.

4. Experiments were built with two-thirds off-the-shelf equipment.

5. Average home-base testing effort by experimenters was less than 10 man-days per experiment.

6. Experiments had no malfunctions on 68 percent of their flights; malfunctions were repaired and resulted in no loss of data on 12 percent of flights; malfunctions with some loss of data occurred on 15 percent; and a complete loss of data on only 5 percent.

7. Data processing needs of experimenters were met by an onboard computer system; no data down-link was requested or provided.

INTRODUCTION

The Airborne Science program at NASA's Ames Research Center has provided research opportunities for the world scientific community since early 1965. Working in such aircraft as a Lear Jet, a Convair 990, and a Lockheed C-141, the airborne scientist has ranged widely over the globe at altitudes up to 15 km. These flying laboratories have provided the setting and facilities for basic research in earth and space sciences including observation of unique astronomical events, the development of earth-observation instruments for use on satellites and to supplement satellite measurements by simultaneous observations in high-altitude flight, and measurement of gaseous and particulate contamination of the atmosphere.

In managing this program, the Airborne Science Office (ASO) has evolved procedures that foster scientific research yet are as informal and free of restrictions and documentation as possible, consistent with flight safety and the attainment of scientific objectives. A unique feature of the ASO operation is the active participation of experimenters in all aspects of the research program. The experimenters have the responsibility to construct and test their equipment, assist with installation in the aircraft, and participate in flights to obtain the scientific data. This one practice, more than any other, underlies the success of the Airborne Science approach. It has been enthusiastically accepted by the scientific community and is productive of research results with a minimum of preparation time, documentation, and controls, and at relatively low cost.

The ASO experience in research management is a reservoir of practical knowledge available to the planners of research operations for the Shuttle Spacelab program. The potential reductions in cost and time that might result for Shuttle from such a transfer of knowledge were first suggested in 1971 in reference 1. Following discussions in the NASA Airborne Research Steering Committee, a two-phase program of study was sponsored by the Office of Manned Space Flight to document the form and effectiveness of the Ames program in airborne sciences. The program is called ASSESS (Airborne Science/Shuttle Experiment System Simulation). Reference 2 further discusses application of the Airborne Science techniques to Shuttle and describes the ASSESS program in some detail.

The initial Phase A effort, summarized in this report, covers the organization and procedures of ASO, and the ongoing Airborne Science research operations from April to November 1972. The full discussion and analysis in support of this summary is presented in Volume II, and additional background material is contained in the appendixes of Volume III of this series (refs. 3 and 4, respectively).

Phase B of the ASSESS program consists of a series of airborne missions constrained to model selected aspects of experiment operations projected for the Shuttle Spacelab. The first of these simulation missions was configured around a Lear Jet aircraft (ref. 5). The second simulation mission was completed in April 1973, using the same facilities with slightly modified constraints. Both of these constrained missions featured optical measurements in far-infrared astronomy, using a 30-cm open-port telescope on targets such as the planets Jupiter and Saturn, nebulae (e.g., M-42), and galaxies (M-82, NGC 253). The third and fourth of these simulation missions are now in preparation for the Lear Jet and CV-990 aircraft, respectively.

Ongoing research projects in the ASO Lear Jet astronomy program were selected for the first three simulation missions as a means of activating Phase B studies quickly, effectively, and economically. The objectives were to obtain preliminary information on various aspects of management and operation for a five-day constrained Shuttle simulation, and to gain experience for greater effectiveness in subsequent simulations on the CV-990 aircraft, which more nearly resembles the configuration planned for the Shuttle Spacelab.

The originally planned simulations using the CV-990 were delayed due to loss of the aircraft in an unfortunate accident. With the acquisition of a replacement aircraft, the first of these multi-experiment simulation missions is scheduled for early 1974.

The C-141 aircraft with a dedicated 91-cm telescope is a new system just being put into operation. Its preparation is being documented and analyzed for the continuing ASSESS Phase A effort, and operational C-141 data for Shuttle application will be published when they become available.

AIRBORNE MISSIONS

Airborne missions are tailored for a variety of scientific objectives. The simplest is a one-experiment mission on the Lear Jet involving four or five locally based flights over a period of one to two weeks. A CV-990 mission with a dozen or more experiments, on the other hand, may include ten or more flights from several remote bases over a time span of four to six weeks. Both the Lear Jet and C-141 are equipped with open-port telescopes for far-infrared astronomy and are "dedicated" almost exclusively to this use in successive single-experiment missions. A CV-990 mission consists of 5 to 15 experiments, either in a single-purpose "dedicated" payload, or in an "agglomerate" payload with several distinct research objectives that are scientifically and operationally complementary.

Research operations during the first observation period consisted of 17 Lear Jet and 5 CV-990 missions. On the Lear Jet, 50 experimenters made 76 data flights, operating 14 experiments for astronomy, and 3 to measure the concentration of meteor dust. On the CV-990, 76 experimenters participated in a total of 43 data flights, including local flights and remote missions in Alaska and to Africa; 62 experiments were operated to observe earth surface and lower atmosphere phenomena, upper atmosphere physics, and the earth's magnetic field, and to collect samples of atmospheric trace contaminants.

Participants in the Lear Jet program were predominantly university scientists who built and operated 12 of the 17 experiments; the remainder were from NASA. In the CV-990 program, 41 of the 62 experiments were flown by NASA scientists, with the balance about equally divided among scientists from other government agencies, industry, and universities. One team of foreign scientists participated.

FORMULATION OF MISSIONS

Airborne Science missions are originated either by NASA for the study of specific natural phenomena or in response to unsolicited proposals from the scientific community (fig. 1). If the mission might interest a large number of investigators, an Announcement of Flight Opportunity (AFO) is issued by the cognizant Headquarters program office, either for a single mission (as for they CV-990) or on an annual basis (as for the Lear Jet and C-141). The AFO is prepared by the appropriate ASO program manager, who later serves on an ad-hoc committee with program office representatives and non-NASA scientists to evaluate experimenter proposals.

Proposals take one of several forms. One may cover a number of closely coordinated experiments constituting a major payload for a CV-990 type mission. If from a NASA center, such a proposal must be approved by the cognizant Headquarters program office that will fund the operation. The ASO, in consultation with the appropriate program office, may consolidate a number of independent proposals into a single payload that justifies a mission. Independent proposals also may be classified as "piggyback" experiments and may fly on a space-available basis at the discretion of the ASO.

