Shared Experiences from NASA Programs and Projects: 1975

by Frank Hoban

This paper summarizes the lessons learned from two workshops held at the National Academy of Sciences in 1975. The workshops were sponsored by NASA in conjunction with the National Academy of Engineering. Vince Johnson, former deputy administrator of the Office of Space Science and Applications, chaired the sessions. The National Academy of Engineering was represented by retired NASA executives Robert Gilruth and Abe Silverstein, retired USAF General King, and Sid Metsger of COMSAT.

The first workshop was held on February 24 and 25, 1975, and covered nine projects:

Atmospheric Explorer Project Goddard Space Flight Center

David Grimes, Manager

The Atmospheric Explorer Project consisted of three Earth orbital missions, each utilizing a spacecraft of approximately 1,500 pounds with a payload of approximately 210 pounds. The science objectives were to investigate the proton chemical process accompanying the absorption of solar ultraviolet radiation in the earth's atmosphere by making closely coordinating measurements of the reacting constituents from the spacecraft. The spacecraft was placed in orbit by the Delta launch vehicle. The project staff never exceeded 14 GSFC employees. The orbital mechanics of the mission permitted an unrestricted launch window, and the launch dates were met within 30 days of the target.

Mr. Grimes offered the following cost control techniques:

- Spread project subsystems throughout the industry, thereby lessening overall risk; do not keep too many subsystems with the prime contractor. (There was not unanimous agreement on this point.)
- Motivate the contractor to keep costs low.
- Have the prime contractor use fixed-price contracts where possible
- Ensure that the project office and the contractor accept one leader, the project manager, for all elements of the project.

Mr. Grimes offered the following recommendations for future projects:

<u>**For Contractors:**</u>

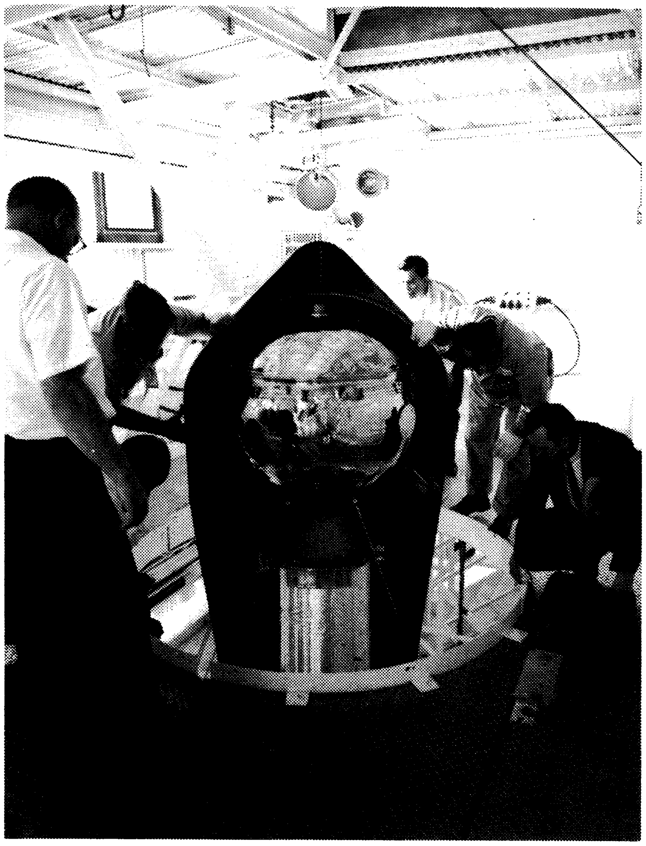
- Be willing to work as part of a NASA/contractor team rather than at arm's length.
- Be extremely cost conscious.
- Be technically aware as well as competent.

<u>**For Project Managers:**</u>

- Get good people on the project team and make sure they talk to each other.
- Be obsessed with cost and schedule — count things.
- Motivate your staff with similar feeling, and instill in them the conviction that success can be achieved.
- Keep encouraging and pushing your people.
- Maintain an information net that alerts you to difficulties within one day.
- Take the calculated risk.

<u>**For Field Center Managers:**</u>

- Ensure that the project leader has effective control of project personnel.
- Ensure there is continuity of assignment of people to the project team.



Engineers at Kennedy Space Center place a nose fairing around NASA's Atmosphere Explorer-B prototype spacecraft in 1966 at Complex 17B.