The primary criteria for the selection of experiments are: intrinsic value or scientific worth, compatibility with the aircraft, compatibility with other experiments, and cost. Selection of experiments for a major mission occurs 6 to 12 months before flight, with shorter times for combined payloads and often only a few weeks for "piggyback" experiments.

MANAGEMENT PROCEDURES

The ASO management approach centers on the close involvement of the experimenter in all aspects of the airborne science mission, and is motivated by one goal: the successful acquisition of scientific data by the experimenter. The experimenter designs and assembles the experiment, subject only to the requirements of flight safety and the interface constraints of aircraft support systems and other experiments. He tests and maintains the experiment to his own standards of performance and reliability, and he operates it in flight.

The ASO provides the airborne platform, overall mission management, and support services, with the content and flow of activities designed to maintain a research atmosphere. Mission managers are experienced research scientists, who provide a single-contact continuity of management throughout each mission. Integration facilities and support personnel are located in proximity to the management office to facilitate a close relationship between the mission manager and aircraft and research personnel.

ASO airborne missions historically have been related to one of three broad scientific categories: astronomy, meteorology and earth observations, and geophysics and space sciences. Each area is under the cognizance of an ASO program manager whose scientific background is in a relevant discipline. Specific airborne missions are directed by one of these program managers (or an immediate assistant) as part of his overall responsibility in the program area. The scientist/manager is directly involved in the preliminary stages of mission formulation. He evaluates the compatibility of proposed experiments to the aircraft and performs preliminary flight program and logistics planning.

When a mission is approved, the ASO program manager is formally assigned responsibility for the preparation and conduct of the complete mission. His specific responsibilities as *mission manager* and his interactions with various support groups are depicted in figure 2. Immediate steps are taken to integrate experimenters into the mission team. Each receives an Experimenters' Handbook, which defines the design requirements for flight safety, the aircraft interfaces and support utilities, and the pertinent features of the inflight environment. Visits to Ames acquaint the experimenter with the aircraft and the mission support personnel, and mission plans and schedules are updated through periodic Experimenters' Bulletins issued by the mission manager.

The mission manager initiates and directs all local preparations for the mission, with the authority to make basic decisions relative to the scientific payload and its integration with the aircraft. During the development period, he is in frequent contact by telephone with each experimenter, working out the details of equipment integration and flight planning. Written communications are seldom necessary. In many cases, the experimenter works directly with cognizant Ames support personnel; for example, he consults with the ASO data-systems manager for the CV-990 to arrange for inflight data recording and processing by the on-board computer; he works with shop personnel for experiment installation, and with inspectors to correct any deficiencies that have been identified.

Prior to flight, the experimenter spends a week or two at Ames assembling, checking, and installing his experiment. During this period, he works directly with ASO support personnel under the overall cognizance of the mission manager (fig. 3). Safety and airworthiness inspections and approvals are mandatory both before and after experiment installation in the aircraft. The Airworthiness and Flight Safety Review Board conducts a formal review of experiment installations and operational procedures, and issues written approval before each mission.

Late in the preflight period for multi-experiment missions (on the CV-990), all flight personnel participate in a final program review, and a separate safety training session is held for experimenters. The final safety inspection with final written signoff is made prior to the initial flight – a pilot's check flight – and is followed by a full-crew, equipment checkout flight, which serves as an operational shakedown for the mission. The simpler single-experiment Lear Jet missions include the same program review and safety training but on a less formal basis. Lear Jet missions are subjected to the same inspection and airworthiness board reviews as the CV-990, with formal written signoffs required.

During the flight phase, the ASO mission manager is the coordinator of pre- and inflight research activities (fig. 4). In the CV-990 program, he flies with the experimenters and coordinates their activities with those of the flight/experiment support crew. In the Lear Jet program, flight and experiment operations are coordinated by the two pilots and two experimenters. In either case, the mission manager meets daily with the experimenters to review mission progress and to make revisions in schedules or specific flight plans that will enhance research opportunities.

The person-to-person informality of ASO management procedures minimizes the need for documentation, while the continuity of management and proximity of support groups allow maximum program flexibility with no compromise of personnel or equipment safety. The motivated scientist has been shown fully capable and effective in moving into this environment, with full responsibility for his experiment, to accomplish his research objectives.

EXPERIMENTER INVOLVEMENT

An airborne research project begins with the interaction between the experimenter or his management and the Airborne Science Office. As an aid to early planning, the experimenter may contact the ASO for informal discussion of his experiment and its suitability as an airborne project. An Experimenters' Handbook is usually given to him at this stage. From the start, it is understood that he will have the entire responsibility to design, construct, and proof test his experiment, subject only to aircraft safety requirements, interference with other experiments, and the practical limits on size and electrical power imposed by aircraft systems.

When the experimenter's formal proposal is approved, the Airborne Science Office, in consultation with all involved experimenters, finalizes the entire schedule. Each experimenter is then committed to assemble and ready his equipment for flight accordingly. On major CV-990 missions, if an experimenter is not ready, he risks missing the mission unless there is a delay for some other basic reason. However, the experimenter, having total responsibility for preparation, installation, and operation of his experiment, is highly motivated to expend the additional effort required to resolve any problems within the constraints of the overall schedule. When such problems develop, the ASO mission manager provides whatever assistance is feasible, but the basic premise of full experimenter responsibility is not violated.

Frequent consultation with the ASO mission manager is necessary during the development phase. The experimenter recognizes that he must do more than design a laboratory-type experiment. He must devise a relatively self-contained research operation, giving consideration to the limitations and hazards of the flight environment; to methods of experiment operation and performance monitoring; to maintenance procedures, spare parts, and equipment; to data handling and analysis; and to the selection and training of research assistants. Ready access to the mission manager and available support personnel allows quick resolution of design problems and shortens the time required for preparing an experiment.

When the design and layout of the experiment have been determined, the experimenter submits the required drawings and stress analysis to the mission manager, who refers them to the Airworthiness Engineering Group for a flight-safety review. Deficiencies in design (if any) are relayed through the ASO mission manager back to the experimenter, usually by telephone. Occasionally, further direct interaction of the experimenter and the cognizant safety engineer is warranted. When all safety-related aspects of the design have been approved, the experimenter is free to complete assembly of equipment and conduct whatever testing he deems necessary. He is not required to document or report the results of his proof testing.