- Encourage the approaches described above.
- Provide the in-house manpower to support the project.

<u>For Headquarters Program Managers:</u>

- Back your project manager.
- Compete with other projects for scarce resources.
- Convince center management that headquarters supports the project and project manager.

Mariner/Venus/Mercury 73 Project
Jet Propulsion Laboratory
Gene Giberson, Manager

The project consisted of a single spacecraft launch to the planets Venus and Mercury during the 1973 launch opportunity. The mission plan's primary objective specified a flyby of the planet Venus with a continuing trajectory toward a flyby of Mercury. Subsequent post-Mercury planning allowed for return encounters of the spacecraft with Mercury. The program had a firm not-to-exceed budget of $98 million with the stipulation that a spacecraft system contractor was to be used for the design, fabrication, and test of the flight spacecraft and test articles.

The experiments and the participation of science teams were also limited to a fixed budget included in the $98 million ceiling. The project experienced excellent cost control throughout and underran the contract effort. The Jet Propulsion Laboratory in-house effort — consisting primarily of mission operations, tracking, data acquisition and science management — also experienced an appreciable underrun. Mr. Giberson elaborated on the following guidelines used by his team during the management of the Mariner/Venus/Mercury Project:

- Establish firm in-house mission specifications and strongly resist any deviation from them.
- Establish firm science mission requirements, including all science interfaces prior to spacecraft design.
- Establish firm cost estimates with principal investigators, and instill within the science team the not-to-exceed philosophy of the project.
- Establish a design carry-over attitude for the subsystem managers and resist any state-of-the-art improvements.

A major point touched on during the discussion was the trade-off between the spacecraft implementation phasing alternatives available and the spacecraft systems contractor. One plan had the contractor work force building up rapidly, with the contractor buying all parts, completing all design effort and subsystem fabrication early before retrenching into a one-year slack period prior to a second manpower build-up for final assembly, test and launch operations. This plan had the obvious advantage of staying ahead of the inflation spiral by completing all costly procurements early in the program. The second plan involved delaying contractor start as late as possible, building up fast, reaching a peak level of effort just prior to final checkout and launch, and then terminating the project activities in a short period of time. The latter plan, adopted by the project, was cost- and success-oriented, but assumed considerable risk. It was recognized that this plan might not be the best approach for a program involving major new developments.

Mr. Giberson submitted the following activities related to project success:

Pre-Project Mission Design

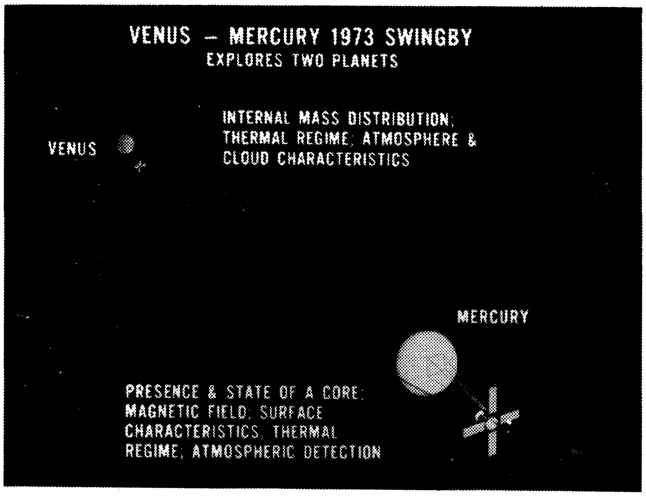
- Establish mission objectives.
- Use science steering group.
- On science/mission/spacecraft design interaction:
  - —Establish technical requirements/ performance trades. Develop preliminary cost estimates.
- Emphasize design carry over approach.
- Establish "baseline" mission trajectory.
- Emphasize cost trade-off analysis:
  - —Implementation models.
  - —Hardware quantities, design inheritance.
- Select "baseline" system configuration.
- Establish target cost.