The experimenter oversees and assists in installation of his equipment in the aircraft. The ASO mission manager and his support people provide assistance during this phase. The equipment must pass safety inspections both before and after installation.

During the mission, the experimenter operates and maintains his own experiment, with the support of his research assistants (if any). ASO personnel may provide assistance, but the experimenter usually handles his own activity. The locally based, single-experiment Lear Jet missions are more easily adjusted in the event of contingencies. On the ground, the Lear Jet experimenter and the mission manager work out any problems; in flight, the experimenter and the command pilot cooperate to achieve optimum research results. Depending on the experimenter, flight planning varies from a complete pre-mission definition of objectives and schedule, to a day-by-day assessment of research results and a choice of objectives for the next flight. After experiment installation on the Lear Jet, one flight per night is the norm; two per night are not unusual.

For CV-990 missions comprising experiments having somewhat different flight-profile requirements but complementary observational objectives, the mission manager usually dedicates one or two flights to each primary experiment on a negotiated rotation basis, with the primary experimenter for a given flight permitted his choice of flight conditions. The dedicated expedition with a payload of closely related, primary experiments having similar flight-profile requirements is under the overall direction of the ASO mission manager. He coordinates experiment operations and mission planning, sometimes with the assistance of a project scientist from the sponsoring center or agency. Regardless of the particular mission configuration, however, the individual experimenter retains the responsibility for the performance of his equipment.

Most of the experiments are characterized by the direct inflight participation of the principal investigator (P.I.). Of the 54 research teams observed in this study period, 36 were headed by the P.I., 15 by a scientist-associate, and 3 by other assistants. Participation by the P.I. assures a highly motivated research effort that usually maximizes data return and minimizes delays due to equipment malfunctions.

EXPERIMENT DEVELOPMENT

Typical physical parameters for airborne experiments are: volume, 0.60 m^3 (21 ft^3); weight, 150 kg (330 lb); and power required, 1 kW. Observations of 79 experiments during this initial reporting period showed that off-the-shelf hardware (defined as cataloged, commercial equipment) dominated experiment construction. Nearly 60 percent of the experiments had a majority of components that were off-the-shelf; most of the remaining 40 percent had a majority that were custom-commercial (produced to specifications by commercial firms). Many of these experiments had been developed for ground-based research programs. By individual count, almost two-thirds of all components used in Lear Jet and CV-990 experiments were off-the-shelf. These, together with the custom-commercial units (neither of which require an in-house fabrication talent) accounted for nearly 80 percent of all components used for all experiments. The use of standard laboratory-type equipment is encouraged by the availability of 60-Hz power and standardized equipment racks in ASO aircraft, as well as the lack of stringent restrictions on experiment size and weight. Furthermore, the experimenter in the Airborne Science program usually has only limited funding, and he can reduce both cost and development time by using commercially available units whenever possible.

Lear Jet experimenters, largely from universities, made over twice as much of their equipment, 24 percent, compared to 10 percent for CV-990 participants, who were largely from government laboratories. In the area of sensors and signal-conditioning electronics, the comparative proportion of home-made equipment in each group is particularly striking, with an average of over 40 percent for the Lear Jet and only 4 percent for the CV-990 researchers (fig. 5).

Nearly one-third of the observed experiments were directly applicable to the flight environment without modification from the configuration used for ground-based research, one-sixth required some modification to adapt them for flight, and half were developed specifically for airborne use. Where modification or development was required, the experimenter was able to use many off-the-shelf components. In general, his special design work was concentrated on the sensor (transducer) element of the experiment and the closely associated units that condition the signal prior to recording.

Testing of components and assemblies at the home laboratory and at Ames is entirely at the discretion of the experimenter. As expected, the amount of testing was generally related to the inherent complexity of the equipment and the amount of development or modification required for a particular mission. Experiments classed as engineering development models (15 percent of the total number), which emanated from satellite projects, had the most exposure to operational and environmental testing. These experiments required an average of only 15 man-days overall in preparation for airborne flights; the two notable exceptions were unusually complex and required 122 and 330 man-days. Newly developed flight experiments (9 percent) averaged 7 man-days of testing, including some relatively simple environmental tests on sensors. Experiments that had flown before (58 percent) or had been used previously for ground-based observations (18 percent) averaged less than 3 man-days of testing, almost entirely to verify operation and to recalibrate.

EXPERIMENT PERFORMANCE

A summary of the performance of the 66 experiments observed in flight is given in figure 6. (The 13 experiments on the CV-990 November 1972 mission were monitored on only one flight and have been omitted here.) The last line of the figure shows that 68 percent of the 494 experiment-flights had no problems (malfunctions). Twelve percent had problems, but because of the investigator's intimate knowledge of the experiment, no data were lost (0.80 all-data reliability factor, less 0.68). In 15 percent of the cases, partial data loss occurred, which often did not significantly diminish overall experiment success (0.95 partial-data reliability factor, less 0.80). In only 5 percent of the experiment-flights was the problem sufficiently severe that the experimenter could not resolve it, and all the data were lost. This loss of data (5 percent) can perhaps be viewed as the penalty of the Airborne Science management approach, which imposes a minimum burden of testing and documentation on the experimenter and at the same time minimizes overall costs.

Experiment problems were evaluated in terms of the frequency and severity of equipment malfunctions, their impact on the research schedule and on data quality, and the ability of the experimenter to resolve the difficulty and maintain his equipment in working order. This analysis is based on a population of 191 problems, in both aircraft programs, that were directly traceable to experimenters' equipment. As noted, the total number of experiment-flights observed in this time period was 494.

Malfunctions were grouped by severity of impact on data acquisition for the flight on which they occurred, considering the results of the experimenter's effort to correct the problem. As shown in the last line of figure 7, 30 percent had no effect on the data, 20 percent caused some reduction in data quality, 39 percent resulted in some loss of data, and 11 percent caused complete data loss. The overall repair record shows that 16 percent of the problems were corrected during the flight and another 32 percent in time for the next flight. Of the remaining 52 percent, 42 percent (mostly of a minor nature) were deferred for later repair, while 10 percent occurred on the last flight of a mission. Only 7 of the 66 experiments observed were not operable on all of the scheduled flights.