Project Definition and Planning

- Restrain staff size.
- Expand "baseline" system designs and interfaces.
- Develop detailed cost estimates for implementation alternatives.
- Establish project guidelines and constraints.
- Conduct scheduling/cost trades:
  - —Maximize cost predictability and control.
- Establish operating budget.
- Budget planning:
  - —Use fixed-cost/variable-scope approach.
  - —Emphasize cost-at-completion.
  - —Use no-year funds approach.
  - —Assure compatibility of scope and resources.
  - —Stress candor on plans, allocations, and status.
- Prepare detailed implementation plans:
  - —Make specific and detailed request for proposals.
  - —Make careful make/buy trade-off assessments.
  - —Use existing documents and administration systems.
  - —Select fee approach.
- Indoctrinate personnel:
  - —Raise cost consciousness.
  - —Make cost goal believable.
  - —Foster an understanding of cost control plans and system.

Project Implementation

- Define contracts prior to start of work.
- Establish organization impedance matching and communications for:
  - —Intense technology transfer.
  - —Cognizant engineer concept.
  - —Work package approach.
  - —Frequent face-to-face meetings.
  - —Timely problem identification and resolution.



— Periodic status/performance reviews.

- Maintain current implementation and budget plans.
- Do only essential work.
- On-load and off-load manpower in timely fashion.
- Use "tiger team" problem solving.
- Tailor test activities.

Recommendations

(1) Plan early and in detail.

(2) "Start" late.

(3) Use existing designs where practicable.

(4) Established cost-at-completion budgeting and control.

(5) Communicate often.

(6) Do only what's essential.

SPHINX Project
Lewis Research Center
Robert Lovell, Manager

SPHINX was the smallest spacecraft discussed during the workshop. The objectives of the project were to obtain engineering data on the interaction between a high-voltage surface and space plasma. Although a launch vehicle failure terminated the operational phase of the satellite, SPHINX was considered successful from the standpoint of cost control and schedule performance. From its inception, the project was considered to be a high-risk, low-cost effort (approximately $1 million), with no redundancy in the spacecraft.

An engineering model and a protoflight model spacecraft were designed, fabricated, and tested in-house. The experiment, a technically difficult, high-voltage instrument package, was designed and fabricated under contract.

Many problems were encountered during the design, fabrication, and test phase of the contractual effort: technical difficulties in developing the high voltage instruments, lack of adequate center engineering support during the early part of the program, unavailability of parts, and the use of research and development contractor personnel for spacecraft support.

Recommendations for future projects of this type were:

(1) Establish a realistic schedule early in the program.

(2) Apply sufficient in-house engineering design effort during the preliminary design phase.

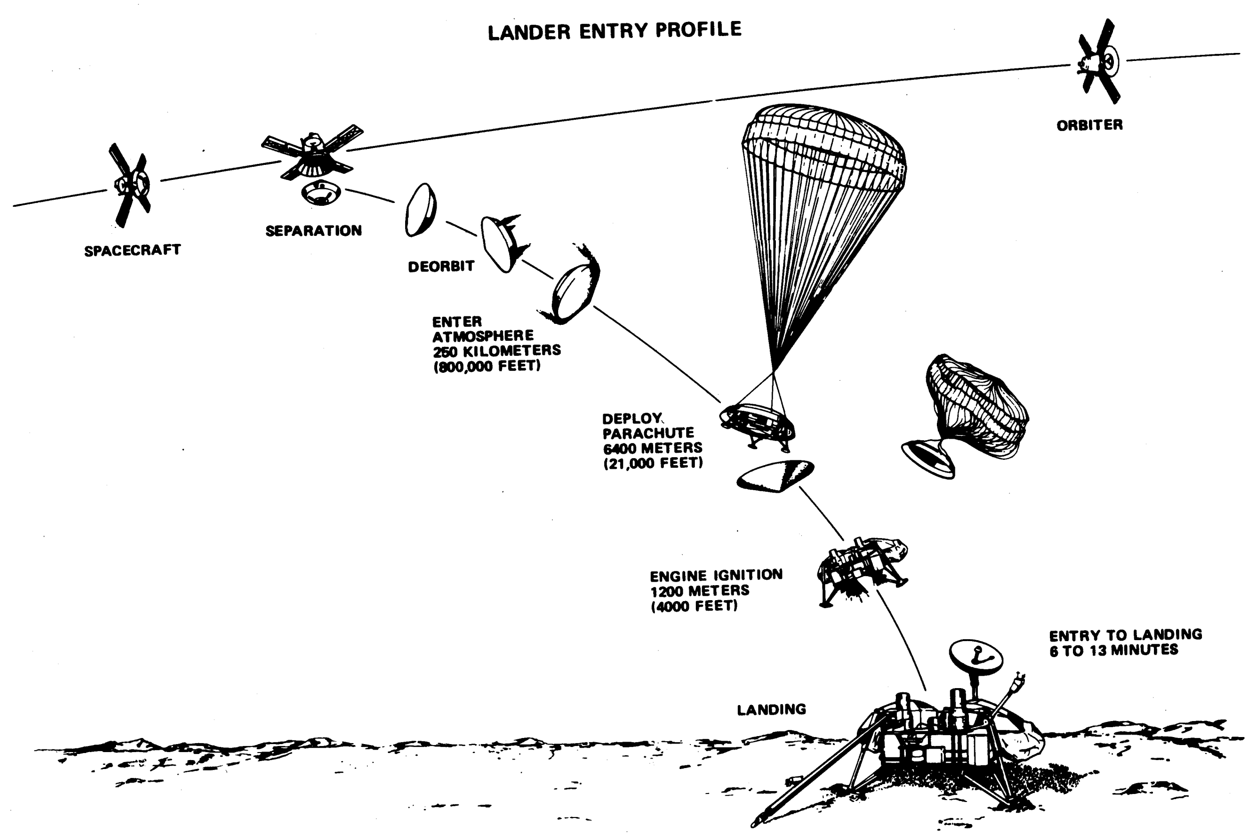
(3) Obtain a complete parts inventory as early as possible.