To evaluate the influence of pre-mission testing, experiments were divided into "new" and "repeat" groups. The principal finding was that the average experimenter who was new to the airborne program did more testing than the majority of his experienced counterparts and performed on a par with them on his first mission. It was also observed that repeat experimenters often performed better (in terms of experiment reliability factor) on succeeding missions, provided they did not modify their experiment. Modifications usually were accompanied by a marked drop in reliability.

DATA HANDLING

Prime responsibility for handling the research data rests with the experimenter. He must either provide suitable recording units as part of his own equipment or, in the case of the CV-990, arrange for recording and processing by the on-board computer system (ADDAS). Many experimenters in the CV-990 program do both, either using the ADDAS as a backup capability in the event of a local recorder malfunction, or using data scanning techniques in their own system and the ADDAS for complete data handling. The ASO is responsible for the operation (hardware) and programming (software) of the CV-990 ADDAS system, and the experimenter must match the magnitude of his data signal to the input requirements. The ADDAS on the CV-990 also accepts and time codes the outputs from selected aircraft instruments, displays flight parameters and research results on television monitors, and makes both magnetic tape and printout records. None of these services is available in the Lear Jet program.

Experimenter use of the ADDAS for real-time data processing varied widely during the observation period. For one integrated payload of experiments, 11 out of 13 required processing of their own data to correlate results during flight. In another mission where most of the data records were photographic film and video tape, only one experiment out of 16 required data processing during flight. On the average, 53 percent of all CV-990 experiments observed in the April to November 1972 period fed data to the ADDAS for processing and/or recording. However, nearly all the experimenters used the flight-parameter display on the television monitors for real-time assistance during flight, and time-correlated ADDAS printouts of flight parameters for postflight data evaluation. Thus, the ADDAS performs a valuable service for essentially all experimenters in the CV-990 program.

On the CV-990 missions, the presence of both ADDAS and experimenter on the aircraft precluded any requirement for an air-to-ground data link. No such link was ever requested by an experimenter. However, with flights lasting at most six hours, there was ample opportunity for postflight data processing on a daily basis.

SAFETY PROCEDURES

From 1965 until the present, the Airborne Science Office has managed its programs of scientific observation from high-altitude aircraft in conformance with the highest standards of safety, and in those areas of responsibility has maintained a perfect record. Several hundred experimenters have been active in the flight programs, and ASO aircraft have logged over 700 flight-hours a year, often in remote areas of the world. The CV-990 accident of April 12, 1973, during final approach to landing at the home field, did not involve ASO safety procedures.

As director of an airborne mission, the ASO mission manager has the widest overview of all activities and, therefore, an overall responsibility for mission safety. The command pilot works closely with the mission manager in preparing for a mission and has responsibility for the safety of the aircraft during flight operations. Surveillance of experiments and installation safety continues from inception of an experiment design through installation, checkout, and the mission itself. Prior to every major or unique mission involving airborne science experiments, an Airworthiness and Flight Safety Review Board reviews all facets of the proposed activity and issues written approval before operations can begin.

The ASO has developed procedures that permit the experimenter wide latitude in the design of his equipment yet satisfy flight safety requirements. The experimenter is responsible for conforming to the safety standards, allowable loads, and other design and installation practices specified in the Experimenters' Handbook. Drawings and stress calculations are submitted to the ASO mission manager who reviews and refers them to an Airworthiness Engineering Group. This group works with the mission manager and the individual experimenter to assure design adequacy. They also act as advisors during the installation period.

Aircraft inspectors ensure the airworthiness of both the aircraft and its payload. Separate inspections of the experimental equipment, before and after installation, verify that mounting hardware and operating procedures are acceptable. A final inspection is made prior to the start of the mission to ensure that equipment within the cabin or external to the aircraft is suitably mounted.

Safety briefings are conducted by the ASO to acquaint the experimenter with both standard and emergency procedures; with the use of safety equipment; and with the use of life-support oxygen, life rafts, and arctic survival gear. Lear Jet experimenters are required to attend a one-day, high-altitude training course using an altitude test chamber provided by military installations near Ames.

APPLICATIONS TO SHUTTLE SPACELAB PLANNING

The development of a plan for managing experiments in the Shuttle Spacelab, with maximum benefits for the user community and a minimum of controls and documentation, can proceed one of two ways: by building on relatively simple concepts and procedures such those practiced by the Ames Airborne Science Office, adding those features judged to be absolutely necessary; or by attenuation of the complex experiment-control networks of existing manned space programs, subtracting features judged unnecessary. The following sections address those features of the Ames airborne science activity believed to be pertinent to current Spacelab planning (ref. 6).

Role and Responsibility of the ASO Program Manager

The management practices and operational procedures of the ASO have evolved from simple beginnings. Early manpower constraints had a two-fold effect: first, the participating scientist had to be wholly responsible for assembling, operating, and maintaining his experiment; second, the operations had to be informal and flexible with a minimum of documentation. This approach, born of necessity, proved to offer unique advantages for conducting research and has remained the basic method of operation. The key position in the management structure is that of program manager. He is an experienced research scientist in his own right and thus can communicate and work easily with the experimenters. He is directly involved in all phases of an airborne mission, from early planning to the post-mission follow-up. The program manager is, in essence, a single point of contact between experimenter and management throughout the entire mission. The close understanding and working relationships that accrue from this continuity are vital to the success of airborne programs.

Role and Responsibility of Experimenters

Full involvement of the experimenter in all phases of the mission is the recognized basis of the ASO program. The principal investigator of each airborne research project is responsible for developing his experiment and operating it in flight. While he may assign the operating function to an experienced associate, there is no equipment turnover to a person or organization outside his control and no shared responsibility for the outcome. As a consequence, motivation and utilization of experience are maximized while training and documentation are minimized. Logically, this same definition of the experimenter's role should be a basic premise of a user-oriented Shuttle Spacelab program. This approach has been eminently successful in airborne research, and as Spacelab operations pass the first pioneering flights and become a well-established routine, full experimenter participation could have similar benefits.

Mission Preparation

Development times for airborne experiments typically vary from 6 to 12 months. This condensed time scale is made possible largely by the close interdependence of the experimenter and ASO management. But it also derives from the use of standard Experimenters' Handbooks as design guides, the use of standard instrument racks to minimize mounting and interface problems, and from the relatively benign conditions in the flying laboratory, which permit the extensive use of standard commercial components and do not necessitate intensive environmental testing. Testing activities in the home laboratory averaged less than 10 man-days per experiment. Based on the performance of 66 experiments during this study period, in which scientific data were obtained in 95 percent of all experiment-flights, this relatively small amount of testing appears adequate in most cases. Obviously, experiment-preparation procedures for Shuttle cannot be as simple as for airborne experiments; nevertheless, adherence to the direct and effective guidelines described herein, together with full experimenter involvement, should lead to minimum experiment costs and development times for Spacelab payloads.

Experiment Monitoring and Maintenance

The airborne experimenter monitors experiment performance at frequent intervals, so he is immediately aware of a malfunction and can begin a corrective action. Little use is made of automatic devices for the monitor function in airborne research; the one-to-one relationship of the experimenter to his equipment normally allows him to detect problems immediately without automatic aids. Instrument repair during flight and between flights effectively resolved nearly all problems serious enough to cause a loss of data. Less than five percent of the scheduled flight opportunities were missed because repairs were not completed and the experiment was not ready to go. Thus, the airborne experimenter can and does maintain his equipment operational for the life of a mission, in some cases as long as five to six weeks. In the Shuttle Spacelab the goal would be the same, to keep the experiment operational for the duration of the mission. If ASO experience is a valid indicator, the experimenter will find a way to make it go, even when work-arounds and rescheduling of data objectives become a real-time necessity.

On-Board Data Processing

An on-board central recorder/computer system is a valuable support to experiments in the CV-990 program. It is used for the real-time display of flight and experiment parameters, for recording research data, and for processing of raw data in support of experiments. Certain coordinated payloads would not be possible without this support, since in-flight assessments of the progress of the total research effort may require processed results from four to six separate experiments. In addition, the on-board computer has reduced the need for postflight data processing, thus increasing the self-sufficiency of the mission payload. With rare exceptions, the experiments on a Spacelab mission could be served similarly by an on-board computer facility, and its value would be enhanced if the experimenter was there to interpret results.

Typical Payload Weight, Volume, and Manpower Requirements

Equipment and operations parameters have been identified that describe experiment payloads developed for the moderately restricted, semi-isolated conditions of Airborne Science missions. Two-thirds of the experiments were either modified or newly developed for flight use; only one-third were direct carryovers of ground-based equipment. Nearly two-thirds of the components in all experiments were off-the-shelf items. Typical experiment weight was 150 kg, and typical volume 0.60 m^3; usually, one or two experimenters were associated with each experiment during a mission.

Of the descriptive parameters listed, experiment manpower is perhaps the most critical for Spacelab application and deserves further attention. Two observations of airborne practice are relevant: first, the space available on ASO aircraft favors two-man teams of experimenters, with a separation of duties along lines of primary experience; second, 23 out of 79 experiments were handled by individuals or by teams having one man per experiment, and 23 more by teams that averaged less than one man per experiment. It should be noted that these lower manpower loadings usually reflected considerable experimenter flight experience and/or the operation of several similar, closely related experiments. Furthermore, almost without exception, equipment was operated by experimenters who had developed it to meet their own research objectives.

Manpower requirements in support of airborne experiments during flight take different forms in ongoing ASO programs. Space and weight limitations restrict the Lear Jet crew to two pilots and two experimenters who coordinate flight and experiment operations for maximum research benefit. Support personnel in the CV-990 program normally vary from 7 to 10 and are diversified into flight crew (3 or 4), payload management (1 or 2), and support equipment operation (3 or 4). Two of the last group perform functions for both aircraft- and experiment-related equipment, and are also available to directly assist the experimenter with equipment repair while in flight. An overall summary of both ASO programs shows that the flight crew and the inflight experiment support personnel are about equally divided; taken together, these two groups are almost equal to the experimenters in numbers of flights made. Planning for Shuttle Spacelab operations will require careful attention in this area, to make the maximum number of flight opportunities available to experimenters.

REFERENCES

1. Bader, Michel and Farlow, Neil H.: Potential Reductions in Cost and Response Time for Shuttleborne Space Experiments. AIAA Paper 71-808, presented at AIAA Space Systems Meeting, Denver, Colorado, July 1971.

2. Mulholland, Donald R., and Neel, Carr B.: Airborne-Science Techniques Aid Shuttle Planning. AIAA, Astronautics and Aeronautics, May 1973.

3. Mulholland, Donald R.; Reller, John O., Jr.; Neel, Carr B.; and Haughney, Louis C.: Study of Airborne Science Experiment Management Concepts for Application to Space Shuttle. Vol. II, NASA TM X-62,287, July 1973.

4. Mulholland, Donald R.; Reller, John O., Jr.; Neel, Carr B.; and Haughney, Louis C.: Study of Airborne Science Experiment Management Concepts for Application to Space Shuttle, Vol. III, Appendixes. NASA TM X-62,289, August 1973.

5. Mulholland, Donald R.; Reller, John O., Jr.; Neel, Carr B.; and Mason, Robert H.: Shuttle Sortie Simulation Using a Lear Jet Aircraft, Mission No. 1, NASA TM X-62,283, December 1972.