(4) If all parts are not available, make the design compatible with the parts that are obtainable.

(5) Insist on project, not research, personnel from the contractor and use an experimental shop approach.

Viking Project
Langley Research Center
Angelo Guastaferro, Assistant Manager

The Viking Project was a two-spacecraft mission to Mars, both scheduled for launch in the summer of 1975. The payload was launched on a Titan/Centaur



launch vehicle. Each spacecraft included an orbiter and a lander capable of soft-landing on the Martian surface and conducting a series of meteorological, biological, and planetological experiments. Viking experienced a considerable cost growth, from $364 million estimated in 1968, to $930 million projected in 1975.

Factors contributing to the early cost growth included:

- Lack of understanding of the magnitude of the project.
- Use of cost estimates scaled up from the previous Lunar Orbiter project.
- Poor appreciation of the effects of inflation.
- No reasonable industry cost estimates.
- Lack of ability to pinpoint critical technological areas requiring state-of-the-art improvement.

During the discussion, the following points were made:

- It was not clear that additional money during the early phases of the project would have been used to the best advantage because the real problems were not well identified.
- Insufficient in-house engineering during the early phases contributed greatly to later problems.
- State-of-the-art improvements need special attention as early as possible.
- The role of the scientist/principal investigator in all projects should be re-examined. The principal investigator on Viking had no direct responsibility for schedule and cost, and limited responsibility for the performance of the experiment hardware. A consensus was that the scientist should be given the total job, including responsibility for cost, schedule, and performance.
- There needs to be more emphasis on in-house engineering.

The deputy project manager provided the following observations and recommendations:

(1) Realistic costs are difficult to estimate using limited parametric studies.

(2) Realistic cost estimates must be developed prior to large expenditures of project funds.

(3) Science definition and scientist participation in instrument development should be managed firmly.

(4) Beware of "state-of-the-art" pitfalls.

(5) Invest significant early money in hardware development and testing.

(6) Assign well-trained contractor management teams to major, critical subcontractors early.

(7) Beware of contractor estimates for:

— Subcontractors.

— Changes.

— Estimates to complete.

(8) Maintain a dollar-reserve posture equal to the degree of uncertainty.

(9) Have a continuous cost-offset/cost-concern program.

(10) Use an aggressive management and flexible staff concept:

— Assign "tiger teams."

— Get outside help.

— Use incremental reviews.

— Keep organization dynamic (matched to phase of project).

(11) Establish cost, including indirect cost management techniques for control, monitoring, evaluating, statusing, and reporting early.

(12) Assign technical/schedule/cost responsibilities for each area of work to a technical manager.

Delta Project
Goddard Space Flight Center

William Schindler, Manager

The Delta launch vehicle project was not involved in a new design effort but rather in an adaptation of an inherited or modified design. The vehicles were built in a limited mass production operation. The project management was primarily concerned with providing to its customers a high reliability launch system at a reasonable cost. A major concern of the project was determining the proper balance between achieving greater reliability and performance, and maintaining a competitive price.

In selecting reliability goals for launch vehicles, consideration must be given to launch vehicle and spacecraft costs. In general, for non-redundant vehicles, reliability levels greater than 90 percent are achievable only at considerable costs, and for reliability goals above 95 percent, the cost may well become prohibitive. The project manager felt that in attempting to assess launch vehicle cost versus reliability, the ratio of the spacecraft cost must be considered; that is, a higher spacecraft cost justifies more effort on launch vehicle reliability. The Delta launch vehicle failures have been determined to be about equally divided among electrical, mechanical, structural, and ordinance (including solids) subsystems.

The project manager felt there was a large quantity of data on projects that varied greatly in their approach to reliability, from "low-cost" projects such as Delta, Scout, and Explorers, to "high-cost" projects such as Saturn, Apollo, and Viking. He suggested a study to determine whether a quantitative relationship could be established between dollars invested and achieved reliability.

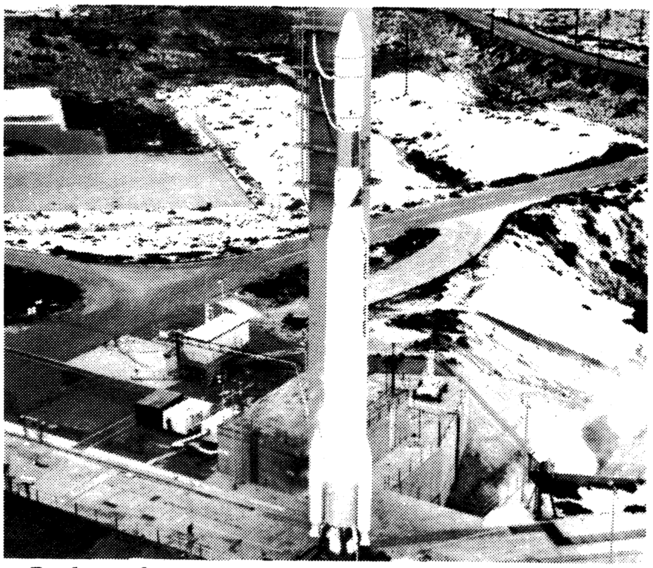
The project manager identified the following cost drivers:

- During development of major configuration change:

  — Component qualifications.

  — Systems integration and compatibility testing.

  — Formal system qualification.



Prelaunch view of Delta rocket in 1973, about to take a new weather satellite into orbit from NASA's western test range in Lompoc, CA.

- During the operational phase:

  — Component production acceptance testing.

  — Requalification requirements.

  — Systems acceptance testing.

  — Amount of field rework/modification permitted.

  — Method of effective governmental acceptance/approval of contractor activity.

  — Flight readiness review process.

Skylab Project
Marshall Space Flight Center
Leland Belew, Project Manager

Skylab, this nation's first space station, made maximum use of existing launch vehicles, spacecraft, hardware, facilities, and equipment. The management experience from past programs and the ongoing Apollo Program was fully utilized. Skylab, with the Apollo spacecraft attached, was 118 feet long, weighed approximately 100 tons, and cost approximately $2.5 billion. Skylab was equipped with solar telescopes, earth sensors, and equipment for space manufacturing. Skylab was launched on a Saturn V launch vehicle and the Apollo spacecraft on a Saturn 1B launch vehicle. Program emphasis was on obtaining biomedical, earth applications, and scientific data. The program had a comprehensive involvement with a large number of scientists and principal investigators. (More than 100 different experiments were conducted.)

Comments by the project manager and other panel members regarding the project are as follows:

- A firm, comprehensive program plan was established in early 1969.

- A principal project guideline was to use existing proven hardware and facilities, allowing only mandatory changes.

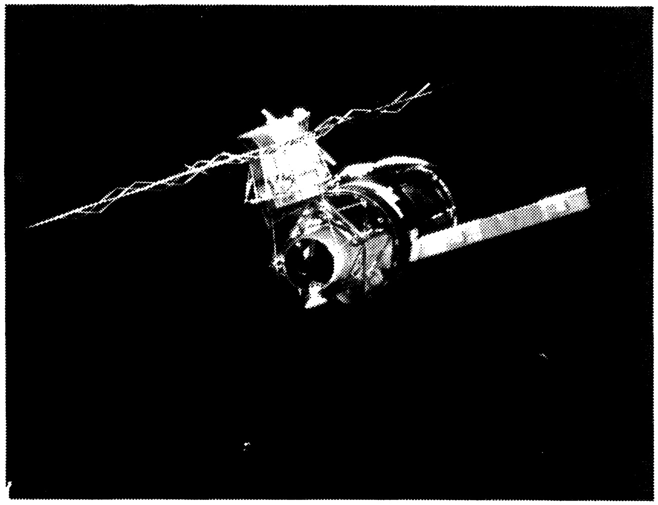
- The design, development, test and checkout, launch and mission operations were carried out using essentially the same team (the team flowed with the hardware). For instance, the principal investigators, the scientists, and the crew (astronauts) actively participated in all the above activities.