6. Sortie Lab Program, Technical Summary of Phase B Definition. George C. Marshall Space Flight Center, October 9, 1973.

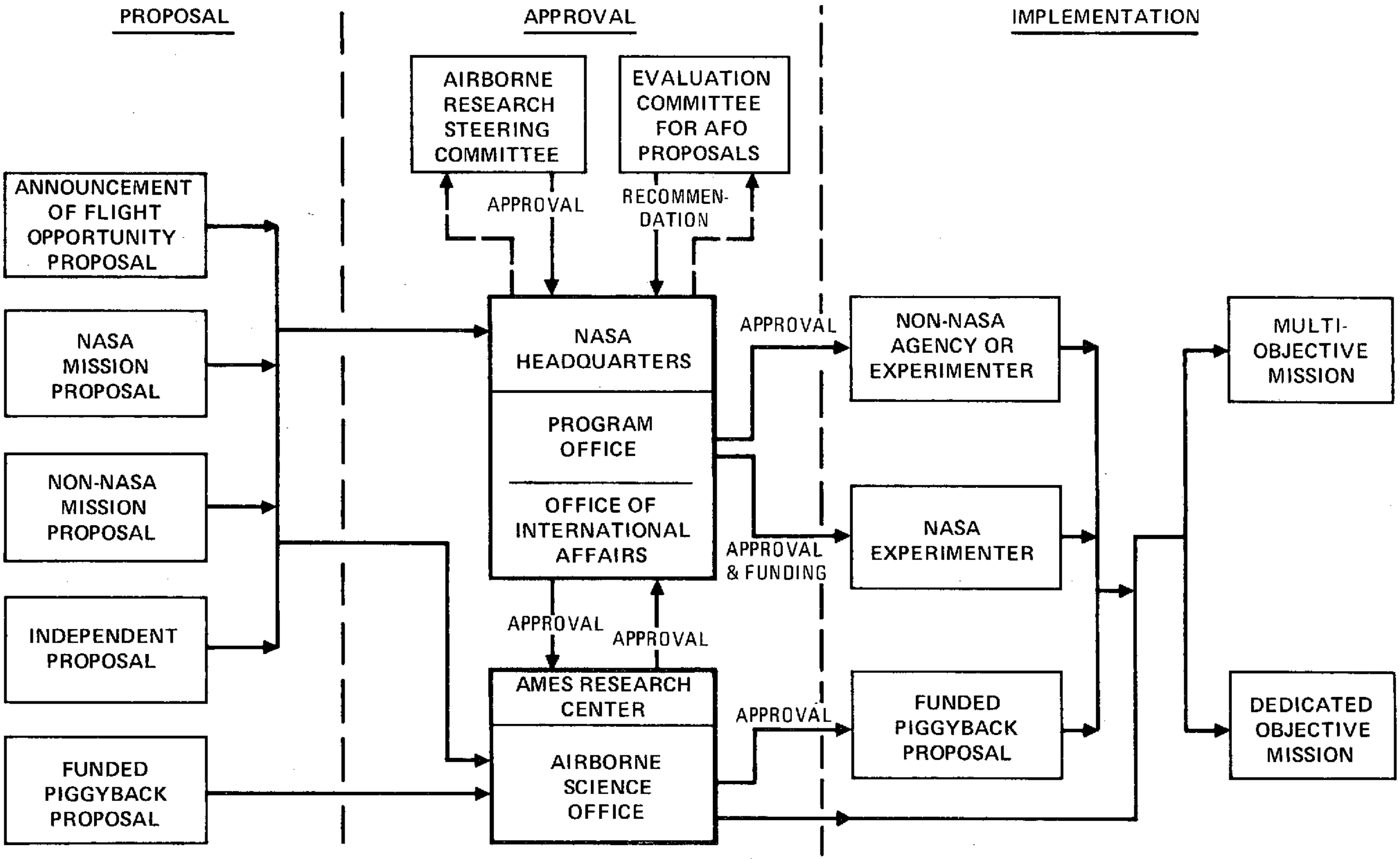

FIGURE 1–. PROCEDURES FOR FORMULATING AIRBORNE SCIENCE MISSIONS

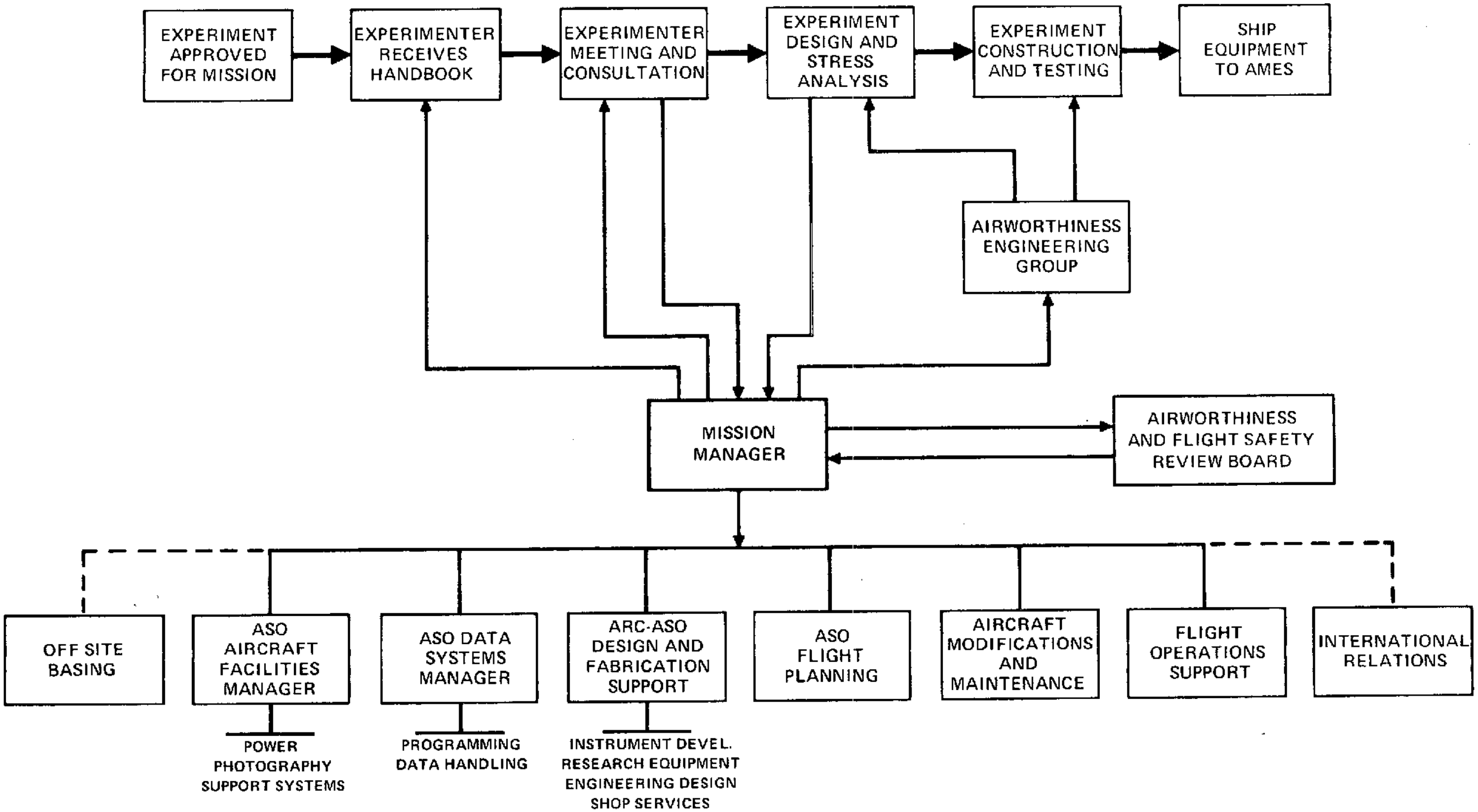

FIGURE 2—. MISSION PREPARATION ELEMENTS

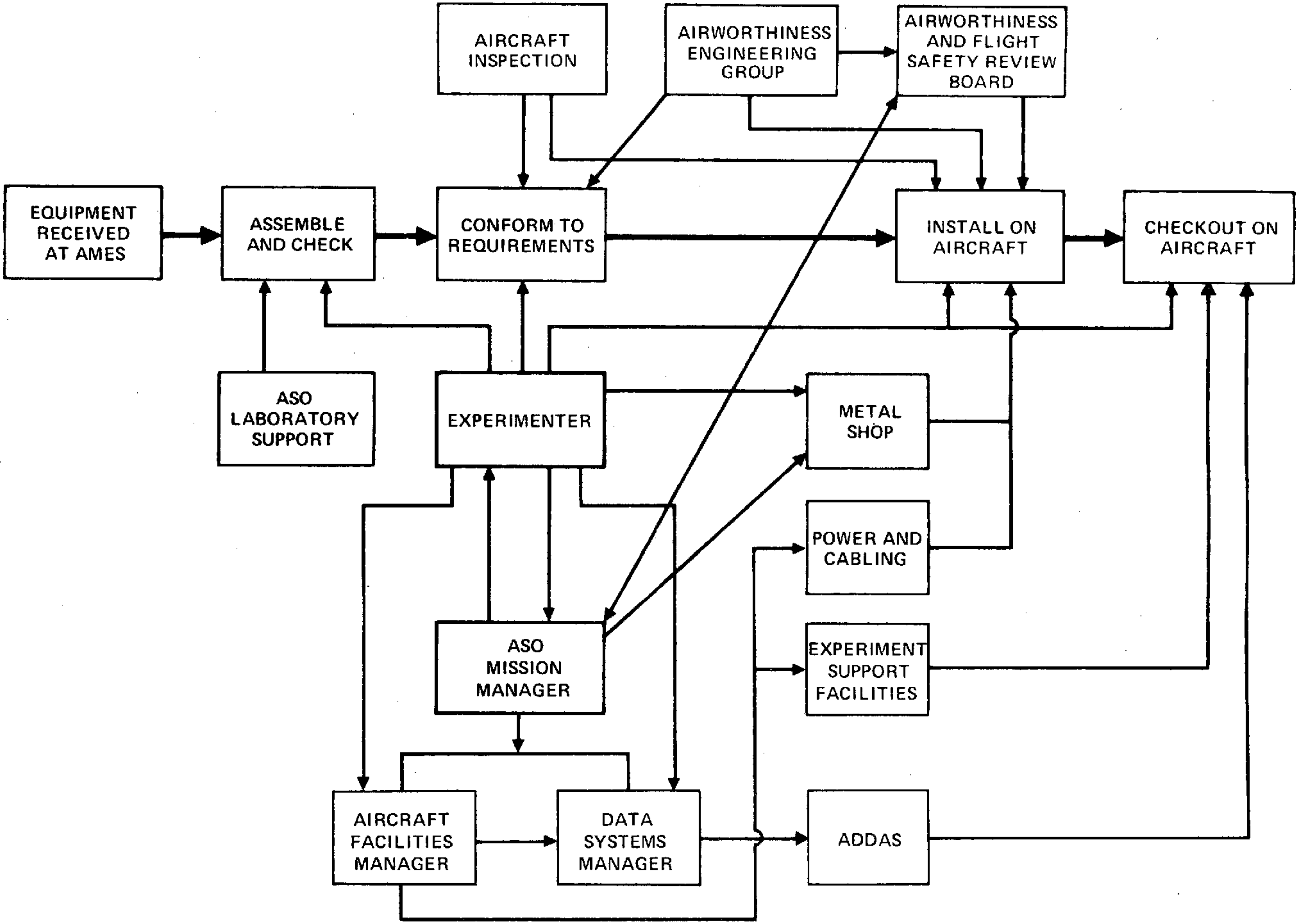

FIGURE 3–. EXPERIMENTAL EQUIPMENT INSTALLATION PROCEDURES

16

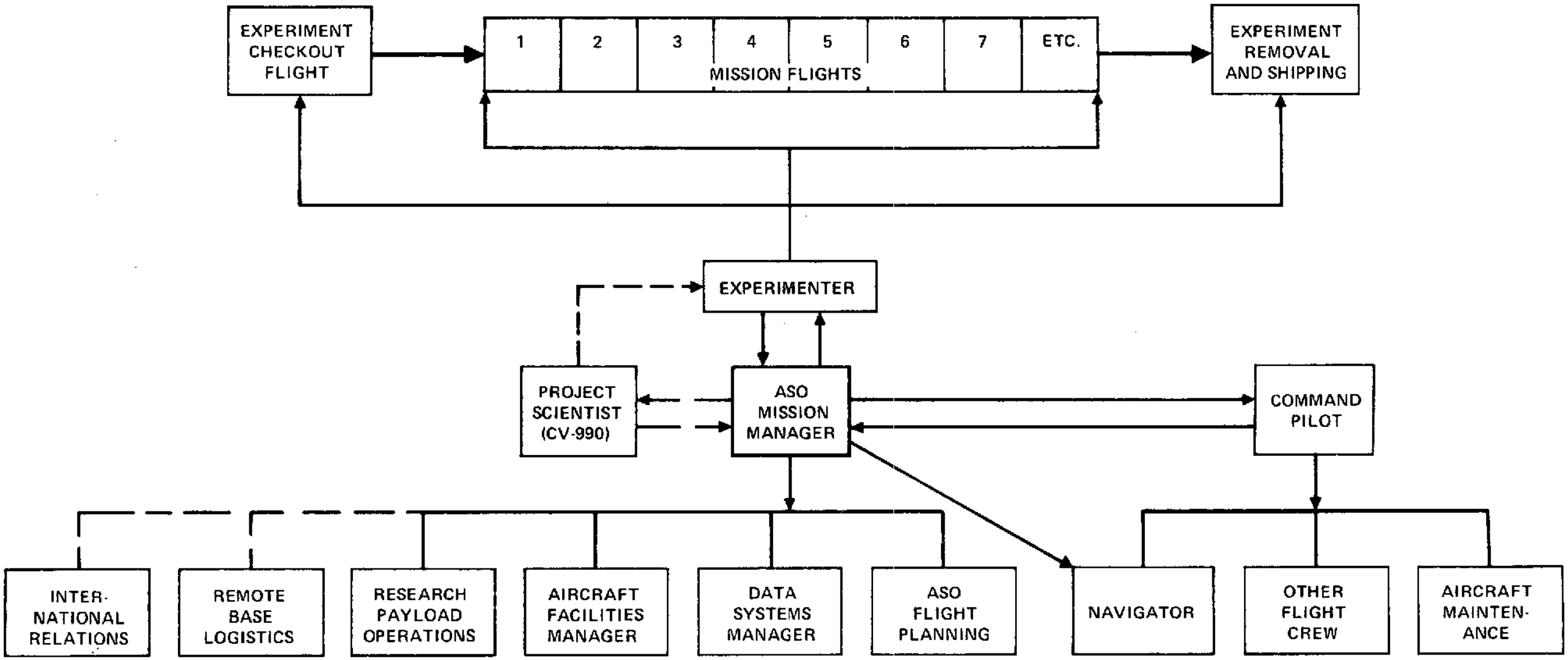

FIGURE 4—. ELEMENTS OF MISSION OPERATIONS

RESEARCH PROGRAM	NUMBER OF EXPERIMENTS	COMPONENTS	SOURCE OF COMPONENTS, PERCENT			
			OFF-THE-SHELF	MODIFIED-COMMERCIAL	CUSTOM-COMMERCIAL	EXPERIMENTER-BUILT
LEAR JET	17	SENSORS	32	0	32	36
		SIGNAL CONDITIONERS	48	0	4	48
		RECORDERS	100	0	0	0
		ALL OTHER	55	0	14	31
CV-990 *	49	SENSORS	49	12	34	5
		SIGNAL CONDITIONERS	75	2	20	3
		RECORDERS	92	4	4	0
		ALL OTHER	53	3	13	31

*NOVEMBER 1972 MISSION NOT INCLUDED

FIGURE 5–. COMPONENTS SOURCES BY FUNCTION

AIRCRAFT	MISSION	DATA FLIGHTS	EFU	EPU	EXPERIMENTER'S EQUIPMENT RELIABILITY FACTOR		
					NO PROBLEMS	ALL DATA	PARTIAL DATA
LEAR	ALL	76	76	33	0.56	0.64	0.88
CV-990 *	AIDJEX	8	98	17	0.78	0.90	1.00
	OCEAN COLOR	15	165	52	0.71	0.85	0.98
	AUGUST 1972	9	38	29	0.28	0.58	0.91
	METEOR SHOWER	10	117	21	0.86	0.94	0.99
	TOTAL	42	418	119			
	EXPERIMENT AVERAGE				0.71	0.85	0.98
	ALL	118	494	152	0.68	0.80	0.95

EFU = EXPERIMENT – FLIGHT UNIT
EPU = EXPERIMENT – PROBLEM UNIT (ONE OR MORE PROBLEMS ON ONE FLIGHT)
RF = 1 – EPU/EFU
*NOVEMBER 1972 MISSION NOT INCLUDED (ONLY ONE FLIGHT MONITORED)

FIGURE 6–. EXPERIMENT RELIABILITY FACTORS

PROGRAM	MISSION (NO. FLTS.)	NO. EXPMTS.	NO. EXPMT. PROBS.	RESEARCH IMPACT (ONE FLIGHT)				EQUIPMENT REPAIR			OCCURRED ON LAST FLIGHT	NO. EXPMTS. MISSED FLT. OPPORTUNITY	TOTAL NO. FLIGHT OPPORTUNITIES MISSED