- A strong in-house systems engineering and integration activity prevailed throughout the program, including a relatively small percentage of representative hardware activity (such as the Apollo Telescope Mount systems and one ATM experiment).

- Interface control documentation was jointly established and controlled between the design and operational centers and contractors early in the program. A control board primarily involving MSFC, JSC, and KSC was established.

- Program cost drivers were the following: (1) Skylab was coupled to Apollo. Apollo supported the basic program relative to common hardware. Skylab launches were in series after Apollo. (2) Crew safety and mission objectives and requirements dictated a design with considerable redundancy. (3) Skylab was a manned, one-of-a-kind, national commitment.

- A deliberate matching of management skills is recommended when the working relationship involves multiple centers.



- Hardware procurements should first consider available items. The most cost-effective path is to use an existing component or system.

Recommendations for future projects are:

(1) Make authority delegations known throughout the project organization.

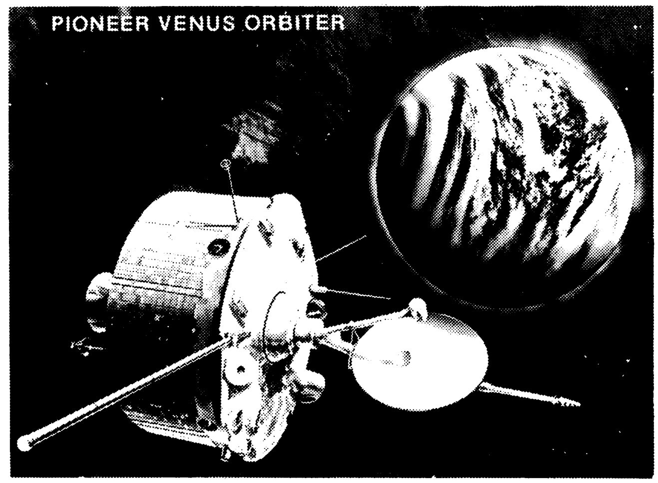
(2) If cost is to be the controlling factor, establish it early in project planning.

Pioneer-Venus Project
Ames Research Center
Skip Nunamaker, Manager

The Pioneer-Venus Project consisted of two launches to the planet Venus scheduled for 1978. The orbiter was to be launched first, followed by the probe launch. The Venus encounter was planned to occur in December 1978, for both the orbiter and probe. The probe was designed to enter the Venusian atmosphere and transmit atmospheric data until impact with the surface.

The Pioneer-Venus budget was $173 million for a six-year period covering fiscal years 1975-1980.

Hughes Aircraft Company was the spacecraft systems contractor for both orbiter and probe. The decision to change launch vehicles from Thor/Delta to Atlas/Centaur allowed much more flexibility in the spacecraft/probe design, and contributed to containing costs. Also, the contractor was instructed to



The Pioneer Venus orbiter is depicted as it approaches Venus in order to study the planet's atmosphere and weather.

plan spare or vacant time in the schedule following each major test. This permitted resolution of test anomalies without impacting other scheduled activities.

Recommendations:

(1) Keep mission objectives specific.

(2) All mission and spacecraft specifications should be prepared in-house and given to the contractor, not the other way around.

(3) Spend time studying and engineering the proposed mission prior to project start. This will pay big dividends later, especially in cost estimating.