				NONE	DATA DEGRADED	DATA LOSS	ALL DATA LOST	IN FLIGHT	FOR NEXT FLIGHT	DEFERRED*			
LEAR JET	ALL (76)	17	48	4 (8%)	10 (21%)	21 (44%)	13 (27%)	3 (6%)	22 (46%)	17 (35%)	6 (13%)	2	6
CV-990	AIDJEX (8)	13	33	16 (49%)	10 (30%)	7 (21%)	0	1 (3%)	5 (15%)	23 (70%)	4 (12%)	0	0
	OCEAN COLOR (15)	13	53	13 (25%)	14 (26%)	22 (41%)	4 (8%)	17 (32%)	21 (40%)	13 (25%)	2 (4%)	2	5
	AUGUST 1972 (9)	7	33	14 (43%)	2 (6%)	15 (45%)	2 (6%)	6 (18%)	8 (24%)	13 (40%)	6 (18%)	2	7
	METEOR SHOWER (10)	16	24	11 (46%)	2 (8%)	10 (42%)	1 (4%)	3 (13%)	6 (25%)	14 (58%)	1 (4%)	1	4
	ALL **	49	143	54 (38%)	28 (19%)	54 (38%)	7 (5%)	27 (19%)	40 (28%)	63 (44%)	13 (9%)	5	16
ALL OBSERVATIONS **		66	191	58 (30%)	38 (20%)	75 (39%)	20 (11%)	30 (16%)	62 (32%)	80 (42%)	19 (10%)	7	22

* MOSTLY MINOR PROBLEMS WITH SMALL IMPACT ON DATA RECOVERY

** NOVEMBER 1972 MISSION NOT INCLUDED (13 EXPERIMENTS)

FIGURE 7–. IMPACT OF EXPERIMENT PROBLEMS ON DATA ACQUISITION