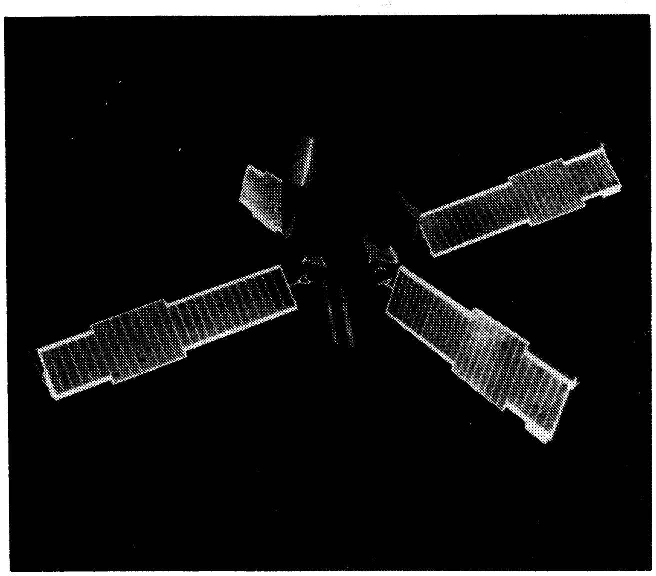
(4) Provide pre-project approval funds for ordering parts. Parts availability and long lead times are big cost items and are difficult to control.

HEAO Project
Marshall Space Flight Center
Fred Speer, Manager

High Energy Astrophysics Observatory (HEAO) consists of three, low-Earth orbit missions whose objectives were X-ray, gamma ray, and cosmic ray-astronomy. The spacecraft was built by Thompson-Ramo-Woolridge (TRW).

The project manager emphasized the thoroughness of definition that preceded the hardware phase and the participation of MSFC engineering in all essential design features. A very high percentage of components and subsystems represented off-the-shelf designs, obviating the need for full qualification testing. Major cost savings were accomplished by accepting the protoflight concept on all instruments and the spacecraft. All HEAO instruments were constrained to allow for substantial initial design margins in weight, power, and volume. Early cost ceilings were established on all instruments, and descoping was performed on those that exceeded ceilings.

There was considerable discussion by the panel on whether or not an existing spacecraft design could have been adapted or modified to satisfy the HEAO requirement. Mr. Speer reported that the HEAO payload originally contracted with TRW was much larger than any existing spacecraft would support. Following the program restructuring in 1973, other spacecraft were considered and found less cost-effective than permitting TRW to scale down its initial HEAO design.



NASA's High Energy Astronomy Observatory project set out to study some of the most intriguing mysteries of the universe, including pulsars, black holes, neutron stars, quasars and supernovas. High-energy celestial gamma and cosmic rays are obscured for ground-based observatories of our atmosphere.

One of the cost-benefit practices implemented by HEAO involved the common electronic piece parts suppliers for both the spacecraft and science experiments. Obtaining piece parts is a major problem for all programs, but especially for experimenters.

Recommendations for controlling costs:

(1) Refine and reduce programmatic requirements.

(2) Concentrate on specific technical requirements.

(3) Use value engineering (contractor shares in savings from proposed cost reductions).

(4) Establish firm budget ceilings for each program element.

(5) Adopt modular payload mode with options to be deleted.

(6) Ensure that experiments are manufactured by qualified hardware contractors.

(7) Encourage commonality and standardization.

(8) Use a design-to-cost approach.

(9) Establish adequate contingency funds.

Sounding Rockets Project
Goddard Space Flight Center

John Busse, Manager

The sounding rockets presentation concentrated on the launch vehicle aspect of project management and did not cover payload or spacecraft. Sounding rockets are low in cost and take a different management approach to cost control and cost benefit analyses.

Sounding rocket launches differ from other unmanned scientific or applications missions in that a large portion of the launch vehicle and payload hardware is recoverable and can be refurbished and reflown. The refly option reduces cost to the point where total reliability is not the concern it would be for a larger, more expensive mission. When failures occur, they are handled in a less formal atmosphere, and the resulting change in hardware or procedures is minimal compared to satellite launches. Mr. Busse emphasized, however, that a rocket launch is never allowed to proceed with a known defect in either rocket or payload. If a repair or design change is judged to be essential, it is accommodated before launch.

Recommendations:

(1) Establish better flight program definition.

(2) Improve the procurement process for standard hardware by lessening time and eliminating paperwork.

(3) Improve cost accounting and compare predicted versus actual costs (both manpower and dollars).

(4) Establish methods of evaluating scientific value of flight against cost to support.

This concluded the first workshop. A second workshop was scheduled for June 1975. The second part of this article will cover the recommendations from six more NASA projects, an overall summary, and a discussion of the recommendations forwarded to the Deputy Administrator.